Beyond Internet Dependency: LoRa for Post-Earthquake Structural Monitoring

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***Abstract*—Acquiring structural response data during and after earthquakes is essential for assessing threats to critical infrastructure; however, conventional transmission systems rely on Internet connectivity that is often disrupted during major seismic events. This study evaluates Long Range (LoRa) radio as a low-power, infrastructure-independent alternative for transmitting building instrumentation data when conventional networks fail. Field experiments were conducted across three New Zealand cities, testing performance under varying radio configurations, elevations, and urban topographies. Results demonstrate reliable urban communication ranges of up to 1.6 km under optimal settings. Elevation was the dominant deployment factor, with packet delivery ratios (PDR) improving from 0–40% at ground level to near-100% at 500 m radial distance when transmitters were positioned on upper floors. Building-to-building links achieved 75–100% PDR with received signal strength values between −55 and −110 dBm, while terrain features such as hills and dense vegetation caused significant attenuation and occasional link failure at shorter distances. These findings confirm the feasibility of LoRa for post-earthquake structural monitoring and provide quantitative guidance for elevation-aware, terrain-conscious deployment in urban environments.**

Keywords—LoRa; Earthquake data; Wireless communication; Telecommunication infrastructure failure; Alternative communication systems.

I. Introduction

Acquiring structural response data during and after significant seismic events is essential for timely safety assessment of buildings and critical infrastructure. This data supports immediate post-earthquake inspection triage, informs repair and reoccupancy decisions, and contributes to the development of earthquake early warning systems [1], [2]. Current instrumentation solutions—such as the RaspberryShake 3D accelerometer—rely on Wi-Fi or cellular connectivity to relay data to remote servers, creating a fundamental vulnerability: the very infrastructure used to transmit earthquake data is often disabled by earthquakes themselves.

Major seismic events disrupt power grids, ...damage fibre and wireless communication nodes [3], and generate surges in network demand that overwhelm surviving infrastructure [15]. The result is an information blackout precisely when accurate, real-time structural data is most needed. A subsequent aftershock with no monitoring capability represents the worst-case scenario from both life-safety and post-disaster management perspectives.

Two primary strategies appear in the literature to mitigate this problem. The first is pre-emptive data evacuation: moving sensor data to safe locations before infrastructure failure using optimised network routing such as the Rapid Data Evacuation (RDE) heuristic, which has been shown to save 64% of transmission time and evacuate 97% more data within fixed deadlines compared to nearest-path approaches [16]. The second is architectural redesign: deploying cloud-integrated mobile ad hoc overlays that provide communication capacity independent of fixed infrastructure [15]. Both strategies, however, fundamentally depend on surviving some portion of

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conventional networked infrastructure and require significant pre-event investment.

Neither approach addresses the scenario in which all conventional infrastructure has failed, post-event data is required, and pre-emptive systems cannot be afforded or have been destroyed. A third approach—employing an independent, infrastructure-free radio communication technology—fills this gap. Long Range (LoRa) radio, using chirp spread spectrum (CSS) modulation in the unlicensed 915 MHz ISM band, operates without reliance on the Internet, cellular towers, or cloud infrastructure, consumes milliwatt-level power, and can achieve kilometre-scale range in urban environments [4].

While LoRa's potential for disaster communication has been explored in search-and-rescue [9], victim reporting [10], satellite-relay seismometry [11], and UAV-assisted relay architectures [12], no study has systematically characterised its performance for building instrumentation data retrieval across the variety of urban topographies found in earthquake-prone New Zealand cities. This paper addresses that gap. We report field experiments conducted in Auckland, Wellington, and Christchurch using two LoRa hardware platforms, providing quantitative performance benchmarks across diverse urban environments and actionable guidance for sensor placement.

II. Related Work

A. The Role of Data in Post-Earthquake Response

Goulet et al. [5] demonstrated that data-driven frameworks enabling progressive learning of the relationship between measured frequency shift and structural damage state can support city-scale safety assessments with minimal manual inspection. McLean et al. [6] documented how delays in data transfer during the 22 February 2011 Christchurch earthquake directly hampered response decisions during the critical early hours, with sophisticated data sources unavailable to local decision-makers due to technical communication failures. Poland et al. [7] further argue that integrating post-event seismic data with simulation and predictive models is essential for infrastructure resilience planning. These works collectively establish the operational imperative for reliable post-earthquake data transmission.

B. LoRa in Disaster Management

Shukla [8] demonstrated an IoT-based disaster detection system using LoRa to extend communication range and reliability. Manuel et al. [9] developed the Titan Disaster Management System, integrating LoRa into search-and-rescue robot coordination, real-time victim communication, and autonomous navigation, and validated LoRa's robustness in post-disaster environments with severely damaged infrastructure. Vithayathil et al. [10] implemented a portable offline network in which survivors connect via Wi-Fi to relay nodes that forward messages to rescue teams via LoRa, demonstrating its utility for last-mile connectivity.

Arifin et al. [11] tested satellite-based LoRa for seismic data collection in remote Indonesia, confirming its feasibility but noting limitations due to attitude-control constraints during low-Earth-orbit passes. Saraereh et al. [12] showed that UAV-relayed LoRa networks can maintain Quality of Service metrics across dynamic ground node configurations. Ranasinghe et al. [13] proposed a multi-hop LoRa architecture for earthquake early warning in New Zealand, demonstrating that SF8 can propagate warnings across 30 km of urban area in 2.4 seconds. Centelles et al. [14] modelled LoRaWAN for citizen emergency coordination in Coquimbo, Chile. Taken together, these studies confirm LoRa's promise for disaster communication, but none provide empirical deployment guidance for continuous building instrumentation retrieval in multi-city, multi-topology urban environments.

III. Methodology

A. Hardware Platforms

Two commercially available LoRa devices were selected to enable cross-hardware comparison and to offer deployment options suited to different operational contexts. The Duinotech RFM96 Arduino Shield (Semtech SX1276) operates at 915 MHz, supports SF6–SF12, and provides transmit power of +14 to +20 dBm with a receiver sensitivity of −148 dBm at SF12. It interfaces with an Arduino Uno or Mega via SPI and draws power from a 9 V battery pack. Its plug-and-play architecture enables rapid field deployment without soldering.

The Heltec Wi-Fi LoRa 32 V3 (Semtech SX1262) integrates an ESP32 microcontroller, 0.96″ OLED display, and LoRa radio on a single compact board. It operates at 915–928 MHz, supports SF7–SF12, and provides transmit power of +14 to +22 dBm with a sensitivity of −134 dBm. Power delivery via USB-C or a 3.7 V LiPo makes it well-suited to permanent or semi-permanent sensor installations. Both platforms used identical omnidirectional SMA antennas mounted vertically throughout all tests.

B. System Architecture and Test Protocol

A peer-to-peer server–client topology was used. The client device transmitted test packets at 1-second intervals; each packet contained a 6-digit number representative of real earthquake sensor output (sequences of acceleration values). The server device continuously received packets, logging RSSI (dBm), SNR, and sequence numbers via a serial connection to an Android smartphone running custom Python scripts for real-time logging and visualisation. Each measurement session consisted of 20 transmitted packets per position. Where operationally feasible, positions were retested on multiple days to capture temporal variability from traffic, vegetation movement, and atmospheric conditions. GPS coordinates were recorded for all positions; distances were computed post-hoc using Google Earth Pro.

The radio parameter space tested was: spreading factor SF6–SF12 (RFM96) and SF7–SF12 (Heltec); transmit power 5–23 dBm; bandwidth 125 kHz and 250 kHz (Heltec only). Unless otherwise stated, results reported use the optimal configuration identified in the straight-line baseline test (SF11–12, 22–23 dBm, 125 kHz). All tests were conducted in the 915 MHz ISM band, as governed by AS/NZS 4268.

C. Test Cities and Building Selection

Three New Zealand cities were selected to represent diverse geological and urban conditions relevant to earthquake monitoring. Auckland features volcanic basaltic topography, a mid-rise urban fabric, and moderate seismic exposure from the Hikurangi Subduction Zone. Wellington, located above the active Wellington Fault and rated the highest seismic hazard of the three cities, combines steep terrain rising to 500 m with a dense, high-rise urban core.

Christchurch occupies the flat Canterbury Plains, extensively rebuilt to modern seismic codes following the 2010–2011 Canterbury earthquake sequence, and is representative of New Zealand regional centres.

Central test buildings were: Murphy Building, Wellington (11 floors); Waipārūrū Hall, Auckland (13 floors); and the UC Central Library, Christchurch (11 floors). These were selected to provide access from the ground floor to the top floor and to represent the building typologies in which seismic instrumentation would realistically be installed.

D. Test Configurations

Five complementary test types were executed, each isolating a specific variable. Test 1 (Straight-Line Range) characterised maximum communication distance under near-ideal flat-terrain conditions by progressively moving the client device away from a fixed server along street-level paths in all three cities. Test 2 (500 m Radius Elevation) evaluated the effect of vertical positioning by testing eight radial points at 45° intervals at 500 m distance from central buildings, comparing transmission from low floors (2nd–3rd) and high floors (11th–13th). Test 3 (Building-to-Building) assessed signal penetration when both devices were inside separate buildings, with the server at low and high floor positions. Test 4 (Floor-to-Floor Vertical) measured intra-building vertical propagation by positioning the server on the top floor and the client on progressively lower floors in both aligned and offset horizontal configurations. Test 5 (Rough Terrain) placed eight measurement points at a 150 m radius around a hilltop server location in residential Wellington, characterising signal behaviour in the presence of slopes, soil, and dense vegetation.

IV. Results

A. Straight-Line Maximum Range

Table I presents the maximum achievable range for the RFM96 across all tested spreading factors and power combinations. The peak range of 1,614 m was achieved at 23 dBm and SF11. A non-monotonic pattern is evident at SF12 and high power levels, where range decreases slightly relative to SF11—a consequence of longer time-on-air increasing susceptibility to interference. The Heltec at 22 dBm with 125 kHz bandwidth reached 1,512 m at SF11 and 1,430 m at SF12, confirming the same trend across hardware platforms. At the lowest tested power (5 dBm), even SF12 reached only 661 m, establishing the minimum practical operating bounds.

TABLE I.

RFM96 Maximum Communication Range (metres) by Transmit Power and Spreading Factor

Power (dBm)	SF6	SF7	SF8	SF9	SF10	SF11	SF12
5	500	531	547	585	602	632	661
11	966	983	995	1018	1070	1126	1138
17	1226	1240	1245	1260	1321	1393	1344
23	1249	1309	1348	1453	1561	1614	1518

TABLE II.

Heltec Wi-Fi LoRa 32 Maximum Range (metres) by Configuration

Config	SF7	SF8	SF9	SF10	SF11	SF12
14 dBm, 250 kHz	861	881	903	918	964	924
22 dBm, 250 kHz	884	965	1052	1161	1225	1120
14 dBm, 125 kHz	986	1055	1139	1276	1358	1264
22 dBm, 125 kHz	1103	1230	1326	1495	1512	1430

B. 500m Radius Elevation Tests

Elevation consistently and dramatically improved PDR across all three cities. In Christchurch, the RFM96 achieved 100% PDR at 6 of 8 radial points from the 11th floor, with Point 4 achieving 20% and Point 8 achieving 80%, compared to a maximum of 40% at any single point from the 2nd floor. The Heltec showed 7 of 8 points achieved 100%, with Point 4 at 85% (mean RSSI −89 to −111 dBm). From the 2nd floor, only 4 of 8 points achieved any reception. In Wellington, moving from the 3rd to the 11th floor of the Murphy Building increased the number of successful connection points from 1 to 4 (Heltec). In Auckland, the Heltec achieved 100% PDR at 4 of 9 points on the 13th floor with RSSI improving by up to 13 dB at paired locations.

TABLE III.

Elevation Test: Points Achieving >80% PDR at Low vs. High Floors (500 m radius)

City / Device	Low Floor	% Points >80% PDR	High Floor	% Points >80% PDR
Christchurch / RFM96	2nd	0 / 8 (0%)	11th	7 / 8 (88%)
Christchurch / Heltec	2nd	1 / 8 (13%)	11th	7 / 8 (100%)
Wellington / Heltec	3rd	1 / 8 (13%)	11th	4 / 8 (50%)
Auckland / Heltec	Ground	1 / 9 (11%)	13th	4 / 9 (44%)

C. Building-to-Building Communication

When the server was positioned on the top floor of the central building, reliable inter-building communication was consistently achieved. In Wellington, the Heltec achieved 100% PDR across all three target buildings from the 11th floor, with RSSI values of −103, −85, and −90 dBm, respectively. From the 3rd floor, Buildings A and B achieved 90% and 100% PDR respectively, while Building C, with the clearest line-of-sight, achieved 100% PDR with a strong RSSI of −55 dBm. The Wellington RFM96 results showed a different pattern: 0% from floor 3 to Buildings A and B, 100% to C; 100% to all three from floor 11.

In Christchurch, the Heltec achieved 100% PDR from the 11th floor to all three buildings. The RFM96 achieved 100% PDR to Buildings A and C from the 11th floor, but only 60% to Building B. From the 2nd floor, neither device connected to Buildings A or B (0% PDR), while Building C reached 75% (Heltec) and 30% (RFM96) PDR. In Auckland, the RFM96 performed poorly at both floor levels, achieving only 10% PDR to Building B and 0% elsewhere regardless of elevation. The Heltec showed a clearer elevation effect: from the ground floor, Buildings B and C achieved 100% PDR while Building

A had no connection; from the 11th floor, Buildings B and C maintained 100% PDR while Building A improved to 44%. These results confirm that elevation of the transmitter can compensate for signal attenuation caused by building envelope materials, though its benefit varies by device and city.

D. Floor-to-Floor Veritcal Communication

Intra-building vertical propagation consistently performed strongly across all buildings and devices. In the Murphy Building (Wellington), the Heltec maintained 100% PDR across 10 floors (11th to 1st) regardless of horizontal alignment (front-to-front: −85 dBm; back-to-front: −102 dBm). The RFM96 achieved 100% PDR across 9 floors (11th to 2nd) when aligned, dropping to 60% when offset. In Waipārūrū Hall (Auckland), the Heltec achieved 100% PDR across 13 floors in both front-to-front and front-to-back configurations, while the RFM96 achieved 100% PDR front-to-front but dropped to 70% in the back-to-front configuration (RSSI −86 to −92 dBm). The UC Central Library (Christchurch) similarly yielded 100% PDR across all tested floor combinations with both devices (RSSI ranging from −87 to −105 dBm). The consistent high PDR across up to 13 floors of reinforced concrete construction confirms that vertical intra-building relay is a viable architectural component of a post-earthquake LoRa sensor network.

E. Rough Terrain and Natural Obstruction

In the Wellington hill test, the Heltec maintained 100% PDR at 6 of 8 measurement points at 150 m radius. Point 5, located down a steep vegetated slope with the earth directly obstructing the first Fresnel zone, achieved only 70% PDR (RSSI −104 dBm). Point 7 achieved 95% PDR (RSSI −104 dBm). The RFM96 recorded complete packet loss at Points 4 and 5, and only 15% PDR at Point 7. Points 1, 2, 3, 6, and 8—all with clear or near-clear line-of-sight—achieved 100% PDR with RSSI values between −88 and −108 dBm (Heltec).

V. Discussion

A. Spreading Factor, Power, and Battery Life

The free-space path-loss model predicts that received power falls as 20 log (d) with distance, which is compensated by increasing transmit power or the spreading factor. Higher spreading factors extend the communication range by improving receiver sensitivity through processing gain—a signal encoded over a longer duration can be decoded at a lower signal-to-noise ratio. However, the relationship is not monotonic at very high spreading factors: SF12 occasionally underperformed SF11 at high power, consistent with the documented increase in time-on-air (TOA). At SF12, only 51 bytes are transmitted in 2,793 ms compared to 242 bytes in 399 ms at SF7 [17], substantially increasing exposure to interference and timing drift during each transmission.

TOA also governs battery consumption. Since earthquake monitoring sensors must remain operational across extended post-event periods—potentially days—without mains power, battery life is a primary constraint. SF11 at 22–23 dBm provides an optimal balance: it delivers the study's highest reliable range (>1,500 m) while keeping TOA and power draw lower than SF12. Stakeholders with access to larger battery banks or solar charging may tolerate SF12 for marginal range gains; those relying on compact battery packs should adopt SF11 or lower. The 125 kHz bandwidth (versus 250 kHz) consistently extended range by approximately 10–15% for the Heltec, at the cost of halved data throughput—a trade-off that is acceptable given the small packet sizes of seismic sensor output.

B. The Primacy of Elevation and Line-of-Sight

The most consistent and impactful finding across all five test types is the overriding importance of elevation and Fresnel zone clearance. Radio signals at 915 MHz do not propagate as a geometric ray but spread into an ellipsoidal region. Any object that intrudes into 60% of this zone produces measurable signal degradation, even when the direct path is visually clear [18]. Elevating either the transmitter or receiver reduces the number of buildings, trees, and terrain features that intersect this zone.

This directly explains the step changes in PDR observed between low and high floors across all elevation test locations. In Christchurch, the transition from the 2nd to the 11th floor converted a near-total communication failure into near-perfect coverage across all eight radial directions. For post-earthquake deployment, this finding mandates that data collection gateways (mobile or fixed) be positioned on upper floors or rooftops of tall buildings, from which a broad angular range can be covered with sufficient Fresnel zone clearance.

C. Terrain Versus Urban Infrastructure as Attenuators

A key distinction emerges between the attenuation behaviour of natural terrain and urban buildings. Building materials—concrete, brick, and metal—introduce moderate attenuation and reflection. Reflections create multipath propagation that can degrade signal quality but also allow partial connectivity around obstructions: this explains why many urban non-line-of-sight positions still achieved partial PDR. Terrain features—particularly wet soil and dense vegetation—absorb electromagnetic energy at 915 MHz far more completely than built materials, frequently causing total link failure even at short distances (150 m in the rough terrain test). The moisture content of New Zealand's hill soils and subtropical vegetation is particularly effective at absorbing sub-GHz radio energy.

This has direct practical implications for cities like Wellington, where building instrumentation sites may be separated from collection points by ridgelines. Network planning in such environments must account for terrain-induced Fresnel zone obstruction using digital elevation models before finalising node placement. By contrast, in Christchurch's flat environment, elevation of the gateway node alone was sufficient to achieve near-universal coverage across all test directions.

D. Hardware Equivalence and System Architecture

Both the RFM96 and Heltec platforms produced comparable PDR and RSSI outcomes under identical configurations. The underlying CSS modulation specified by Semtech is hardware-agnostic, and observed differences were attributable to environmental factors rather than chipset performance. Deployment constraints, therefore, govern the choice between devices: the RFM96's plug-and-play Arduino interface suits temporary or rapidly deployed field nodes; the

Heltec's compact integrated design with LiPo charging suits permanent sensor installations.

The floor-to-floor results support a relay architecture in which sensors on lower building floors—where external connectivity is often impossible—transmit data vertically to upper-floor relay nodes. These upper-floor nodes, benefiting from improved Fresnel zone clearance, then communicate to a mobile collection gateway operated by a damage assessment team after the seismic event. This avoids the need for each floor to maintain an independent external radio link, and the results confirm that even 13-floor vertical separation is comfortably within LoRa's capability through reinforced concrete.

VI. Conclusion

This study confirms the feasibility of LoRa technology as an Internet-independent alternative for transmitting building instrumentation data in post-earthquake scenarios. Systematic field tests across Auckland, Wellington, and Christchurch produced several key quantitative findings. First, reliable communication is achievable at 1,100–1,614 m in urban environments using SF11 at 22–23 dBm, with 125 kHz bandwidth providing a 10–15% range advantage over 250 kHz. Second, elevation is the dominant deployment parameter: transitioning from low floors to upper floors transformed near-complete communication failure into near-universal coverage at 500 m range in all tested cities. Third, building-to-building communication from upper floors achieved 75–100% PDR with RSSI values ranging from −55 to −110 dBm, supporting multi-hop relay architectures. Fourth, intra-building vertical communication remained reliable across 13 floors of reinforced concrete construction, enabling a data relay strategy from sensor floor to rooftop gateway. Fifth, natural terrain—particularly wet hillside soil and dense vegetation—is a more severe attenuator than urban building materials, causing complete link failure even at 150 m when obstructing the first Fresnel zone.

Based on these findings, the following deployment recommendations are offered: (1) position mobile collection gateways on upper floors or rooftops of tall buildings with broad angular exposure; (2) configure devices at SF11, 22–23 dBm, 125 kHz bandwidth for optimal range-to-battery-life balance; (3) use digital elevation models and Fresnel zone analysis during pre-deployment network planning; (4) implement a vertical relay strategy within multi-storey buildings rather than requiring each floor to maintain an independent external link; and (5) in terrain-dominated environments such as Wellington, plan for direct links between buildings on ridgelines rather than across valley floors.

Future work should address antenna selection and orientation optimisation, energy-efficiency strategies including duty-cycle management and adaptive spreading-factor selection, integration and testing with Canterbury Seismic Instruments hardware and binary seismic data streams, data compression and corruption detection for seismic waveform payloads, and extended testing across varied weather conditions and building construction typologies.

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