The Open Seismometer Network as a Collaborative P2P Infrastructure that is Scalable, Distributed and Robust

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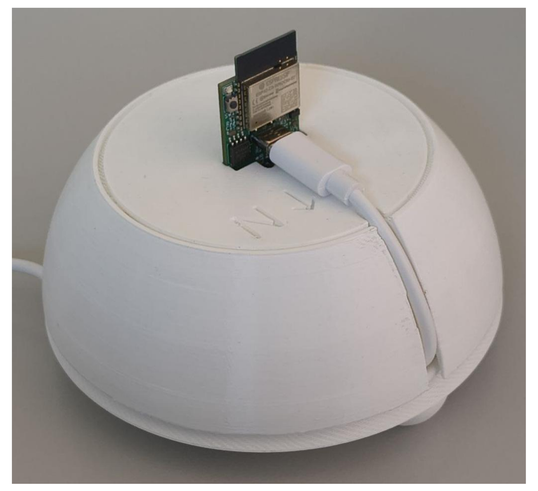
Introduction

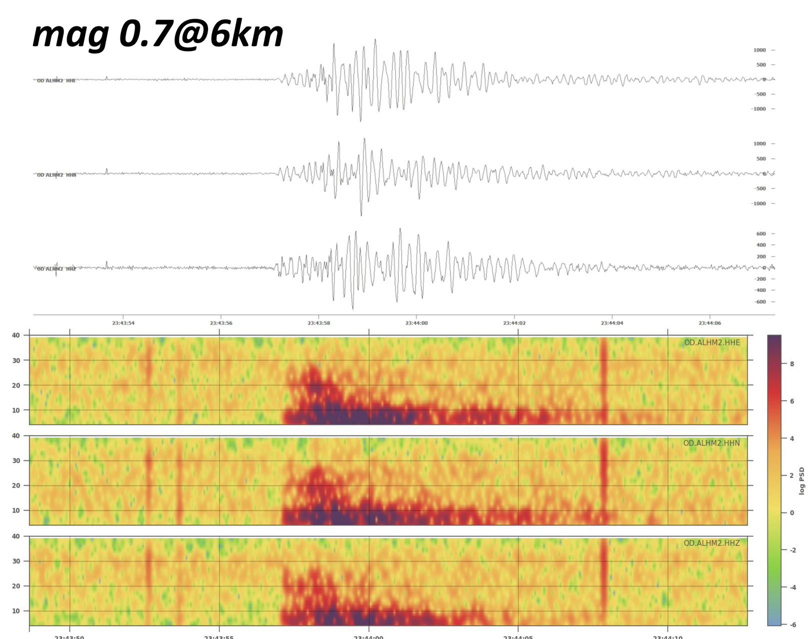
In today's seismic network infrastructures, deployment and permanent storage are increasingly constrained by the rising costs of traditional commodity hardware, especially RAM and SSD shortages driven by the growing demand for AI-related enterprises. In this context, we have taken the challenge to improve upon our last year's network proposal [1] by moving from a centralized architecture to a novel distributed peer-to-peer (P2P) model. The goal is to improve resilience, scalability, data continuity and integrity and to facilitate sharing seismic records among institutions, researchers & the general public.

Open Seismometer design



The ultra-low-cost seismic sensor is designed to deliver a performance approaching that of broadband instruments by remaining modular, simple, and robust. Its architecture avoids the dependencies and variability of large operating systems, instead being optimized for rapid wireless data extraction.

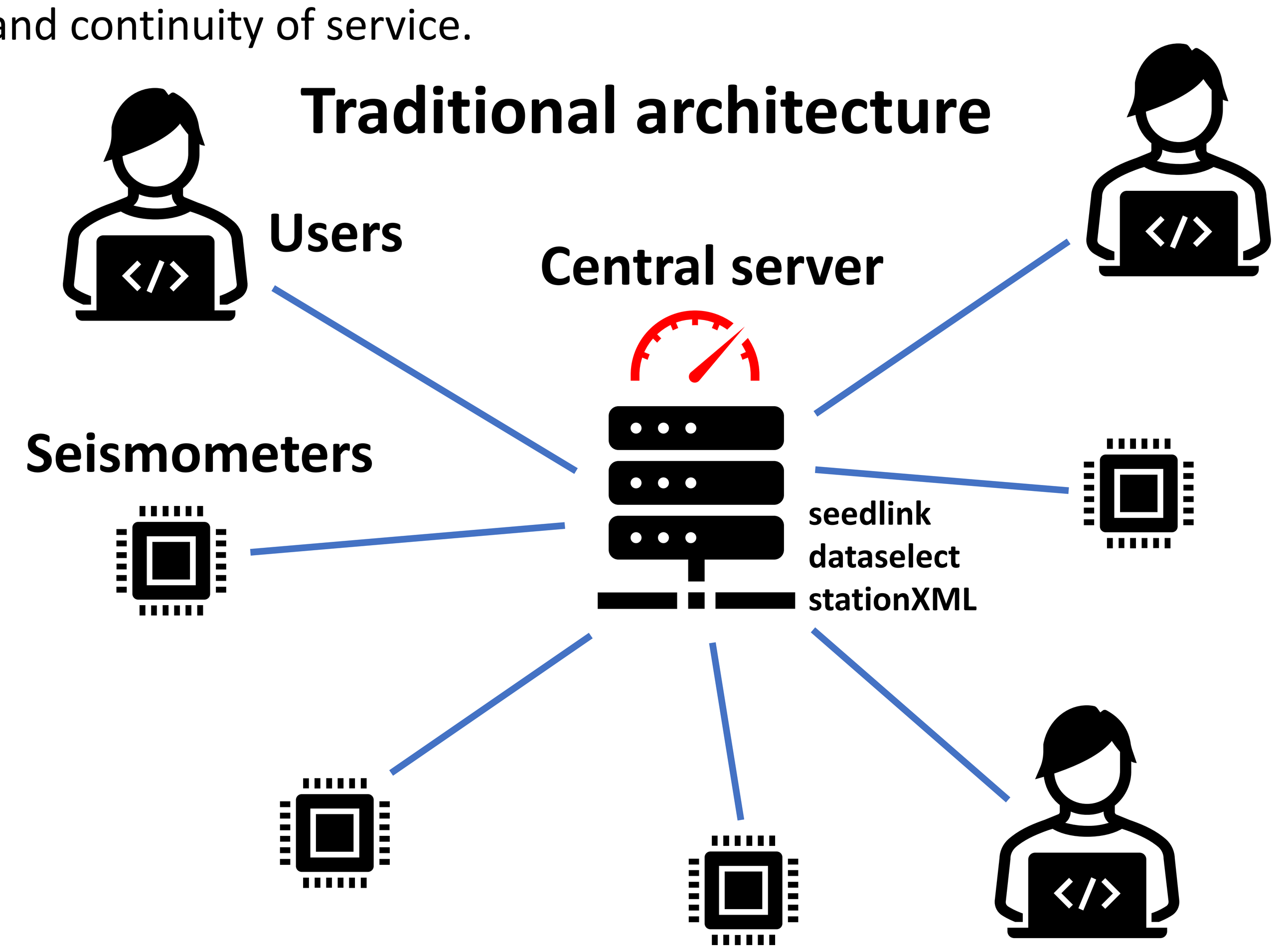
Because the device is inexpensive and easily replaceable, it can be deployed in dense networks, helping to capture many small seismic events that are often missed or cannot be located by conventional sparse instrumentation. The increased coverage, even in noisy environments, can thus provide a more complete view of Earth's real seismic activity.



Three-component record seismogram/spectrogram from a 0.7 magnitude earthquake registered within an epicentral distance of 6km by an OpenSeismometer station located in Alhama de Murcia (Spain).

Distributed Seismic Infrastructure

A collaborative architecture based on peer-to-peer principles can distribute the workload across both servers and users. Instead of concentrating all storage, processing, and data delivery on a single overloaded server, seismic data can be propagated through a dense network of interconnected nodes. If one link or node fails, alternative paths remain available, providing greater redundancy, fault tolerance, and continuity of service.

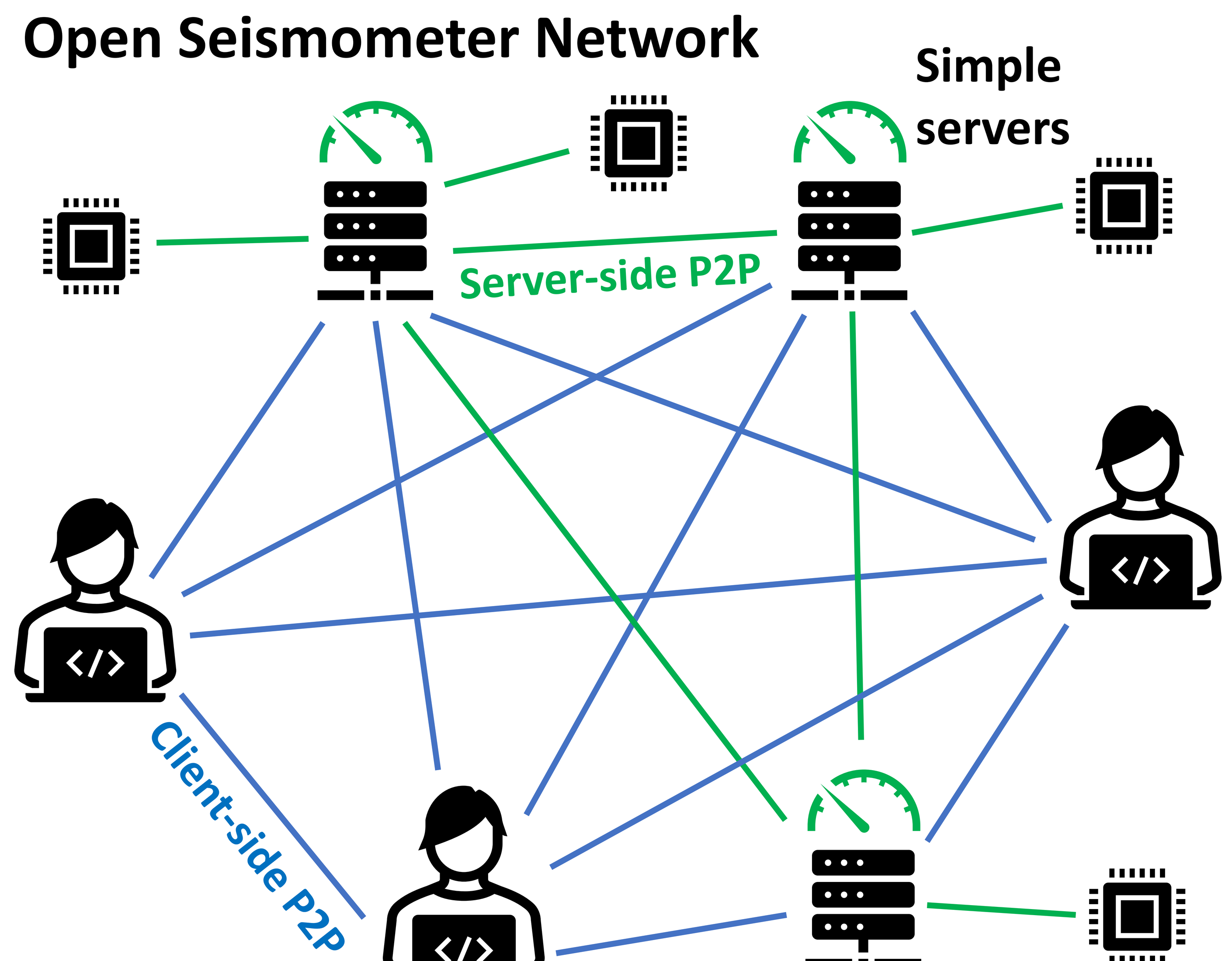


The new approach (right panel) can operate at two complementary levels: On the server side, P2P mechanisms support efficient data retrieval, synchronization, and propagation between seismic data nodes. On the client side, users can also contribute to archive storage and data sharing, reducing repeated downloads from central services. Together, both layers help balance the load among all participants, making the infrastructure more scalable, resilient, and suitable for serving real-time seismic waveforms to a large user community.

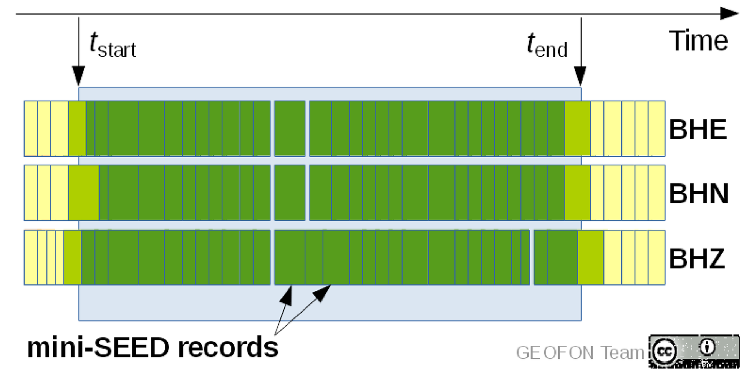
Data onboarding is a critical part of seismic infrastructure, traditionally solved with VPNs or centralized password/token authentication. Instead, we propose a decentralized public/private key architecture where every packet sent by the seismometers is signed at origin with a key that is unique and private to each device, thus ensuring end-to-end data integrity and authenticity even in a public distributed network.

Thanks to an efficient real-time distribution scheme based on the latest ringserver seedlink [4], seismic waveform data can be served in real time in both miniSEED 2 and miniSEED 3 formats. This dual-format capability ensures compatibility with modern data workflows while preserving support for existing legacy seismic networks, allowing institutions to maintain operational continuity without requiring immediate changes to established acquisition, processing, or distribution systems.

Seismic data archival is implemented through the InterPlanetary File System IPFS [2], a distributed network for content-addressed storage that splits files into addressable chunks that naturally match the packetized nature of seismological data streams. Notably, existing IPFS "web gateways" can be used to easily access/redistribute data through standard web browsers and client-side visualization with SeisPlotJS [3].



A unified dataselect/stationXML service can provide a single access point for waveform data and station metadata while moving beyond the limitations of traditionally centralized FDSN web services [5]. By reshaping these services around a distributed architecture, using an IPFS content addressing scheme, data requests can become much more selective and efficient: servers can retrieve only the waveform packets and metadata they need, rather than relying on a single central copy of the entire seismic archive.



In this system, each node just needs to store a small fraction of the network data, such as the stations it operates or mirrors. No individual node needs to contain the complete archive, which facilitates redundancy and resilience. At the same time, the system can distribute real-time waveforms to a large body of users, supporting modern seismic data access while reducing the load on critical infrastructure.

Conclusions

The proposed architecture enables the deployment of a modular, scalable and sustainable seismic infrastructure designed for both real-time access and long-term archival. Its structure allows all institutions to share data and resources simultaneously without placing the full technical burden on a single organization. This can benefit different types of users:

- Scientific and governmental institutions requiring SeedLink services, data archives or advanced software tools [6,7,8].
- Early warning networks that need continuous and reliable access to seismic data and connect it to people in real time.
- Citizen science projects to facilitate communicating seismic information to society and for educational purposes.

Robust long-term archival ensures that seismic records can be reused in the future for research, catalogue revision, new detection methods and improved seismic monitoring.

In an era where technology keeps becoming increasingly centralized and subscription-based, building open research infrastructures is more important than ever. The Open Seismometer Network connects modern low-cost instruments with effective seismic networks, helping create a truly open and sustainable environment for seismic research.

References

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Acknowledgements

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