Earthquake Early Warning Instrumentation and Efficient Workflows

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Abstract

To optimize earthquake early warning (EEW) systems, much can be learned from existing and industry proven EEW solutions and how they can be efficiently deployed with high quality ground motion seismic stations capable of delivering the highest fidelity and low latency data sets to the processing data centers' detection algorithms. Specifically, public safety EEW systems require strict service level agreements (SLA) with regards to overall uptime, prompt arrival of high quality data, and issuance of accurate and timely warnings. This can only be achieved via the proper definition and selection of sensors, dataloggers, power systems and communication systems. Also, when planning EEW Networks it is important to consider the end-to-end workflow, from system definition and roll-out, through to network operation, maintenance and ongoing validation to ensure the system continues to satisfy its mandate. Deployment of an EEW system can represent a significant challenge to monitoring agencies, but leveraging proven implementations and technology partners can greatly reduce the associated risk and implementation timeline.

Strong Motion | **Telemetry** | **Software** | **Timely** | **Quality Data** | **Turn-Key**

Discussion

Richer Catalog of Events to Inform Science

Complete Data Set

Combined Strong & Weak Motion Instrument

The selection of instrumentation is critical especially when the seismicity amplitude range at a site is unpredictable

- ★ Deploy stations with both a low self-noise seismometer and an accelerometer with a high clip level to maximize dynamic range
- ★ A rich event catalog, produced via broadband monitoring with low noise seismometers, allows improved fault delineation for seismic hazard mitigation
- ★ To minimize the development cost, consider integrated units that have the added benefit of simplifying the installation with one hole to dig, a single cable, and which the mutual alignment is guaranteed by the manufacturing process

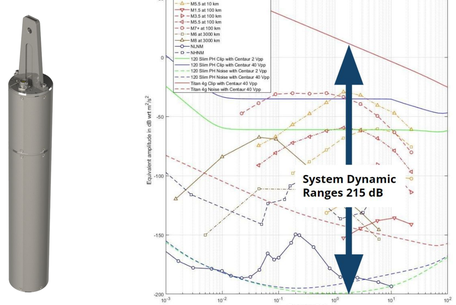

Figure 1: On the left is an image of the Cascadia 120 Slim Posthole sensor, which combines a seismometer and a class A accelerometer. On the right is a plot of the self-noise, clip level and dynamic range of Cascadia 120 Slim and sample event spectra. (John F. Clinton, Thomas H. Heaton; Potential Advantages of a Strong-motion Velocity Meter over a Strong-motion Accelerometer. *Seismological Research Letters* 2002;, 73 (3): 332–342)

Complete Datasets

Redundant Data Processing

End-to-End Waveform Data Delivery

Data path redundancy may be implemented at each stage to maximize data completeness

- ★ Dual, active-active telemetry routes from each monitoring station
- ★ Multiple, geographically redundant data centers, each independently receiving station data
- ★ Dual, redundant acquisition and processing tool chains within each data center

Figure 2: Mission-critical systems requiring multiple layers of redundancy (8 in the example) to achieve maximum data completeness may be implemented efficiently and cost-effectively with NP protocol multicasting

Timely Alerts

Robustness and Efficiency

Adaptable data acquisition protocol

EEW systems perform best when using protocols that provide the right configurability to optimize key network performance metrics.

- ★ UDP-based data acquisition benefits from less packet header overhead vs TCP (>20% increase in transmitted data when using TCP/Seedlink)
- ★ System provides the ability to prioritize the transmission of live packets over packet retransmissions
- ★ IP multicasting provides support for high availability / redundancy in streaming architectures without the cost of additional network bandwidth
- ★ Data transmission can be throttled to protect against saturation of bandwidth-constrained telemetry links, and ensure capacity for command and control traffic
- ★ Data latency can be minimized by reducing packet size

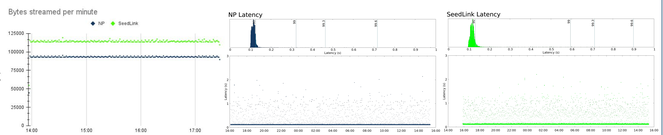

Figure 3: The plots show the significant bandwidth improvement of using Nanometrics NP Protocol over UDP to reduce bandwidth usage and latency.

Maximize Real-Time Waveform Availability

Data Delivery Stress Testing

End-to-End peak data delivery simulation

Heavy shaking associated with large earthquakes results in sudden spikes in bandwidth demand. Confidence in EEW system performance during these events may be maintained by simulating large earthquakes using appropriate fleet management tools and system performance dashboards.

- ★ Modify the data compression of multiple stations in a single operation.
- ★ Evaluate acquisition performance via data availability and latency performance dashboards

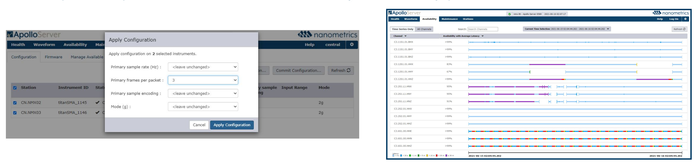

Figure 4: The image on the left shows the Apollo Server Fleet Management interface for batch configuration of multiple stations, which may be used to execute a network bandwidth stress test. The image on the right shows the Apollo Server dashboard for monitoring acquisition system performance, which presents data completeness and latency over time.

Maximum Uptime

Enhanced Monitoring

Workflow Automation

It is important to quickly determine if equipment is online/offline; a common interface for health monitoring of instrumentation and networked devices using industry standard tools is powerful.

- ★ Simple Network Management Protocol (SNMP) enabled network devices allow operators to easily track network uptime metrics
- ★ Integration is simplified by using industry-standard monitoring tools such as Nagios®, SolarWinds®, or others.

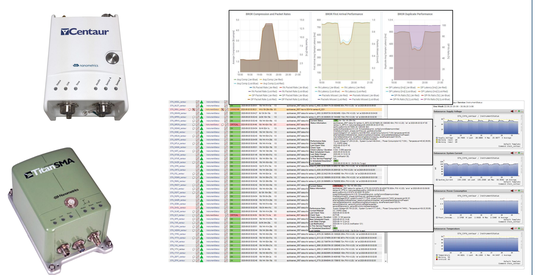

Figure 5: Centaur and TitanSMA, on the left, provide SNMP support. The screen capture on the right shows how state-of-health information can be integrated into custom dashboards to monitor any aspect of system performance.

Standardize Deployments

Turn-Key Solutions

Field proven Strong Motion Station

Operators should be allowed to focus on their program's core vision and mission and reduce the effort and risk of delivering EEW systems by using turn-key solutions that deliver key capabilities

- ★ High fidelity and low latency data acquisition
- ★ Network security with site-to-site encrypted virtual private networks
- ★ Pre-configured power systems with battery back-up and charging systems
- ★ Services for station site selection and field installation

Figure 6: These photos show turn-key strong motion systems provided by Nanometrics for EEW networks.

Conclusion

Earthquake Early Warning systems are critical to seismic loss mitigation programs. In the above, we described a number of key considerations when designing a system and how industry proven tools can enable organizations to more easily implement EEW systems that will deliver Complete Data Sets via Redundant Communications, with Robustness and Efficiency. Also described is the importance of the supporting workflows that enable Enhanced Monitoring and continuous validation via periodic Data Delivery Stress Testing to ensure the systems will deliver at the critical moment when they are needed most.