# Mission-Critical Real Time Data Acquisition: An Earthquake Early Warning Case Study

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## Abstract

Ensuring the reliable acquisition of real time seismic data from remote monitoring stations is an inherently challenging task. Stations are often in isolated locations with little to no supporting infrastructure, creating limitations on power and communications systems which demand design tradeoffs. When the data is driving mission-critical public safety systems, such as Earthquake Early Warning (EEW) networks, real time acquisition performance is of critical importance.

In particular for EEW, acquisition performance must be measured not only in real time data availability, but also data latency and bandwidth utilization. Beyond these key performance metrics, it is critical that the system is robust, with layers of redundancy to ensure continued operation in the event of a damaging earthquake. A comprehensive system test and acceptance program is needed to ensure performance requirements are met and to have confidence the system will function as intended at the critical moment.

This study examines the factors considered, the approaches taken and the outcomes in the design and implementation of a real time acquisition system for the Israeli National EEW Network, TRUAA.

## Introduction

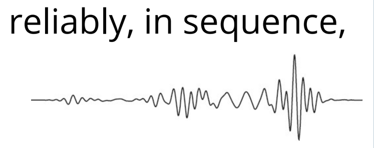
### Definitions

Mission-Critical: Essential to the operation of a system. Without it, the system simply can not function.
Real Time: Operations with guaranteed response times. It's not good enough to just come up with the correct result - it has to be done on time or not at all. The threshold for what is considered real time can vary depending on the application.
Data Acquisition: Transfer of remotely generated data, in a geographically distributed monitoring network, from the remote stations to a central location for processing.

Examples in Seismology:
- National seismic networks with reporting mandates
- Tsunami warning systems
- Induced seismicity traffic light networks
- Earthquake Early Warning (EEW) networks

### Performance Metrics and Design Considerations

Data Availability / Completeness
- The data is available and complete where it needs to be, which is assured via the continuous and reliable operation of a robust system with layers of redundancy. Data must arrive reliably, in sequence, to avoid resetting pickers and continuous waveform processing modules.



Latency
- The data arrives in time to be able to do what is needed to be done with it by the time that result is required. This drives technology decisions based on telemetry speed, as well as decisions regarding how data is prepared and packaged for transport. In the acquisition of seismic data, encoding choices have a major impact on average sample latency.

Bandwidth
- How much bandwidth is needed to achieve the required performance since, for many telemetry options, especially satellite communications, this can be considered a proxy for cost.

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## TRUAA Project Overview

**Client:** Geological Survey of Israel
**Project:** National Earthquake Early Warning Network - TRUAA
- 121 strong motion monitoring stations and 2 data centres
  - 24 stations with co-located broadband sensors
  - 9 stations with co-located GNSS receivers with SDB Monuments
- Full turnkey system supply and deployment
- Execution start: May 2017
- Full EEW Operation: February 2022

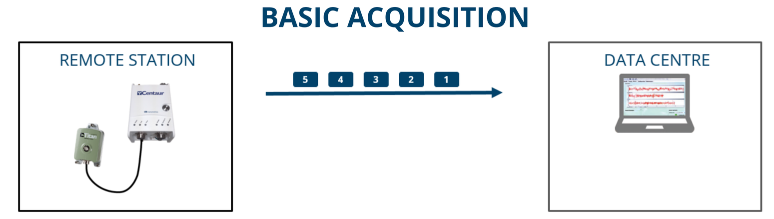
**Prime Contractor:** Nanometrics
- Partnered with Motorola Solutions Israel

## TRUAA Acquisition System

### System Requirements

As a national public safety system, the GSI set out a detailed list of close to 300 requirements defining a robust system with layers of redundancy throughout. Many requirements were directly related to or impacted data acquisition, including the requirements for two data centres, redundant acquisition servers within each data centre and two active-active telemetry routes from each station.

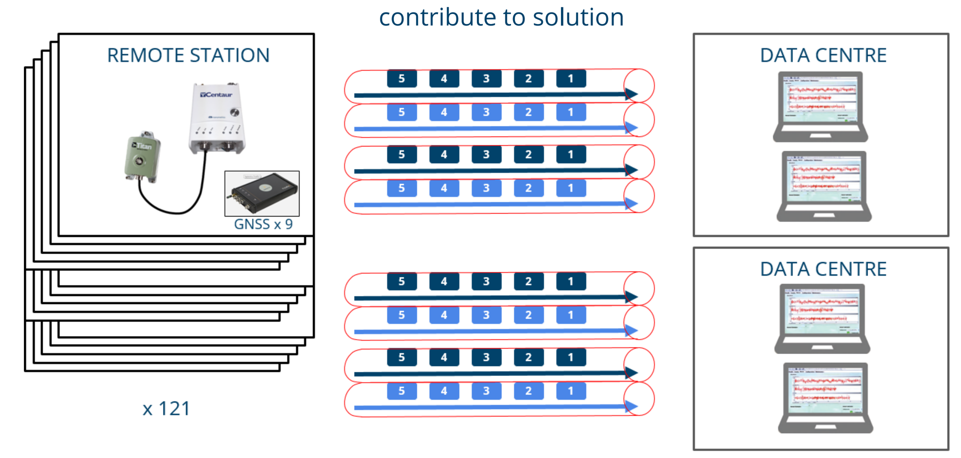
BASIC ACQUISITION




**Key Acquisition Requirements**
- Two alternative telemetry routes from each station (8.1)
  - Main route with Telemetry Latency < 1 s for 99% of packets (8.8)
  - Back up route with Telemetry Latency < 3 s for 99% of packets (8.8)
- Preference for existing communication infrastructure (landlines, cellular, etc.) (8.5)
- Subset of stations (29) must use satellite (8.6)
- Two geographically separate redundant data centres (11.7)
  - Dedicated symmetric high capacity line between data centres (8.11)
- Redundant acquisition within each data centre (11.3)
- Both routes to be transmitted to the main data centre (8.9)
- Automatic failover to backup data centre (8.10)
- Bandwidth (8.13)
  - Greater than 2 x baseline data rate
  - Greater than 1.5 x uncompressed data rate
- Private and dedicated telemetry routes (8.12)
- Secure, authenticated communications (14.3, 14.6, 14.11)

ROBUSTNESS REQUIREMENTS

**TRUAA ACQUISITION FUNCTIONAL REQUIREMENTS**
8 opportunities for each packet to contribute to solution

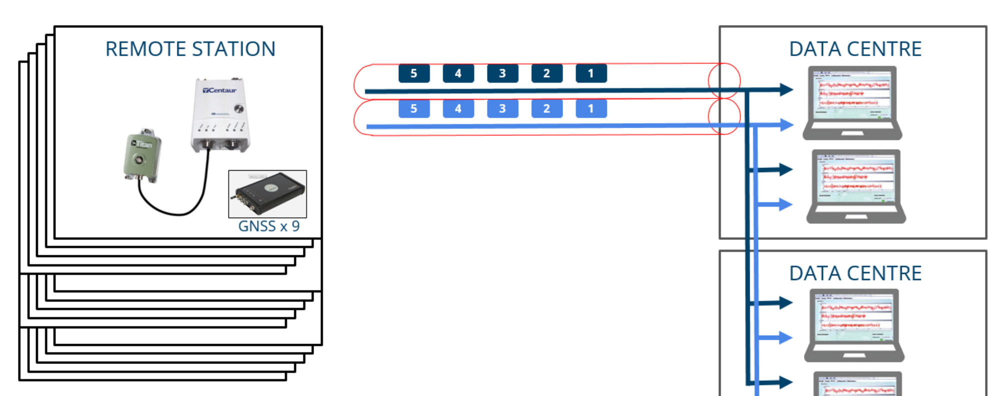



Abstracted view of a "basic acquisition" strategy to meet all requirements, yielding eight separate channels per station and prohibitively expensive operational cost (bandwidth).

### System Architecture

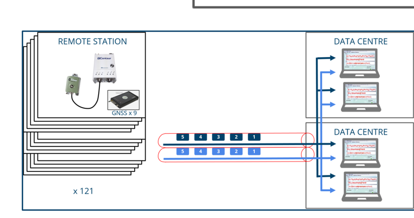
Network Backbone: Partner Communications dedicated Virtual Routing and Forwarding (VRF) Network
Telemetry: VDSL (preferred), Cellular, VSAT (2 of 3 from each station)
Protocol: Dual NP UDP Multicast streams from Centaur data logger
- Multicast: single packet routed to multiple destinations
- Bandwidth throttled for route telemetry
- Robust automatic gap recovery
- Unified acquisition of seismic, state-of-health and GNSS data

Network Security: Dual IPSec VPN Tunnels from remote sites to the main data centre
- Automatic failover to backup data centre



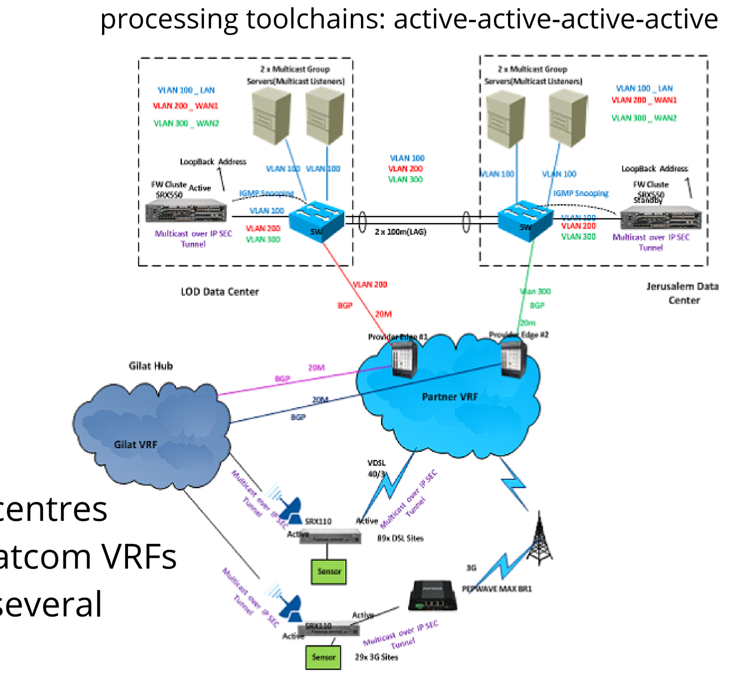

- Automatic Multicast stream forwarding to backup data centre
  - Independent of data acquisition and processing modules at main data centre
- Dual redundant front end acquisition servers at each data centre
  - Total of four independent acquisition and processing toolchains: active-active-active-active

Abstract view of the TRUAA acquisition system architecture, meeting all redundancy requirements while minimizing operational cost (bandwidth).




Failover data flow

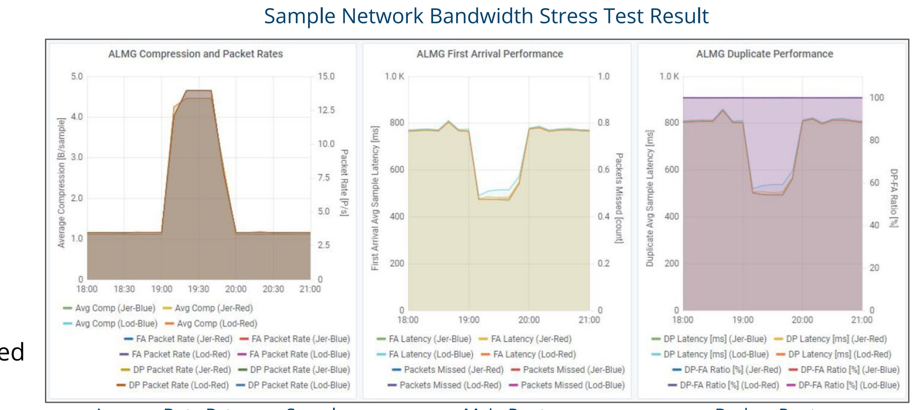
- VRF Network (private cloud)
  - Incoming traffic routed to one of two Provider Edge (PE) routers, each associated with a data centre
  - PE to data centre via dedicated fibre optic line
- Dedicated network security device at each station
- High capacity services gateway router at each data centre
  - Geographically distributed High Availability Cluster
  - Automatic failover to backup data centre gateway
- Two redundant high capacity fibre optic lines between data centres
- Two redundant fibre optic lines between Partner and Gilat Satcom VRFs
- Multicast routing over IPSec, and to backup data centre, via several protocols (OSPF, GRE, PIM, IGMP…)




## Implementation

When building a complex mission-critical real time acquisition system, it is important to plan a deliberate and layered implementation strategy, in which complexity is incorporated incrementally. For TRUAA, the following stages were used:
- Proof of Concept Integration Testbed – Nanometrics
- Live Network Integration Testbed – Partner Communications
- Main Data Centre Installation (Lod)
- Station Deployment Rollout
  - Equipment Staging Communications Test
  - Station Commissioning and Acceptance
- Backup Data Centre Integration
  - Equipment initially co-located with Main DC for side-by-side testing
  - Transferred to Jerusalem when the new facility was ready and retested
- Formal System Acceptance Test Program
  - 108 "test cases" in four major categories: Infrastructure Robustness, Functionality, System Security, Disaster Recovery
  - Included a Network Bandwidth Stress Test (NBWST), in which seismic data was streamed uncompressed, for the full network, to simulate (exceed!) the impact of a large event.

Sample Network Bandwidth Stress Test Result




Average Data Bytes per Sample and Packet Rate | Main Route Average Sample Latency and Packets Missed | Backup Route Average Sample Latency and Backup: Main Packet Count Ratio

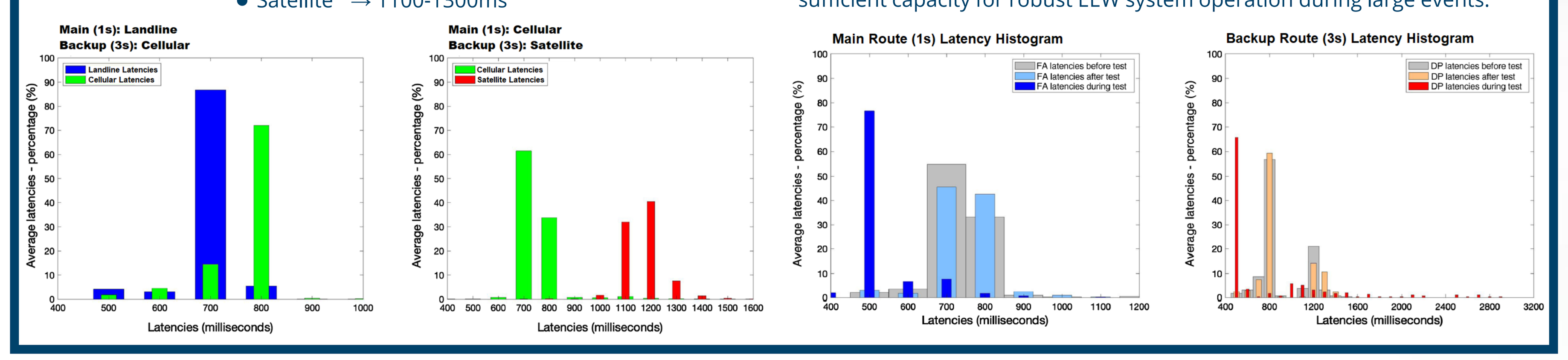
Test execution is confirmed by the average data bytes per sample and packet rate. Success is evaluated by average sample latency and data completeness. The NBWST requires digitizer support for uncompressed operation, batch configuration management and comprehensive acquisition performance monitoring.

## Performance

Key performance indicators, latency and data availability, were evaluated for a 30 day period for 98 stations. Data availability was found to be 99.86% overall, with outages generally due to digitizer reboots or station power issues, where there is no data to recover. Latency performance is below left.

Average sample latency for the 30 day period:
- Landline → 600-800ms
- Cellular → 700-850ms
- Satellite → 1100-1300ms

Network Bandwidth Stress Test Performance
Over 3 runs, with >20 minute tests, there was a 100% pass rate for Main routes and 94% pass rate for Backup routes (98.8% for run 3), demonstrating sufficient capacity for robust EEW system operation during large events.




## Summary

**Network Mandate => Performance Requirements**
Start with a clear mission statement that defines the mandate and purpose of the network. From this, specific and detailed performance requirements can be defined. For mission-critical real time data acquisition, these performance requirements are specified in latency and real time data availability.

**Technology / Instrument Selection and System Design**
Based on those requirements select the technologies and instrumentation that will achieve them, and design an acquisition topology with as much redundancy as needed to provide the necessary robustness and reliability. Consider cost, flexibility and scalability for future growth. Avoid single points of failure.

**Integrate Early and Often**
Take a layered and deliberate approach to implementation and integrating complexity into the system. Look for ways to de-risk today, what has to be done tomorrow. Small steps generally yield small problems - big steps can yield big ones!

**Invest in Test, and Test Tools**
Test to your requirements and make regression testing easy. It's not always easy to simulate the real world, but seek ways to be as representative as possible. Spend the time to build tools and test frameworks that will allow efficient repeat testing following major upgrades or as part of preventative maintenance program.

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