SEI 01 GeoNet: A Platform for Rapid Distributed Geophysical Sensing

SEI 01.1 People

- Principal Investigator: Paul Davis, Deborah Estrin
- Faculty: Paul Davis, Earth and Space Sciences, UCLA; Deborah Estrin, Computer Science, UCLA; John Wallace, Civil and Environmental Engineering; William Kaiser, Electrical Engineering, UCLA
- Researchers: Thanos Stathopoulos, CENS, UCLA; Derek Skolnik, CENS, UCLA
- Graduate Students: Martin Lukac, Computer Science, UCLA; Igor Stubailo, Earth and Space Sciences, UCLA; Dustin McIntire, Electrical Engineering, UCLA

SEI 01.2 Overview

The science objectives are to use a rapidly installable wirelessly linked seismic network to measure earthquake or volcano sources in the near field to understand the underlying physics, or in buildings to understand earthquake damage. To accomplish these objectives, we collaborated with Reftek to construct a new generation digital acquisition system (DAS) based on the CENS-developed LEAP (low-power energy aware processing) system and a newly developed low-power A/D converter from Texas Instruments (TI) that became recently available.

During the second year of GeoNet, one of the leading manufacturers of seismic recording systems, Refraction Technology, Dallas Texas, or Reftek, constructed several prototypes. They will be extensively tested in a field environment during a number of deployments.

In preparation for GeoNet, we have used the Mexico and Peru networks to test the software including improving Disruption Tolerant Shell (DTS), measurement of radio link quality (ETT), network logging, an embedded web interface based on Emstar for deployment and maintenance, network timing, a new routing protocol that caches the routes across sleep cycles for a fast startup. The Peru network has already been installed and we can add to it GeoNet nodes for further testing and debugging.

SEI 01.3 Approach

We used the Mexico and Peru networks as testbeds for GeoNet systems software research.

In anticipation of the GeoNet prototypes, a number of advancements have been made to the software system during the recent seismic deployment.

The field objective is to have only two separate parts: DAS and a seismic sensor. The DAS would have a solar panel attached on top, battery inside (with external power plug), internal GPS antenna (with a possibility attaching an external one), external N-type connector to attach an antenna. Field installation would involve attaching the box to a post and bury the seismometer (fig 1). It would then be a node in a wireless network of neighbors, e.g. along a dirt road that could bring event data out in real time, or, in the low power mode, on a duty cycle, e.g., 5 min every hour. The radios would also deliver network time, a backup to GPS.

In a building, the instrument would not need the solar panels, although after an earthquake power may be unavailable. Instrument plus Episensor (or other) would be installed on various floors. Radio connectivity through the floors would be used to provide network time (essential) and transport event data. Where available (e.g., near windows) GPS time would calibrate network time. With no solar energy available, the battery with an active sensor would last 4 days. Longer deployments would require a larger external battery.

We therefore suggested that in the spirit of the highly successful RefTek Texan instrument the GeoNet be 3 or 6 channels, have internal 12AH lead acid battery, internal GPS antenna with external plug as an alternative, passive instrument A/D interface (and/or Episensor interface), internal 802.11 radio with external antenna plug, external LEDs to signify functions (or LCD), attached external flash compartment, GPS and network time stamps with 0.1 ppm time precision, external sensor conditioner control-box for active sensors, Linux operating system, LEAP computer with sleep-wake modes compatible with CENS networking software, brick type ecnlosure (to allow stacking) with lip around plugs for protection, and screw holes for attached solar panel. External serial and ethernet/USB plugs.

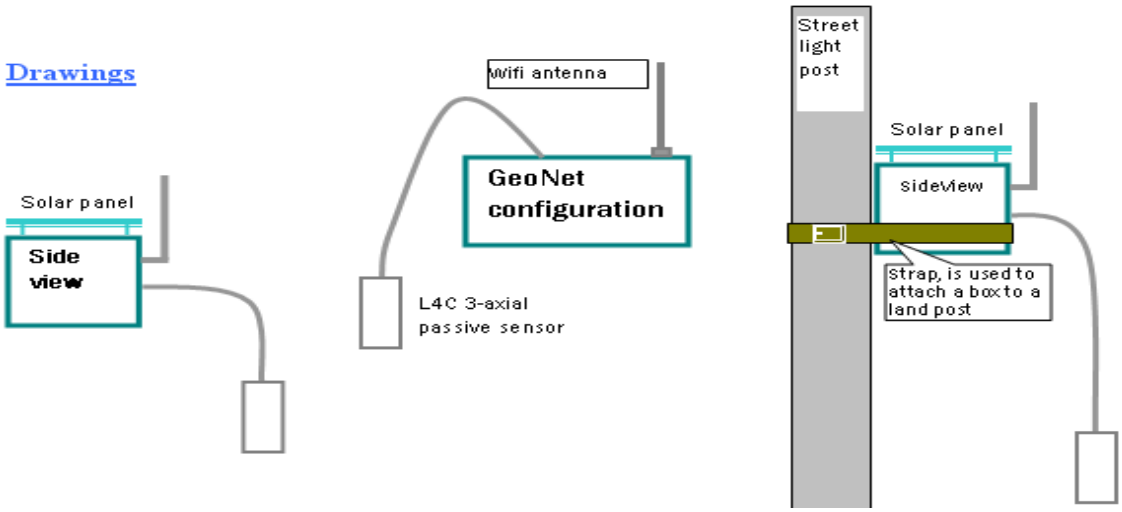

Fig.1. Schematics of possible field instalations. Reftek is expected to deliver several prototypes in March 2009:

The software design for the seismological community would include CENS networking, auto routing, and the low-power configuration ability of the hardware. To conserve power the processor will duty cycle between sleep and wake states.

Fig.2. A prototype of a GeoNet box with modular approach inside.

The node is based on the Linux operating system, with 802.11 capabilities for wireless networking. Software development is required for array-event detect, network and GPS timing, multi-hopping the data, and near real-time data analysis and modeling. The software system will be based on the infrastructure used in the Peru network. However, the existing software system is not directly applicable because of a number of factors introduced by the application requirements. These include duty cycling, non linear network topologies, array event detect, and the time span of the deployments. We are developing software to deal with these new factors, in particular: sleep schedule aware data delivery, disk space based routing, deployment tools, and integration with Wavescope to enable streaming, network processing, and cooperative event detection.

Disruption Tolerant Shell, A Case Study in Peru
In preparation for the Peru seismic deployment, we have improved the Disruption Tolerant Shell

(DTS) system used in the Mexico seismic deployment. In particular, we improved the efficiency of the underlying network service called statesync, lowering the total amount of traffic generated by DTS. Also, the routing protocol is improved to detect and eliminate routing loops.

We developed a new link quality estimation component for use in our deployments. Our previous link quality estimators were based on the ETX (expected number of transmissions) metric. While ETX worked well for our seismic and acoustic deployments, there were some issues with the stability and accuracy of the metric, which can be improved. These issues are well known and are solved with the ETT (expected transmission time) metric. The new component is being used in the Peru seismic deployment.

Network time synchronization has been well researched as a service. However, over the years we

have discovered that having a network time synchronization service is often not enough. Disruptions in the network, faults in nodes, and startup time can cause the network time synchronization service to not always be on. In that case, the system misses events or possibly results in incorrectly synchronized data. In the seismic deployments, the hardware used was able to properly timestamp the seismic data; however system logs and status were always based on node system time, which would be reset after a reboot.

We created a component, which addresses this problem for the Peru deployment and provides a framework for more robust time synchronization implementations in the future. It provides the ability to use multiple time synchronization services, each with different accuracies, overheads, and startup times. It also adds meta-data about the time synchronization protocol in uses and its estimated accuracy. Our first implementation of the enhanced time synchronization service is called Timekeeper and is being used in the seismic Peru deployment. It focuses on maintaining system time so that system log data is correctly time-stamped.

In our previous deployments, there was no persistent log recording system. DTS enabled the viewing of live log data but it did not provide the ability to save all the logs data from the entire network. Since it is impossible for someone to attend to the network all the time, we were unable to observe faults, status, and events through the logs well after they had happened. For this reason, we built a component to collect the logs periodically, compresses them, send them to the central repository using the same data delivery channels as used to seismic data.

We also added a web interface utilizing the existing Emstar web framework to help with site deployment and to make site maintenance visits easier by providing a simple and clear interface to relevant data. In addition, the new web interface can also be used to configure the seismic sensors (Q330).

We began work on adapting the base software system used in Mexico and Peru to GeoNet. GeoNet will be a heavily duty cycled system and the entire software system needs to be aware of the sleep scheduling in particular routing and data delivery. The existing software will probably work, but it will be inefficient causing a loss in the overall amount of data that can be delivered. We began adapting the routing to have a fast startup after a sleep cycle with a fast and reliable route confirmation mechanism. The new routing caches the routes across sleep cycles for a fast startup.

While time synchronization in our software system does work, there were components that were missing and incomplete, for the GeoNet project. These components synchronize an RBS network time with that of a GPS. This is important for GeoNet because the system needs to be aware of the true length of a second to properly record data and enable it to be referenced to external systems.

SEI 01.4 System(s) Description and/or Experiments
The best experiment for GeoNet is an afterschock deployment, but it could also cover any seismic experiment where rapid deployment is necessary (volcanoes, explosions of opportunity). A pool of identical instruments would be available to either install in buildings or in the field and could be standalone or where appropriate nodes in a

wireless network. The objective is to measure strong shaking from the largest aftershock for both science and engineering objectives. The GeoNet/SHM requiremenets have much in common, but there are differences. Building installations do not have access to GPS time, may or may not have power. Field installations, being remote and widepread, need power. Building sensors tend to be active (Episensor). Field installations can have passive sensors, requiring significantly less power. We are going to test 2 GeoNet stations with passive sensors (L4-C) in the Salton Sea area (California) for a week in April during a gephysics field trip. This will allow us to further improve the case design and user interface.

We also will test some units in our Peru network. They will be mixed with high quality broadband Guralp 3T sensors and nodes running DTS software. We will be comparing data quality and the behaviour in a larger network while having the real time access to the sites. The final topology on the sites in the Peru deployment is illustrated in the (fig.3).

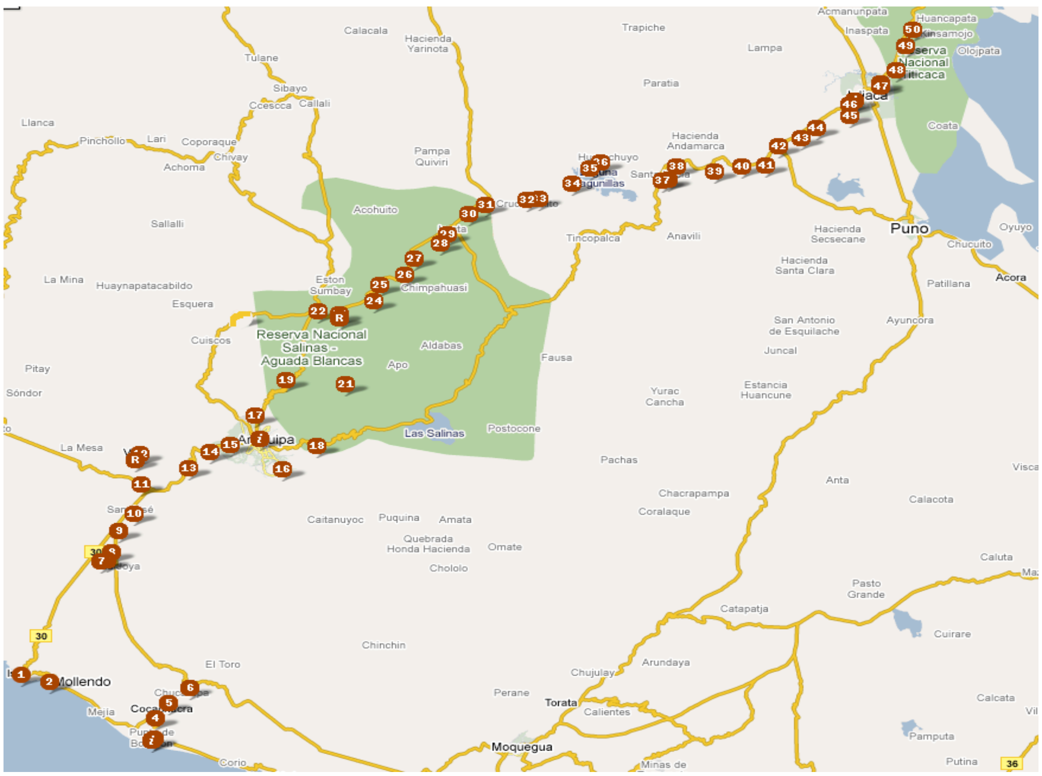

Fig.3. Peru network as of February 2009.

SEI 01.5 Accomplishments

The new communication and data collection software was tested and installed on the CENS data communications controllers during the seismic deployment in Peru. A number of posters were presented about different features of system (software and hardware) at the AGU-2009 meeting as well as papers published. A contract for Reftek construction was signed and several prototypes will be delivered soon.

Martin Lukac, Igor Stubailo, Rob Clayton, Paul Davis, Deborah Estrin (2008), “Correcting time offsets in seismic array data using noise correlation: Examples from a seismic array installed across Mexico”, EOS Trans. American Geophysical Union, 89(53), S43D-1923

Martin Lukac, Paul Davis, Robert Clayton, Deborah Estrin, “Recovering Temporal Integrity with Data Driven Time Synchronization”, Information Processing in Sensor Networks, 2009. IPSN 2009. To appear 8th International Symposium on

SEI 01.6 Future Directions

We will continue working on integrating duty cycling with existing software based used in Mexico and Peru. This includes further developing a robust routing algorithm that can deal with nodes with limited storage space with a complete a centralized method to dynamically schedule duty cycling and transmissions.

We will develop software to deal with sleep schedule aware data delivery, disk space based routing, as well as tools for network processing and cooperative event detection. The GeoNet instruments will have application over a wide range of field applications involving wide area networks and low power processing and delivery of event data. They will run on small batteries with a laptop sized solar panel. We expect delivery of the GeoNet nodes in March 2009. They will be tested during a week-long geophysics field trip in April.

SEI 01.7 External Research Partnerships

- Refraction Technology, Dallas Texas
- Paul Passmore, Phil Davidson