Out of the Fog:

Use Case Scenarios

Industry	Energy-Civil-Environment Industry
Application	Real-time Subsurface Imaging

"Performing important decisions and analytics inside fog nodes – instead of waiting until all information is sent to the cloud – helps real-time monitoring systems obtain reliable and timely data for making decisions."

Dr. WenZhan Song
Director of Sensorweb Research Laboratory
University of Georgia

Executive Summary

Subsurface imaging and monitoring in real time is crucial for understanding subsurface structures and dynamics that may pose risks or opportunities for oil/gas exploration and production, civil infrastructure, etc.

A sensor array deployed on surface that computes and illuminates subsurface dynamics is essentially a subsurface camera and camcorder. This camera requires access to compute resources (storage, communications, applications, etc.) that are most efficiently provided by fog nodes.

Fog computing is the key enabling technology for this subsurface imaging and monitoring.

Challenges	• Large-scale networks of high-fidelity sensors • Data intensive computing • Limited resources including energy, bandwidth and computing • Provision of real-time subsurface imaging for timely decision-making • The environment must be resilient to nodes failures
Solution	• Fog nodes discover each other to self-form mesh networks • Fog nodes perform certain stream data processing tasks • Fog nodes communicate with each other to compute the subsurface image in the network • Fog computing algorithm is resilient to packets and nodes disruption/loss • Fog computing network is self-adaptive to the energy and bandwidth changes • Fog computing network transmits only important and final images for decision making
Technology	• Fog computing architectural approach for subsurface imaging and monitoring

Fog computing is the key enabling technology of Real-time Subsurface Imaging

Background

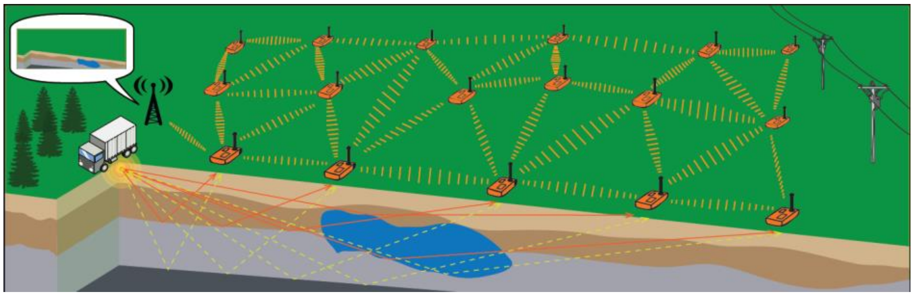
Oil and gas exploration is largely an inefficient and time-consuming process. Surface seepages that occur only over a small proportion of deposits are sought after by prospectors because they are an indicator of underground reserves.

Today, this traditionally expensive and painstaking activity can be accomplished by real-time subsurface imaging. Imaging allows more efficient management of fields and better evaluation of exploration prospects. This reduces the need to drill numerous exploratory wells, thus saving money and minimizing environmental damage.

Subsurface exploration and monitoring requires hundreds to thousands of seismic sensors in order to generate a high-resolution seismic imaging. Today, seismic data is digitized and stored in a local SD-card/ hard-disk at each station. The images are then manually retrieved to a central server for post-processing and seismic imaging. The whole process may take months to complete and the deployment and maintenance cost is very high.

New wireless data acquisition systems can retrieve data from sensors to a server wirelessly. However, they cannot handle large-scale deployment; each sub-system is limited to small-scale deployments along a wire line. Further, the systems require heavy maintenance, such as replacing the batteries every month or so. Because data is collected and processed in a backend server, the infrastructure is expensive to set up.

Breakthrough Technology with Fog Computing



Real-time In-situ Subsurface Imaging (RISI), a technology developed by Sensorweb Research Laboratory and commercialized through Intelligent Dots, monitors and maps subsurface geophysical structures and dynamics in real time, enabled by fog computing algorithms. A RISI system is a wireless seismic network that senses and processes seismic signals, and computes 3D undersurface structures in-situ in real time.

Instead of collecting data to a central place for post-processing, the distributed seismic data is processed and inversion computing is performed in the in-situ network. The evolving 3D image (i.e. 4D imaging) is computed and delivered in real time for visualization.

This approach can detect the naturally occurring low-energy seismic noise emitted from a reservoir during hydraulic fracturing stimulation. It provides real-time awareness (<1 second) of hydraulic fracture operations in unconventional oil and gas plays.

Fog nodes increase the efficiency, cost and processing speed of the entire monitoring and mapping process, reducing the process from days (or weeks or months) to seconds with low deployment and maintenance costs. The fog-based approach is autonomous, self-healing and self-sustainable, and requires no interventions during operations.

Each fog station is equipped with a smart energy management module with its own solar panel and rechargeable battery for a perpetual lifetime. Intelligent fog computing and networking techniques distribute the data processing and inversion computing load among all the stations within the bandwidth and energy resource constraints of the network.

To minimize the risk of data loss from real-time information retrieval in remote environments where connectivity is intermittent, this approach uses fog nodes to collaboratively utilize the limited communication, energy and storage resources to combat network disruptions and maintain reliable operations.

Performing important decisions and analytics inside fog nodes – instead of waiting until all information is sent to the cloud – helps real-time monitoring systems obtain reliable and timely data for making decisions.

Key Features Enabled by Fog Computing

- Real-time subsurface imaging

  The fog architecture monitors and maps the subsurface geophysical structures and dynamics in real time. Instead of collecting data to a central place for post-processing, distributed seismic processing and imaging algorithms are performed in the in-situ network in real time. This generates the constantly evolving 3D seismic image for visualization.

- Self-adaptive and fault-tolerant

  The fog network has built-in self-forming and self-healing capabilities. When more stations or events are added, fog processing and computing will self-adapt to compute higher resolution images with higher accuracy. With fog, the failure of partial networks will not break down the whole system.

- Reduced cost and risk of E&P process

  Fog is the first system that can provide real-time (<1 second) monitoring of the uncertainty inherent in the Exploration and Production (E&P) process. Fog helps oil and gas companies understand how the reservoir responds to stimulation and its impact on customer economics. This reduces operations costs and mitigates environmental risks.

- Plug-and-play, autonomous and scalable

Fog node deployment is a simple plug-and-play platform; it take 10 seconds per station to deploy. The fog node will self-form a mesh network for autonomous sensing, communication and computing. More stations can be added to form larger systems – or removed to form smaller systems – with little interruptions to current processes.

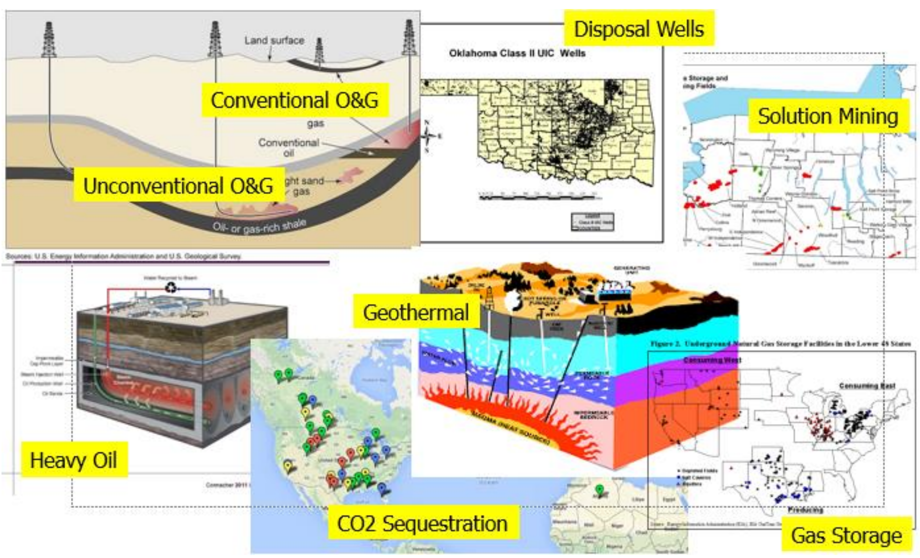
- Near-zero maintenance

The fog network is self-healing and self-sustainable, and requires no interventions during operations. Each station equips smart energy management modules including a solar panel and rechargeable battery. This achieves perpetual lifetime under normal weather conditions. The fog node can also be an add-on to commercial data loggers for seamless integration with existing systems.

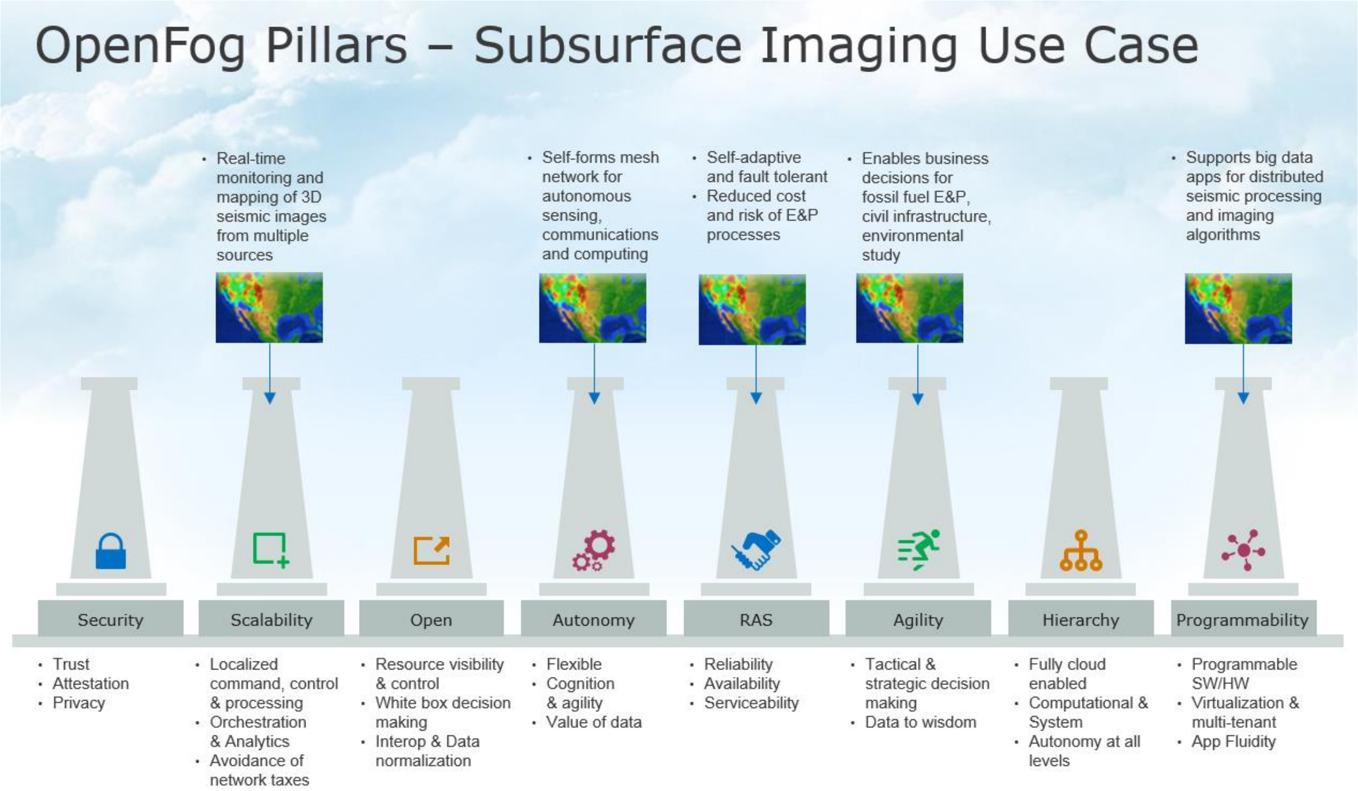
Business Applications

Business applications of real-time subsurface imaging are already emerging in these three segments:

1. Oil/gas exploration and production (E&P, for fossil fuels and for minerals)
2. Civil infrastructure and environmental study
3. Monitoring, hydrothermal, gas storage, groundwater well drilling and monitoring, etc.



An Architectural View



The 8 pillars of an open fog computing architecture. Source: OpenFog Consortium

What is Fog Computing?

Fog computing is a system-level horizontal architecture that distributes resources and services of computing, storage, control and networking anywhere along the continuum from cloud to things.

- **Horizontal architecture:** Supports multiple industry verticals and application domains, delivering intelligence and services to users and business.
- **Cloud-to-Thing continuum of services:** Enables services and applications to be distributed closer to things, and anywhere along the continuum between cloud and things.
- **System-level:** Extends from the Things, over the network edges, through the cloud, and across multiple protocol layers – not just radio systems, not just a specific protocol layer—not just at one part of an end-to-end system, but a system spanning between the things and the cloud.

The OpenFog Consortium

Real-time subsurface imaging is just one of many industry use cases whose commercial viability will depend on fog computing to achieve the rapid response, bandwidth and communication necessary in advanced digital applications.

The OpenFog Consortium is helping to enable game-changing innovation enabled by fog computing through an open architectural framework. ARM, Cisco, Dell, Intel, Microsoft and Princeton University founded OpenFog in November 2015. Today, the consortium has members throughout North America, Europe and Asia.

Learn more at www.OpenFogConsortium.org.