Global Multi-Scale Distributed Strain Sensing

Key Points:

- Climate change is accelerating the impact of geohazards
- Strain signals occur during and before hazard events
- There is an emerging vision for planetary scale strain monitoring
- Satellites, communication fibers, and fiber strain sensors
- Potential for global detection and prediction of hazards
- Cloud technologies are crucial for deployment
- MoMacMo is working on low-cost sensors and cloud-based systems for acquisition, processing, and monitoring of geohazard strain signals

Geologic Hazard Monitoring and Prediction

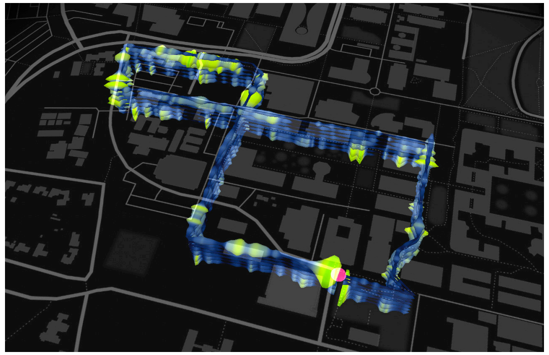
- Earthquakes
- Volcanic eruptions
- Landslides
- Glacial outburst
- Subsidence
- Pipeline leaks



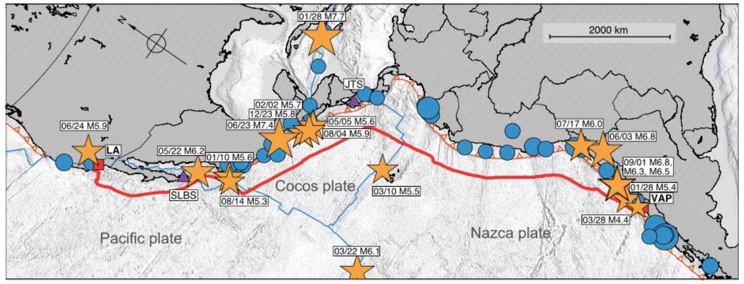

Using communication fibers for strain monitoring

- An active subject in academia
- U Calgary city fiber monitoring (Rob Ferguson)
- Stanford used fibers on campus to detect earthquakes
- Berkeley used a seafloor dark fiber for DAS
- UCLA used Google's Cirrus fiber in transmission
- UW Madison has proposed "Internet Photonic Sensing"

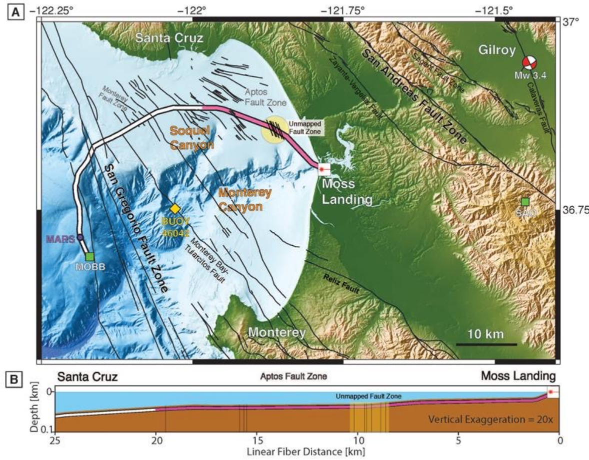
Stanford DAS



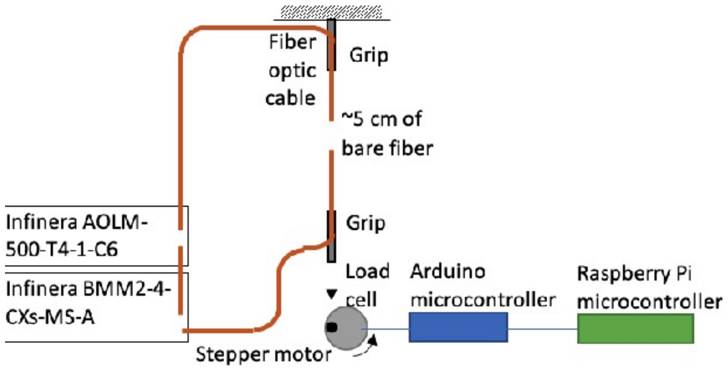
Google-UCLA Cirrus Fiber Monitoring

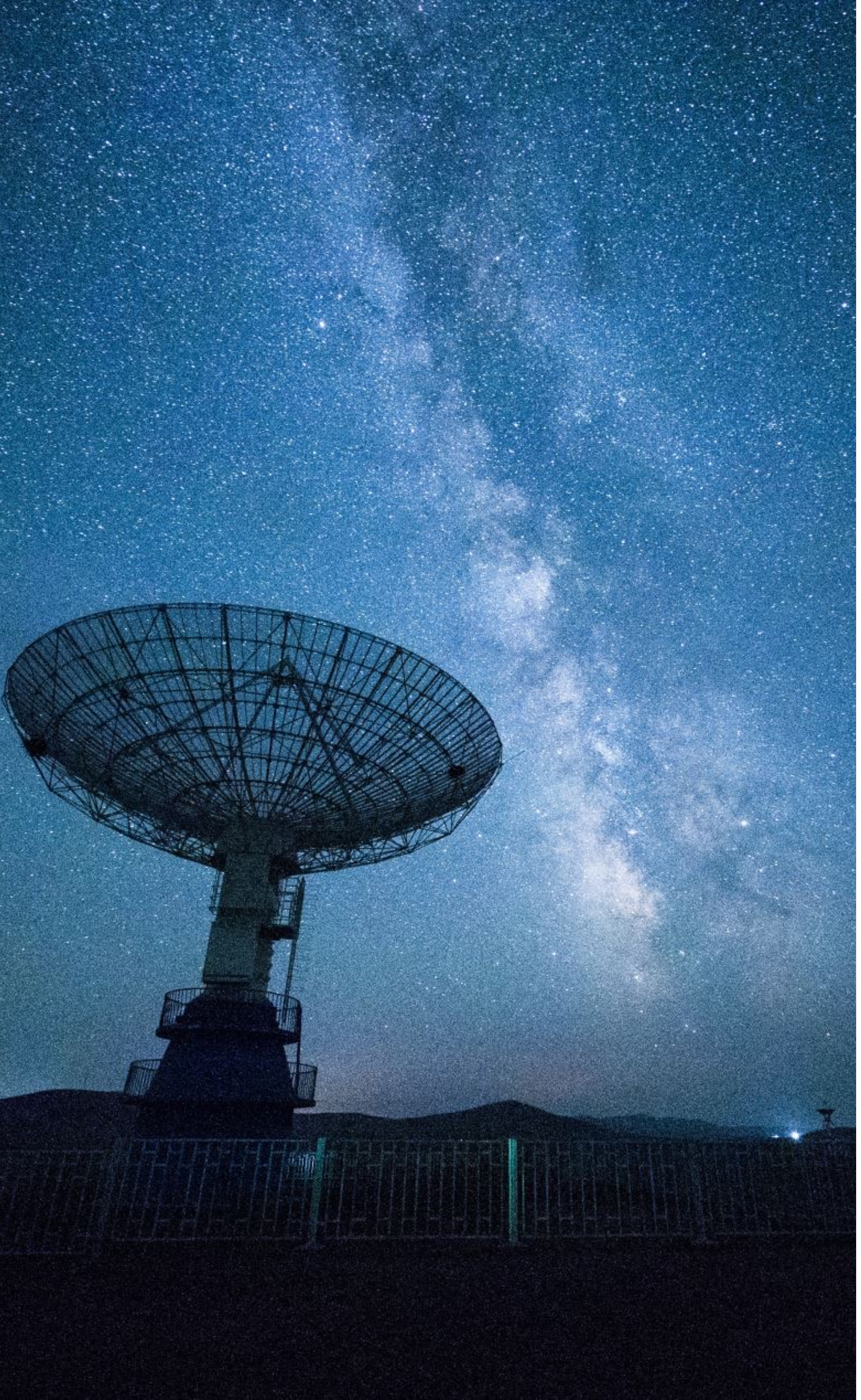


Berkeley Dark Fiber DAS



UW Madison
Internet Photonic Sensing





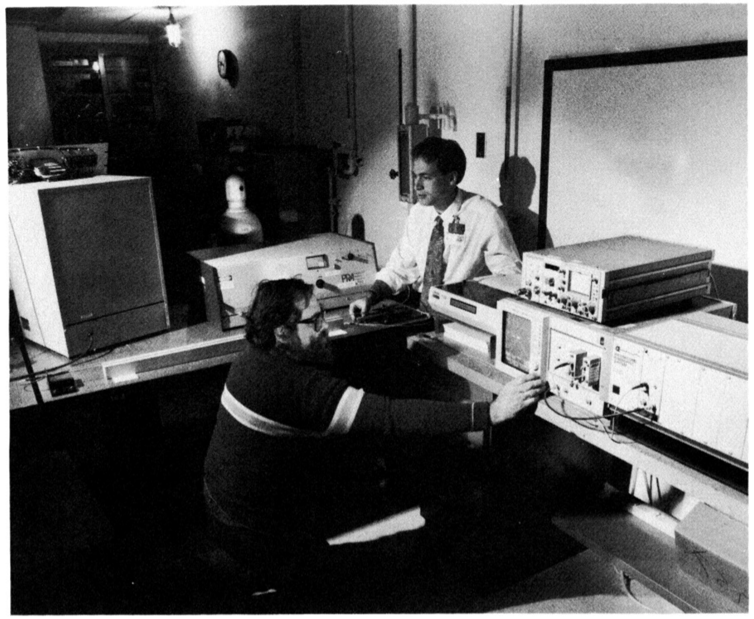
Global Multi-Scale Distributed Strain Sensing

What does it look like ?

- Satellites and geodetics for large scale strain
- Communications fibers for sparse medium scale strain
- Distributed Acoustic Sensing for localized high-resolution strain
- Low cost fit-for-purpose fiber strain sensors for medium scale strain over large areas
- Internet of Things communications networks (e.g. The Thing Network, Helium LoRaWAN)
- Cloud infrastructure for acquisition, processing, machine learning, prediction, and alarms

Measuring strain with OTDR’s

- There are many systems today that use fiber to measure strain
- They tend to be expensive and require specially made fibers
- In the 1990’s it was shown that an OTDR could measure 1e-4 strain over 1 meter of fiber
- I decided to build a lab in my basement to see if I could replicate this result



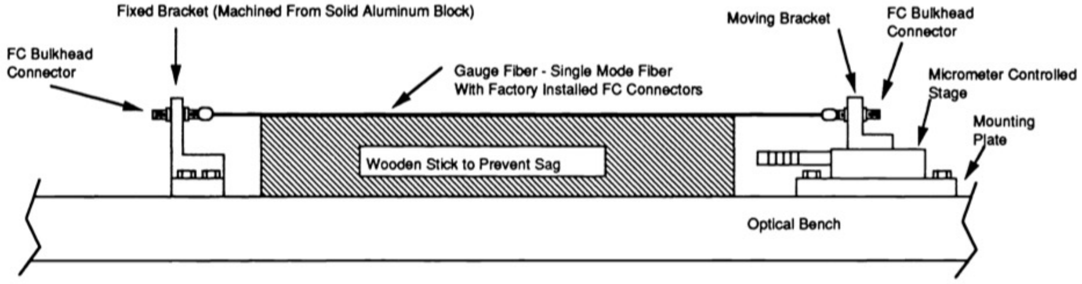


Fig. 4. Mechanical support of gauge fiber.

Chuck’s Basement OTDR Lab

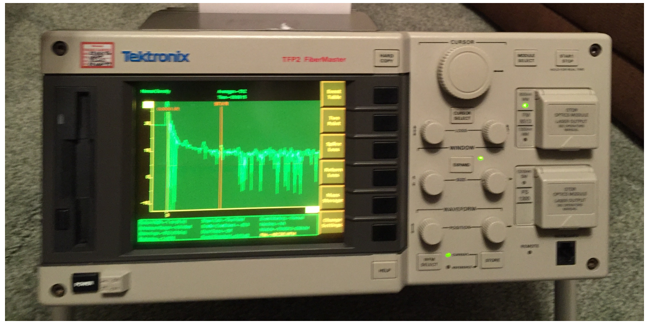
- Studied OTDR’s and fiber manipulation on the web
- Purchased surplus equipment on eBay
  - 1987 Tektronics FiberMaster 2
  - Old fusion splicer
  - Tools and supplies
- Calculated how a typical fiber would respond to strain
- Learned how to splice fibers
  - It’s Hard !!!

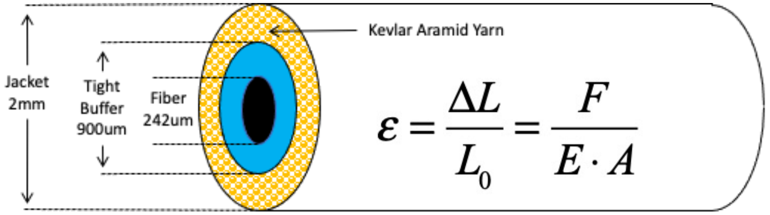
Tektronix FiberMaster
From 1987, $300

Siemans Fusion Splicer
From 1998, $200

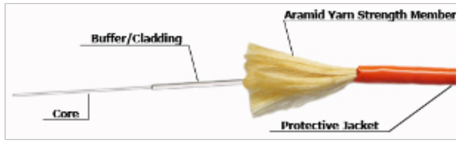
Launch Cable
$100

Tools and Supplies
$100





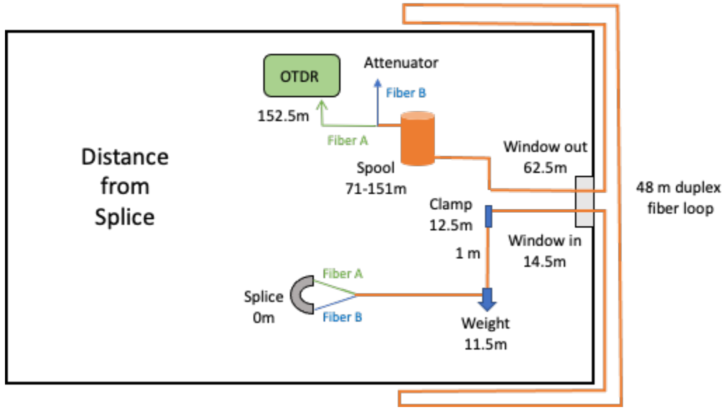
$$\varepsilon = \frac{\Delta L}{L_0} = \frac{F}{E \cdot A}$$

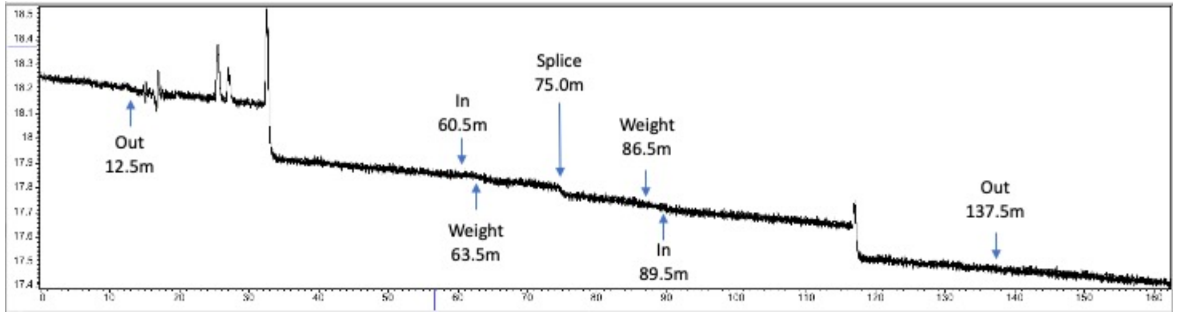


- Bare fiber: Core, Cladding, Coatings, E_{eff}=22 GPa
- Tight Buffer: Nylon, E=3 GPa
- Strength Member: Kevlar 29 Aramid Yarn, E=150 Gpa
  - Filament diameter 12 um, E=150
  - 1000 filaments
- Protective jacket: Nylon, negligible impact on elastic behavior

Reproducible Results

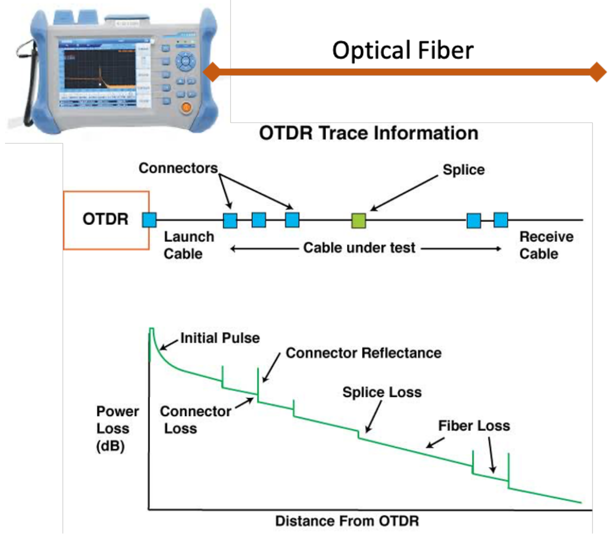
- I ran 150 m of fiber around the gardens outside my house
- I used clamps to apply 1 kg of weight to 1 m of fiber
- The effect of the strain on the fiber was clearly visible in the OTDR traces
- The strains I introduced and measured matched the 1993 results

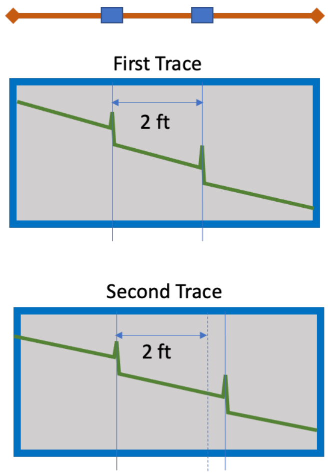




Distributed Strain Sensing with OTDR (DSS-OTDR)

- Distributed Strain Sensing with Optical Time Domain Reflectometers
  - Uses Commodity-Off-The-Shelf Optical Time Domain Reflectometers
  - Acquires a ”trace” where reflections represent defects along fibers with lengths from 1-100 km
  - If the fiber is stretched, the time between defects will increase
  - Time Strain is defined as the change in travel time between defects when repeated measurements are made
  - Time Strain Inversion algorithms can be used to monitor strain as small as 10^{-6} at 1 cm to 10 m resolution
  - COTS OTDR can acquire traces at 1 to 60 second intervals





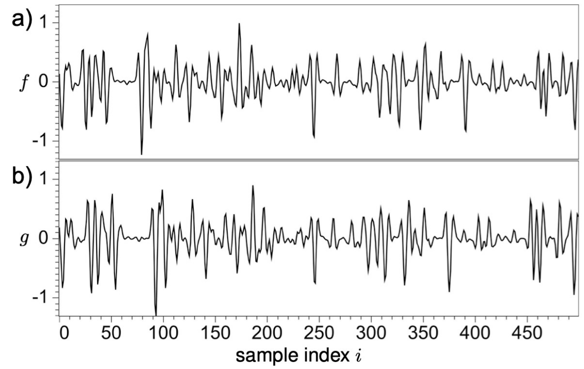
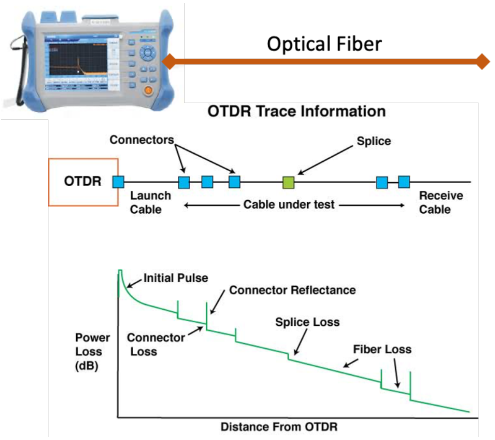
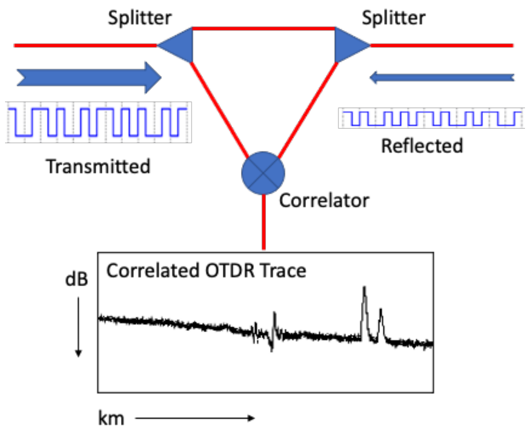


Figure 2. Two synthetic seismograms $f[i]$ (a) and $g[i]$ (b) corresponding to misaligned reflection coefficients, used as inputs to the dynamic time warping algorithm. Reflections in $f[i]$ also appear in $g[i]$, but are squeezed toward the middle of the sequence.

MoMacMo Technology for Low Cost Strain

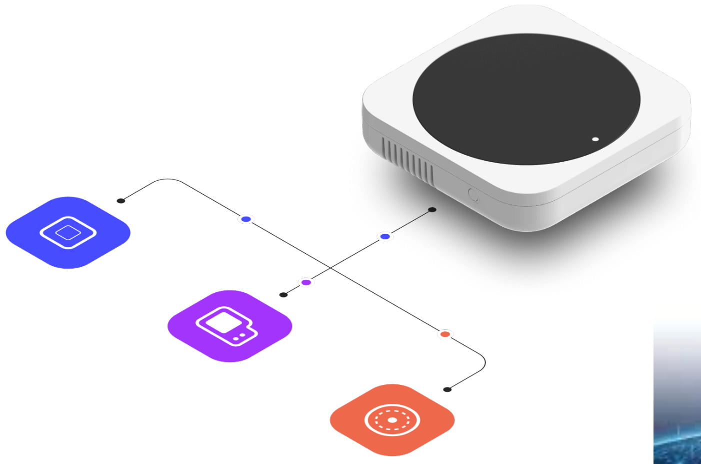
- DSS-OTDR: Distributed Strain Sensing with Optical Time Domain Reflectometers
    - Low cost strain monitoring for 1-10 km fibers (~$500 per sensor)
- DSS-IoT: DSS Internet of Things
    - Thousands of sensors connected by IoT communication networks
- DCSS: Digital Communication Strain Sensing
    - Uses binary signals on internet fibers as an encoded strain sensor
- DSS-Cloud: Cloud-based DSS processing
    - Geophysical inverse and machine learning solutions for global strain

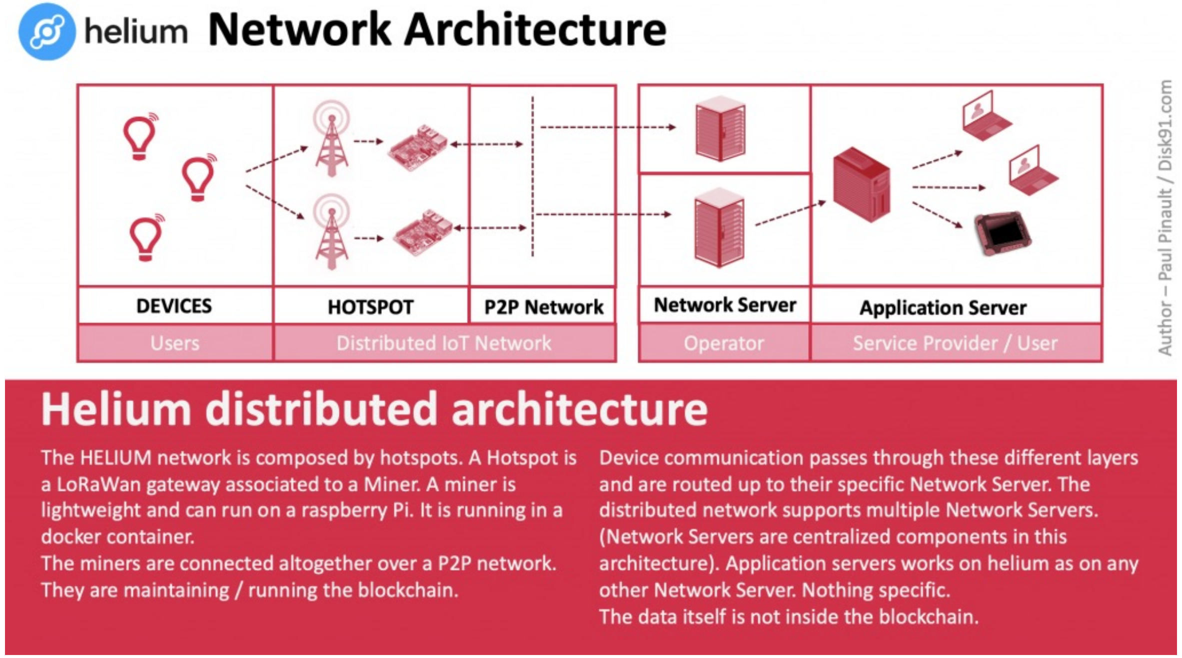




The Helium Network

- “The People’s Network”
- Low power radio wide area network (LoRaWAN)
- Funded by HNT cryptocurrency
- “Miners” deploy hotspots
- “Users” pay for access to bandwidth
- Most pervasive IoT network
- We could use this to deploy 1000’s of MoMacMo sensors





Distributed Strain Sensing IoT (DSS-IoT)

- City scale strain sensing
  - Low cost DSS-OTDR sensor ($500 USD), fiber cost $150 per km
  - One sensor with a 10 km fiber could continuously monitor subsidence for 16 city blocks
  - IoT networks (cellular, LoRa, or mesh) can collect data from 1000's of sensors
  - Cloud based processing and machine learning for analysis and alarms