Mahali: Space Weather Monitoring Using Multicore Mobile Devices

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Importance of Space Weather Monitoring

- Affects performance and reliability of critical applications

- **Our goal:** Leverage entire ionosphere as a sensor for
  - Space-based phenomena (e.g., Solar wind)
  - Earth-based phenomena (e.g., Earthquakes, Tsunamis; Song et al. 2007; Galvan et al. 2011; Komjathy et al. 2013)

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**Storm Enhanced Density feature**

(Rideout & Coster 2006)

**Feb 12, 2013 North Korea Nuclear Test**

(Komjathy, Yang, Butala, Ijima, Mannucci. Beacon Satellite Symp. 2013)

**Texas Fertilizer Plant Explosion Apr 18**

**Chelyabinsk Meteor**

**Tohoku-Oki Earthquake and Tsunami**

(NASA JPL Photojournal PIA14430/Caltech, 2012)
Problem: Sensor Sparsity

GPS Total Electron Content Map for 01-Jun-2013 5:30-6:00

(Source: Anthea Coster, MIT Haystack)
Filling the Gap: Technology Trends

Top500 Supercomputers, 1993
CM-5 Los Alamos
- 1024 processors
- 59.7 GFLOPS
[1 GFLOP = 10^9 floating point ops]

2013
iPhone 5S (A7 64 Bit)
76.8 GFLOPS (GPU@300MHz)
iPad3
38.4 GFLOPS (GPU@300MHz)
[Source: AnandTech.com]

Processor Trends

General-Purpose
- 60 Cores
- 48 Cores
- 2 - 16 Cores

Special-Purpose
- Thousands of Cores (GPUs)
- 192 Cores (Networking)

Hybrids
- 4 CPU + 16 GPU (Ivy Bridge)
- 2 CPU + 4 GPU (ARM A6X)

Mobile Processors

Clock Rates [GHz]
Jeffers & Reinders, 2013

http://www.top500.org/timeline/
Filling the Gap: Technology Trends

Mobile Devices

- **Parallel computers**
- **Network connections** (cell, WiFi, Bluetooth, USB) → “Last Mile Data Transmission Problem”
- **Local storage** (GB) → asynchronous data collection; GPS is time-tagged
- **Low cost; software productivity; COTS hardware**
- **Extensibility** (sensors, hardware, software)
- **Adaptable intelligent behavior** (e.g., profiles for battery / power, network type, etc.)
- **Ubiquity**: CEO Ericsson: ~6.4 billion devices in 2013, ~9.3 billion in 2018

Source: Wikimedia Commons; World Bank, Miniwatts Marketing Group

Rural Gambia; Source: Wikipedia
Mahali: Space Weather Monitoring Everywhere

GPS L1, L2

Cell Phone Network

GPS Dual-Frequency Receiver Gateway

→ Relays (Mobile Devices)

Ionosphere Total Electron Content

Computational Reconstruction Cloud

WiFi

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Potential of Crowdsourcing

• Gaining popularity in data acquisition

• The base skeleton of Mahali does not require external participation, but crowdsourcing can add benefits
  • Fill observational gaps at low cost \(\rightarrow\) “Last Mile Problem”
  • Bandwidth enhancement. Donate bandwidth to transmit more data (e.g., at higher sampling rates)
  • Network shifting. Collect and store data locally, move to other locations, upload over more affordable networks (WiFi)
  • CPU time donation for data scrubbing (local multipath and bias removal, Rideout & Coster 2006). Upload high-quality data into the cloud

• Challenges: Motivation
  • High-quality images in exchange for efforts
  • Leverage educational aspects and environmental issues
Computational Reconstruction

Consecutive 5-minute images of three-dimensional ionospheric density patterns observed with the Poker Flat Incoherent Scatter Radar (PFISR) during a geomagnetically active period. (After Semeter et al. ‘09, ‘10)
Cloud Environment

(A) Mahali Mobile Phone App
(B) Mahali Control Server
(C) Mahali Computational Reconstruction Cloud

Phone-Local Data Processing Pipeline

Aggregated Results

Cloud Setup, Control, Feedback-directed Adaptation

Multicore Processor

Data Cleansing
Bias Removal

Aggregated Results
Conclusions

• **Mobile technology** is a game changer for observatories

  • Range, variety of networks for data transport
  • Pervasive use
  • Processing power: Local parallel computing on multicore processors, cloud connectivity for more complex tasks
  • Local storage
  • Expecting dual-frequency GPS in every device (e.g., for precise navigation)
  • Synchronous & asynchronous data processing

• Long-term goal: Leverage entire ionosphere as sensor for ground-based and space-based phenomena
Thanks!

• We thank the National Science Foundation for supporting the Mahali project under INSPIRE grant no. AGS-134396

• We also thank UNAVCO and our collaborative colleagues for their willingness to provide us access to dual-frequency GPS receivers for use in this project