Implementing a Wireless Geophysical Sensor Network

Tracy Camp

SmartGeo

smartgeo.mines.edu

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Road Map

- SmartGeo Applications, Goals, and Challenges
- Resource Constrained Hardware
- Data Collection in SmartGeo Environments
- Classification of Data

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An interdisciplinary graduate program in the area of Intelligent Geosystems

NSF

Intelligent Geosystems

natural or engineered
earth systems enabled to
sense their condition and
adapt to meet their objective

An interdisciplinary graduate program in the area of Intelligent Geosystems

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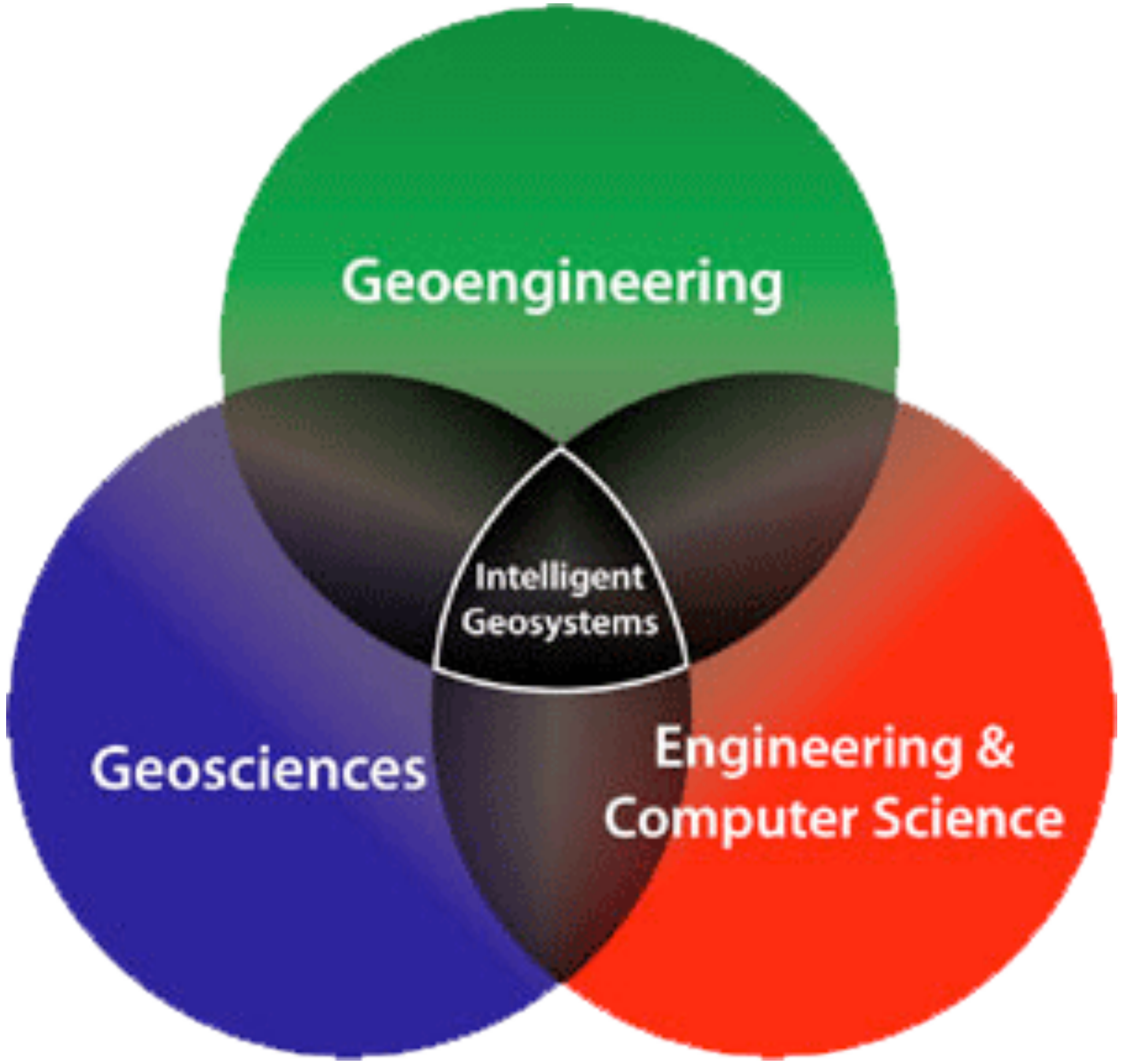
Civil (Geotechnical)
Geological
Environmental



Geophysics
Geology
Mathematics

Mechanical
Electrical
Comp Sci

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Intelligent Earth Dams/Levees

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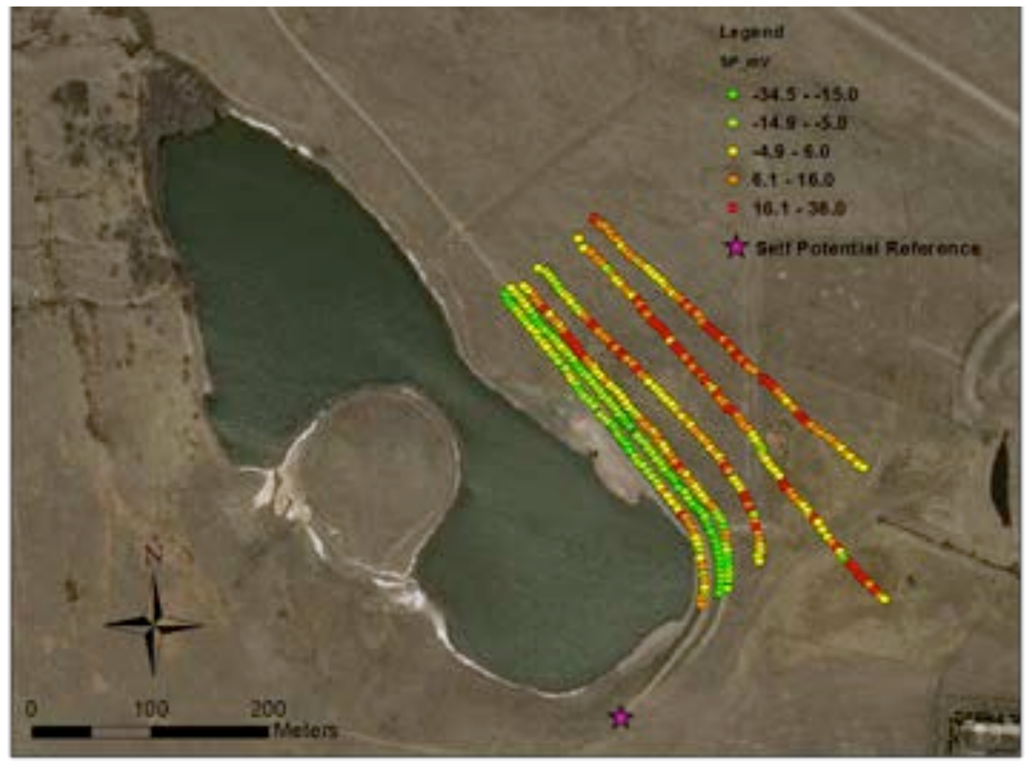
Pomme de Terra Dam, MO

Long Lake Dam Golden, CO



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Potrerillos Dam
Argentina

IJkdijk Test Levee
Netherlands

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Tunbridge Dam, Australia

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Current State of Practice: Periodic Wired Geophysical Monitoring

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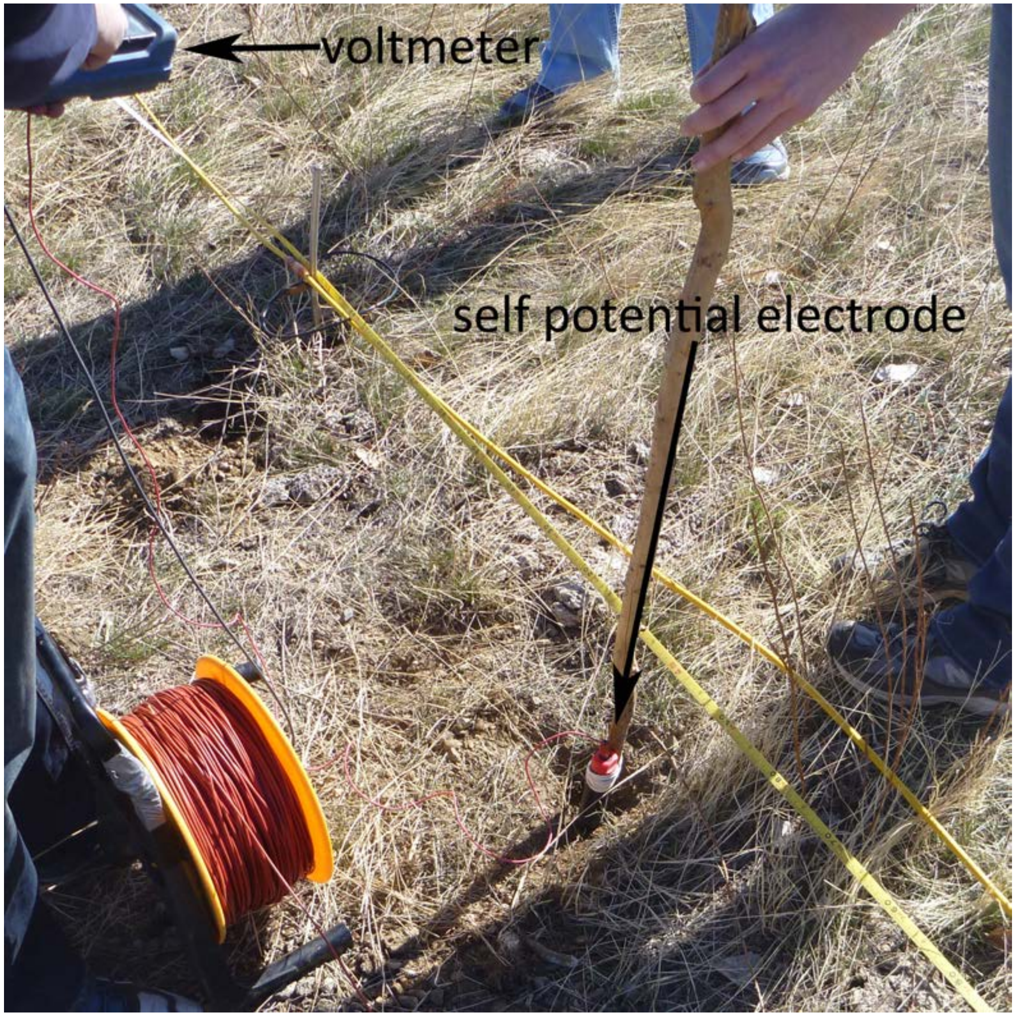
Wired Geophysical Monitoring



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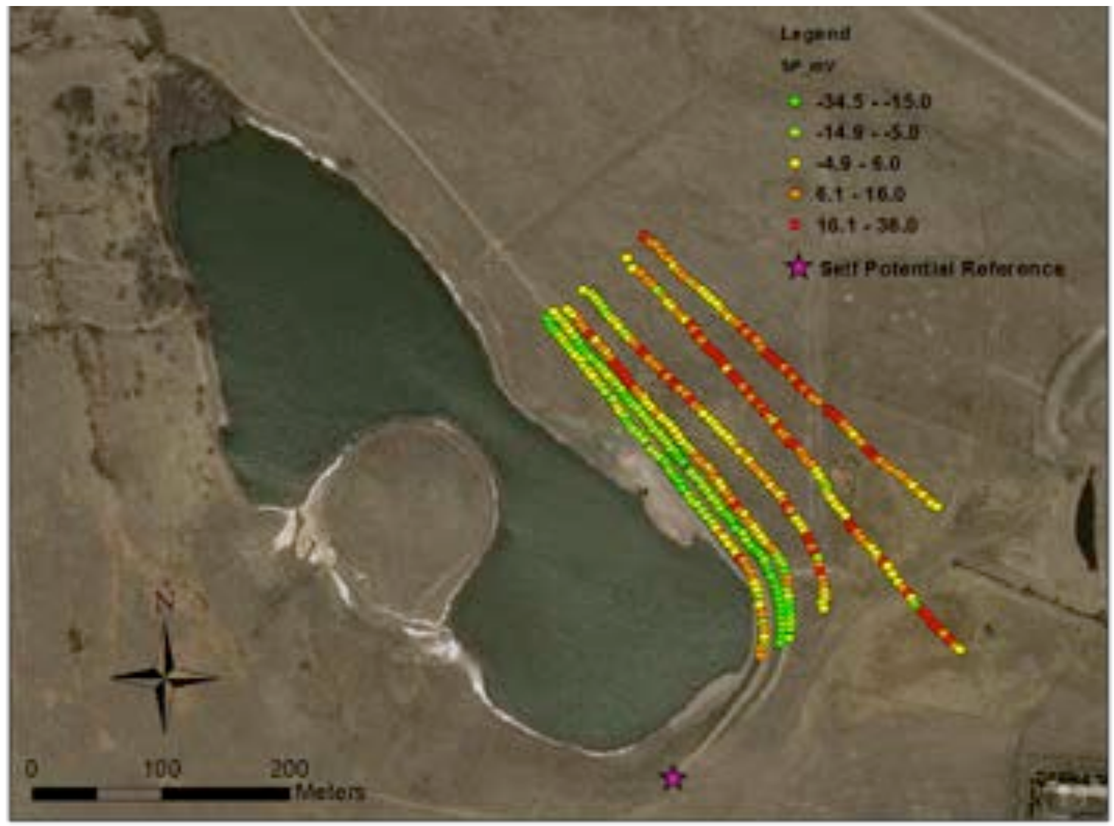
Goal: ‘continuous’ monitoring using a (geophysical) WSN

earth systems/ structures enabled to sense their environment and adapt to meet their objective

Long Lake Dam, Golden, CO



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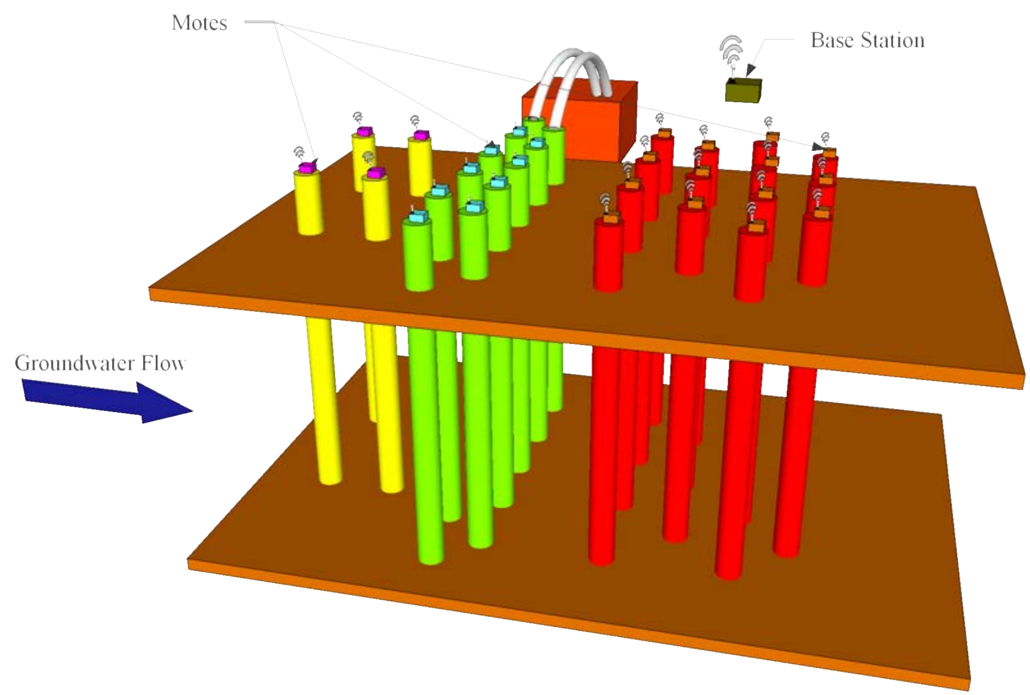
Intelligent Earth Dams/Levees

Intelligent Remediation



Intelligent Construction

Intelligent Avalanche Monitoring

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CS/EE Technical Challenges

- unable to integrate geophysical measurement techniques into off-the-shelf mote platforms
- collection of data in a resource constrained environment = use compressive sampling?
- geophysical measurement techniques require localization accuracy at the cm level
- geophysical measurement techniques require time synchronization at the micro-second level
- processing of data (ML and HPC)

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Current State of Practice: Periodic Wired Geophysical Monitoring

signal filters
110dB amplifier
24 bit ADC

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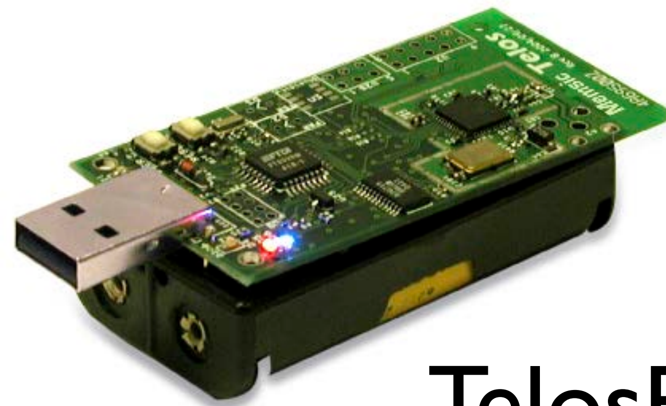
Popular Mote Platforms

Iris

MicaZ



TelosB

have limitations

(ADCs, RAM, etc.)

gsMote: geophysical sensing Mote

- geophysical sensors: self potential, seismic, infrasound, resistivity
- High/Low pass hardware filters
- Amplifier
- AVR XMEGA256A microprocessor
- 24-bit off chip ADC
- 64kB FeRAM
- 2-32GB persistent flash storage
- 802.15.4 Radio (900 mHz with 2km range)

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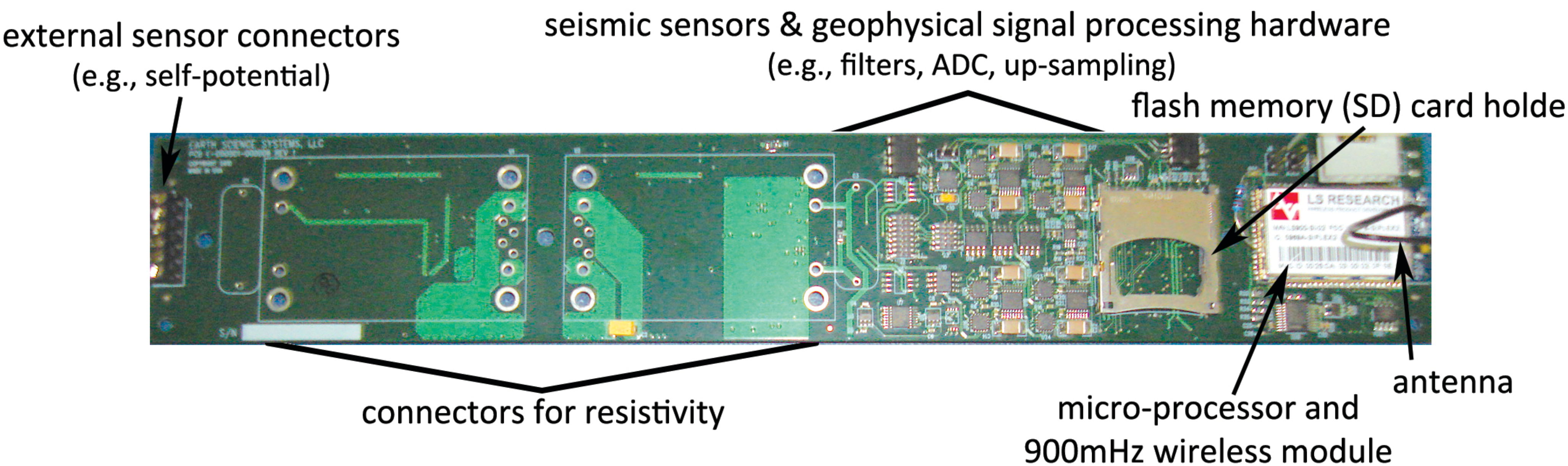
gsMote PCB



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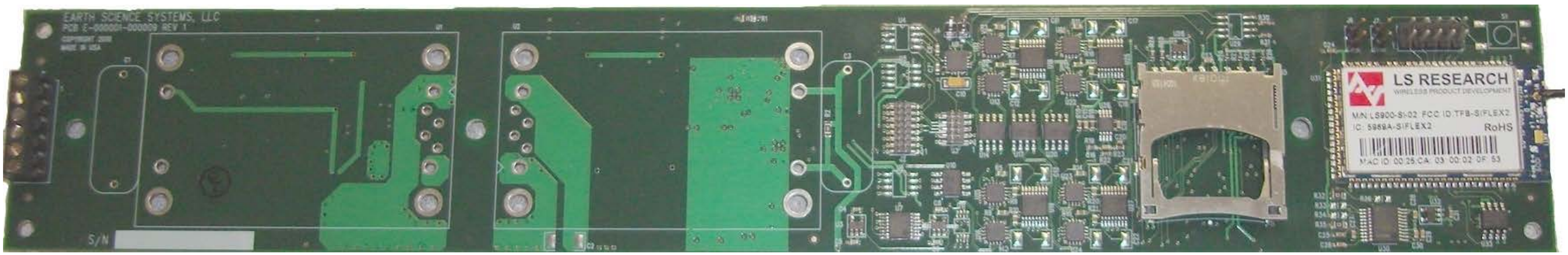
gsMote Example

front



back

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Basic Mote Properties

- Sense
- Compute
- Store
- Communicate

LIMITED RESOURCES/ENERGY!

Road Map

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Road Map: Data Collection

- Compressive Sampling Introduction
- Implementing On-Mote Compressive Sampling
- Performance Evaluation

  Experiment 1: Sinusoids

  Experiment 2: Real Seismic Data

  Experiment 3: Power Consumption

Compressive Sampling

- SmartGeo motes have very limited resources
- SmartGeo apps. have moderately high sampling rates

==> need to REDUCE amount of data

*Why go to so much effort to acquire **all** the data when **most** of what we get will be thrown away?*

David Donoho

IEEE Transactions on Information Theory

2006

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Compressive Sampling

- SmartGeo motes have very limited resources
- SmartGeo apps. have moderately high sampling rates

==> need to REDUCE amount of data

replace "sample THEN compress"
with "compress WHILE sampling"

http://dsp.rice.edu/cs

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Compressive Sampling

- works if original signal has low information (e.g., sparse)

$$x = \Psi\alpha$$

- transform original signal (x of length N)

  to vector (y of length M, where M << N)

$$y = \Phi x$$

↖ measurement matrix (MxN)

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Measurement Matrics

- Random Gaussian
- Bernoulli
- Random Fourier
- Random Binary

Signal Recovery

- solve the underdetermined linear system

$$y = \Phi x$$

- by employing numerical optimization methods to approximate the original signal

$$\widehat{x} = argmin_{x'} ||x'||_{\ell_1} \quad \text{subject to} \quad y = \Phi x'$$

Signal Recovery

- solve the underdetermined linear system

$$y = \Phi x$$

- $\ell 1$-norm minimization
- re-weighted $\ell 1$-norm minimization
- $\ell 0$-norm minimization
- $\ell 2$-norm minimization

Compressive Sampling

- works if original signal has low information (e.g., sparse)

$$x = \Psi\alpha.$$

- transform original signal (x of length N)
  to vector (y of length M, where M << N)

$$y = \Phi x$$

measurement matrix (MxN)

Matrices Evaluated

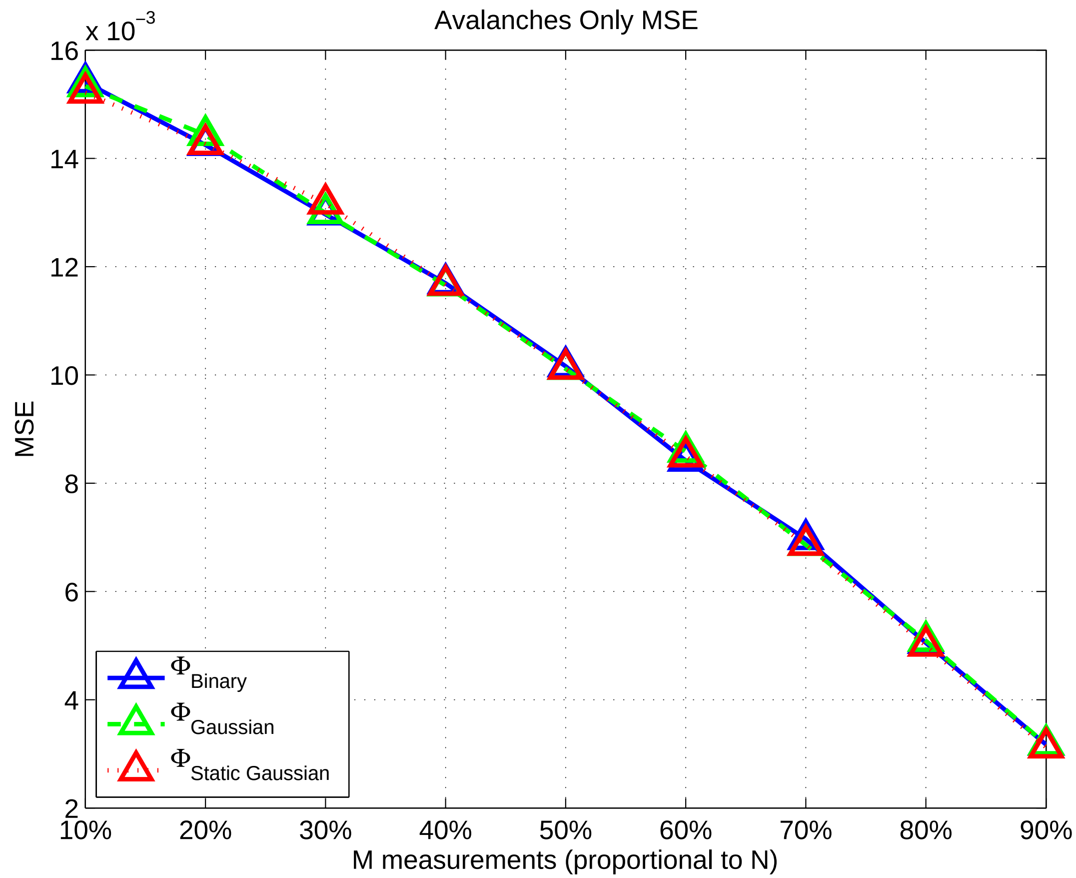
- Random Gaussian
- ‘static’ Random Gaussian
- Random Binary

$$\Phi_{binary} = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & 1 & 0 \\ 0 & 0 & 0 & \cdots & 0 & 1 \end{bmatrix}$$

(MxN)

Matrices Evaluated

- Random Gaussian
- ‘static’ Random Gaussian
- Random Binary



Compressive Sampling

- SmartGeo apps. have moderately high sampling rates
- SmartGeo motes have very limited resources

==> need to REDUCE amount of data

will compressive sampling help??

Question 1: how to implement compressive sampling on a wireless mote?

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Road Map: Data Collection

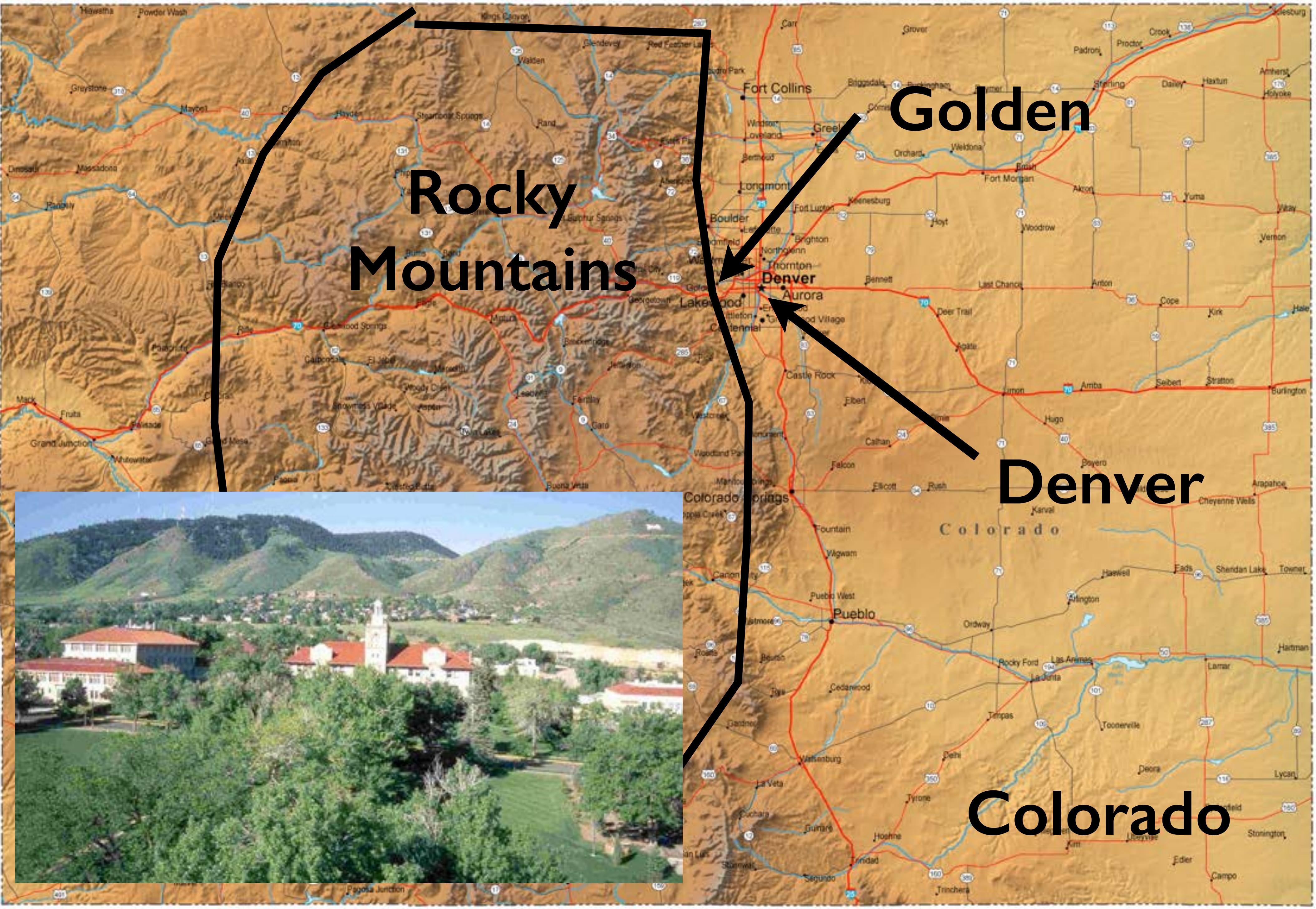
- Compressive Sampling Introduction
- Implementing On-Mote Compressive Sampling
- Performance Evaluation

  Experiment 1: Sinusoids

  Experiment 2: Real Seismic Data

  Experiment 3: Power Consumption

Where is the Colorado School of Mines?


Golden
Rocky Mountains
Denver
Colorado

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On-Mote Compressive Sampling

- Additive Random Sampling (ARS)

  costly floating point operations

- Sparse Binary Sampling (SBS)

$$y = \Phi x$$

- Randomized Timing Vector (RTV)

$$\Phi_b = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \Longrightarrow V_t = \{0, 1, 0, 1, 1\}$$

Compressive Sampling

- SmartGeo apps. have moderately high sampling rates
- SmartGeo motes have very limited resources

==> need to REDUCE amount of data

will compressive sampling help??

Question 2: how do these algorithms compare?

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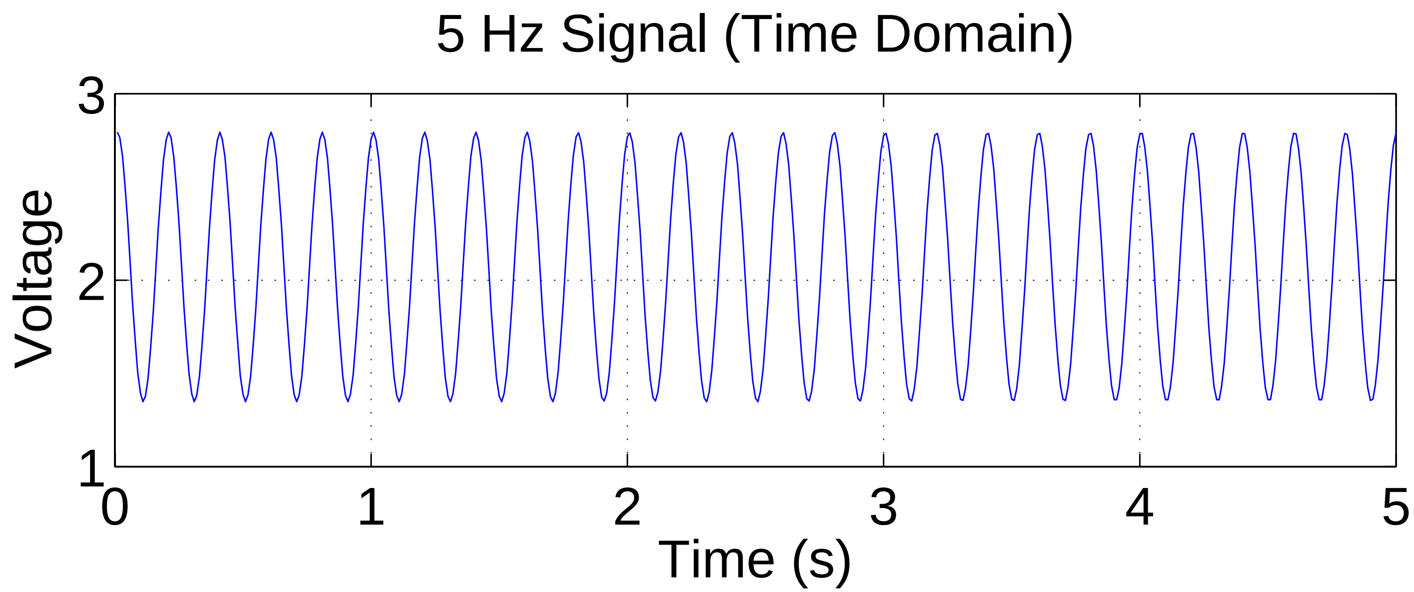
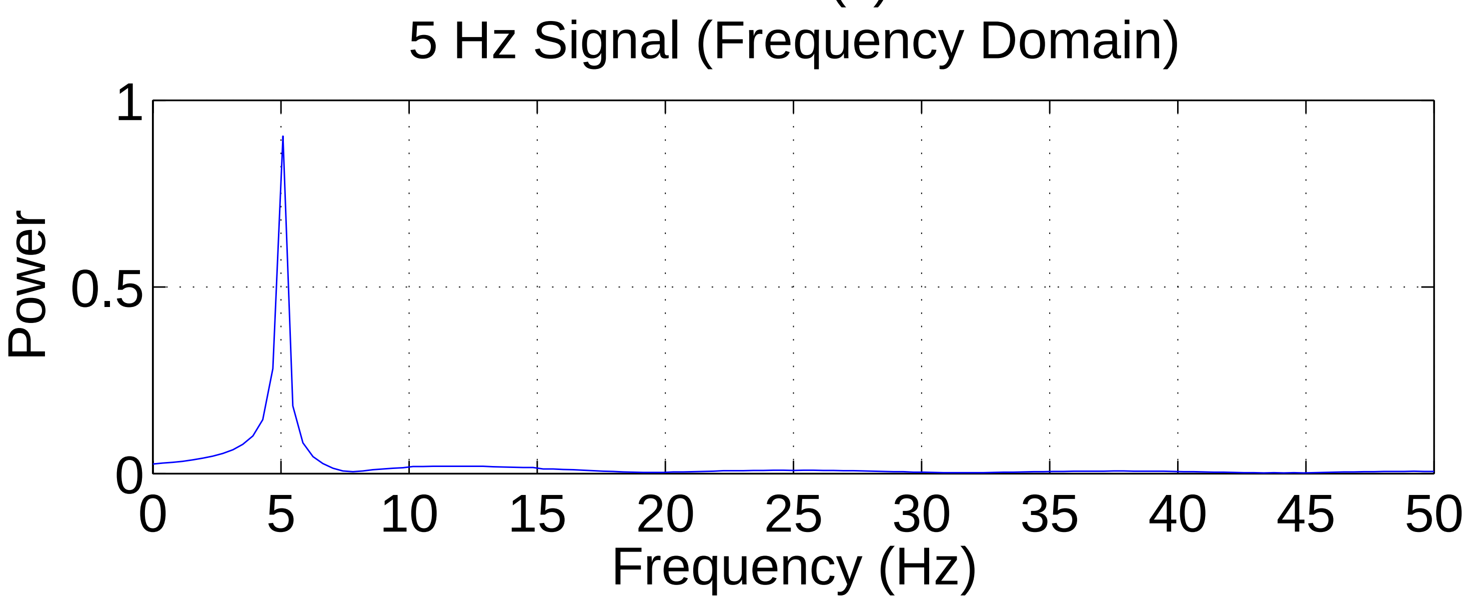
Experiment: sinusoids

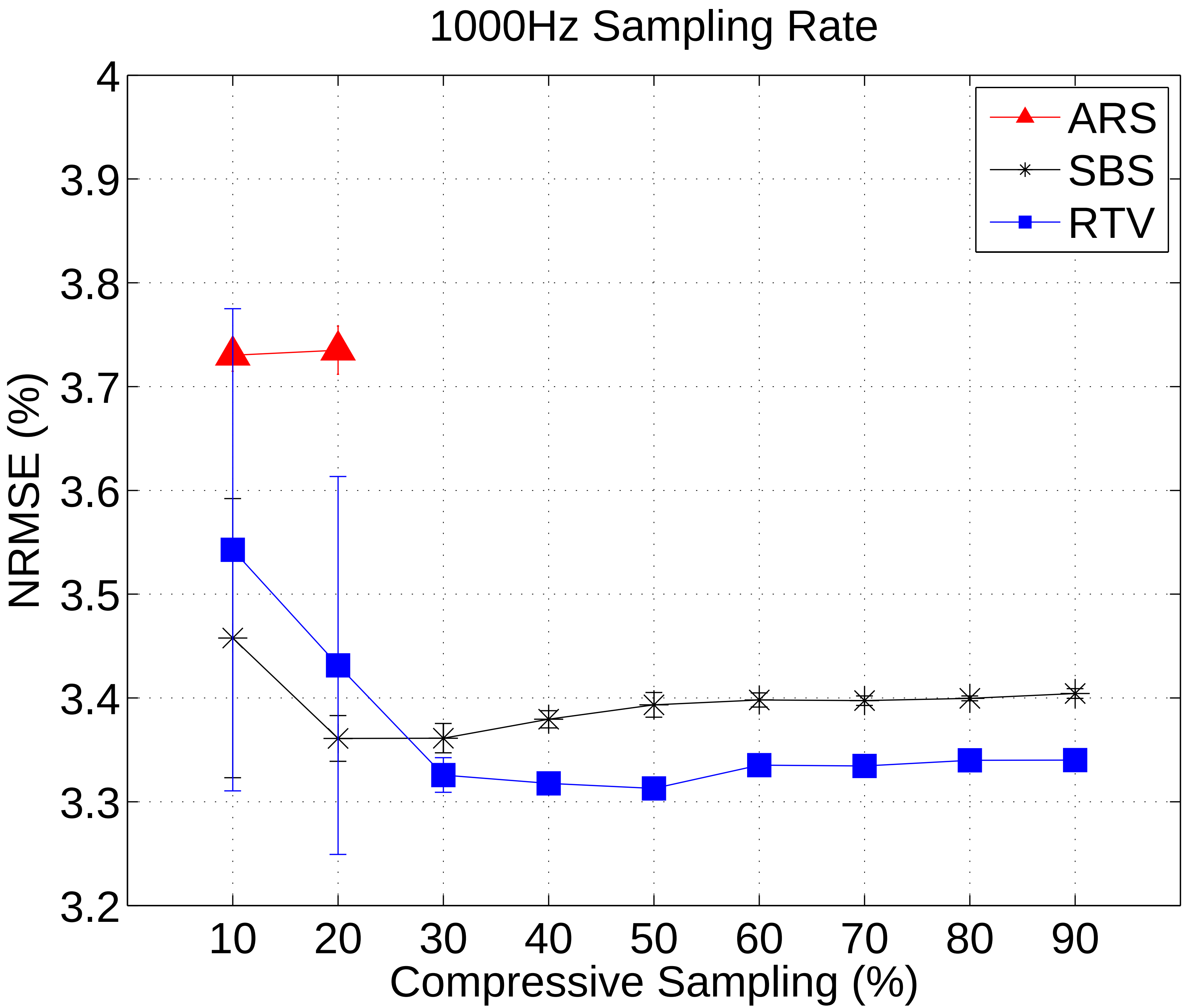


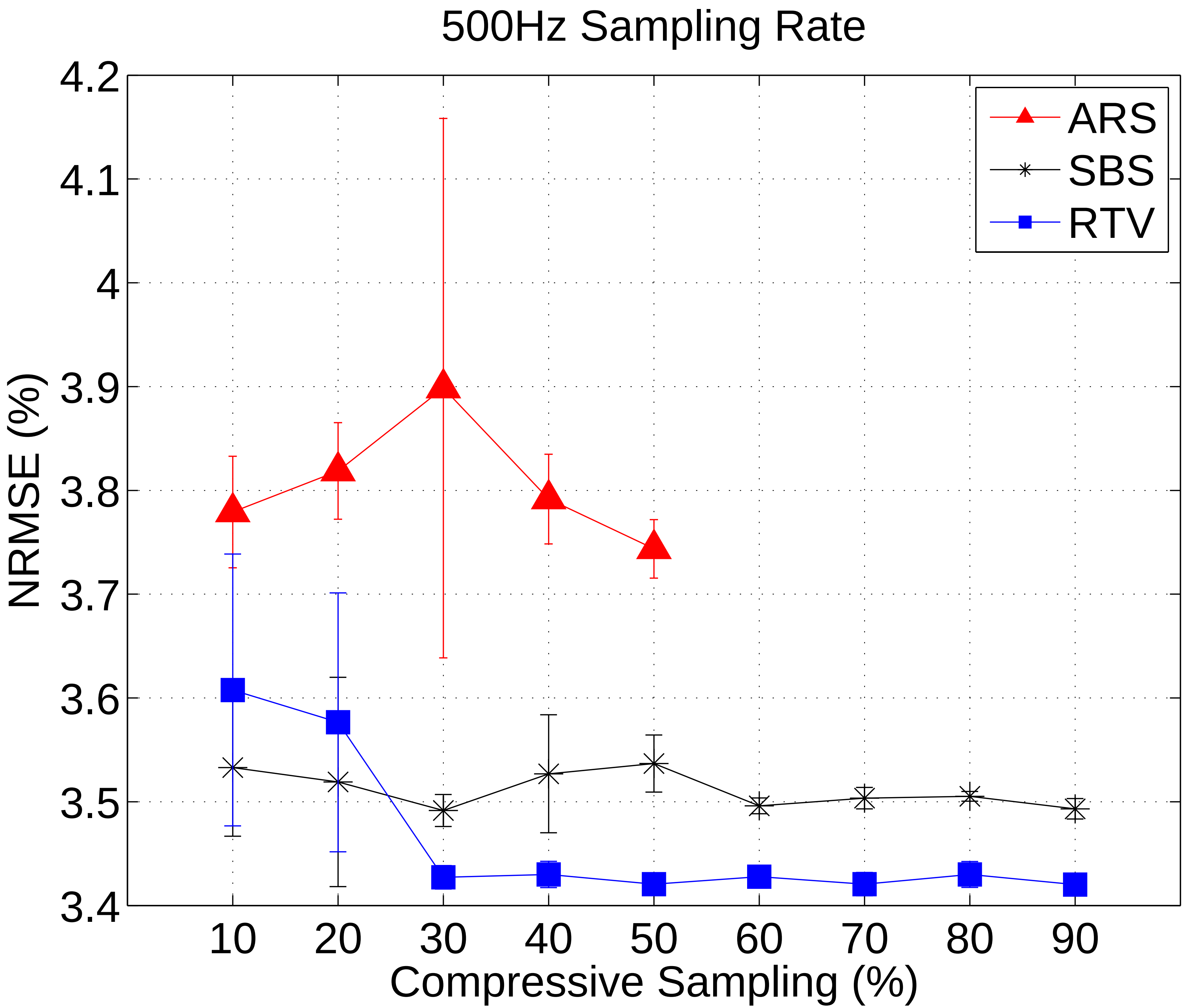


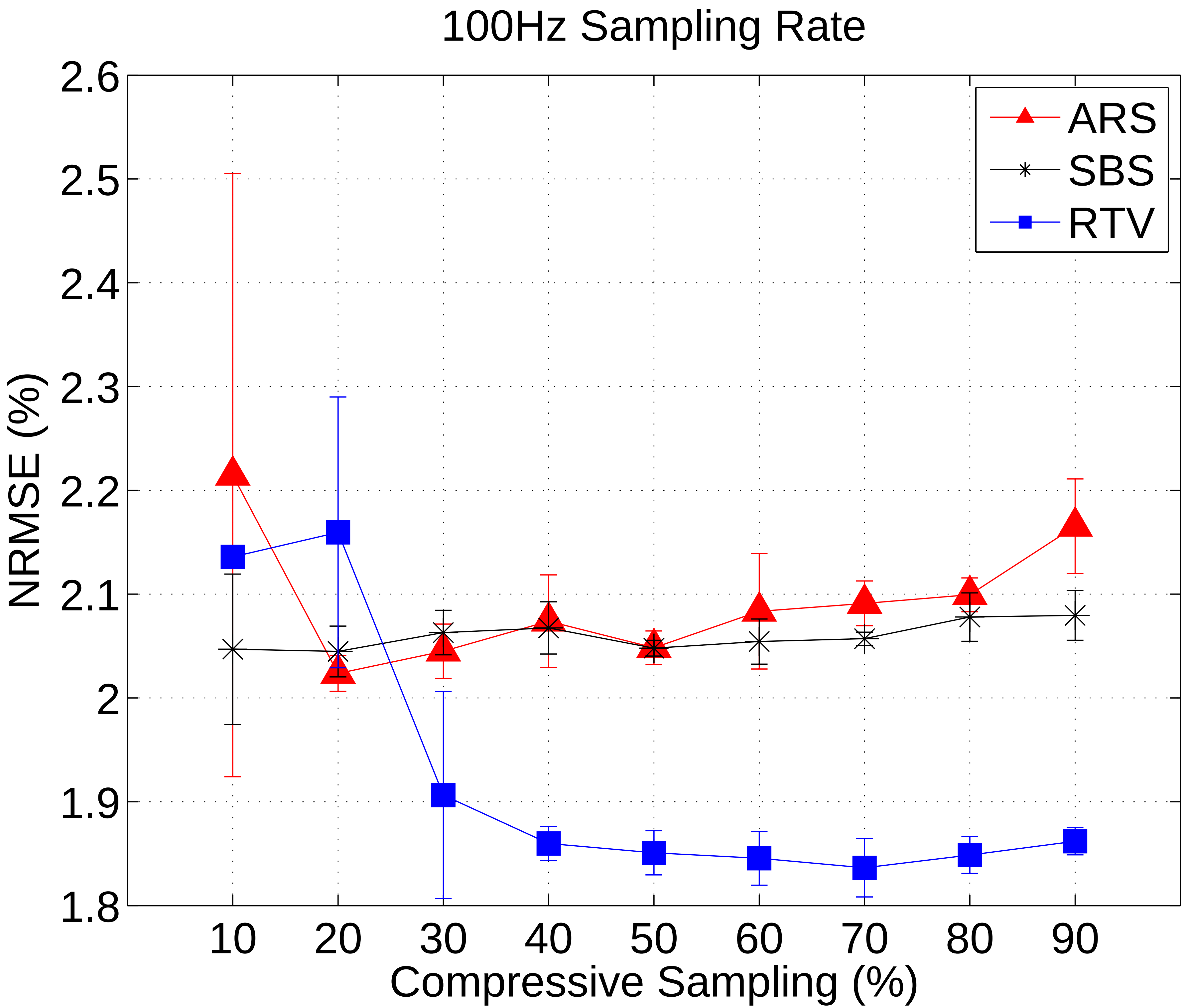
Experiment: sinusoids

$$NRMSE = \frac{\sqrt{mean((x - \widehat{x})^2)}}{max(x) - min(x)} \times 100$$

9 different sampling rates (10% to 90%)
10 different seeds
95% confidence intervals
first 500 samples only


1000Hz Sampling Rate
NRMSE (%)
Compressive Sampling (%)
ARS
SBS
RTV
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
10
20
30
40
50
60
70
80
90


500Hz Sampling Rate
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
NRMSE (%)
10
20
30
40
50
60
70
80
90
Compressive Sampling (%)
ARS
SBS
RTV


100Hz Sampling Rate
ARS
SBS
RTV
NRMSE (%)
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
10
20
30
40
50
60
70
80
90
Compressive Sampling (%)

Road Map: Data Collection

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Experiment: real-world data

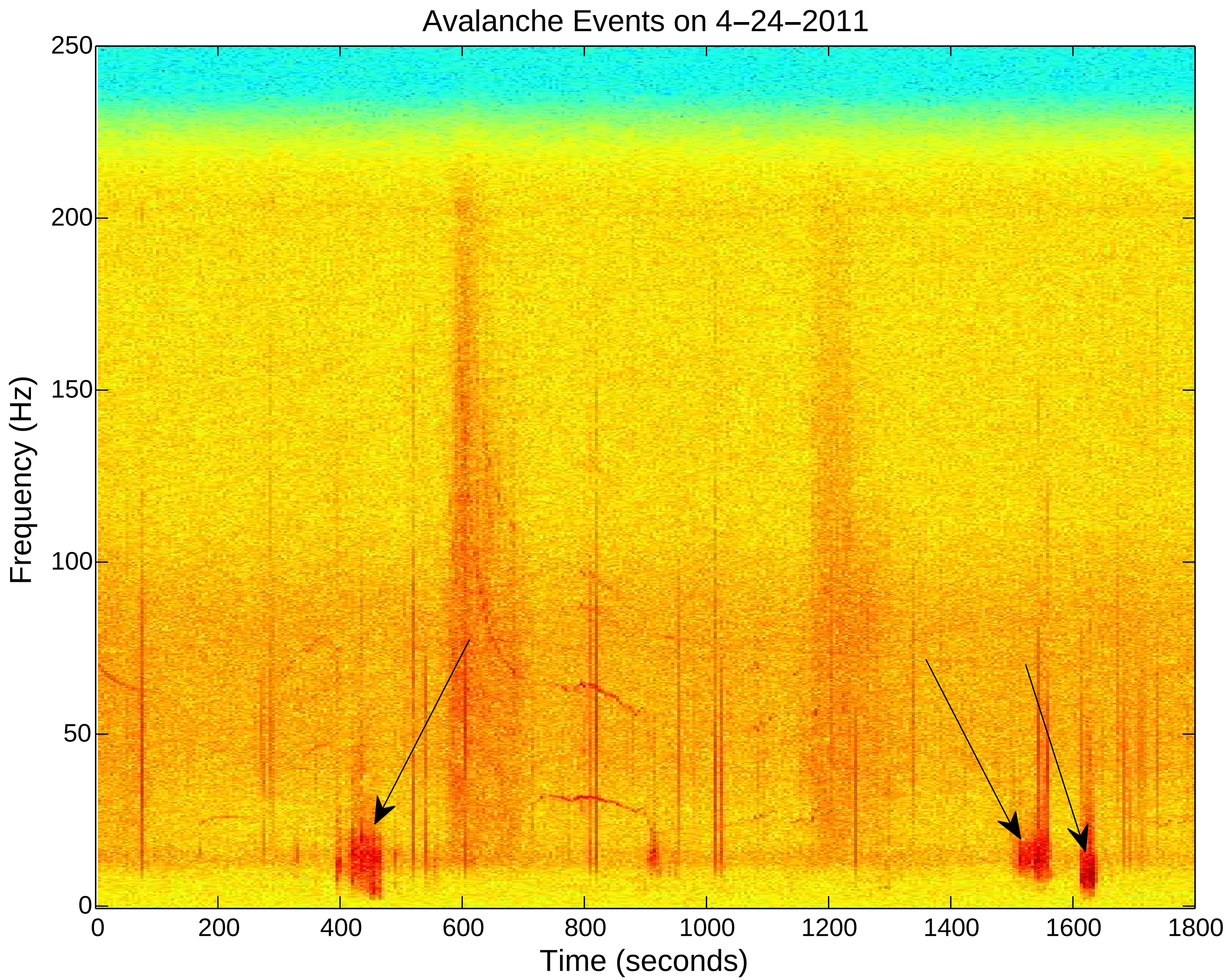
$$NRMSE = \frac{\sqrt{mean((x - \widehat{x})^2)}}{max(x) - min(x)} \times 100$$

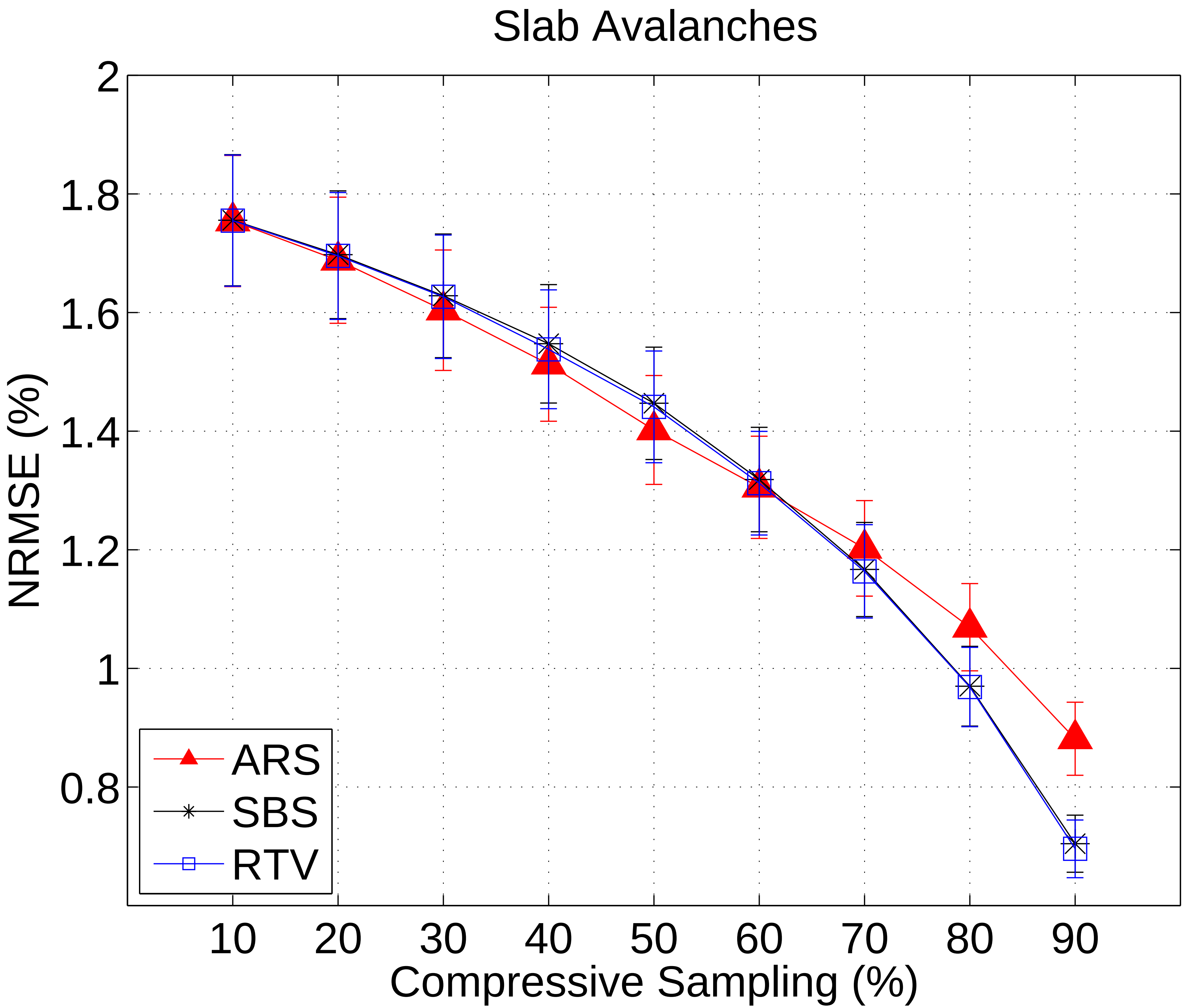
9 different sampling rates (10% to 90%)
10 different seeds
95% confidence intervals

Experiment: real-world data

(500Hz data)

Experiment: seismic data





Slab Avalanches
NRMSE (%)
2
1.8
1.6
1.4
1.2
1
0.8
10
20
30
40
50
60
70
80
90
Compressive Sampling (%)
ARS
SBS
RTV

Road Map: Data Collection

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- Performance Evaluation

  Experiment 1: Sinusoids

  Experiment 2: Real Seismic Data

  Experiment 3: Power Consumption

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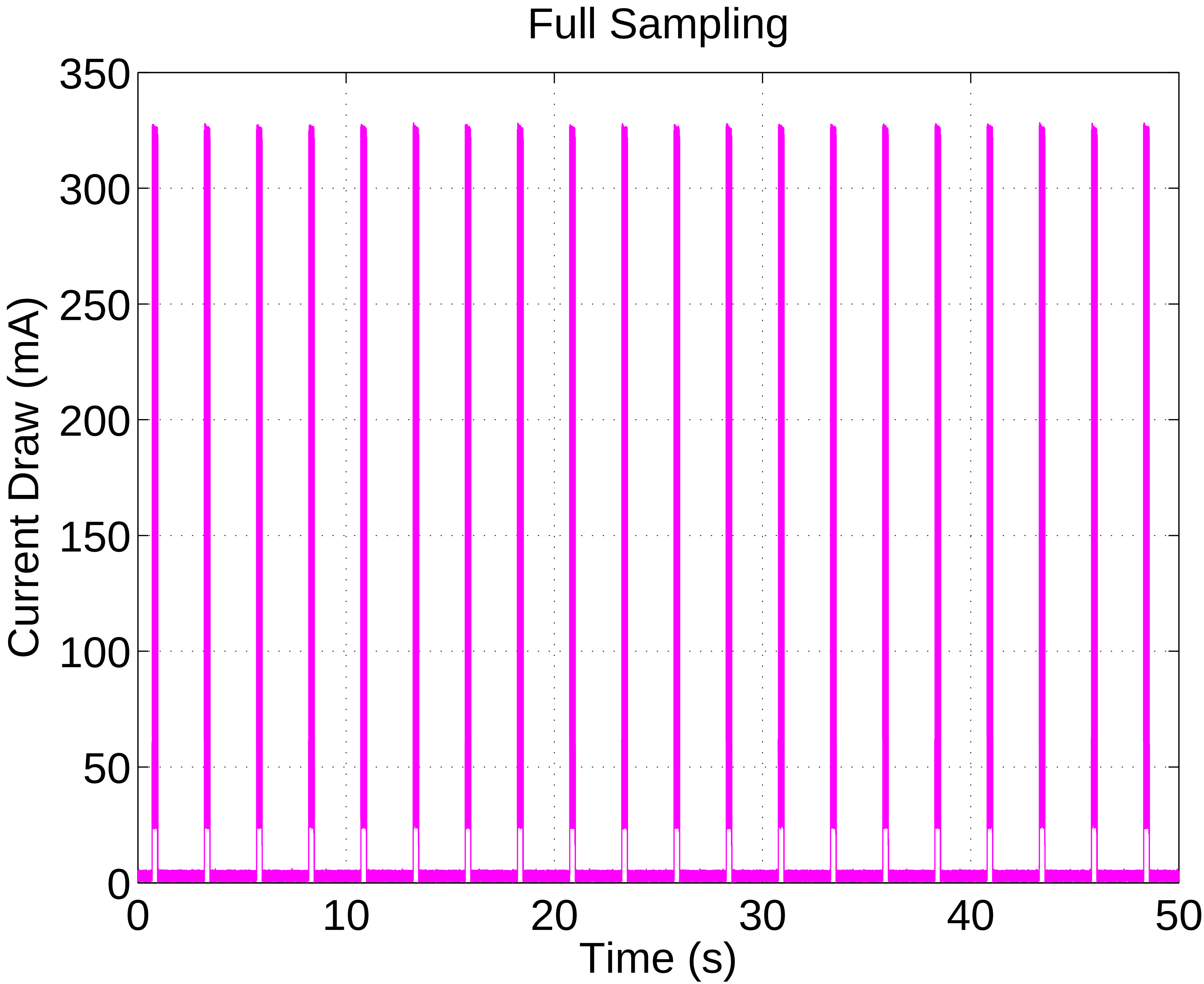
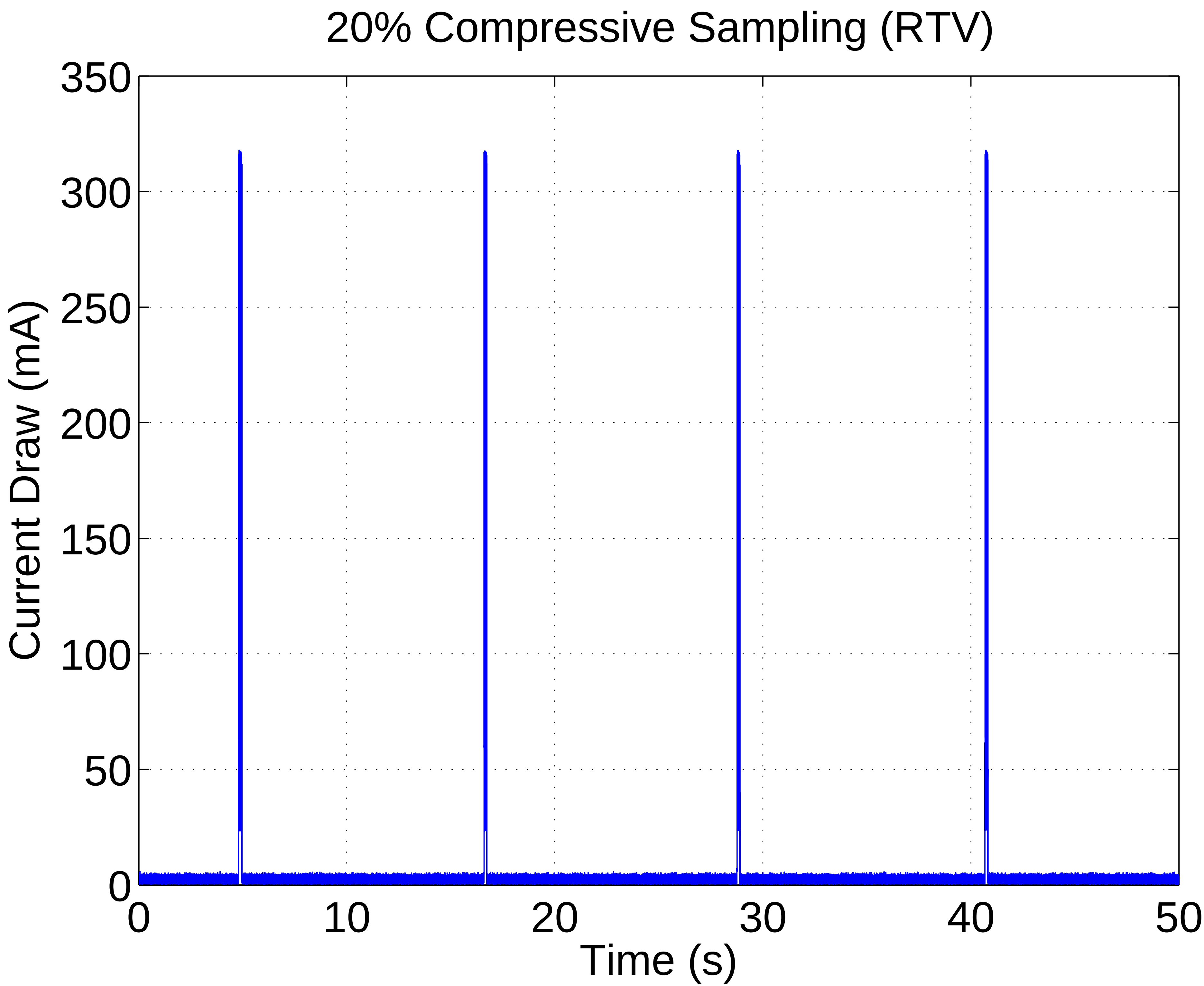
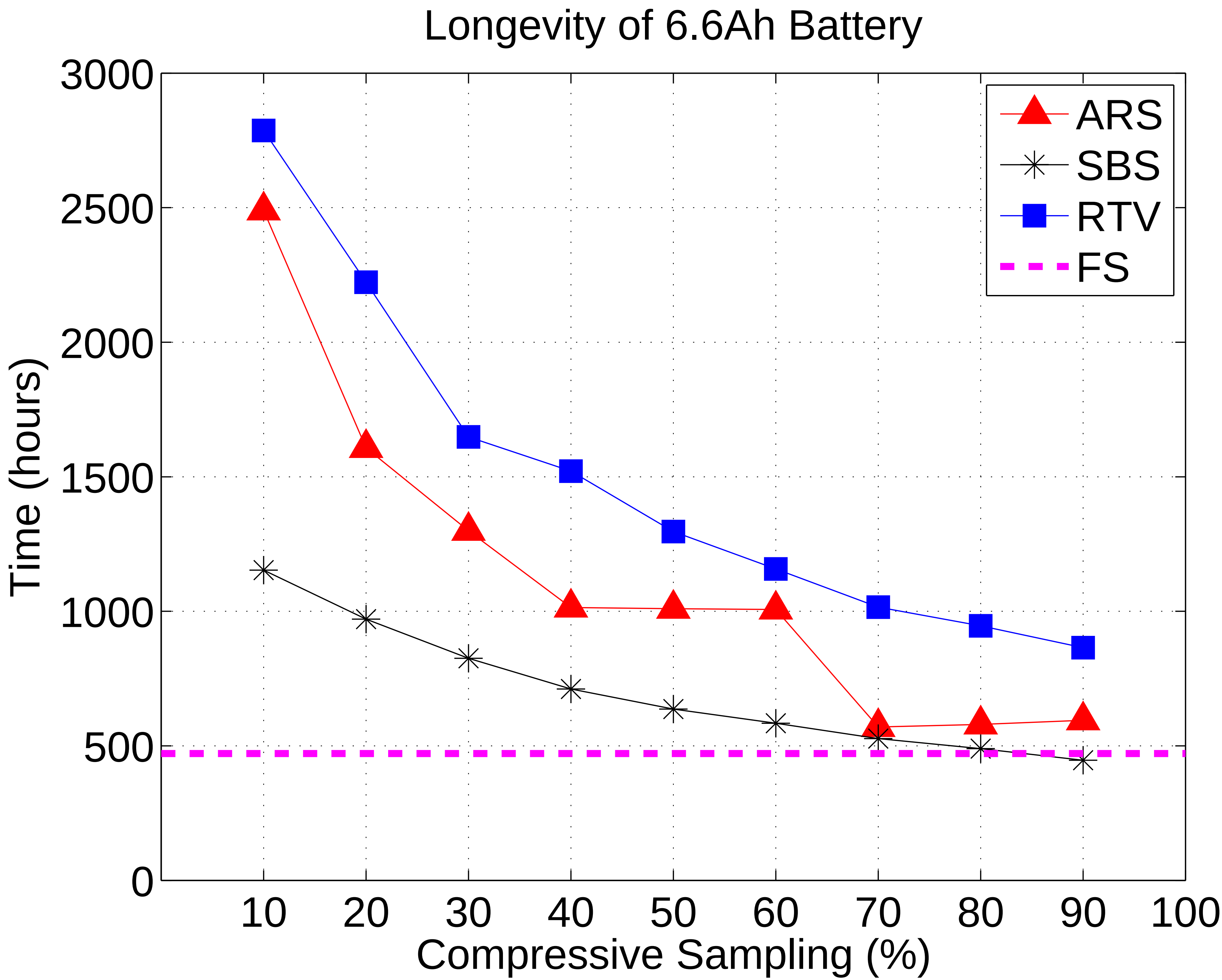

Full Sampling
Current Draw (mA)
350
300
250
200
150
100
50
0
0
10
20
30
40
50
Time (s)


20% Compressive Sampling (RTV)
Current Draw (mA)
Time (s)
0
50
100
150
200
250
300
350
0
10
20
30
40
50



Longevity of 6.6Ah Battery
Time (hours)
Compressive Sampling (%)
ARS
SBS
RTV
FS
0
500
1000
1500
2000
2500
3000
10
20
30
40
50
60
70
80
90
100

Road Map: Data Collection

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Compressive Sampling

- SmartGeo apps. have moderately high sampling rates
- SmartGeo motes have very limited resources

==> need to REDUCE amount of data

will compressive sampling help??

Question 3: does compressive sampling work?

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Road Map

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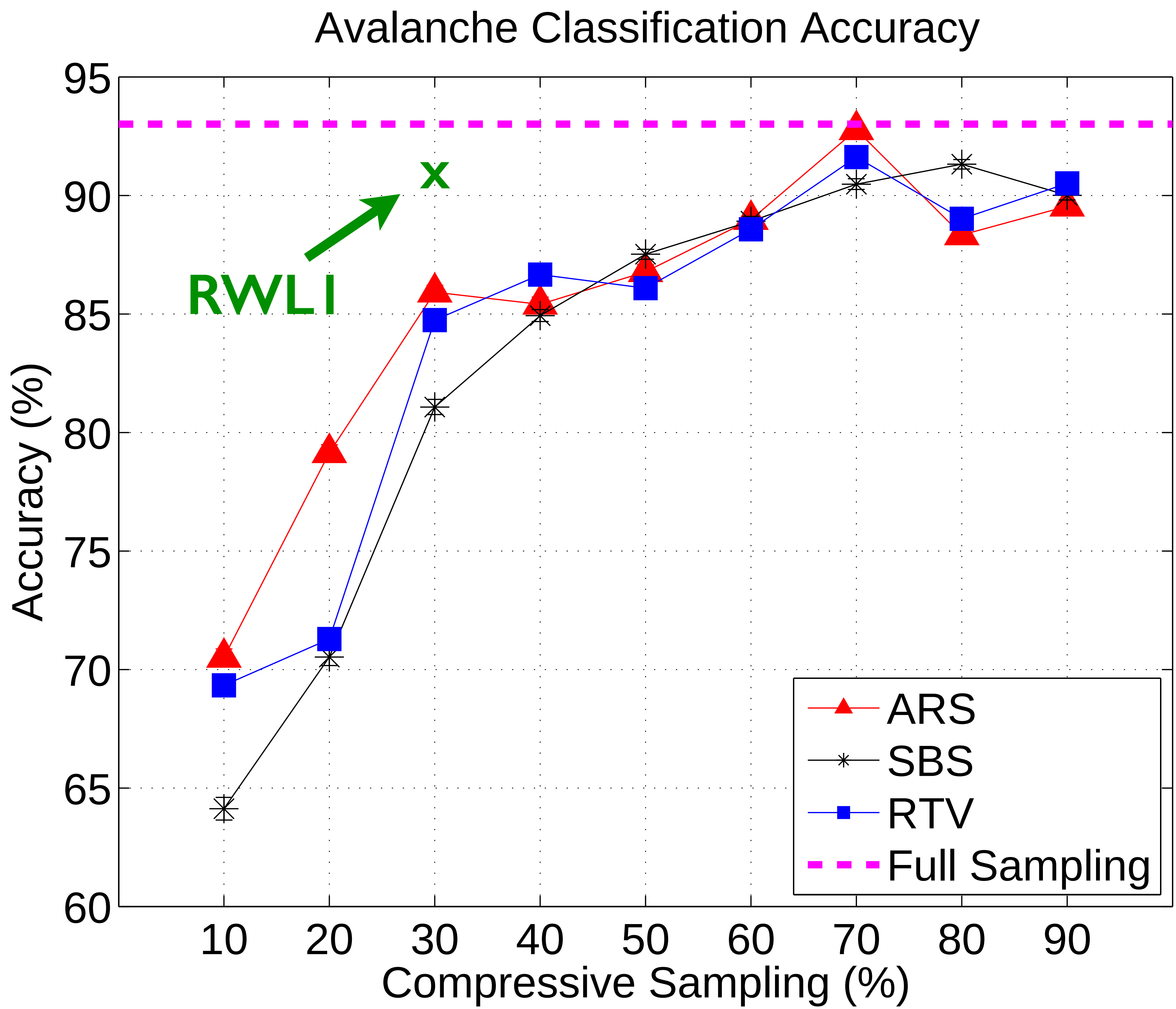
Experiment: Classification

- Features
  - centroid, flux, kurtosis, rolloff
  - 10 statistics (mean, median, standard deviation, variance, skewness, range, geometric mean, flatness, sum, and maximum)
- Training data
  - 495 5-second avalanche frames
  - 495 (random) 5-second non-avalanche frames


Avalanche Classification Accuracy
95
90
85
80
75
70
65
60
Accuracy (%)
10
20
30
40
50
60
70
80
90
Compressive Sampling (%)
RWL1
x
ARS
SBS
RTV
Full Sampling

Main Take Aways

Compressive sampling is FEASIBLE

for collection of seismic data

ON a wireless sensor mote

Still lots of challenges to implement

a wireless geophysical sensor network

Intelligent Geosystems

natural or engineered
earth systems enabled to
sense their condition and
adapt to meet their objective

My Students Rule

Recently graduated Ph.D. students: Doug Hakkarinen, James Maher, Aarti Munjal, Marc Rubin, and Kerri Stone

Current Ph.D. Students: Wendy Belcher, Henri van den Bulk, and Blair Watkinson

M.S. Thesis Students:

Santiago Gonzalez, Blake Jackson, Travis Johnson, and ...

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In closing ...

"I do not think that the wireless waves I have discovered will have any practical application."

Heinrich Hertz, 1890