

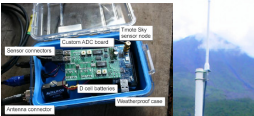
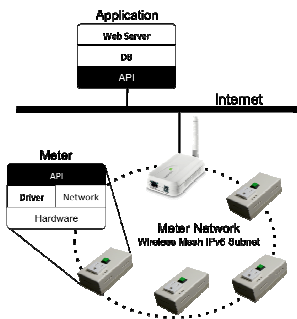
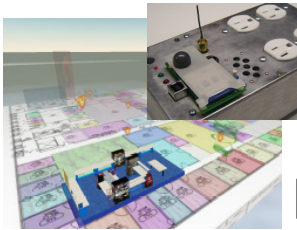
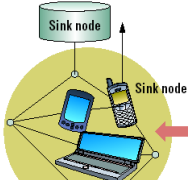


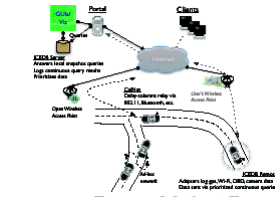
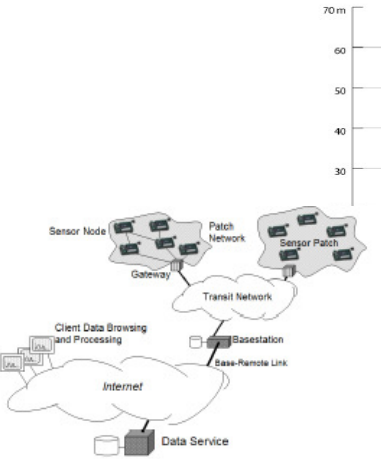
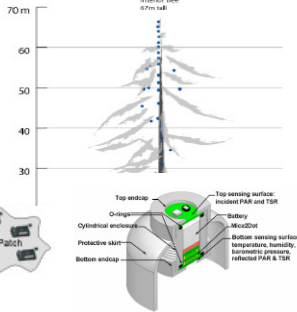

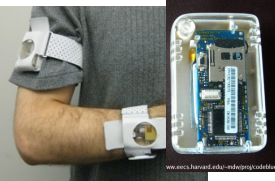

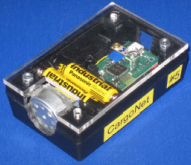

# Mobility Change Everything in Low-Power Wireless Sensornets

Prabal Dutta and David Culler

Computer Science Division  
University of California, Berkeley  
{prabal,culler}@cs.berkeley.edu

# “Applications are of course the whole point..”

Low Mobility High

 <p>[Werner-Allen06]</p>  <p>[Jiang09]</p>  <p>[Lifton07]</p>	 <p>[Abdelzaher07]</p>  <p>[Liu04]</p>  <p>[Aoki09]</p>  <p>[Hull06]</p>	<p>High</p>
 <p>[Szewczyk04]</p>  <p>[Tolle05]</p>	 <p>[Wark07]</p>  <p>[Lorincz08]</p>  <p>[Ganti06]</p>  <p>[Malinowski07]</p>  <p>[Thiele08]</p>	<p>Power</p> <p>Low</p>

# “Applications are of course the whole point..”

Low Mobility High

**“Macrosopes”**

**“Micropower Mobiscopes”**

**High Power**

**Low Power**

**Low Mobility**

**High Mobility**

[Werner-Allen06]

[Wang09]

[Afton07]

[Abdelzaher04]

[Aoki04]

[Hull06]

[Szewczyk04]

[Tolle05]

[Wark07]

[Incz08]

[Malinowski07]

[Thiele08]

# “Applications are of course the whole point..”

Low Mobility High

**ACTIVE** [Werner-A, ang09]

**ACTIVE** [Abdelz, 04]

**SOLVED** [Tolle05]

**EMERGING** [Wark07, incz08]

**“Macroscopes”**

High

Power

Low



# Periodic Limb Movement Disorder: “Stop jerking, you keep waking me up!”

- Affects 30% of those over 65
- PLM = limb muscle jerks mostly while asleep
  - Not Restless Legs Syndrome
  - Formerly called *nocturnal myoclonus*
  - Not hypnic jerks (they're lower freq)
- Diagnosing the disorder
  - Most are unaware of their kicking
  - Must link movements to poor sleep
  - Requires nights in sleep study lab
- Treatment depends on whether motion
  - Disturbs only the bed partner
  - Disturbs the patient



FIGURE 1-1

My wife tells me that my legs were restless again last night. She said that she didn't sleep a wink, but I slept fine.

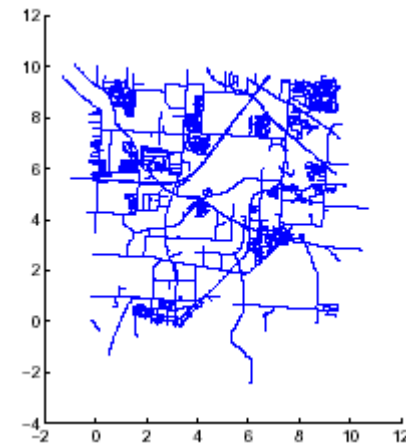
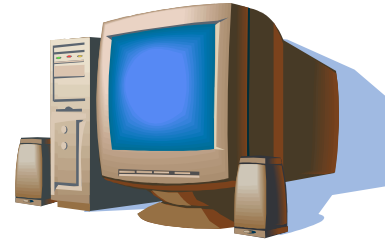
[Buchfurher06]

The bed partner's complaint of being kicked is often the main reason for seeking medical help for PLMS, because maintaining harmony in a relationship that is disrupted by nighttime kicking can be an important issue.



# Persistent Spatial Queries: “Catching thieves in the act”

- “LoJack” for everyday things
  - You: Tag your things
  - City
    - Deploy a network of detectors
    - Track stolen objects
- Cost and convenience dictates
  - \$10/tag
  - 10 years of lifetime
  - Small size
- Tags must run on 2  $\mu\text{A}$  average current
  - Sleep for years normally
  - Active for days after theft



[Mitra09]

Brave, new world

**Houston, we have a problem**

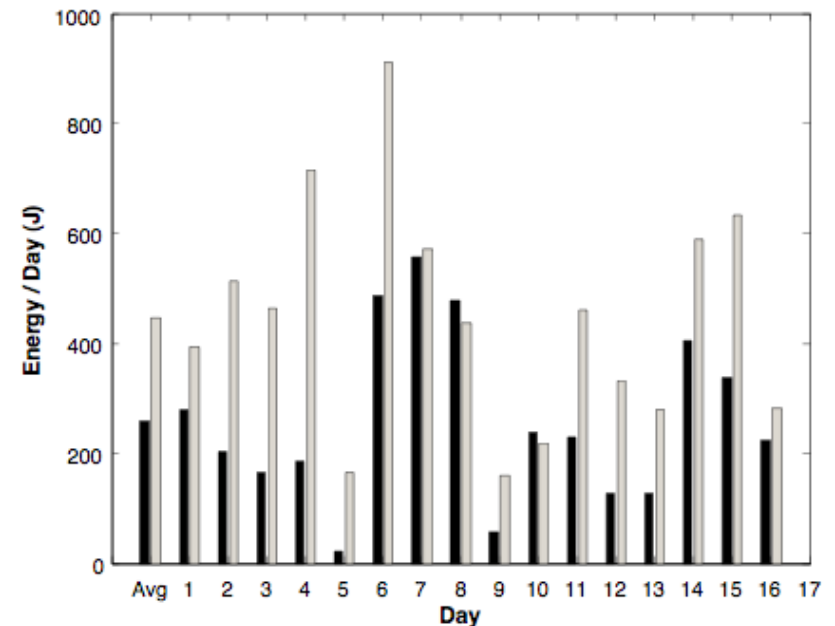
Obligatory outrageous claim

Enabling technology

# Mobility makes energy and communication challenges fundamentally harder in low-power systems

- Energy
  - Must carry it along
  - Or harvest it from the ambient environment
  - And deal with inherent uncertainty of harvesting
- Link dynamics
  - Link. What link?
  - Never before seen link
  - What radio channel?
  - When to look?
  - Can't just probe during deployment
  - History is a poor guide
  - History is no guide
- Network
- Transport

“Weather + mobility = uncertain energy budget”  
- Jacob Sorber, Sensys 2007



J. Sorber et al., “Eon: A Language and Runtime for Perpetual Systems”, *Sensys'07*, Sydney, Australia



# Energy is the defining constraint, but most other resources are also limited

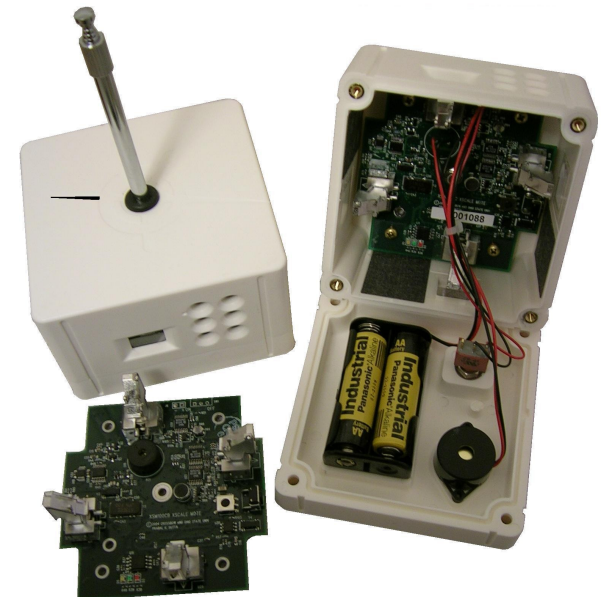
- Limited energy source
  - Fraction of 2 “AA” batteries
- Wider lifetime (average power)
  - PLMD: Weeks (50  $\mu$ A)
  - AutoWitness: Decade (2  $\mu$ A)
- Wider dynamic range
  - O(10 mA) active current
  - O(1  $\mu$ A) sleep current
  - O(0.001 - 1%) duty cycle
- CPU O(10 MIPS)
- RAM O(10 KB)
- ROM O(100 KB)
- Radio O(100 kbps)
- Flash O(1 MB - 1 GB)\*



200 mA-Hr  
Irene [Dutta09]



200 mA-Hr  
RatPack [Thiele08]



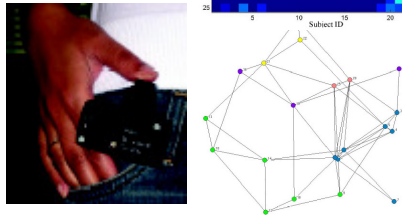
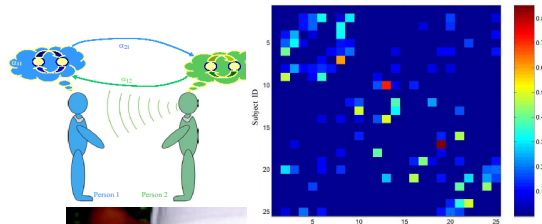
2000 mA-Hr  
[Dutta05]

# Mobility drives new communication patterns

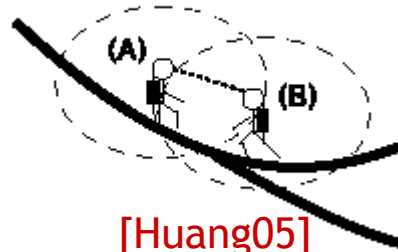
## Talking



[Liu04]



[Choudury04,07]

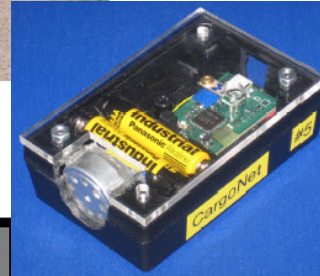


[Huang05]

## Docking



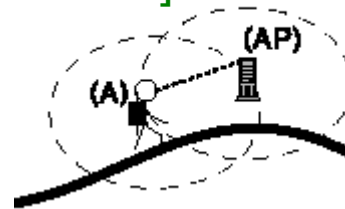
[Wark07]



[Malinowski07]



[Borriello04]



[Huang05]

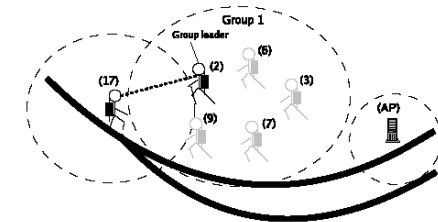
## Flocking



[UP08]



[Eisenman08]



[Huang05]

## Mobility invalidates assumptions in many static designs

- Neighbor discovery
  - One-time or periodic discovery is sufficient
- Link layer packet retransmissions
  - Retry failures (with binary exponential backoff)
- Routing
  - Offer a (stable) route for others
- Forwarding
  - Treat all route-through traffic identically
- Transport
  - End-to-end reliability and flow control is sufficient

Brave, new world

Houston, we have a problem

**Obligatory outrageous claim**

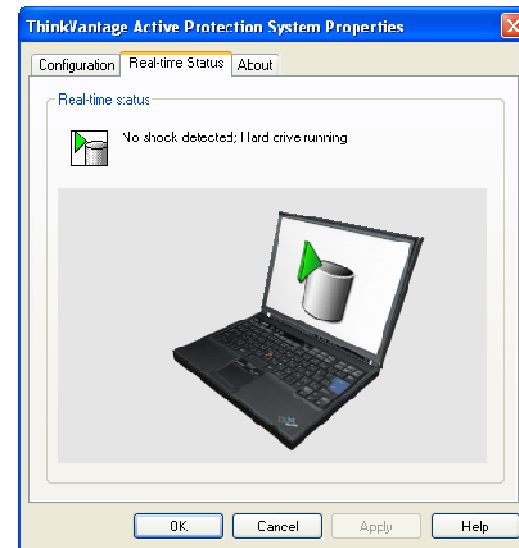
Enabling technology

## The Claim

**We can turn the mobility bug into a feature**

## Motion ObserVed (MOV): Proposal for a new metric

- Common metrics in the network stack
  - Received Signal Strength Indication (RSSI)
  - Hop count
  - Expected Number of Transmissions (ETX) [De Couto03]
  - Expected Transmission Time (ETT) [Draves04]
- MOV: Many kinds of “motion” can be observed
  - “Shock”
  - “Vibration”
  - “Acceleration”
  - “Free Fall”





# Mobility invalidates assumptions in many **static designs**; Real-time mobility awareness enables better **mobile designs**

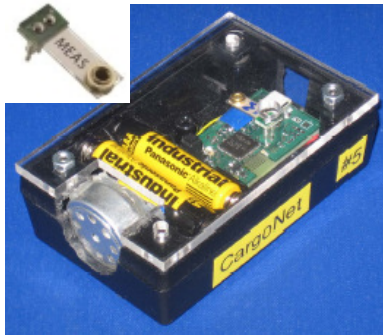
- Neighbor discovery
  - **One-time or periodic discovery is sufficient**
  - **Continuous, asynchronous discovery is preferred**
  - **Modulate discovery as a function of mobility**
- Link layer packet retransmissions
  - **Retry failures (with binary exponential backoff)**
  - **Retry immediately, use alternate next-hop, then buffer it**
- Routing
  - **Offer a (stable) route for others**
  - **Don't offer a route (unless a data mule?)**
  - **Invalidate routing table entries on (sufficient) movement**
- Forwarding
  - **Treat all route-through traffic identically**
  - **Prioritize traffic from mobile or transient nodes**
- Transport
  - **End-to-end reliability and flow control is sufficient**
  - **Hop-by-hop might offer better delivery and throughput**

## Defining the MOV metric

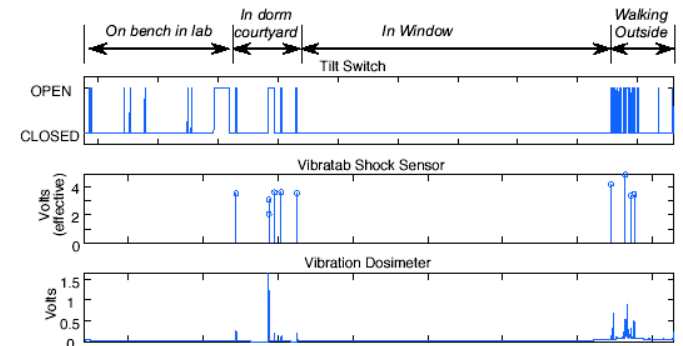
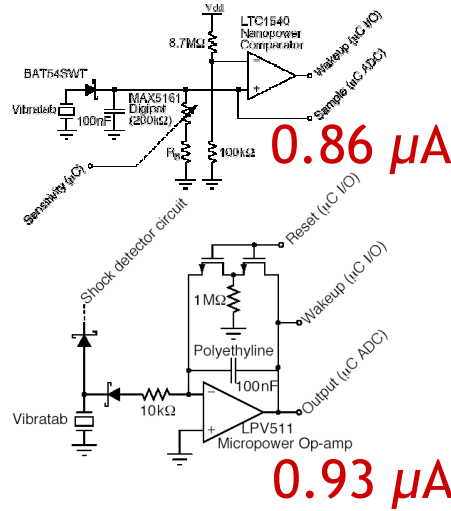
- Many possible MOV metrics
  - Shock, Vibration, Acceleration, Free-Fall, Tap, Double Tap
- Is MOV an event? A family of binary events?
  - What is (are) the test statistic(s)?
    - Acceleration? Power?
  - What is (are) the decision threshold(s)?
    - Constant? Moving average?
  - Computed over what timeframe?
  - Is it programmable?
- Are MOV events “named” or do they have “units”?
- Can simple sensors support complex MOV gestures?
  - HW/SW interplay
- Can complex gestures be multiplexed on one sensor?

Brave, new world  
Houston, we have a problem  
Obligatory outrageous claim  
**Enabling technology**

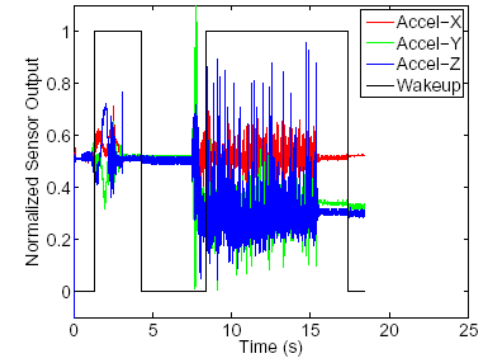
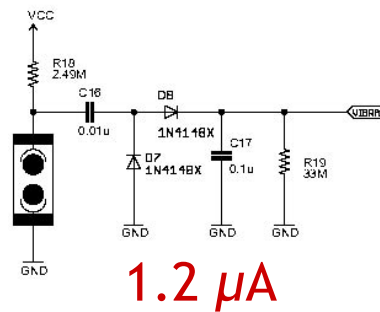
# Feasible to gather “MOV” on a near nano-power budget



CargoNet Node  
[Malinowski07]



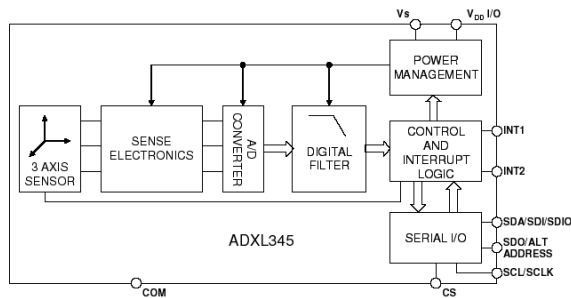
Irene Mote  
[Dutta09]



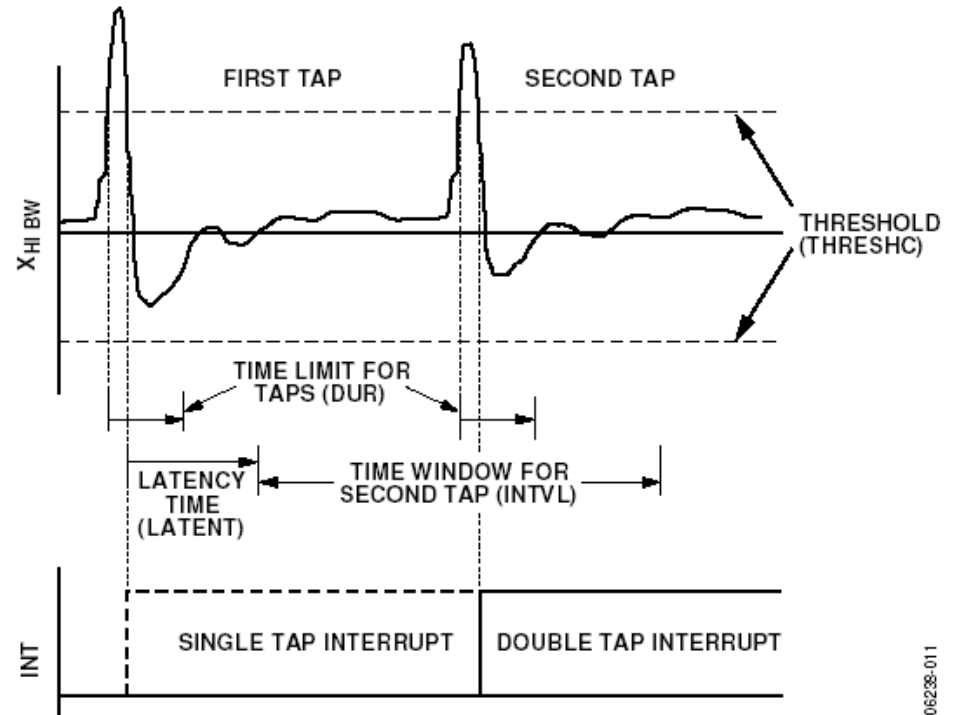
# Feasible to gather “MOV” using COTS accelerometers



ADXL345  
[Analog Devices, 2009]



25  $\mu$ A @ 25 Hz



06238-011

## Perpetual operation: Living off the land (or air)



[Sample09]  
**Harvest  $60 \mu\text{W}$**   
From 4.1 km away  
Using 5 dBi antenna  
From a 960 kW TV station  
On channel 48



[Powercast09]  
**Harvest milliamps**  
From centimeters away  
Using a 0 dBi antenna  
From your iPhone



## Closing thoughts

- Mobility changes everything
- Knowing you're MOVing sure helps
- We should (should we?) redesign around MOVement