Z25 Adaptive and Mobile Systems
Dr. Cecilia Mascolo

Energy-Efficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with ZebraNet

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Zebranet as Biology Research

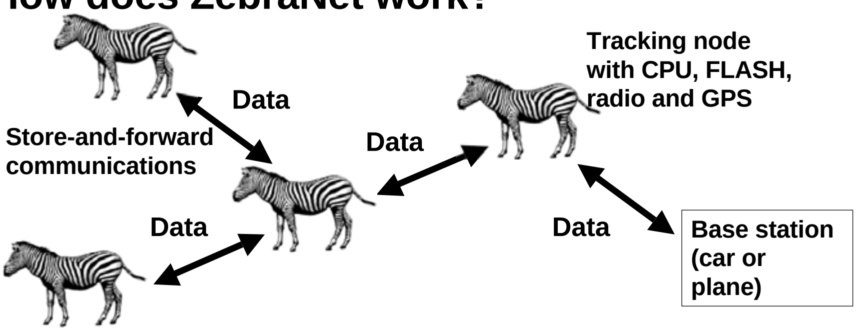
- Biologists want to track animals
  - Long-term
  - Over long distances
- Questions:
  - Interactions within a species?
  - Interactions between species?
  - Impact of human development?
- Current technology is limited:
  - VHF Triangulation is difficult & error- prone
  - GPS trackers limit data to coarse sampling and require collar retrieval
  - Overall, energy and info retrieval are key limiters
  - Peer-to-peer offers opportunity to improve

Biologists' Wish List

- Lightweight
  - Energy-efficient
  - Detailed 24/7 archival position logs
  - GPS-enabled
  - Mobile
  - Wireless
  - No fixed base station (no cellular service)
  - Peer-to-peer routing and data storage
  - Restricted human access to systems
  - Plan 1 year of autonomous operation

ZebraNet:
Mobile sensor net with mobile (intermittent) base station.
Stringent energy limits relative to needed communication range

How does ZebraNet work?



- Long-term, long-range wildlife tracking
- Individual nodes log GPS position data every few minutes, store in non-volatile flash memory
- Every two hours, nodes look for nearby peers
  - If found, swap data
  - Intentionally sparse network: often no collars in range

Zebranet vs Other Sensor Networks

- All nodes mobile: Even “base station” is mobile; intermittent drive-bys upload data
- Large spatial extent: 100s-1000s of sq. kilometers
- Coarse-Grained nodes: Storage and processing capability >> many other sensor systems
- GPS on-board: Interesting protocol, system tricks
- Long-running and autonomous: Reliability and energy-efficiency are key

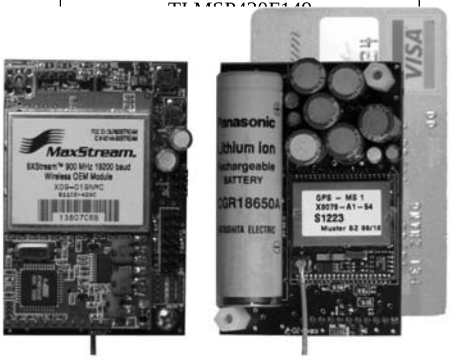
Hardware Challenges

- GPS Energy vs. Accuracy tradeoffs
  - Cannot keep GPS “warm” at all times, yet want good data
- Radio Support for Sparse networks
  - Need radio range ~5 miles
- Designing for bursts of communication
  - Infrequent peer-to-peer encounters means relatively high data rate (19.2 kbps) when communicating
- Power Management and Power Variability
  - Large variations between peak and minimal current complicates power supply design in most sensor hardware platforms
- Energy Scavenging
  - Energy must be generated to allow for the use of high energy peripherals during long periods of autonomous operation

Hardware Introduction

Microcontroller

FLASH



Power supplies, solar modules, charging circuits

Power and Weight Information

Idle	<1 mA
GPS Position Sampling & CPU / Storage	177 mA
Base Discovery only	432 mA
Transmit Data to Base	1622 mA

GPS chip + CPU	8 grams
Short-range Radio	20 grams
Long-range Radio and packet modem	296 grams
Rechargeable Batteries	287 grams
Solar Cell Array	540 grams
Total	1151 grams

•CPU: Order of magnitude less energy than data transmission!

Total Weight Goal 3-5 lbs.

Energy Goal: 5 days if no recharge

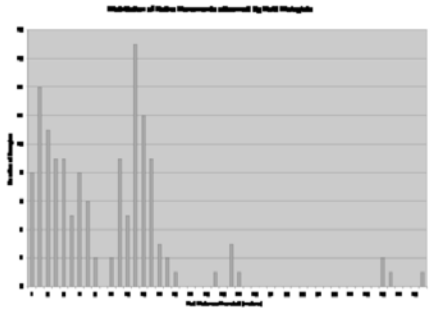
What data?

- Current:
  - GPS Position sample every 3 minutes
  - Sun/Shade indication
  - Detailed information for 3 minutes every hour:
    - Detailed position sampling: standing still or moving? Speed? “Step rate”
    - ~256 bytes per hour.
    - 1 collar-day of info ~ 6KB
- Future:
  - Head up or down: bite rate, Ambient temperature, Body temperature, Heart rate, Low resdigital images, ...
  - Bit rate & storage needs could increase further...

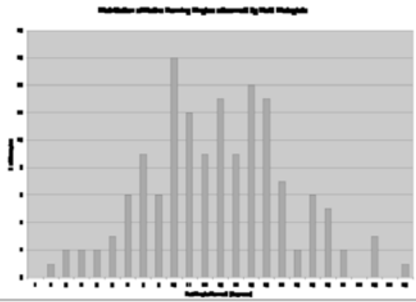
Day to Day as a Zebra

- Social Structure
  - One type of Zebra moves in ‘Harems’
    - Generally, only one male in the ‘harem’ => reducing the number of collars need to track a large number of zebras
  - Groups of ‘Harems’ form Herds
    - These dynamics challenge ecologists, but will help ZebraNet transfer information between ‘harems’
- Movement Patterns
  - Distance Moved
    - Net distance moved in a 3 minute period
      - One of three states: Grazing, Graze-Walking, Fast Moving
  - Turning Angle
    - How far does the animal turn during each of the 3 phases
  - Water Sources and Drinking
    - Need to find water sources at least once per day
  - Sleep
    - Must rely on keeping watch and fleeing from predators

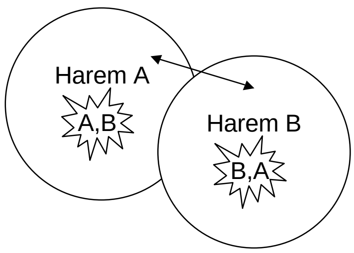
Zebra Movement Speeds



- From Field Data
  - Grazing:
    - 0.017m/s
  - Graze-walking:
    - 0.072 m/s
  - Fast:
    - 0.155 m/s
  - Turns ~ < 60°

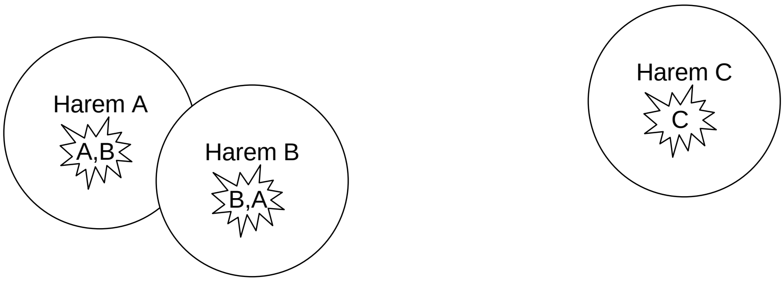


Basic Protocol in Action



Harem A and Harem B come within short range radio range. They transfer their own information with each other

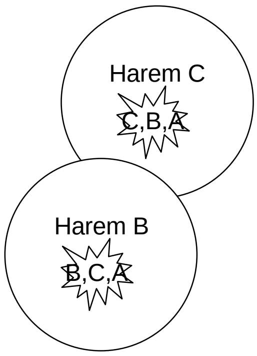
Basic Protocol in Action



Harem A and Harem B move away from each other, but Harem B moves within range of Harem C, transferring both B's and A's information to C. Harem C transfers its information to B.

Basic Protocol in Action

Now Harem C is within Long Range Radio range of the mobile base station and can transfer its information along with B's and A's. The base station has the information from all the animals even though it only came within range of Harem C.

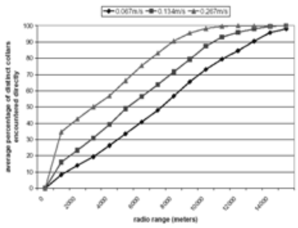


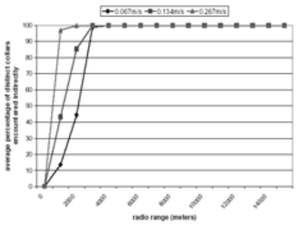
Protocol Design

- Two peer-to-peer protocols evaluated here
  - Flooding: Send to everyone found in peer discovery
  - History-Based: After peer discovery, choose at most one peer to send to per discovery period: the one with best past history of delivering data to base.
- Compared to “direct”: no peer-to-peer, just to base
- Success rate metric: Of all data produced in a month, what fraction was delivered to the base station?

Experimental Results

- Used ZNetSim simulator to vary parameters and determine best solution
- When only direct delivery used, 100% delivery is reached with ~12Km while with indirect contacts the radio range needs to be much smaller to reach 100%.





Experimental Results (cont)

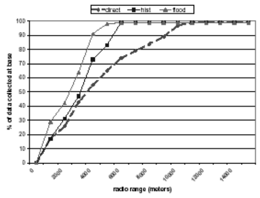


Figure 10: Success rate with infinite storage and bandwidth.

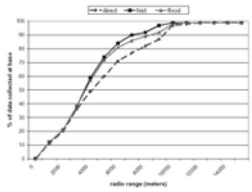


Figure 11: Success rate with constrained storage and infinite bandwidth.

Buffer: 10 collar-days

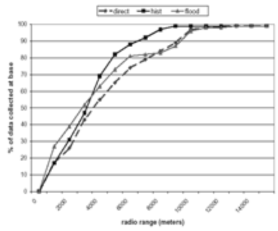


Figure 12: Success rate with infinite storage and constrained bandwidth.

Direct Connection proves to be the least reliable type of connection

Experimental Results (cont)

- Radio range key to data
  - homing success: ~3-4km for 50 collars in 20kmx20km area
- Success rate:
  - Ideal: flooding best
  - Constrained bandwidth: history best
- Energy trends make selective protocols best
- Mobility model key to protocol evaluations
  - Fast random moves hurt history
- Chicken and Egg:
  - mobility model is the biology research goal

Conclusions

- ZebraNet as Engineering Research:
  - Early detailed look at mobile sensor net with mobile base stations
  - Demonstrates promise of large-extent, long-life sensor networks with GPS
  - Detailed look at power/energy concerns
- ZebraNet as Biology Research:
  - Enabling technology for long-range migration research
  - Good view of key inter-species interactions

Related work

- Mobile sensor networks: some delay tolerant protocols
  - Including our SCAR
- Delay tolerant protocols
  - Prophet
  - CAR
  - Message ferrying
  - Epidemic dissemination
- Realistic mobility model work
  - Social mobility model
  - City mobility
  - Car mobility
  - Traces to mobility models

Discussion Questions

- Does this model what they want?
- Is this really scalable to other situations?
- What other animals could be fitted with these sensors?

- Which is the best protocol?
- What is the best technology?
- Is the duty cycling use appropriate?

WILDSENSING

- Project just started at UCL
- Tracking Badgers with mixture of sensor and RFID
  - Collaboration with zoologists in Oxford

- Other collaboration with Sea Mammal Researchers on tracking seal