How to Include Zebras in the Wireless Revolution

Prof. Margaret Martonosi

What if?
- No cellular coverage…
- No “normal conversation”…
  - Data aggregation rather than src->dest
- No human users…
  - Lions or Zebras or “Sensors”: Oh My!

=> ZebraNet!

Roadmap
- Background & Terminology
- ZebraNet: Problem Statement
- ZebraNet Design Details
- Protocol Design Tradeoffs
- Current status and next steps

Wireless without Cellular…
- So far in class, you’ve talked a lot about cellular service:
  - Cellular towers receive voice/data/signals from cell phones and then relay across wired network
- But what if that infrastructure isn’t present?

Peer-to-Peer Communication
- Wireless devices cooperate to forward data along, rather than via a central service.
- Imagine if your cell phone served as a carrier for other cell customers’ voice/data!
- Each node acts like a router, in addition to originating data.

Sensor Networks
- Sprinkle tiny sensors/computers across an area. Use wireless communication to send data “home”
- Static vs. mobile sensor networks
  - Airflow and engine temperature on new jet design
  - Regional climate studies
  - Traffic Sensors & congestion control
Data Aggregation

Many-to-one communication

Also Data Aggregation

- Many-to-one communication, but with more cooperation between nodes

Wireless “Ad Hoc” Networks

Refers to wireless networks in which nodes in the network discover their neighbors and self-organize to perform peer-to-peer data routing

Ad Hoc Networks: Forming Routes

Hi B! This is A! I’ll add you to my reachable nodes.

Hi A! This is B! I’ll add you to my reachable nodes.

Ad Hoc Networks: Forming Routes II

Hi! This is D. Does anyone know how to get to A? Give me your data and I’ll pass it along.

So far…

- Sensor nets
- In areas without cellular coverage
- Using peer-to-peer communication
- With “ad hoc” methods for discovering network routes and keeping them up-to-date

Ok, but… Hurry up and get to the zebras already!
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ZebraNet: The Big Picture

- Biologists want to track animals
- Current trackers: surprisingly primitive
- ZebraNet: Wireless ad hoc network of zebras...
  - Intelligent tracking collars placed on sampled set of zebras
  - Sensor network: data collected includes GPS position info, temperature, ...

Wildlife Tracking: How it’s done now

- Current technology is surprisingly primitive
- Most common: VHF transmitter on a collar
  - Flyovers to gather data
  - Only get data when you’re flying
  - Know where animals are, but not where they’ve been
  - Limits knowledge about night behavior...
- Satellite collars: Available but expensive and unreliable...
- Sometimes: GPS collars now available, but less reliable and in limited use.
  - Little data storage, so still not much info on nighttime behavior

Whom to track?

- Harem: Long-term bond between 1 male and several females + offspring
- Herd: Looser coalition of several harems
- We track samples from several harems

Data to track: Or… what are the sensors in this sensor net?

- 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”
- Future:
  - Head up or down: “bite rate”
    - Amount they’re eating or drinking gives clues about whether they’re migrating for food/water or some other reason.
  - Ambient temperature
  - Body temperature
  - Heart rate
  - Interactions with other species
  - ZebraCam!

Overall Design Challenges

- Need sufficiently long range (100-500m for herbivores, longer if tracking carnivore)
  - No fixed antennas available
  - Looking at 802.11 or VHF transmission
- Difficult terrain
- Power generation & storage; Power efficiency
- Reliability & fault tolerance
  - Swap data for redundant copies
  - Manage truncated transfers intelligently
- Good physical design for ruggedness
ZebraNet as an Ad Hoc Network
- Nodes (aka tracking collars) collect logs of GPS position and other information.
- Peer-to-peer communication aggregates data back to researcher base station

ZebraNet as an Ad Hoc Network II
- Nodes (aka Zebras) collect logs of position information.
- But researcher base station is not fixed. Rather, it moves and is only intermittently available...

ZebraNet Collar Block Diagram

ZebraNet: Baby Picture!

ZebraNet: Weight & Battery...
- Goal: weight limit ~3lbs (Not crucial for zebras... very crucial for smaller carnivores like hyenas...)

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
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<tbody>
<tr>
<td>GPS chip + CPU</td>
<td>8 grams</td>
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<tr>
<td>Short-range radio</td>
<td>20 grams</td>
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<tr>
<td>Packet Modem</td>
<td>140 grams</td>
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<tr>
<td>Long-range radio</td>
<td>156 grams</td>
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<tr>
<td>Lithium-Ion batteries</td>
<td>226 grams</td>
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<tr>
<td>Solar cell array</td>
<td>540 grams</td>
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<tr>
<td>Total</td>
<td>1090 grams (2.4lbs)</td>
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Power Management

- Weight limits constrain battery capacity
- Battery capacity constrains energy
- ZebraNet designed to operate for 5 days without solar recharge

Energy Saving Tricks:
- When listening for other tracked animals: polling less frequently will save power…
- Scheduled polling based on GPS clock
- Short-range radio for “peer” transfer
- …

Summary so far:
- Sensor net, to track position, temp etc.
- Ad hoc network, since no cellular coverage
- Weight limits constrain energy usage
- …
- Ultimate goal: Highest possible “success rate” on getting data home…

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ZebraNet Protocols
- Tracking collars can be programmed with one of several “protocols” for aggregating data.
- Flooding: Every 3 minutes, zebras look for other zebras in range. Send to everyone they find.
- History-Based: Every 3 minutes, zebras look for others in range. Of the ones found, only send to one: the one with the best success rate at delivering data.

Evaluating Protocols
- ZNetSim: Probabilistic simulator to evaluate protocol tradeoffs under different mobility assumptions.
- Mobility models drawn from biologist observational data
- ZNetVis: Visualizer of Zebra Motion

Data Homing Success Rate
Necessary Collar Capacity

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Status
- Currently have a pair of partially-functional prototype nodes
- Refining protocol designs to work better with moving base station
- Coming soon: Final decision between 802.11 vs our in-house transceiver design

Wildlife research scenarios
- Wild Horses in NC & Virginia
  - Barrier islands off US Atlantic coast still have wild horse populations
  - Excellent nearby locale for studying social organizations among these animals
- Zebra migrations in Kenya
  - Central Kenya becoming more densely populated with smaller landholdings and more crop acreage.
  - How do fences and human presence affect large scale (tens of kilometers) migration?

Other issues: Dealing with Terrain
- Managing communication in rugged terrain
  - No fixed antennas
  - No cellular service
  - Short line-of-sight

Other issues: Packaging for Reliability & Ruggedness
- Waterproof
- Shockproof
- Biteproof! (Carnivores typically tough on collars…)
- Currently: Antennas often break off in first week or month of use. Drastic drop in range/functionality.
Real Users of the system…

- Generation 0: Domesticated horses in NJ
- Generation 1: Wild horses in VA/NC
- Generation 2: Full ecosystems (lions, zebras, hyenas…) at Mpala Research Centre, Kenya

Summary

- **ZebraNet as Engineering Research:**
  - First detailed look at mobile sensor net with mobile base stations
  - An early look at large-scale, long-life sensor networks with GPS
  - Detailed look at power/energy concerns
- **ZebraNet as Biology Research:**
  - Enabling technology for long-distance migration research
  - First looks at key inter-species interactions

Any questions?

People

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- PhD: Hide Oki, Philo Juang, Yong Wang
- Undergrad: Karen Tang, Kinari Patel, Jeremy Wall, Chido Enyinna

Current Model Assumptions

**Movement**
- 3 minute atomic time unit
- Moves 10 meters per time unit
- Moves any direction with equal probability

**Movement grid**
- 3x3 weighted grid
- Re-evaluated every cycle

**Terrain**
- 20 km x 20 km area
divided into 10m x 10m squares
- Base station located at (100, 100)
- Single cycle satisfaction of thirst

**Data Transfer**
- Infinite storage capability
- Instantaneous data transfer
- Perfect communications link

Measured Movement Data

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Measured Turning Angle

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