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

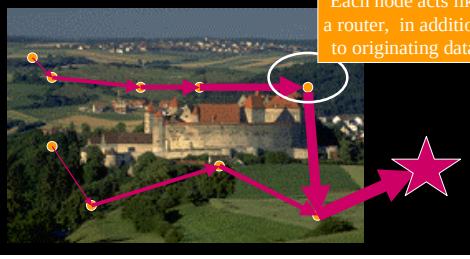
- Background & Terminology
- ZebraNet: Problem Statement
- ZebraNet Design Details
- Protocol Design Tradeoffs
- Current status and next steps

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!



Sensor Networks

- Sprinkle tiny sensors/computers across an area. Use wireless communication to send data "home"
- Static vs. mobile sensor networks

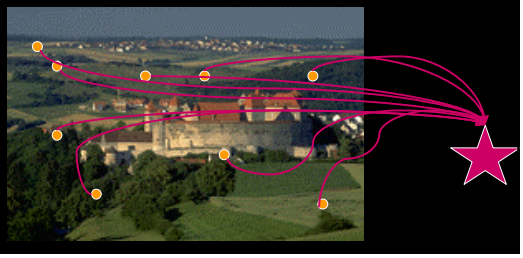
Regional climate studies

Airflow and engine temperature on new jet design

Traffic Sensors & congestion control

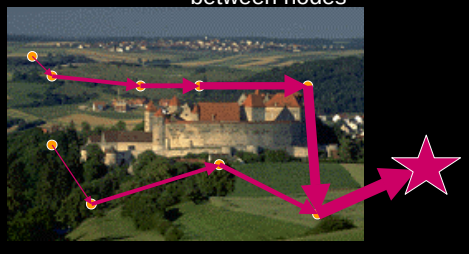
Data Aggregation

Many-to-one communication



Also Data Aggregation

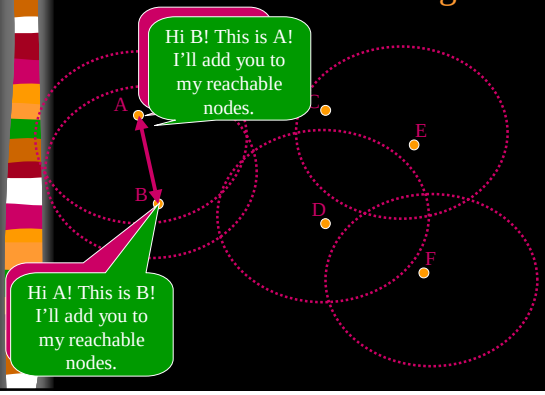
- Many-to-one communication, but with more cooperation between nodes



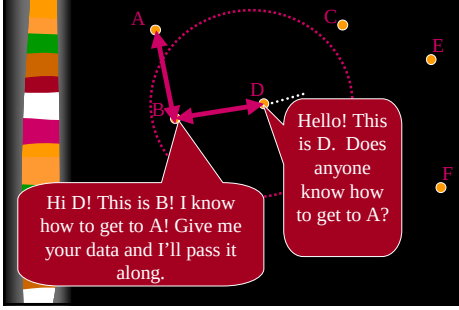
Wireless "Ad Hoc" Networks

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

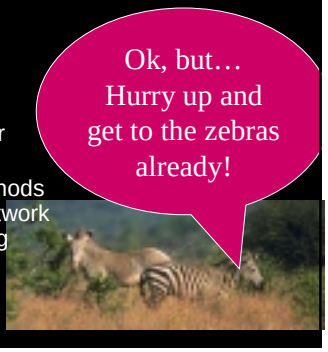


Ad Hoc Networks: Forming Routes II



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



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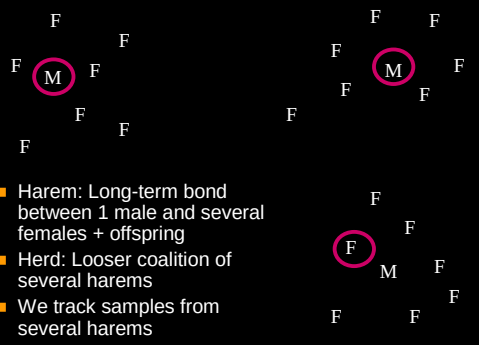
ZebraNet: The Big Picture

- 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

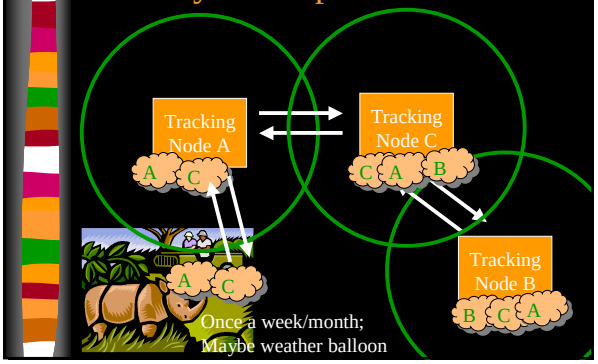
Data to track: Or… what are the sensors in this sensor net?

- 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

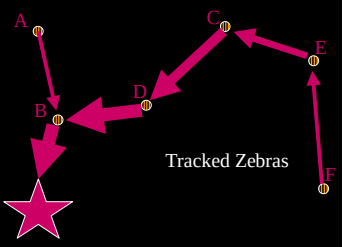
- Need sufficiently long range (100-500m for herbivores, longer if tracking carnivore)
  - No fixed antennas available
  - Looking at 802.11 or VHF transmission
- Difficult terrain
- Power generation & storage; Power efficiency
- Reliability & fault tolerance
  - Swap data for redundant copies
  - Manage truncated transfers intelligently
- Good physical design for ruggedness
- Variable frequency for use in US + Kenya + elsewhere.

Basic System Operation



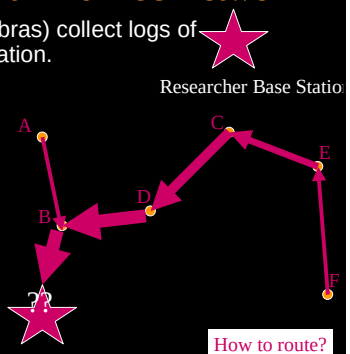
ZebraNet as an Ad Hoc Network

- Nodes (aka tracking collars) collect logs of GPS position and other information.
- Peer-to-peer communication aggregates data back to researcher base station

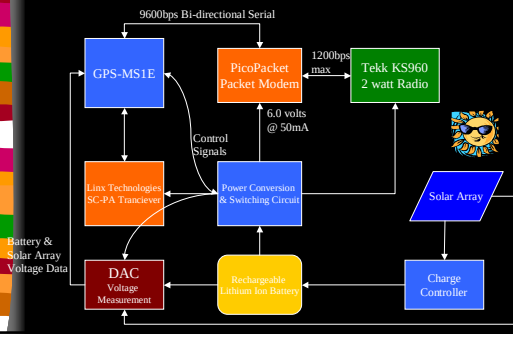


ZebraNet as an Ad Hoc Network II

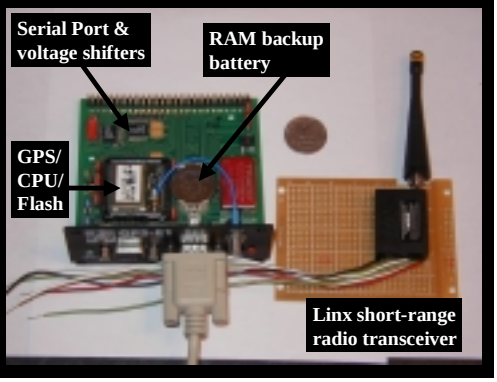
- Nodes (aka Zebras) collect logs of position information.
- But researcher base station is not fixed. Rather, it moves and is only intermittently available…



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…

GPS chip + CPU	8 grams
Short-range radio	20 grams
Packet Modem	140 grams
Long-range radio	156 grams
Lithium-Ion batteries	226 grams
Solar cell array	540 grams
Total	1090 grams (2.4lbs)

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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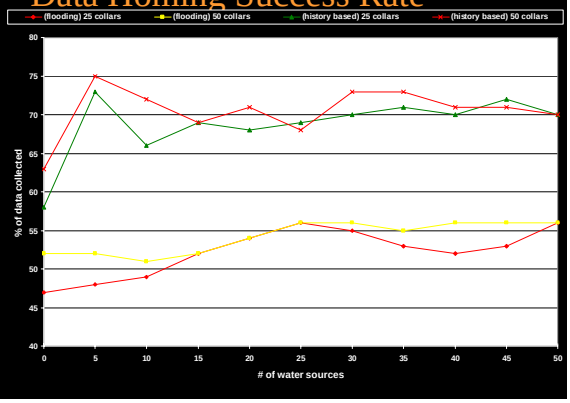
ZebraNet Protocols

- 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.

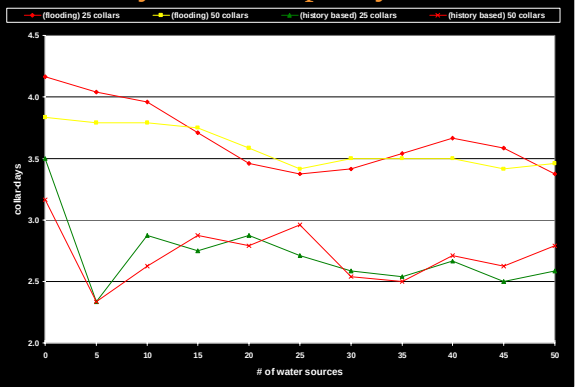
Evaluating Protocols

- 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

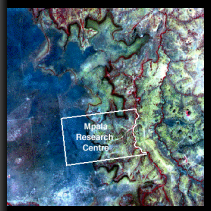
Wild Horses in NC & Virginia

- 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

Ewaso Ngiro River, Mpala Ranch, Kenya

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

ZebraNet

Any questions?

People

- Profs: Margaret Martonosi, Li-Shiuan Peh, Steve Lyon, Dan Rubenstein (EEB)
- PhD: Hide Oki, Philo Juang, Yong Wang
- Undergrad: Karen Tang, Kinari Patel, Jeremy Wall, Chido Enyinna

Current Model Assumptions

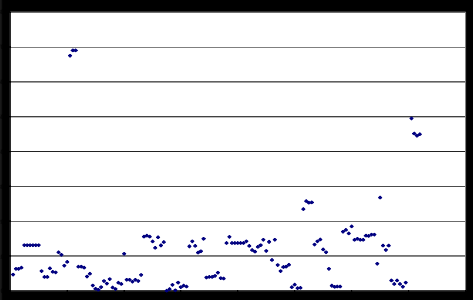
Movement
- 3 minute atomic time unit
  - Moves 10 meters per time unit
  - Moves any direction with equal probability

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



Measured Turning Angle