

# Energy-efficient Computing for Wildlife Tracking

Design Trade-offs and Early Experiences with  
ZebraNet

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# Agenda

- Introduction  
(*Jensen Mwombeki*)
  - Overview
  - Design goals
  - Requirements and Factors
- Collar Design  
(*Wichukorn Nilmanat*)
  - Collar HW design
  - Protocol design
- Results and Evaluation  
(*Anup Aravindakshan*)
- Related work and Future Plans  
(*Li Wei*)
- Critique and Conclusion  
(*Daniel Madadi*)



# 1. Introduction

## 1.1 What is ZebraNet? Why ZebraNet?

- Collaboration research work between wildlife biologists and mobile network computer scientists
- Tracking nodes (collars) with GPS, Flash Memory, wireless (radio) transceiver, small CPU
- Peer-to-peer data communication
- Wireless sensor network for wildlife tracking

## 1.2 Design considerations

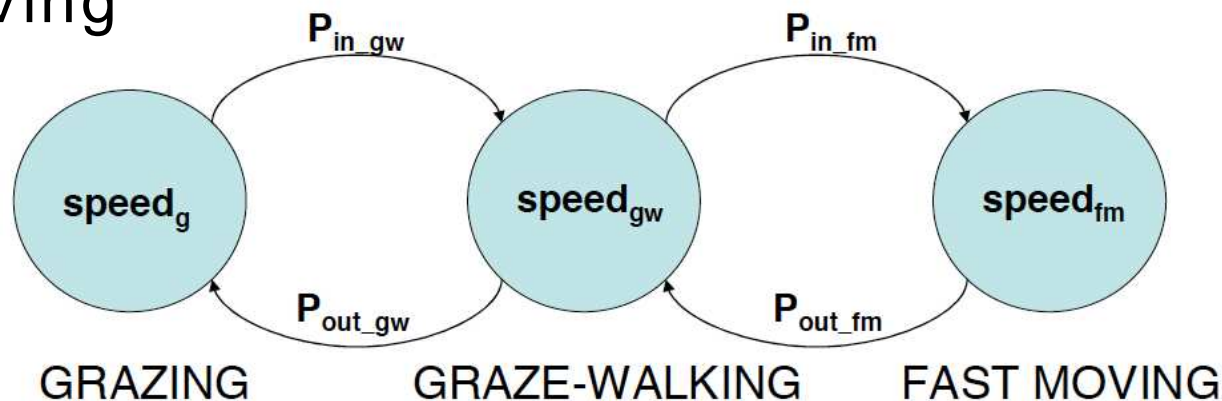
- mobile base station
- nodes mobility models (unknown)
- energy trade-offs

## 2 Design Goals

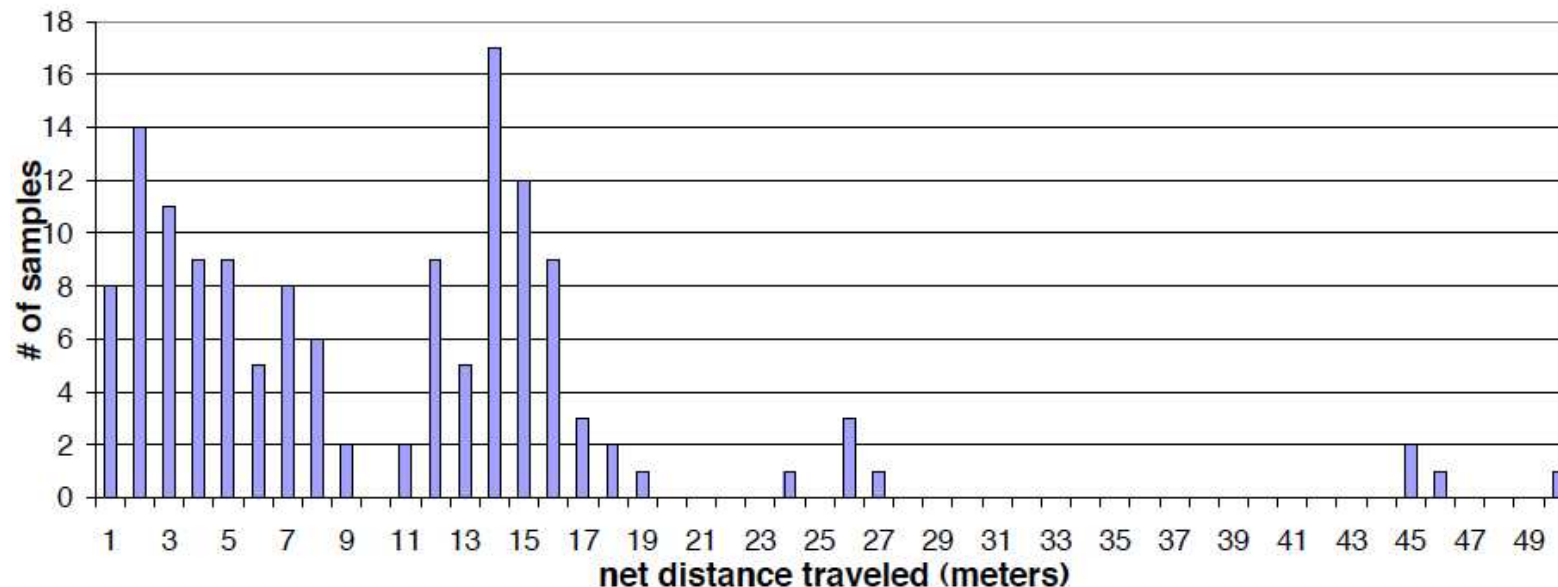
- Zoologists' requirements
  - GPS position samples, every 3 minutes
  - Activity logs, taken 3 minutes every hour
  - 1 year of operation with no human intervention
  - Operate over thousands of square kilometers
  - No fixed base station, antennas, cellular network
  - High delivery rate of data logs (Latency is not critical)
  - Limited collar weight (e.g. 3 -5 lbs for zebra collar)
- Implications to design
  - Weight limit, energy limitation
  - Transmission range
  - Storage capacity

## 3. Effect of Mobility

- Nodes (collars) fitted on zebra
- To understand node mobility requires understanding of how fast, in what direction and with what forces of attraction/repulsion zebras move.
- Movement patterns: grazing, graze-walking, fast-moving



- Distance moved:
  - Net movement in a 3 minute interval
  - Grazing (mean 3.1m) and graze-walking (mean 13m) movements



- Turning Angle; Water Sources and drinking
- Sleeping time

# Collar design

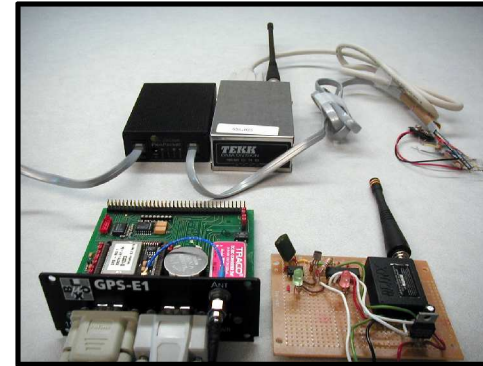
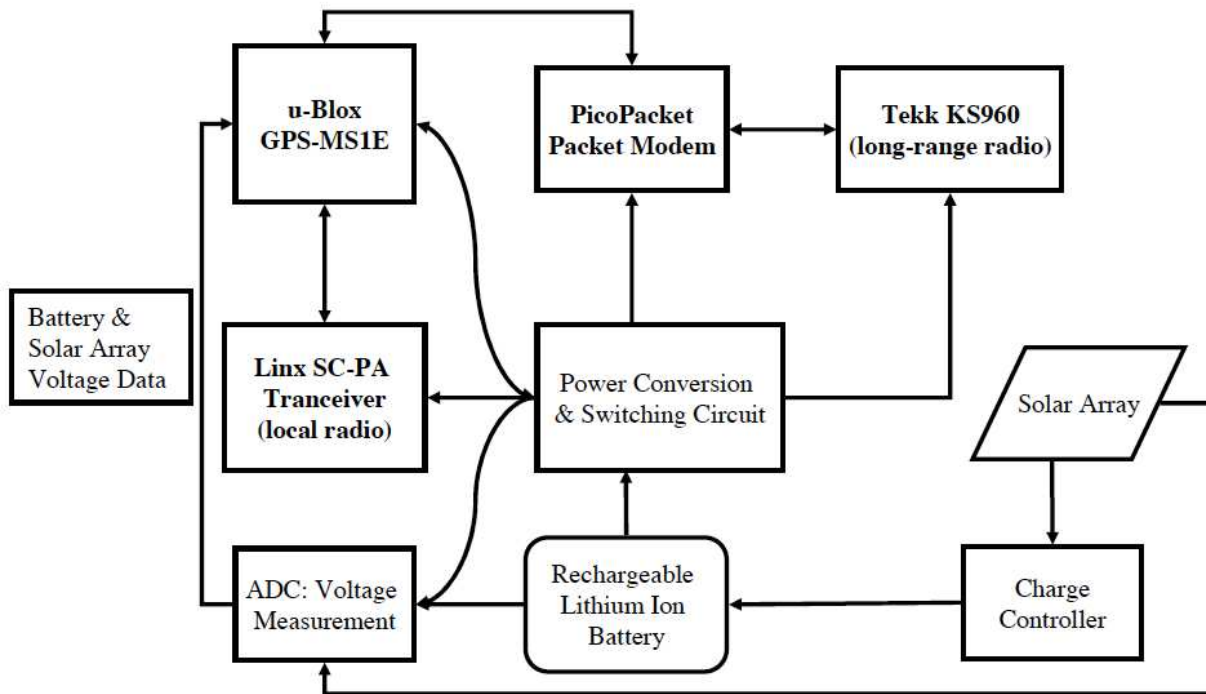
- Design goals
  - Total weight ~ 3-5 lbs
  - Energy 5 days of no recharge
  - Battery rechargeable using solar cell
- Amount of data
  - 30 coordinates per hour
  - 240 bytes per hour
  - 1 Collar-day ~ 6KB

# Collar design

- GPS Enable
  - u-Box GPS-MS1E (20Mhz SH1, 1 MB Ram, 12 channels GPS)
- Communicating with base station (Long range)
  - PicoPacket Packet modem with Tekk KS-960 radio range of 8 km
- Communicating with other collars (Short range)
  - Linx SC-PA series low energy, radio range of 100 m
- Battery and Solar Cell
  - Sony Lithium Ion polymer Cell (3.7 V)
  - Unisolar USF5 Flexible amorphous silicon array (5 Watt)



# Collar design



# Short Range Radio Protocol

For short range radio (Linx radio)  
ZebraNet firmware must perform  
following

- Packetization and Error Checking
  - Maximum 300 bytes with 16 bit CRC
- A unique collision avoidance protocol
  - GPS provide extremely precise sync clock
  - Peer to peer search can queries in non-overlapping predetermined timeslot

# Energy and Weight

Collar State	Current drain from 3.6 V
Stand by	< 1 mA
Peer Discovery/Transfer	177 mA
Base Discovery	432 mA
Peer and Base Discovery	469 mA
Transmitting Data to base	1662 mA

Energy Goal 5 days no recharge

- 30 sample/hr, 24hrs
- 6 hrs/day use short range radio
- 3 hrs/day use long range radio (**overlap** with short range)

Weight Goal ~ 3-5 lbs

Item	Weight
GPS-MS1E	8 grams
Linx SC-PA	20 grams
Tekk KS960 and Packet modem	296 grams
Battery	287 grams
Solar cell array	540 grams
<b>Total</b>	1,151 grams (2.54 lbs)

# Protocol

- ZebraNet Characteristic
  - Not every collar is within range of the base station
  - The nodes(collar) move around almost constantly
  - Base station is also mobile
  - Base station is active from time to time
  - High success rate is important (latency is not critical)
- Protocol Strategies
  - Flooding protocol
  - History-based protocol

# Flooding protocol

- Flood data to all neighbors whenever they are discovered
- Base station contact just few nodes may be enough
- Give high success rate
  - They should assume that they will collect the data before storage overflow. Otherwise, it will lead to message drop and give a very poor result.
- Large amount of data can lead to excessive demands for bandwidth storage and energy

# History-based protocol

- After peer discovery, choose at most one peer to send to per discovery period: the one which best past history of delivering data to base
- Can reduce amount of data in network
- ZebraNet is very dynamic (both collars and base station are mobile). Then, this protocol may mis-direct traffic and get a poor success rate

# Experimental Results

- ZNetSim – the simulator
- Network connectivity
- Evaluations
  - Protocol evaluations
  - Storage constrained evaluation
  - Bandwidth constrained evaluation
- Metric – energy consumption
- Design choices

# Experimental Results

- ZNetSim
- Based –Field Observations of Zebra behaviour
- User defined constraints
- Returns two metrics- Success Rate & Energy Consumption
- Mobility Models
  - Based on 3 tier mobility model
  - Predators Ignored
  - Random time – Seeks Water
  - Base Station – 3hours per day and 30 km/hr



# Experimental Results

- ZNetSim
- Simulation Methodology
  - Four Communication Phases- 30 Minutes
    - Peer Discovery
    - Base Discovery
    - Peer Transfer
    - Base Transfer
    - Priority of Data

# Experimental Results

- Network Connectivity
- Determined by Animal Movements
- Two types of Connectivity
  - Direct Connectivity
    - 100 % connectivity – 12 kms
  - Indirect Connectivity
    - 100 % Connectivity – 2000 m
    - Well-Exploited by Peer-peer protocols

# Experimental Results

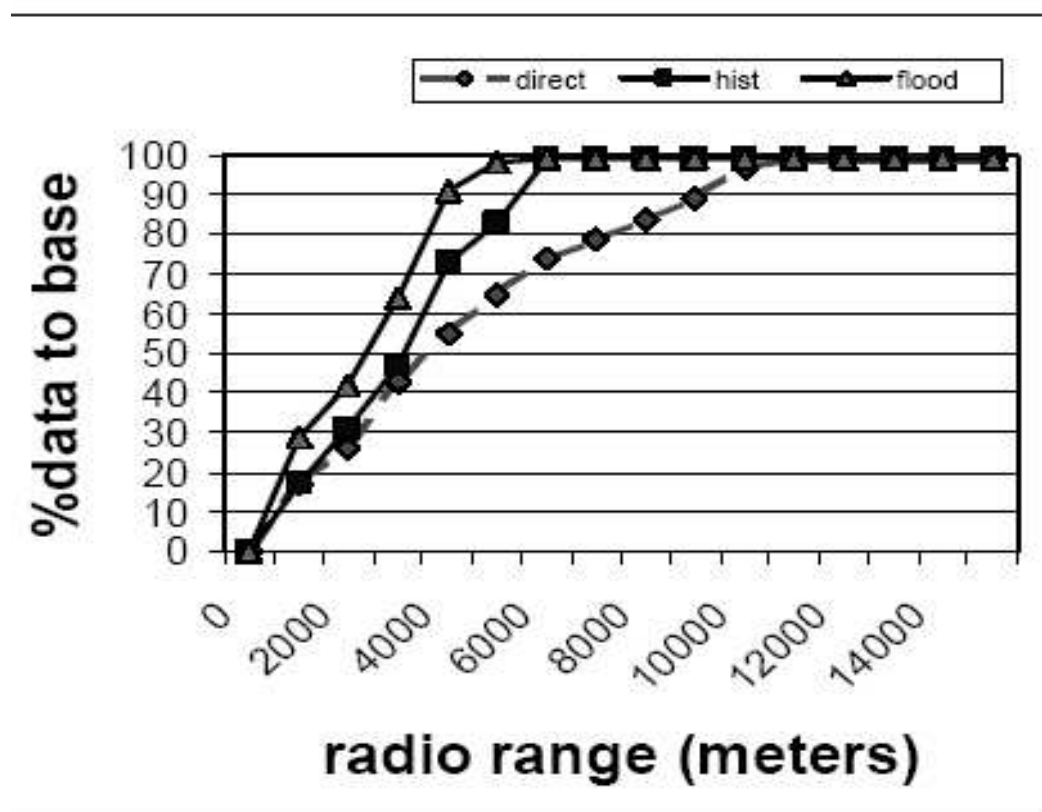
- Evaluations
- Protocol Evaluations
  - Baseline established –infinite storage & bandwidth
  - Peer to peer has better Performance
  - Flooding better then History based protocol
- Storage Constraints
  - Peer to peer performs better, flooding suffers
  - Deletion Strategy

# Experimental Results

- Evaluation
- Bandwidth Constraints
  - Bandwidth made lower –12kbps
  - Short Radio Ranges-low radio connectivity
  - Long range – Saturates bandwidth
    - Flooding affected
    - History based Protocol more effective

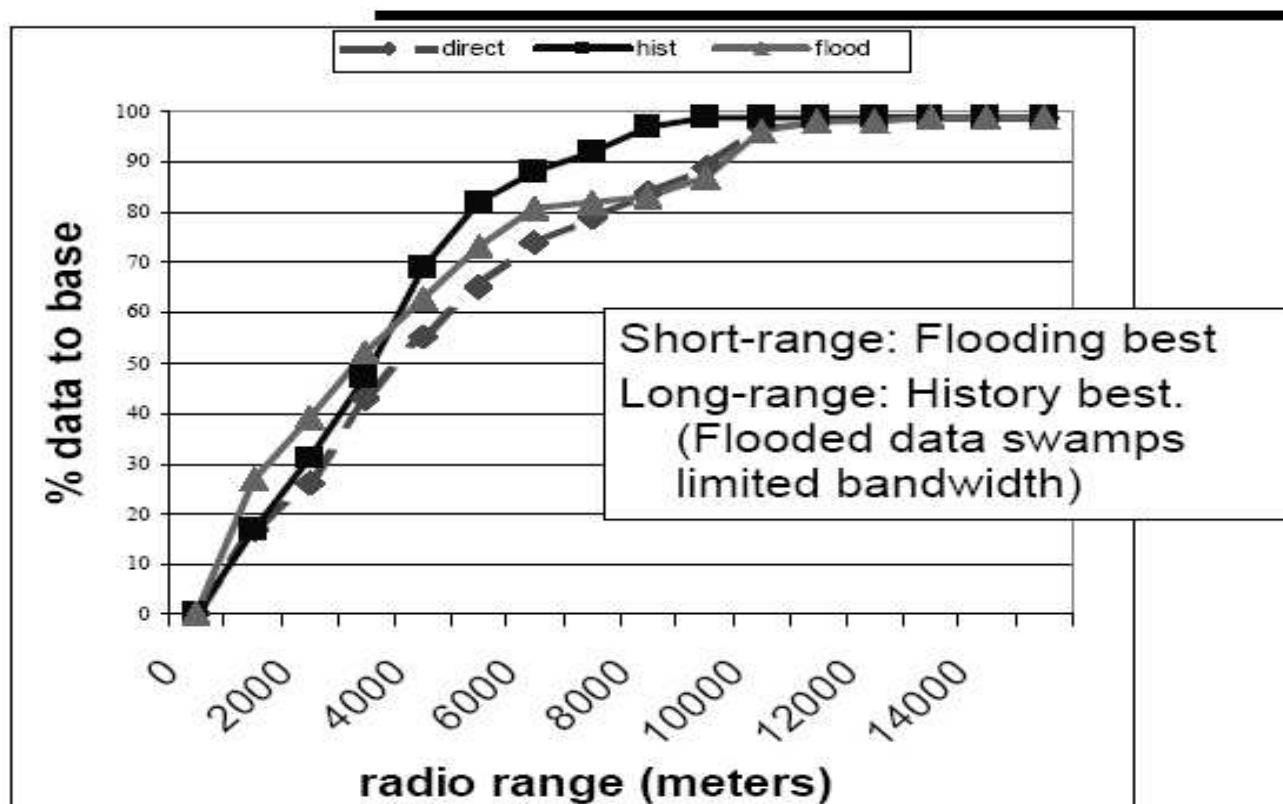
# Experimental Results

## Protocol Success Rate: Ideal



- Radio range for 100% delivery:
  - No peer-to-peer: ~12km
  - With Peer-to-peer: ~6km

# Experimental Results



Protocol Success Rate:Constrained Bandwidth

# Experimental Results

- Metric – Energy Consumption
- Flooding – 8 times more at large radio ranges vs Direct
  - Sends to everyone
  - Lots of redundant data
  - Flooding best- peer to peer short range
- Design Choices
  - Two Radios □Short and long range
    - Short Range -low power for peer-peer(100m , 19.2 kbps)
    - Long Range – for base transmissions(8 km, 2.4 kbps)

# Impala - A Middleware Architecture for ZebraNet

- **Characteristics of ZebraNet**
  - Harsh Surroundings
  - Hundreds of Nodes
  - Distributed over huge geographical area
- **So that ...**
  - It is nearly impossible for a single protocol to be appropriate all the time
  - Software updates will also be a problem
  - By adopting a middleware layer that can update and adapt applications dynamically, new protocols can be plugged in at anytime, and switches between protocols can be performed at will



# Impala - Layered System Architecture

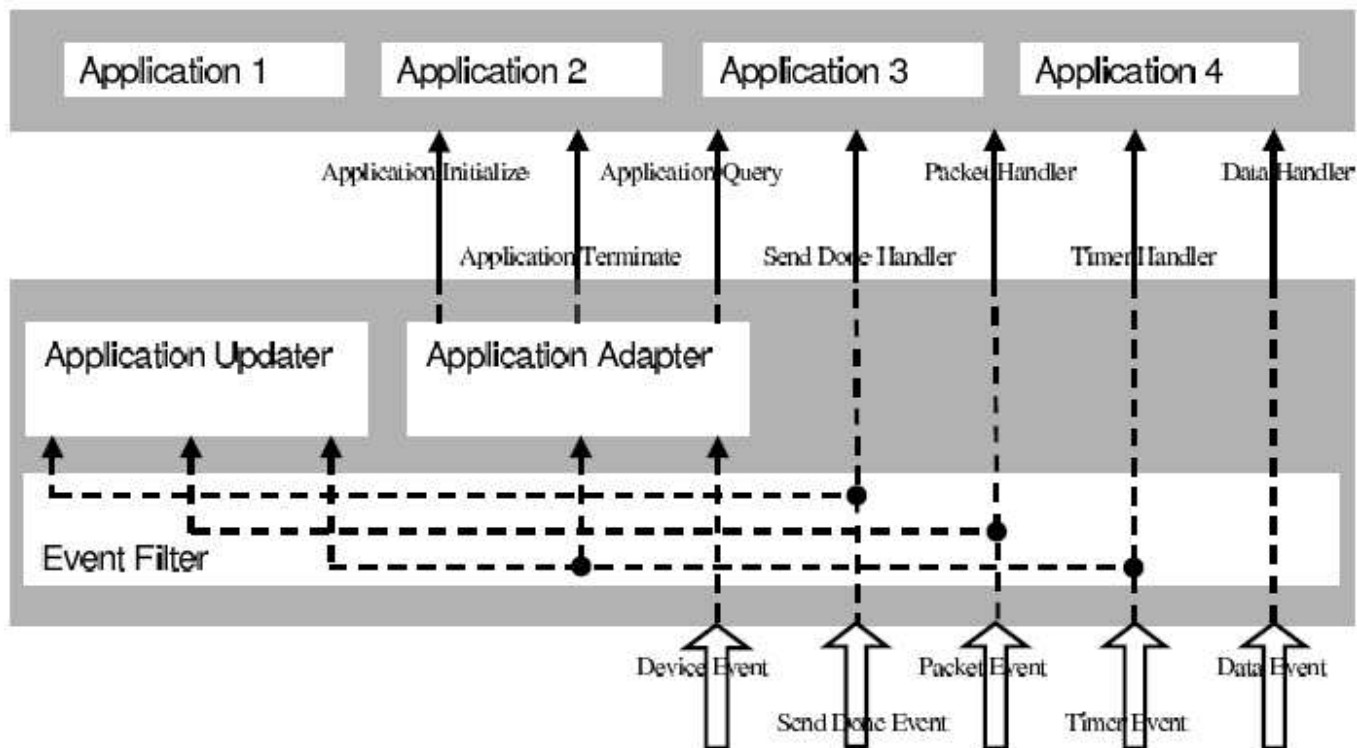
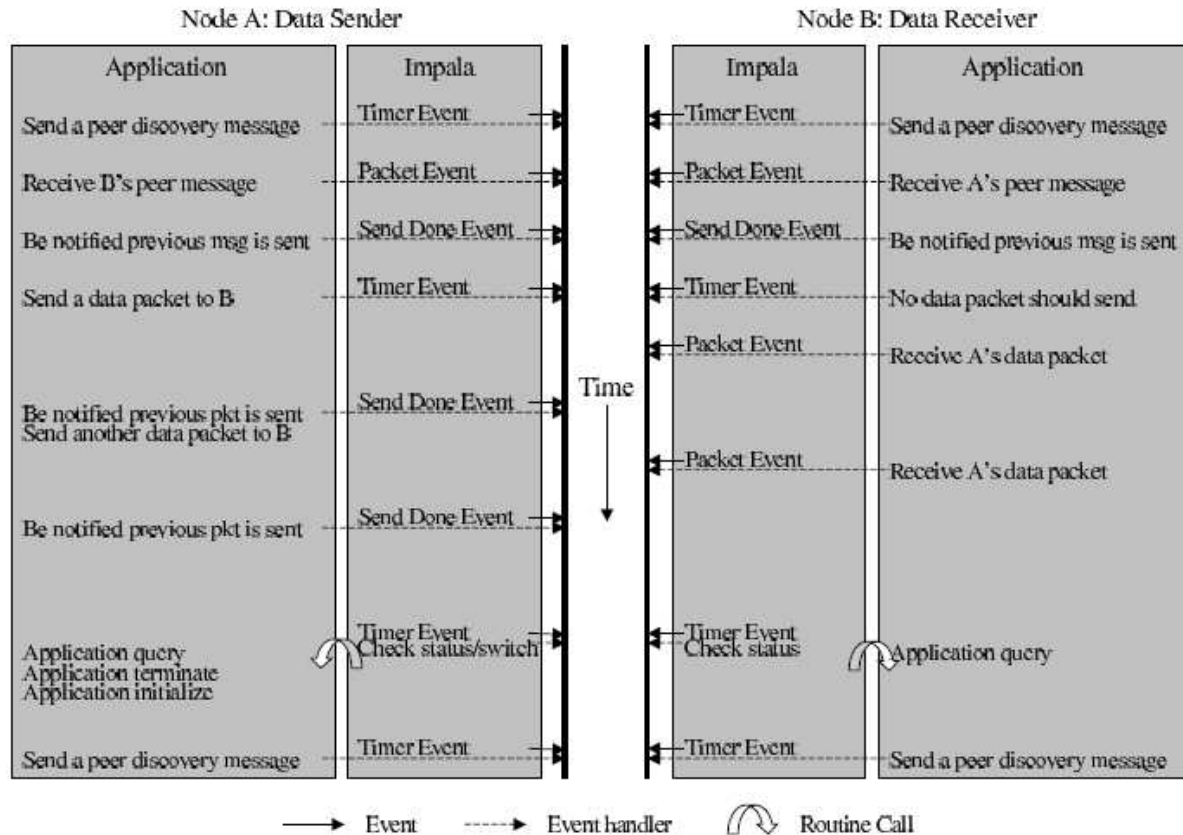


Figure 1: Layered system architecture.

# Impala - Application Programming Model

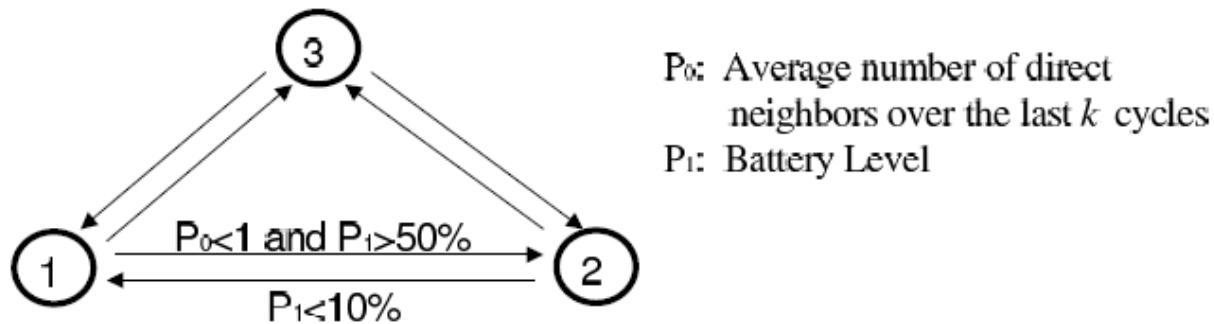


# Impala - Application Adapter

Two Purposes:

Adaptation to changes of parameters

Adaptation to device failures

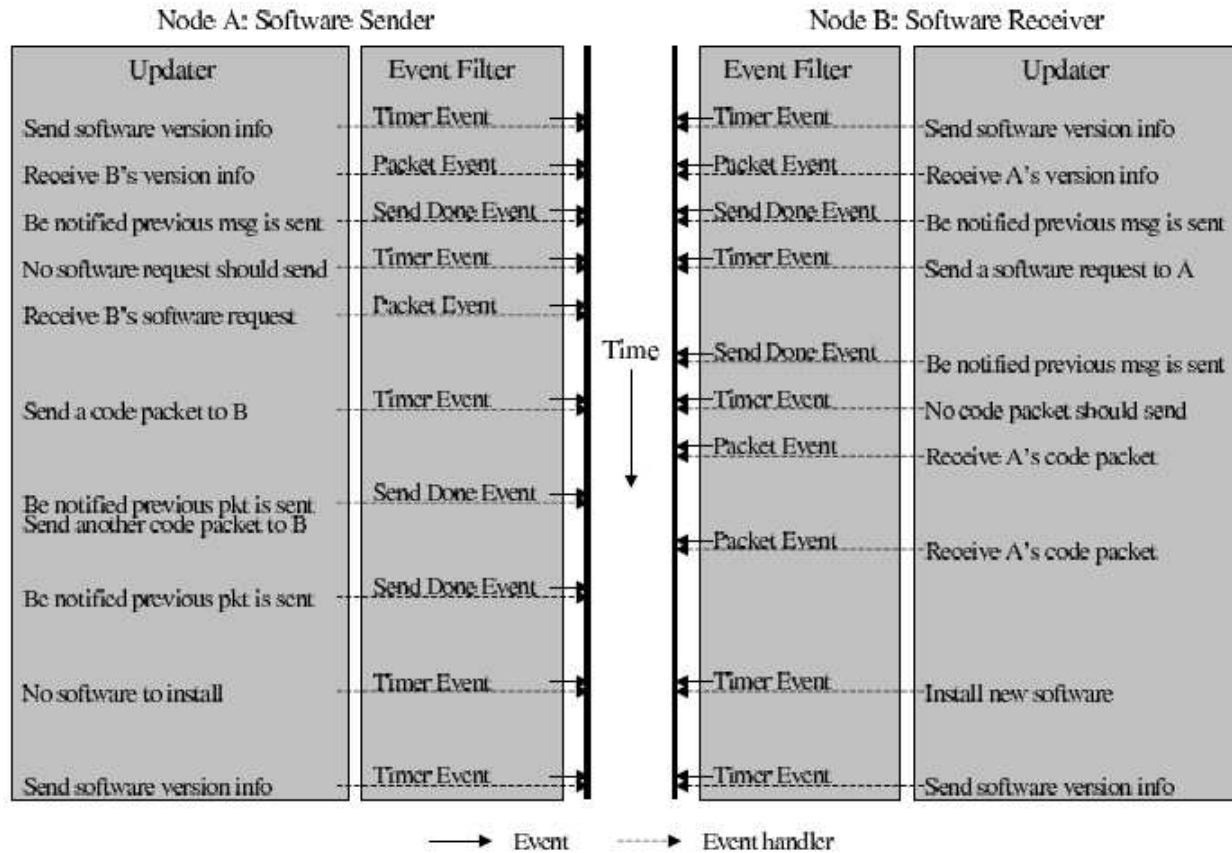


*Adaptation Finite State Machine*

# Impala – Application Updater

- Goal: to achieve an effective software update mechanism under resource constraints
- Store both complete and incomplete update versions in the code memory
- Sensor nodes periodically exchange software version info before exchanging the actual code: On-demand transmission strategy
- Implementation: the updaters wake up every two hours to exchange software updates.

# Impala - Event-based software transmission



# Related Work

- **Impala**  
Impala: A Middleware System for Managing Autonomic Parallel Sensor Systems  
*T. Liu and M. Martonosi, PPOPP, 2003*
- **Other Related Work**
- **Delay Tolerant Network Technology**
- **Sensor Node Design**
  - The TinyOs and TinyNetworkedDevices project
- **Protocol Studies**
  - Routing protocols study
  - Connectivity and coverage problems in mobile ad hoc networks
- **Environmental and Wildlife Sensing**
  - the prior research were supported by relatively low-technology VHF transceivers, or GPS based trackers relied on high-power transmitters.

# Timeline of the ZebraNet Project

- **Deploying the Collars - June 2005**
  - Collaring the zebras Jun 24th 2005
  - Donkey trial Jun 14th-21st 2005
- **Preparing for the Deployment - May 2005**
  - Horse tests May 1st-11th 2005
- **First Deployment - Jan 2004**
  - An initial set of prototypes deployed Jan 2nd-24th 2004
- **Some photos of collaring from: <http://www.princeton.edu/~csadler/>**



## Critique – Simulation Setup

- ZNetSim Network Simulator used. Very little data given and unavailable online.
- Simulation Type (i.e. terminating or steady state?)
- Variable Definition. 674 variables defined in an NS-2.27 ns-default.tcl file.
- Propagation Model. No Details given.



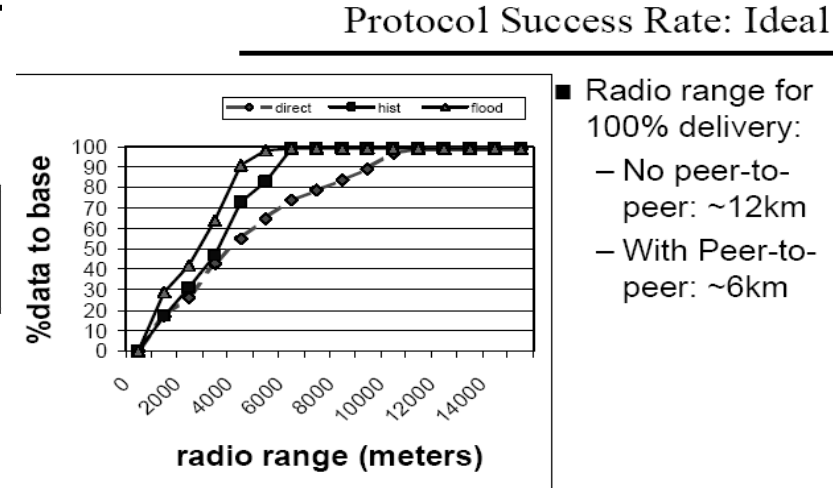
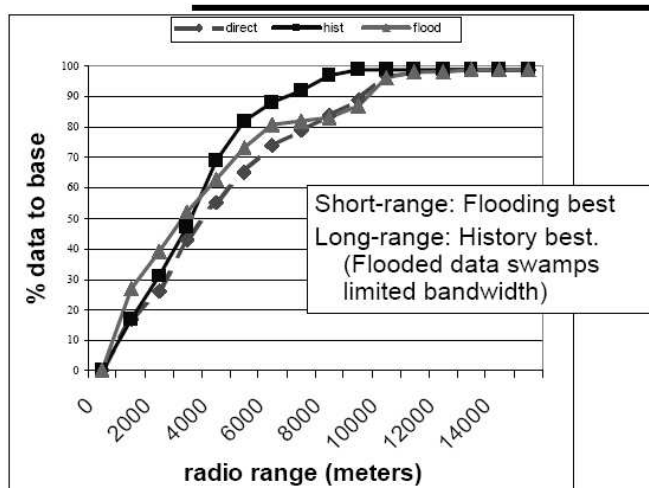
## Critique – Simulation Setup

- **Simulation Execution.** How were simulations seeded? Random initialisation per simulation not justified.
- **Mobility Model.** Model based on field results deemed to be inaccurate. Ignores predators and other inter-species interactions. Are turning angles assumed to be constant over all three movement phases? Simulation graphs show independent curves for different node speeds. Implies that node speed was constant with 3 different types of node (unrealistic).

# Critique - Output Analysis

- Single Data Sets Given. Simulations not repeated?
- No Statistical analysis of results (e.g. error bars, confidence intervals, etc.)
- No plot given for constrained bandwidth AND constrained storage (i.e. the real world situation)

# Critique - Output Analysis



- Inconclusive results. No gain in data recovery shown in constrained bandwidth case (left) at selected radio range.

# Conclusions

- Overview of ZebraNet system given.
- Experimental Results presented.
- Future and Related work discussed.
- Critique conducted and concluded that, as presented in the paper, simulations carried out are not sufficient to justify design choices. Could the same data recovery percentage and power consumption be achieved using purely direct transmission?

Questions?