Analysis of Wireless Sensor Networks for Habitat Monitoring

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Introduction

- This paper has discussed the application of Wireless Sensor Networks(WSNs) in a real-world habitat monitoring.
- It describes the experiences of a four month long deployment on a remote – Great Duck Island.
- Deploying WSNs in an area needs a complete system composed of communication protocols, sampling mechanisms and power management.
- The impact of sensor networks is measured by their ability to enable new applications and produce results otherwise difficult to obtain.

Why WSNs?

- Life scientists are interested to obtain data about the environment with high fidelity.
- Traditional methods include use densely instrumented sensors on probes. However,
  - Expensive
  - Messy due to excessive cables
  - Large in size
  - Sensor and the recording and analysis equipment need to be adjacent.
  - Their presence disturb the natural processes and behavioural patterns.
  - There are chances of missing significant short term variations.
- Another way is to install weather stations very close to the area of interest
  - Cannot gauge whether the station monitors a different micro-climate due to the distance.
- Advantages of WSNs
  - Nodes can be deployed prior to the sensitive period
  - Nodes can be deployed on areas which might be unsafe for repeated visits.
  - Permit real time data access remotely.
  - Can be re-tasked in the field
  - Economical

Great Duck Island

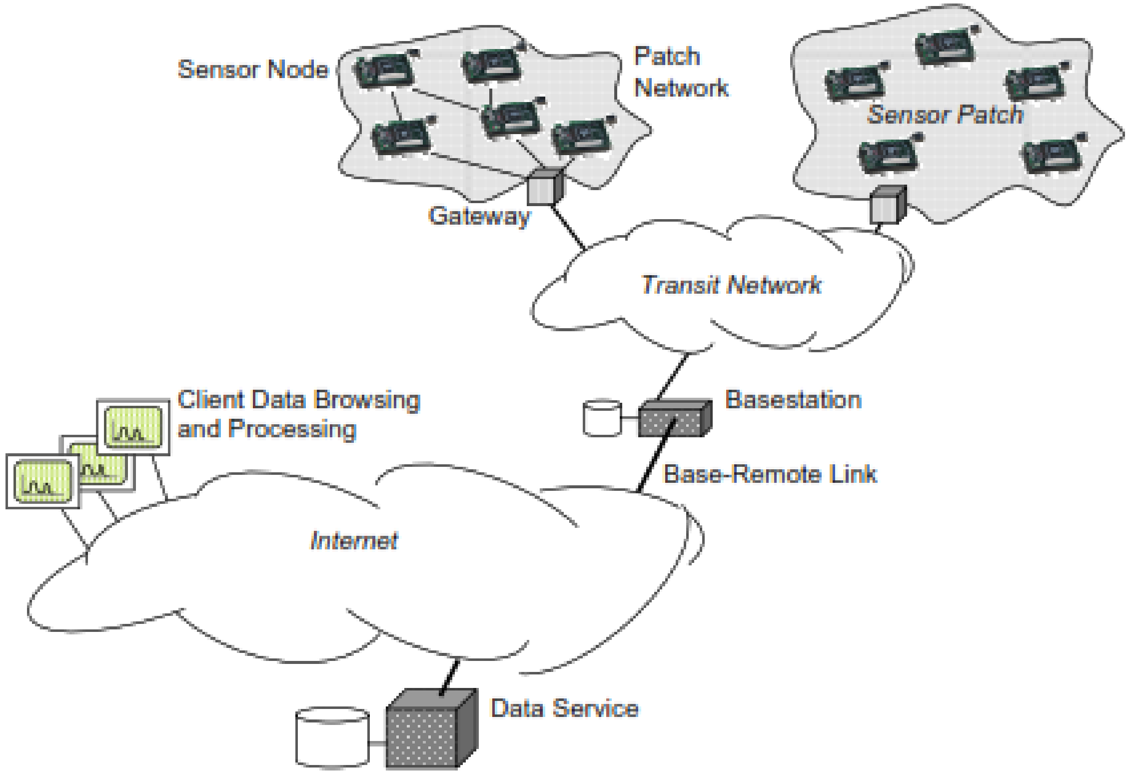
- It houses approximately 5000 pairs of Leach's Storm Petrels, nesting in discrete patches.
- Three major habitat types – Spruce forest, meadow and mixed forest edge.

- Interest Areas:
  - Usage pattern of nesting burrows when the breeding pair alternates between incubation and feeding duties
  - Environmental changes inside the burrow and on the surface during the breeding season
  - Which of the conditions yield an optimal microclimate for breeding, incubation and hatching.
  - Differences between areas that contain large number of nesting petrels and those that not.

Sensor Deployment

- Petrels nest in underground burrows with relatively constant temperature and humidity.
- One sensor node per burrow such that the sensor and the petrel can coexist without interference.
- Some burrows are left with sensor nodes to verify if any disturbance is caused.
- Monitoring the environment above each burrow, biologists can examine differences between above-ground and in-burrow microclimates.
- The deployed system must efficiently manage its power consumption through low duty cycle operation in order to operate for an entire field season.

Network Architecture



Application Software

- Operating System
  - TinyOS
- Periodic Task
  - Every 70 seconds, the sensor will collect the data and transmit in single 36 byte data packet. The packet will also timestamped with 32-bit sequence number.
  - After transmit, the board will enter low power mode for 70 seconds

Application Hardware

- Integrated off-the-shelf sensors onto Mica mote board
  - Photoresistive sensor
  - Digital temperature sensor
  - Capacity humidity sensor
  - Digital pressure sensor
  - Passive infrared detector
  - 12-bit ADC
- Problem
  - Didn’t consider fault isolation. One fail sensor is likely affect other sensor.

Packaging strategy

- Purpose
  - To encounter harsh environment on offshore island
    - Rain, dew, dense fog, flooding
    - Extreme low pH (less than 3)
  - Waterproofing is main concern
- Conformal coating & enclosures
  - In burrow : Only parylene coating due to space constraint
  - Above ground : Parylene coating & acrylic enclosures

Experiment goals

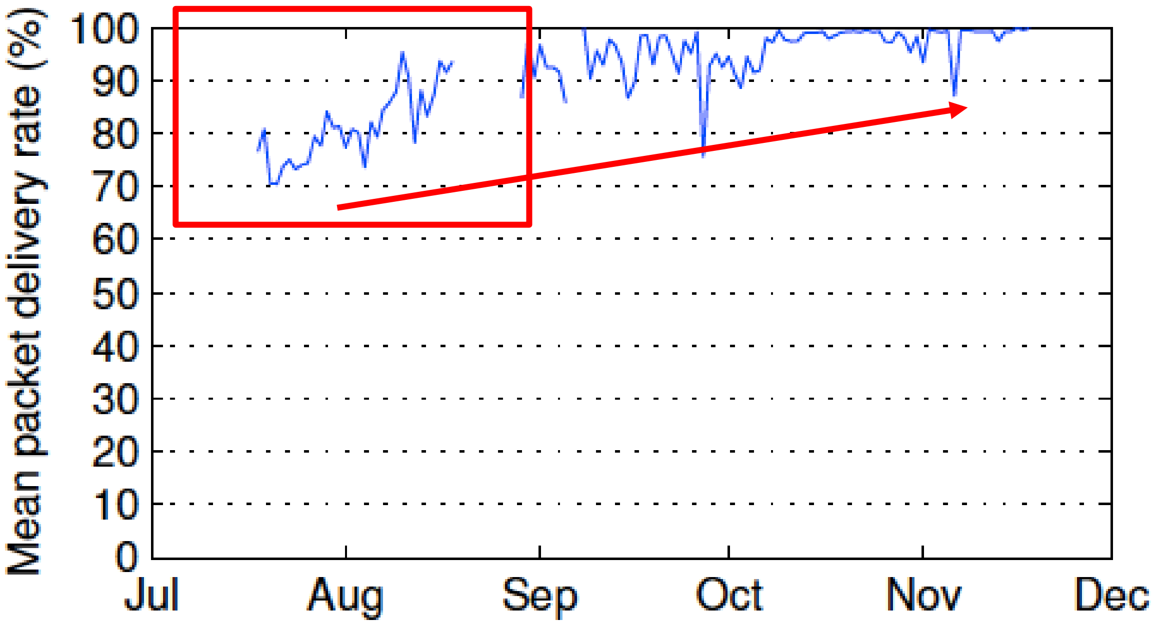
- To prove the feasibility of deploying low power WSNs for long term usage.
  - Sealant
  - RF performance in and out of burrows
  - Usefulness of data
  - System and network longevity

Evaluation

- Network Analysis
  - Packet loss
  - Network dynamics
- Node Analysis

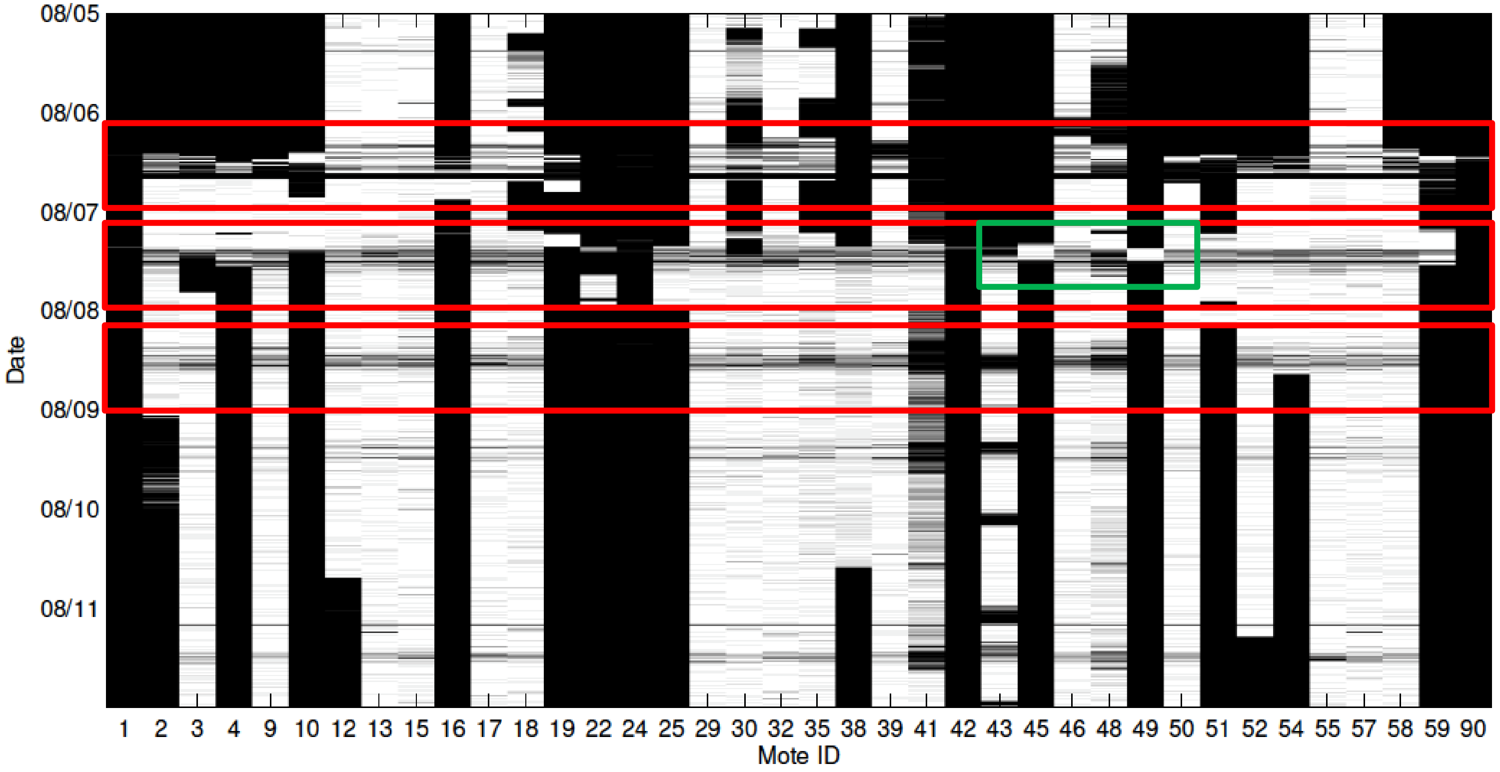
Packet loss

- Observed features
  - High initial loss rate
  - Network improve over time
- Possible explanation
  - Motes with poor packet transmit die quicker
  - Radio channel experiences less contention
- How to prove?
  - Prove that the packet loss event is not independent



Examination - 1

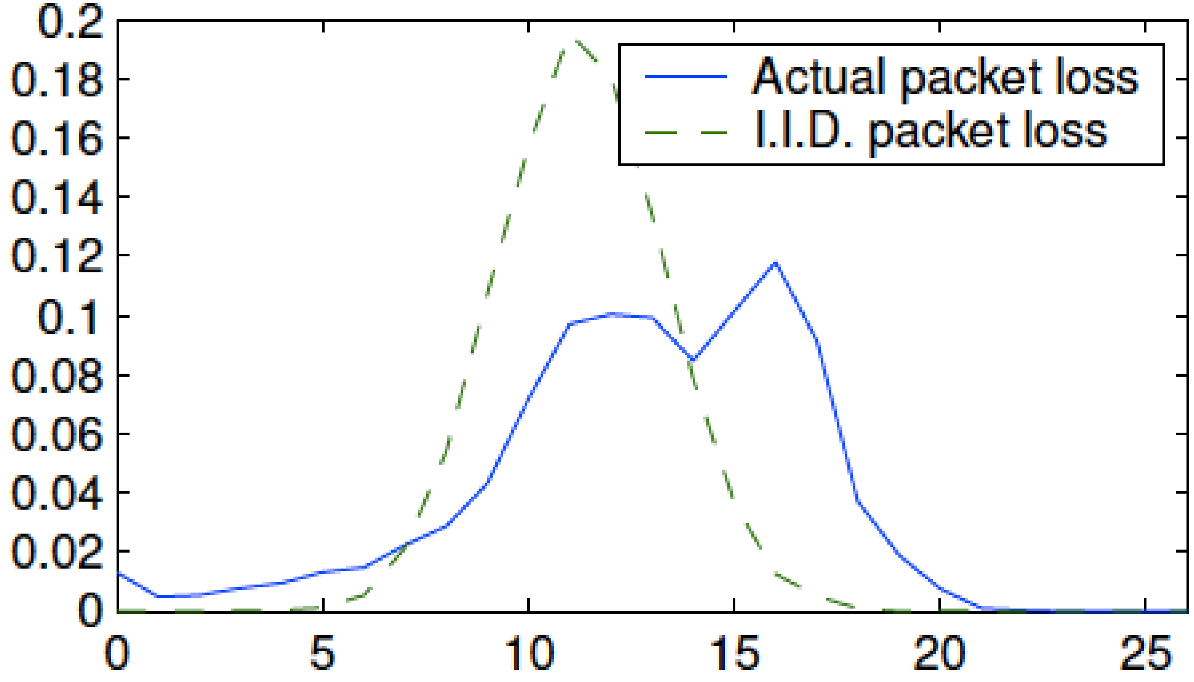
- If all the loss are independent, the graph will look like gray square



Black line : loss, White line : success

Examination - 2

- Chi squared test and rank test both reject the hypothesis that the two distributions are the same.



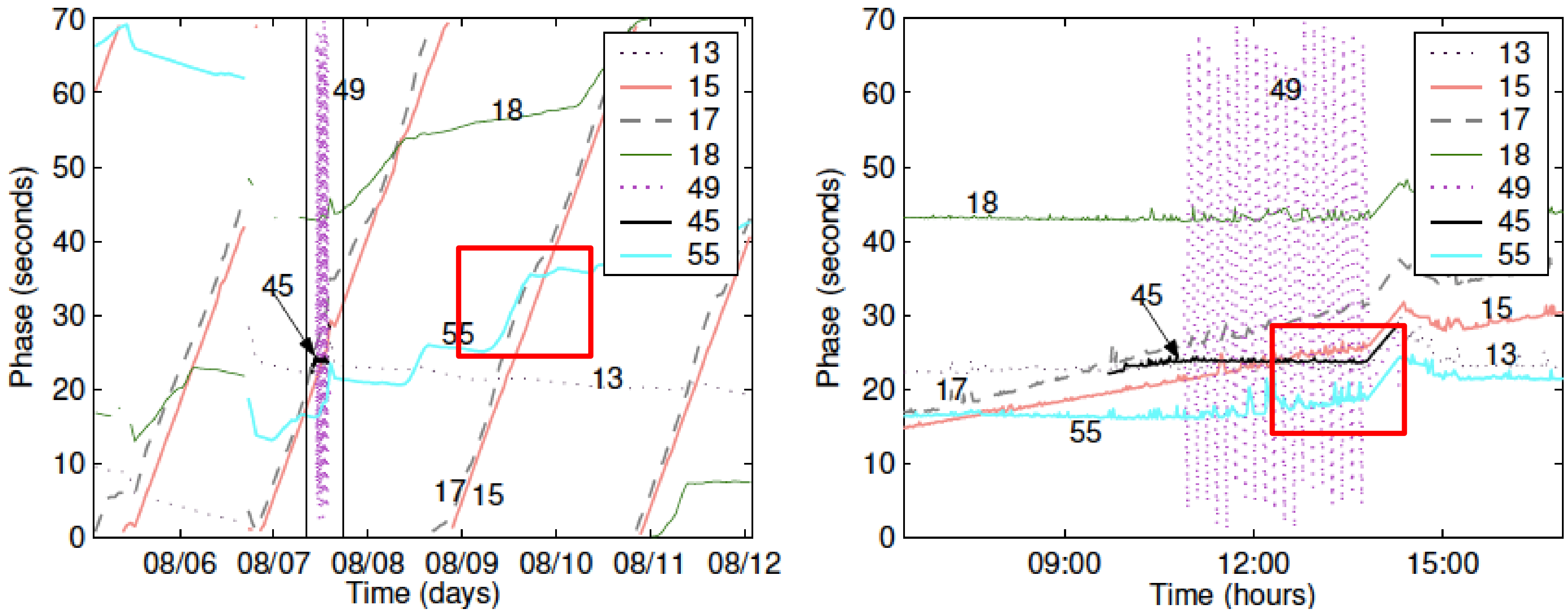
Note : The superposition of two Gaussian function refer to two hops in the network.

Network dynamics

- Observed feature
  - It seems impossible that the collision will play a significant role when the expected network utilization is low (less than 5%).
  - However, mote 45, 49 can only transmit data when most motes fail.
- To prove that it's possible to have collision.

Phase of Nodes

- The slope lines refer to clock drift and MAC delay.
- The collision will occur only at the intersection of lines.



Node Analysis

- Performance and reliability depend on the environmental factors
- Network can use loss of expected sensing patterns to send notifications to request maintenance
- Battery voltage is examined to test power management model

Sensor Analysis – Light sensor

- Known photoresistor – used as baseline to test board functionality
- During the day – light value saturated at maximum ADC value
- During the night - zero
- Operated most reliably
- Only failure – Expected readings replaced by high values
- 7/43 nodes failed; 6/7 cases were accompanied by other sensor failures

Sensor Analysis – Light sensor

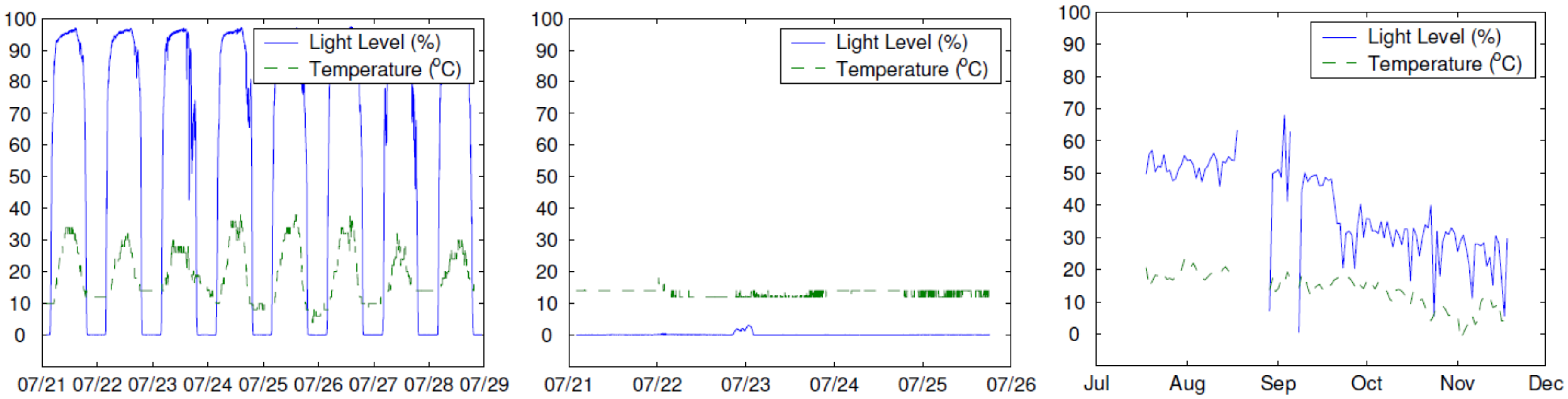


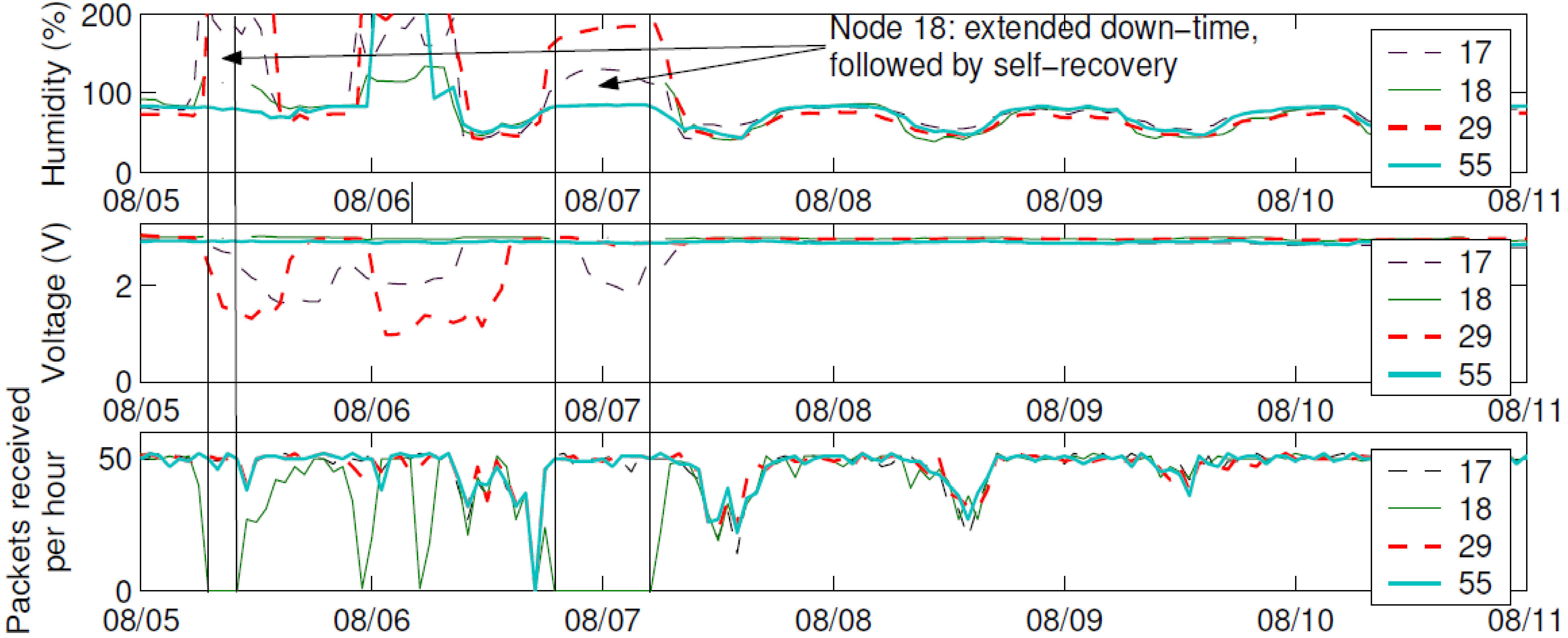
Figure 18.8. Light and temperature time series from the network. From left: outside, inside, and daily average outside burrows.

Sensor Analysis – Temperature sensor

- Sensor resolution changed from 0.0625°C to 2°C
- Temperatures measured inside the enclosures were significantly higher than the ambient temperatures measured by traditional weather stations
- On cloudy days temperature matched
- Failure – on direct contact with water
- 22/43 nodes gave faulty readings; 2/22 nodes recovered

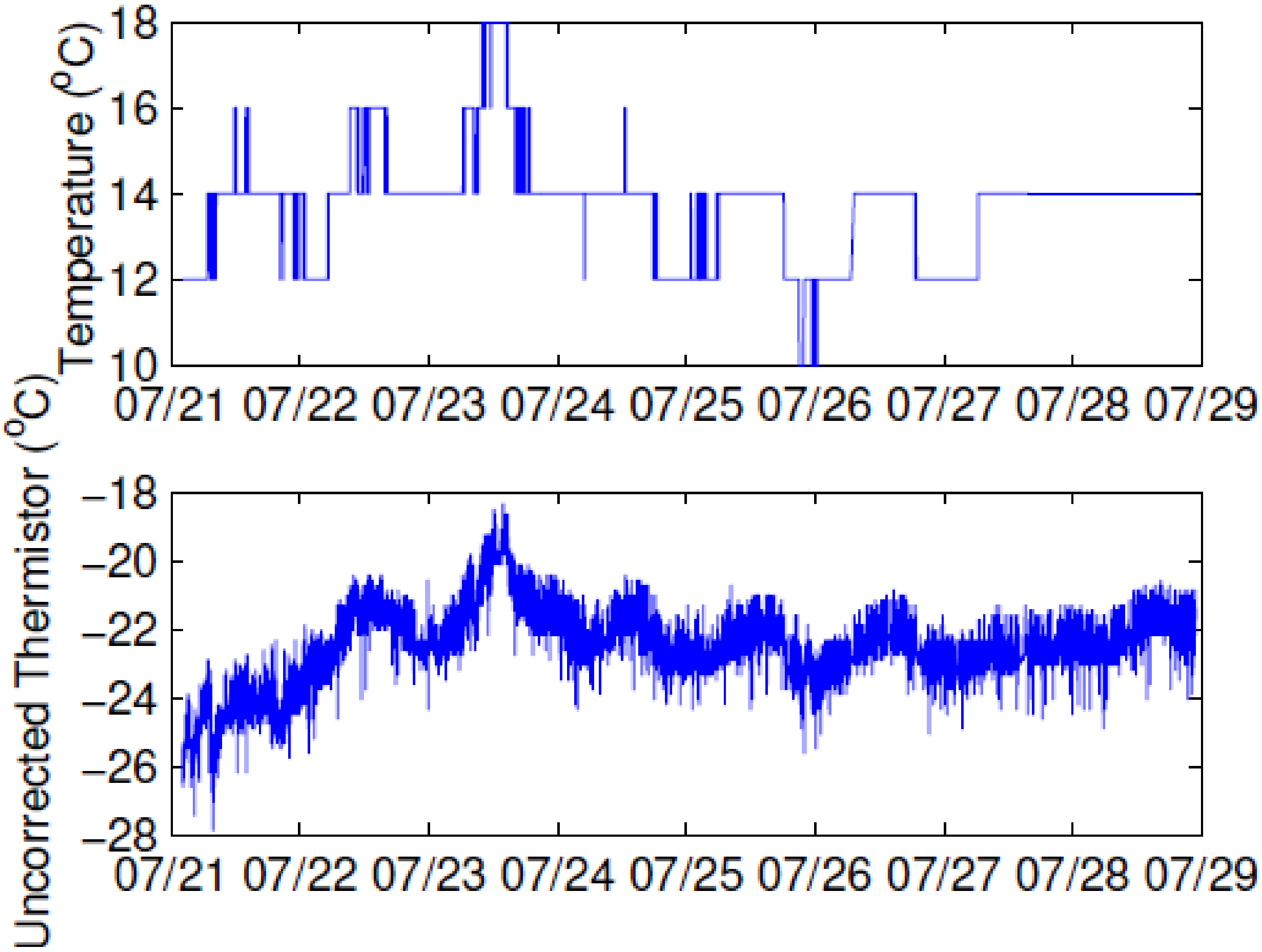
Sensor Analysis – Humidity sensor

- Capacitive sensor; Not coated with parylene
- No individual calibration were performed prior to deployment, reference conversion function was used to convert the readings into SI units.


Humidity (%)
200
100
0
08/05
08/06
08/07
08/08
08/09
08/10
08/11
Node 18: extended down−time,
followed by self−recovery
17
18
29
55
Voltage (V)
2
0
Packets received
per hour
50

Sensor Analysis – Thermopile readings

- Two readings – Ambient temperature and IR incident on element
- Sum of these two readings yields the object surface temperature
- The data exhibits a lack of any periodic daily patterns
- Data is inconclusive


Temperature (°C)
18
16
14
12
10
07/21 07/22 07/23 07/24 07/25 07/26 07/27 07/28 07/29
Uncorrected Thermistor (°C)
−18
−20
−22
−24
−26
−28
07/21 07/22 07/23 07/24 07/25 07/26 07/27 07/28 07/29

Power Management

- Battery voltage is measured
- Analysis of aggregate population is difficult due to failures
- Only 5 nodes out of 43 have clearly exhausted their original battery supply.
- Use batteries with stable voltage
- Discourage use of boost converters

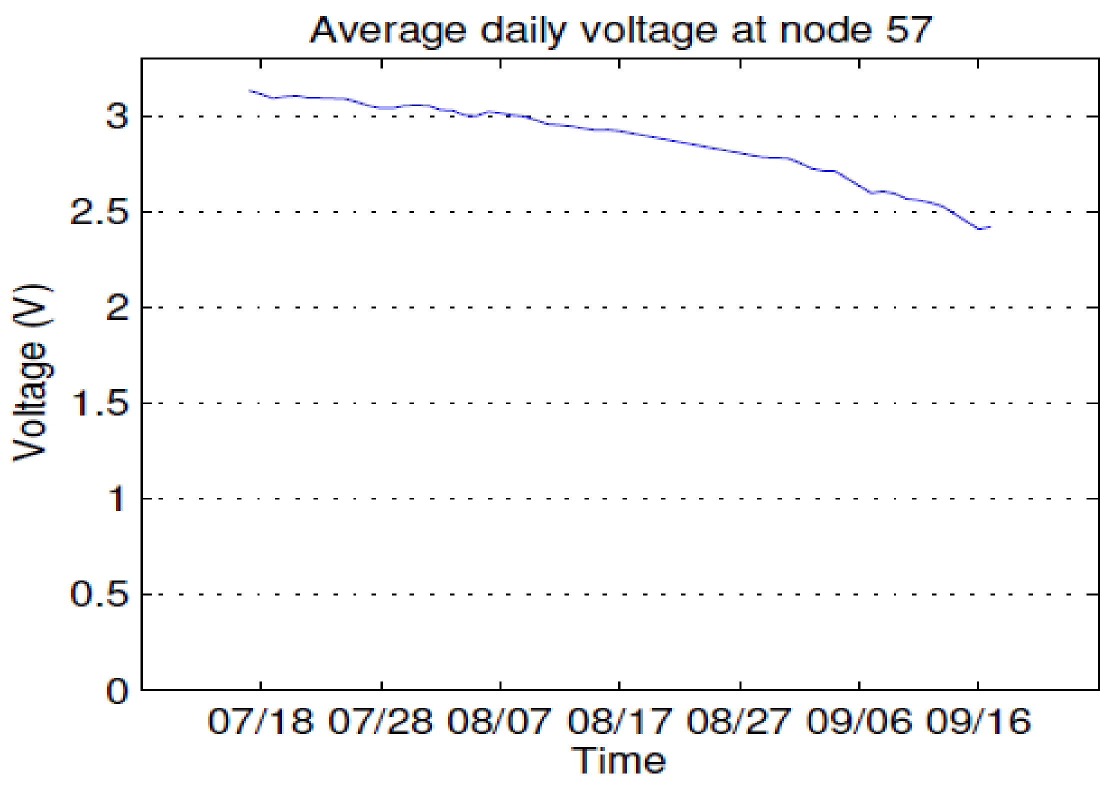


Figure 18.11. Voltage readings from node 57. Node 57 operates until the voltage falls below 2.3V; at this point the alkaline cells can not supply enough current to the boost converter.

Node Failure indicators

- Humidity sensor – health indicator
- High spikes – recoverable mote crashes; 0 V – permanent mote outage
- In packet phase analysis, motes with slower clocks served as failure indicators
- Above mentioned analysis had low false positive rate

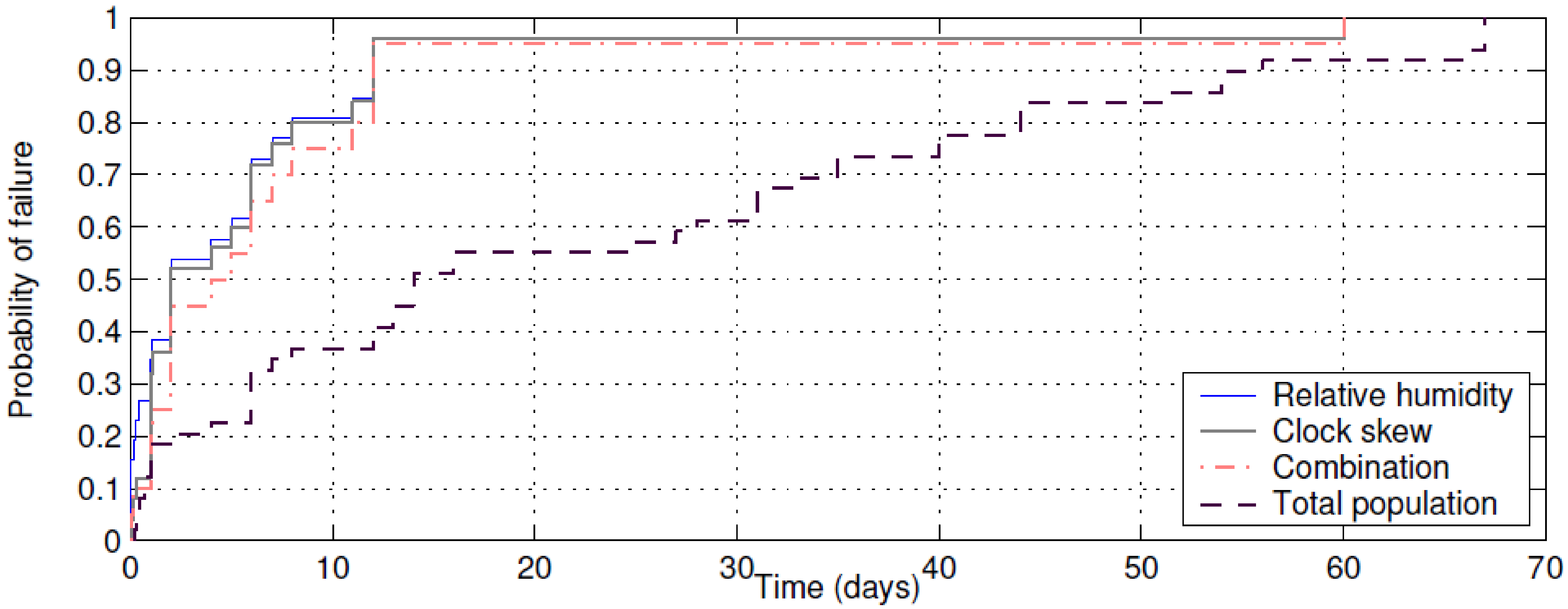


Figure 18.12. Cumulative probability of node failure in the presence of clock skew and anomalous humidity readings compared with the entire population of nodes.

Related Work

- Muti –tiered architecture for habitat monitoring by Cerpa et. al.
- Acoustically identify animals using a hybrid iPaq and mote network by Wang et. al.
- ZebraNet is a wireless sensor network design for monitoring and tracking wildlife
- Extensible Sensing System at the James Mountain Reserve in California by CENS
- Intel Research has recently deployed a network to monitor Redwood canopies in Northern California and a second network to monitor vineyards in Oregon.

Conclusion

- WSN are important for habitat monitoring
- First outdoor deployment had many failures
- Features leading to node failure were identified
- Data anomalies can be used to predict failure

Questions?

THANK YOU!