Potential-Based Entropy Adaptive Routing for Disruption Tolerant Networks

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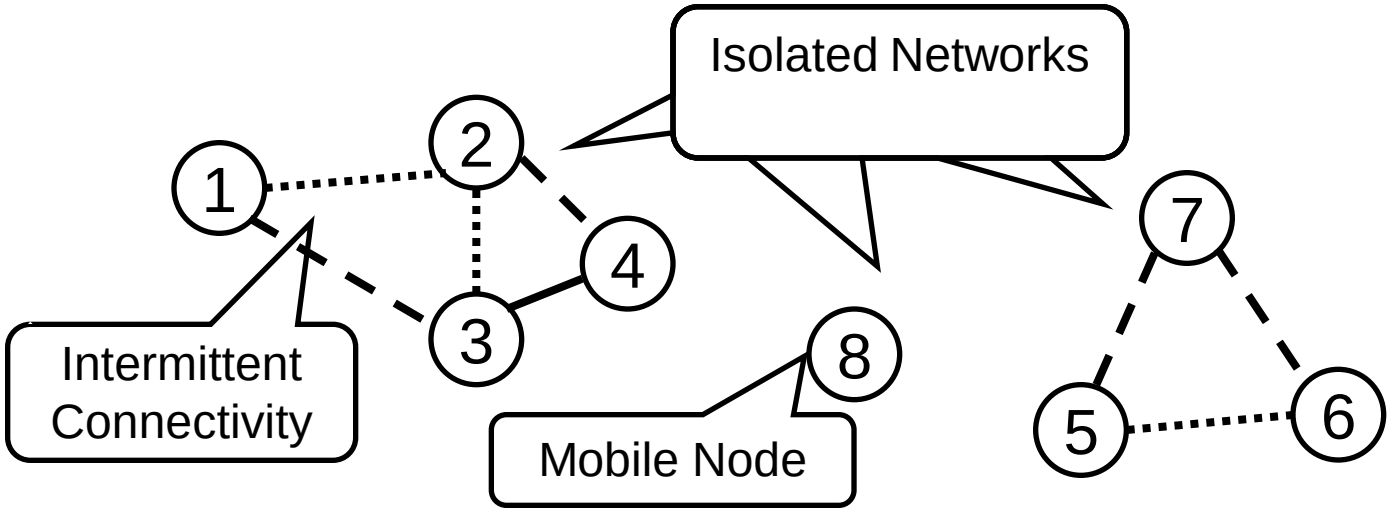
DTNRG, IETF 76 Hiroshima, 2009-11-13

Outline

- Introduction
- Potential-based entropy adaptive routing
- Prototype implementation
- Campus-wide experiment
- Conclusion

Introduction

- DTN for opportunistic networking
  - Isolated sensor networking / vehicular ad-hoc networks
  - Intermittent connectivity / isolated networks



- API
  - void sendMessage(ID dst, String msg);
  - void recvMessage(ID src, String msg);

- All the nodes are always virtually connected.

Contributions of this work

Implementation and deployment of

potential-based entropy adaptive routing (PEAR)

– PEAR autonomously enables message delivery in ad-hoc manner.

– PEAR dynamically adapts to wide-range of mobility patterns without being aware of mobility pattern itself.

- In general, the performance of routing algorithms are strongly dependent on mobility patterns.

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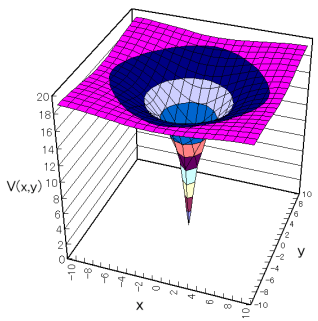
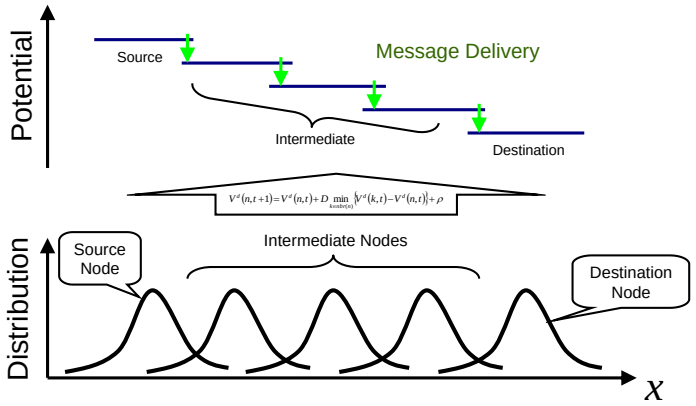
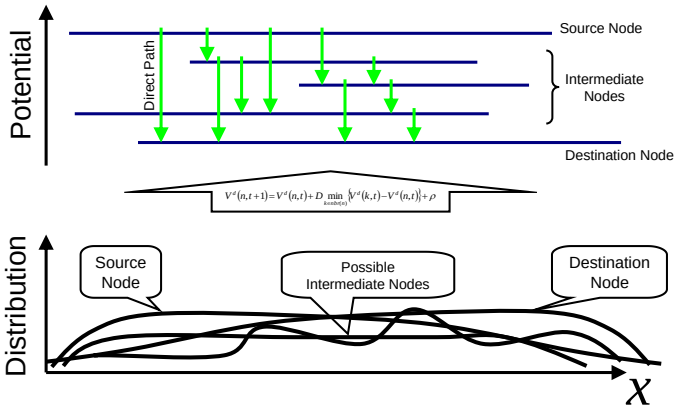


Potential-field

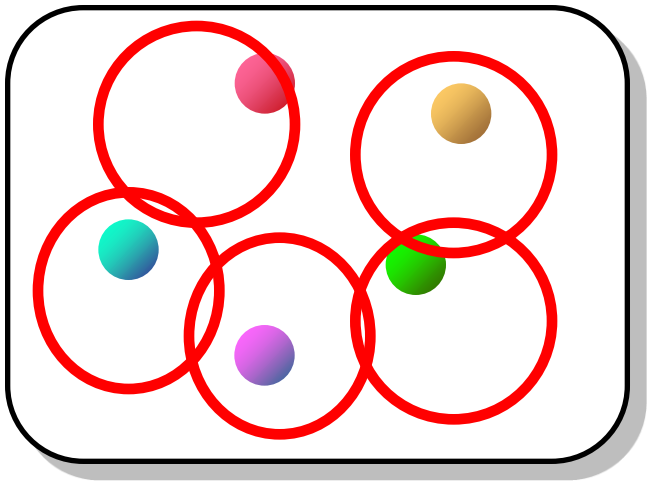


Small entropy case



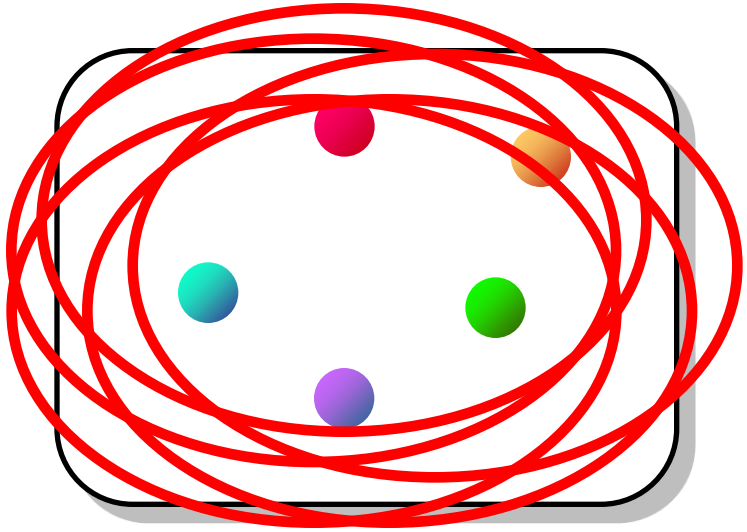
Large entropy case

Characterize Mobility Pattern by Entropy



Small Entropy Case

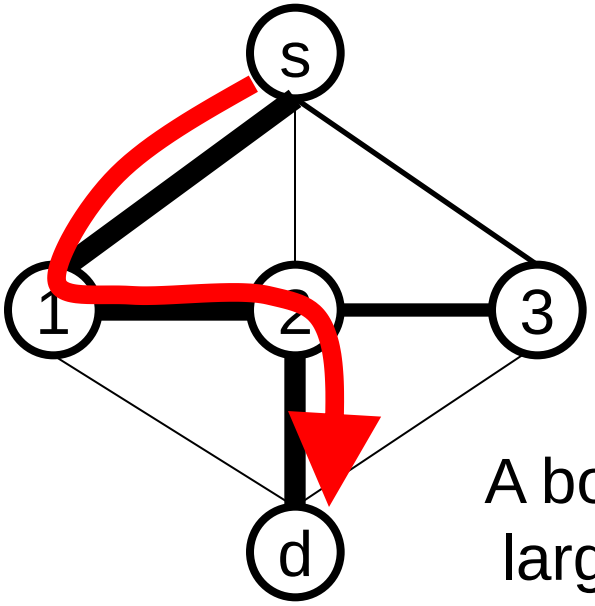
Locally Distributed



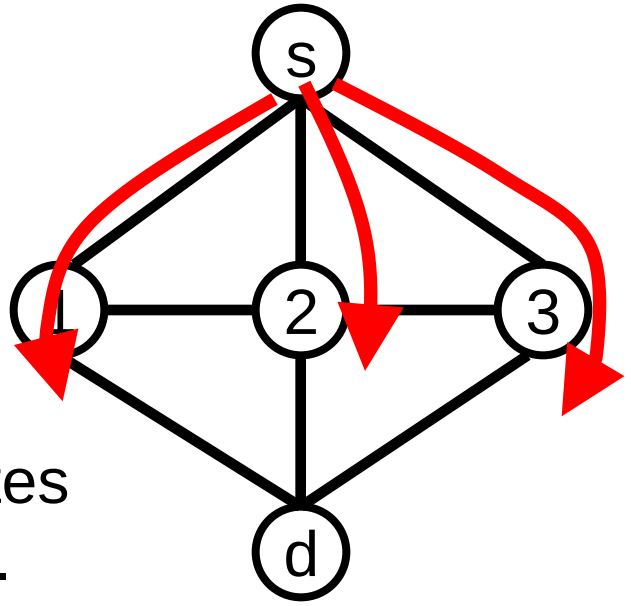
Large Entropy Case

Widely Distributed

Entropy and Delivery Pattern



A bolder link indicates larger contact time.



Small Entropy Case

Biased contact

It should choose the best path

Large Entropy Case

Uniform contact

It should improve delivery rate by increasing redundancy.

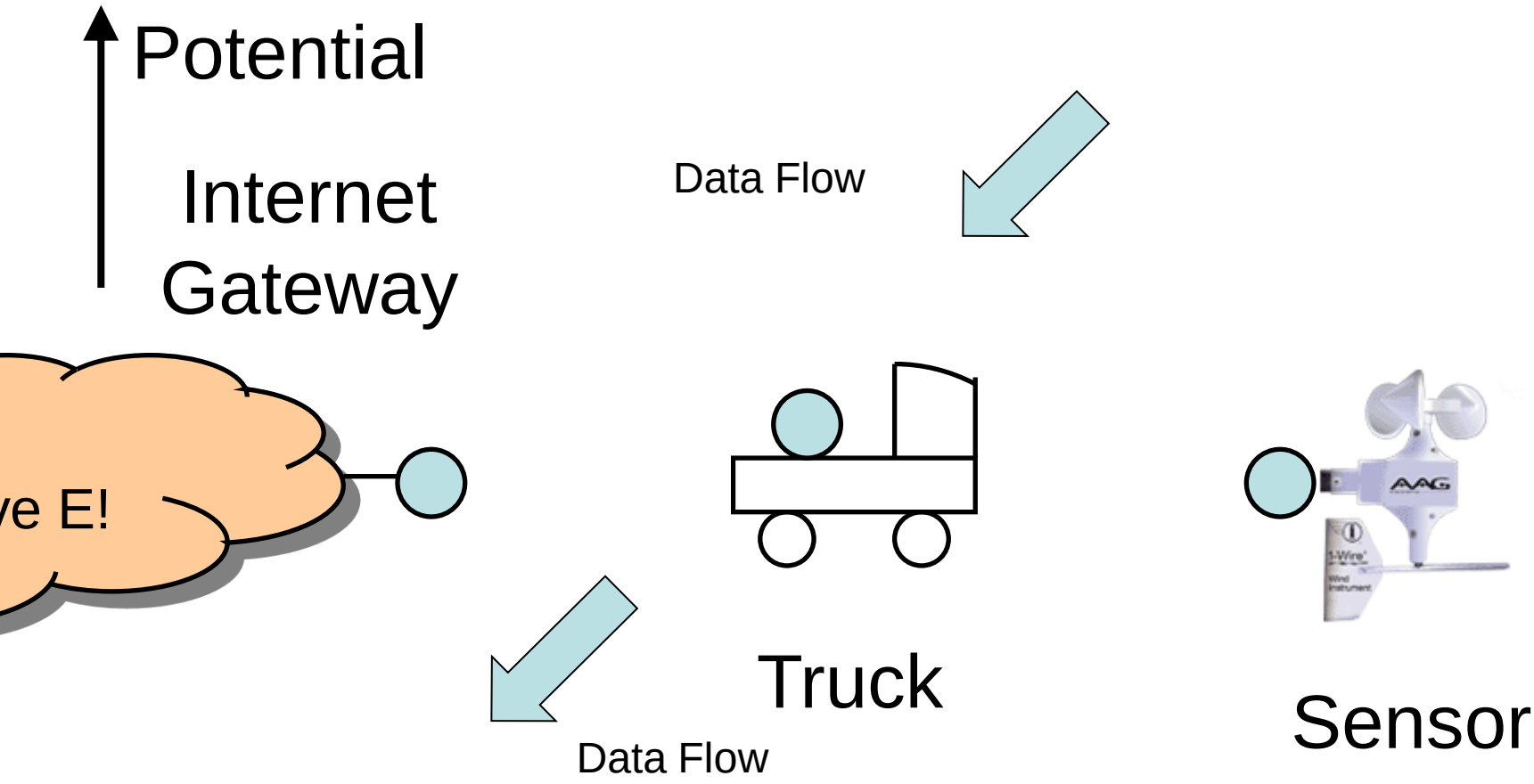
How does PEAR achieve that ??

- For choosing the next hop node:
  - Potential-based routing
  - Potential-field construction (inspired by diffusion theory)

- For message delivery
  - Copy-based message delivery

    ⇔ Transfer-based message delivery

Potential-Based Routing



To deliver sensor readings to the Internet GW

: Wireless Device

Potential-Field Construction in PEAR

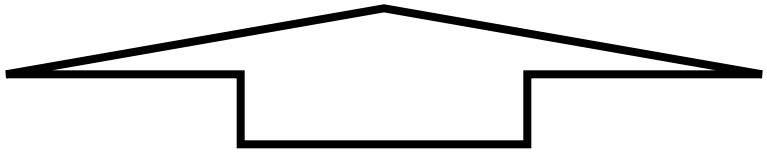
Potential-Field Construction

$$V^d(n,t+1) = V^d(n,t) + D \min_{k \in nbr(n)} \left\{ V^d(k,t) - V^d(n,t) \right\} + \rho$$

$$\forall n \in N, \left(V^d(n,0) = 0 \right)$$

$$\forall t, \left(V^d(d,t) = 0 \right)$$

$$D(>0), \rho(>0) \quad const.$$

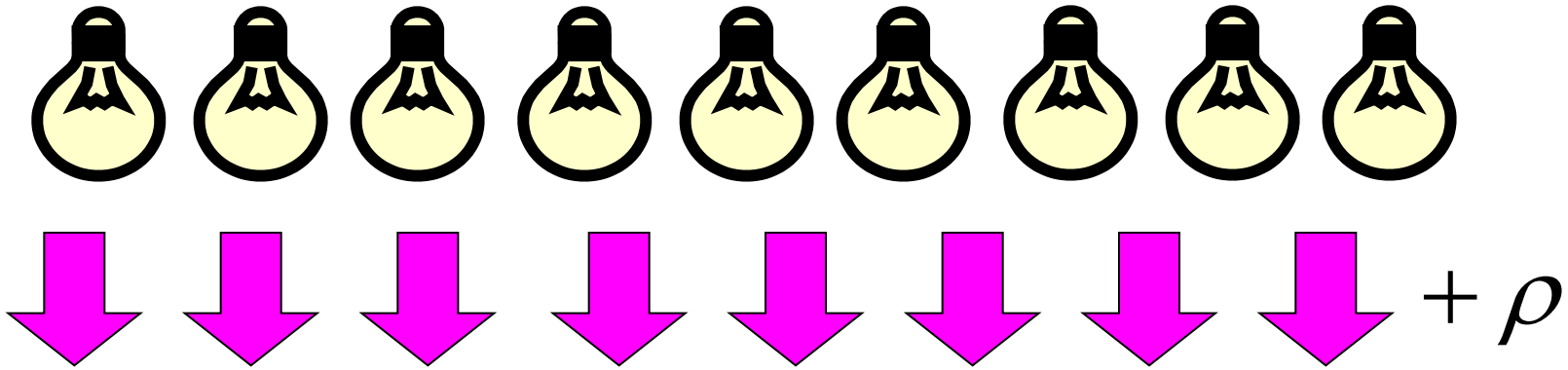


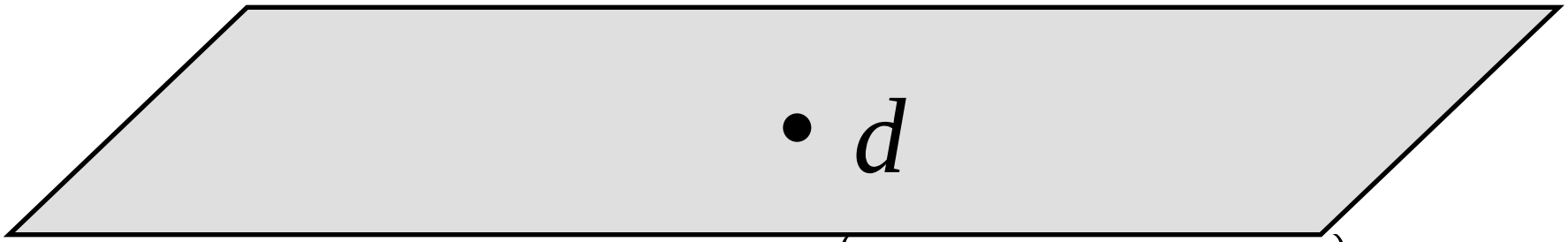
Diffusion Equation

$$V^d(n,t+1) = V^d(n,t) + D \sum_{k \in nbr(n)} \left\{ V^d(k,t) - V^d(n,t) \right\}$$

Potential-Field Construction

$$V^d(n,t+1) = V^d(n,t) + D \min_{k \in nbr(n)} \left\{ V^d(k,t) - V^d(n,t) \right\} + \rho$$

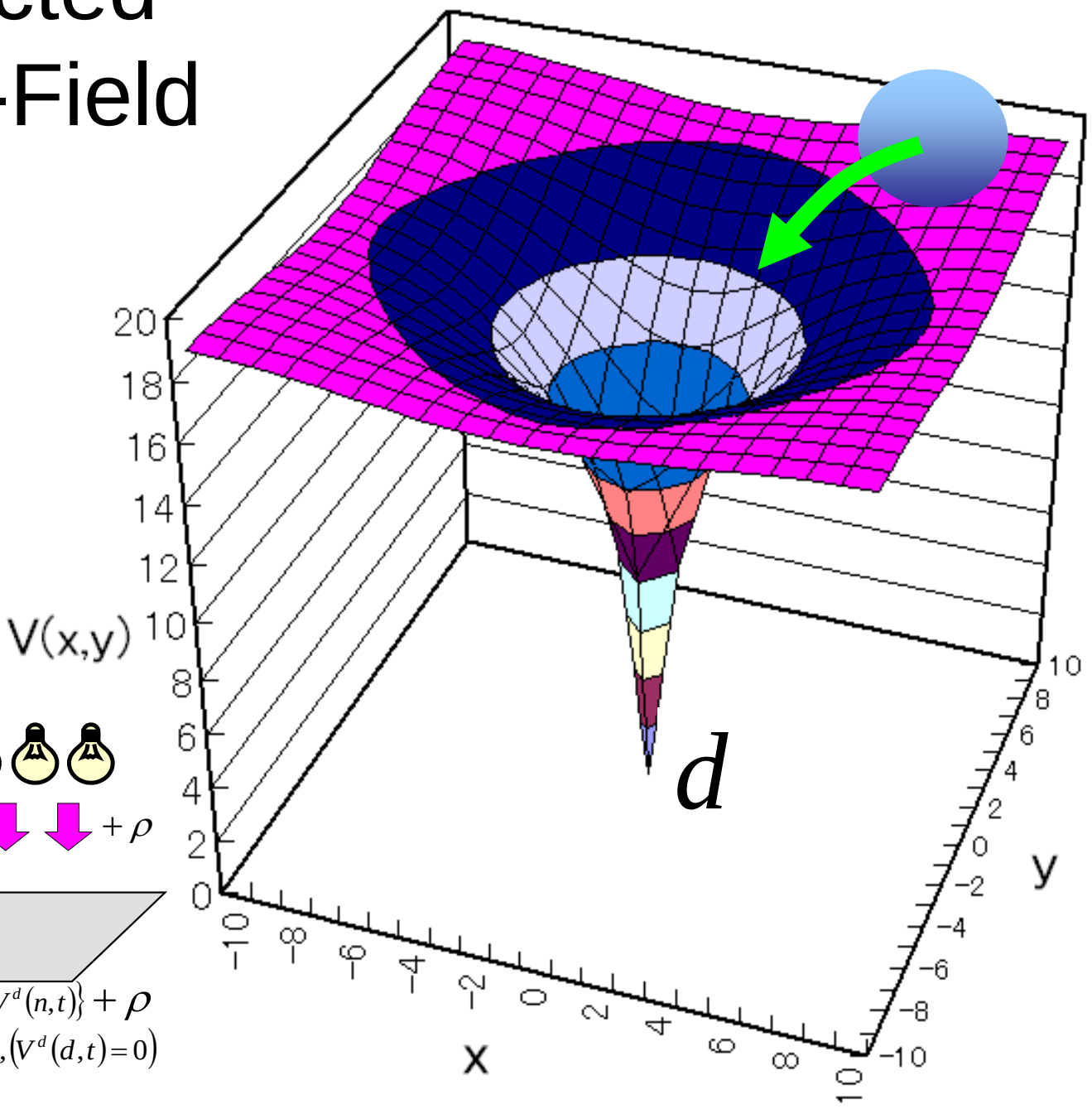


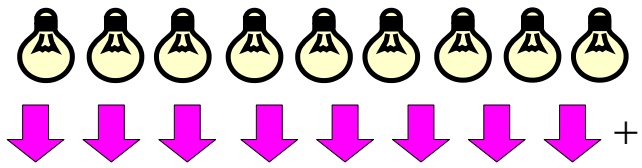


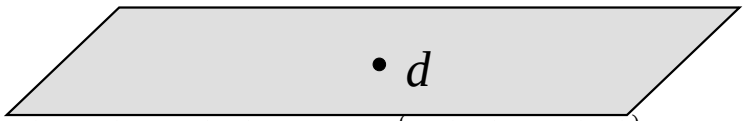
$$V^d(n,t+1) = V^d(n,t) + D \min_{k \in nbr(n)} \left\{ V^d(k,t) - V^d(n,t) \right\} + \rho$$

$$\forall t, \left(V^d(d,t) = 0 \right)$$

Constructed Potential-Field



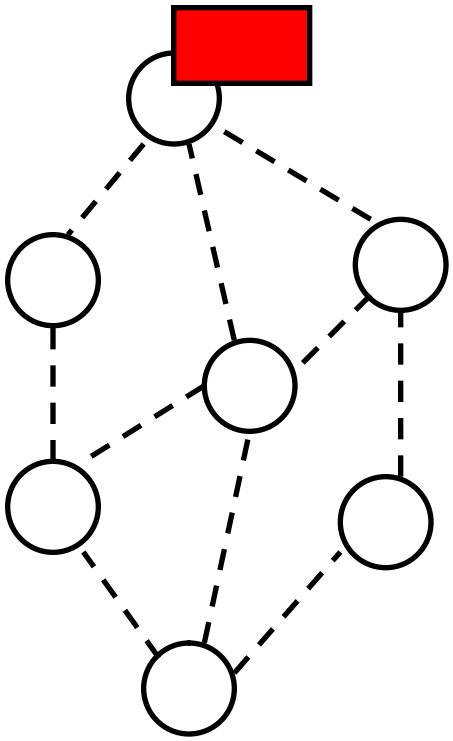




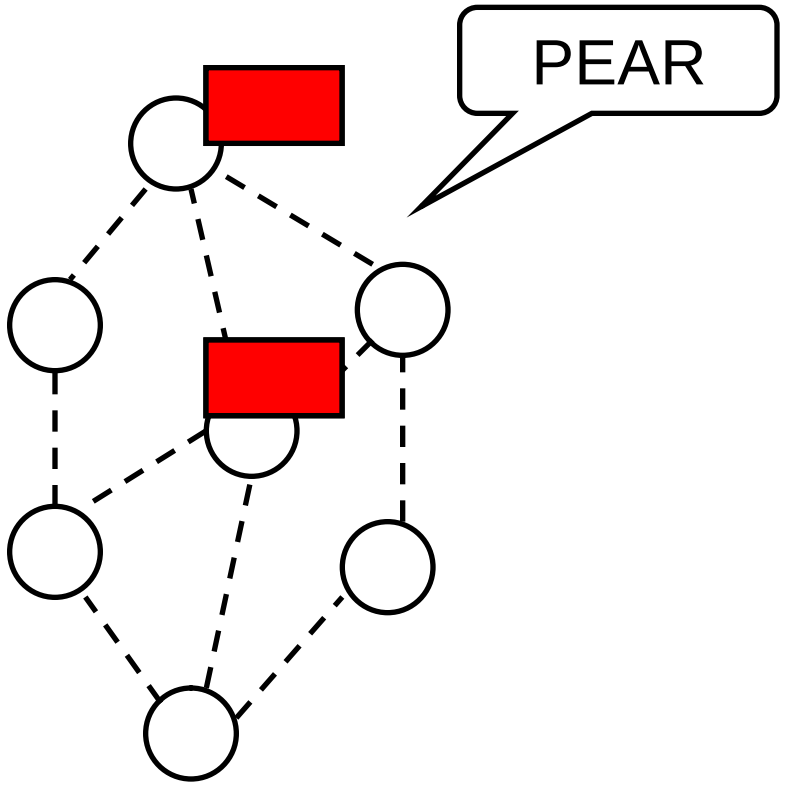
$$V^d(n,t+1) = V^d(n,t) + D \min_{k \in nbr(n)} \{V^d(k,t) - V^d(n,t)\} + \rho$$

$$\forall t, \left(V^d(d,t) = 0\right)$$

Transfer-Based v.s. Copy-Based Message Delivery

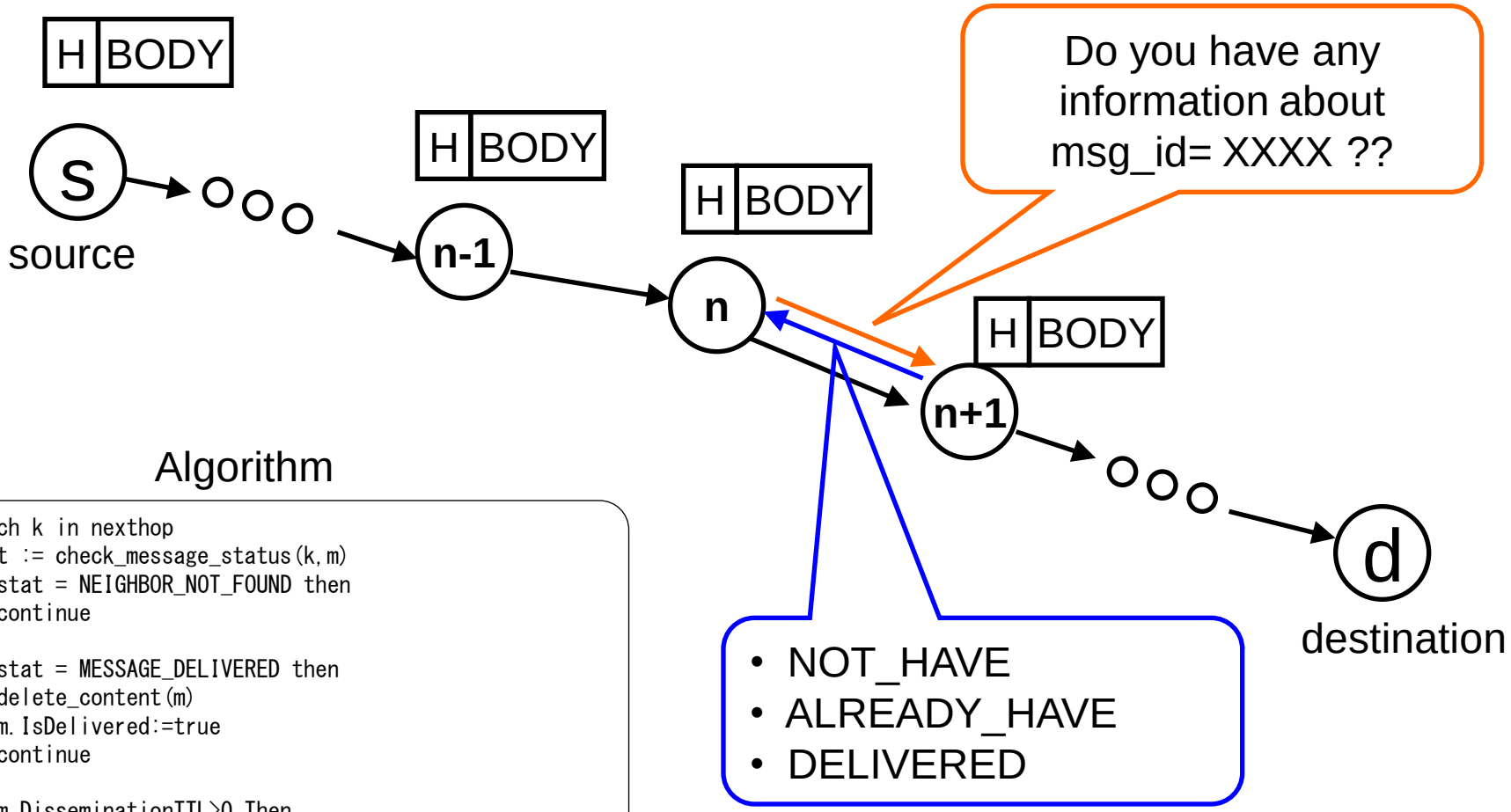


Transfer-Based
Message Delivery



Copy-Based
Message Delivery

Copy-Based Message Transfer in PEAR

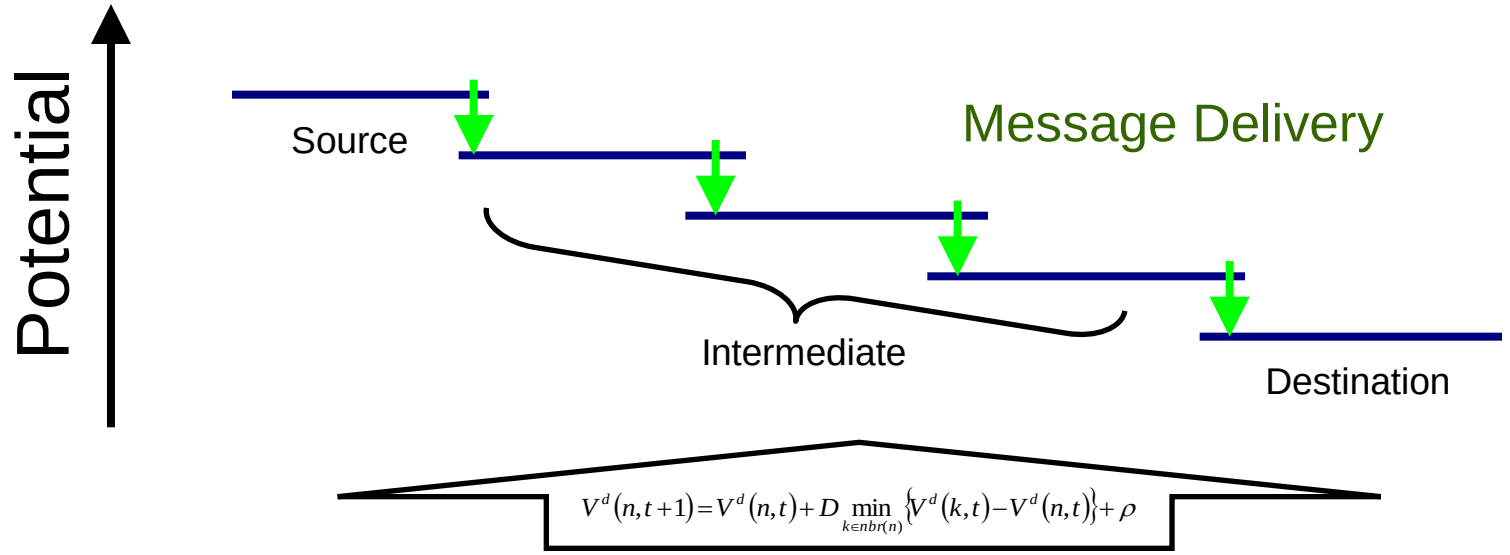


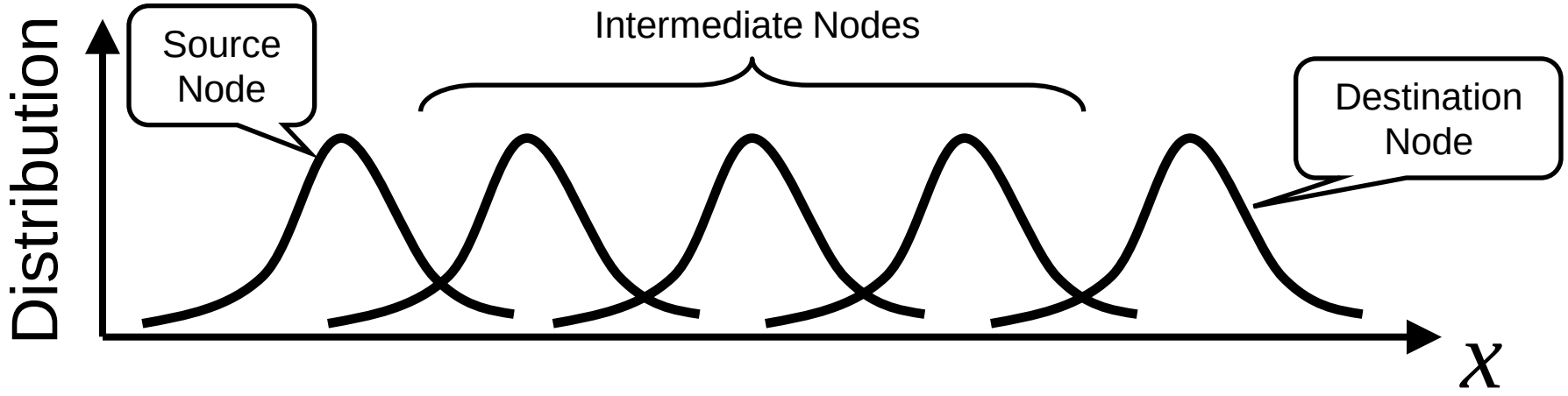
Algorithm

```
For each k in nexthop
   stat := check_message_status(k,m)
   if stat = NEIGHBOR_NOT_FOUND then
      continue

   if stat = MESSAGE_DELIVERED then
      delete_content(m)
      m.IsDelivered:=true
      continue

   if m.DisseminationTTL>0 Then
      if stat = NOT_HAVE Then
         copy(k,m)

      if m.DisseminationTTL > DISSEMINATION_MODE_TIME then
         m.DisseminationTTL :=DISSEMINATION_MODE_TIME
```

Potential and Message Routing

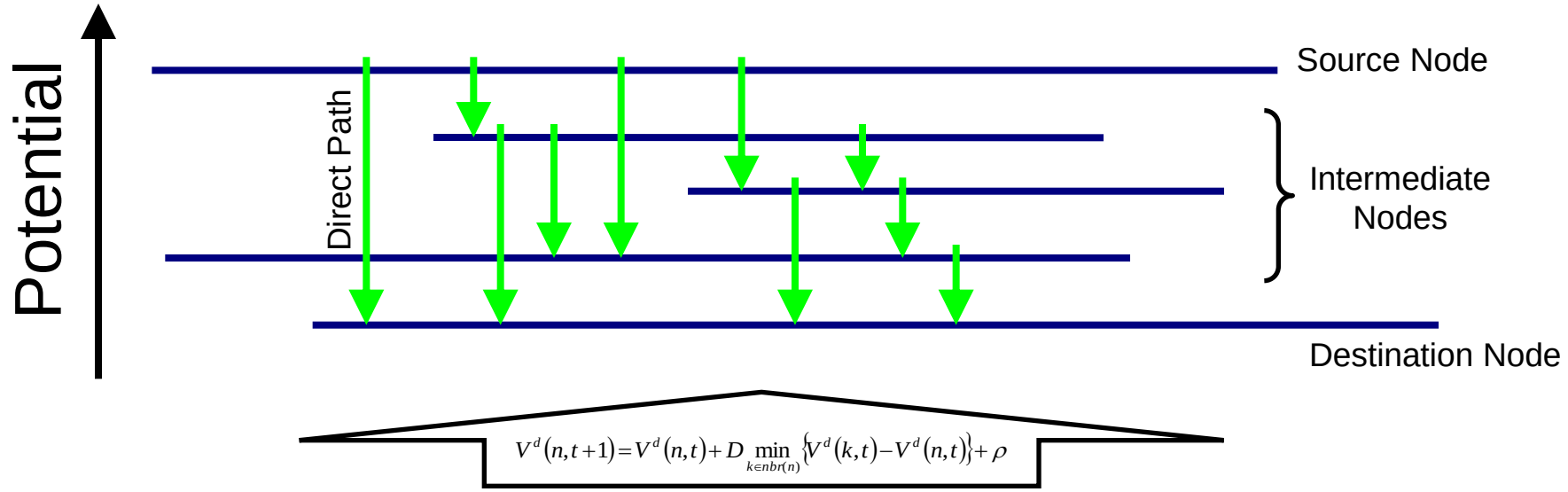
Small Entropy Case

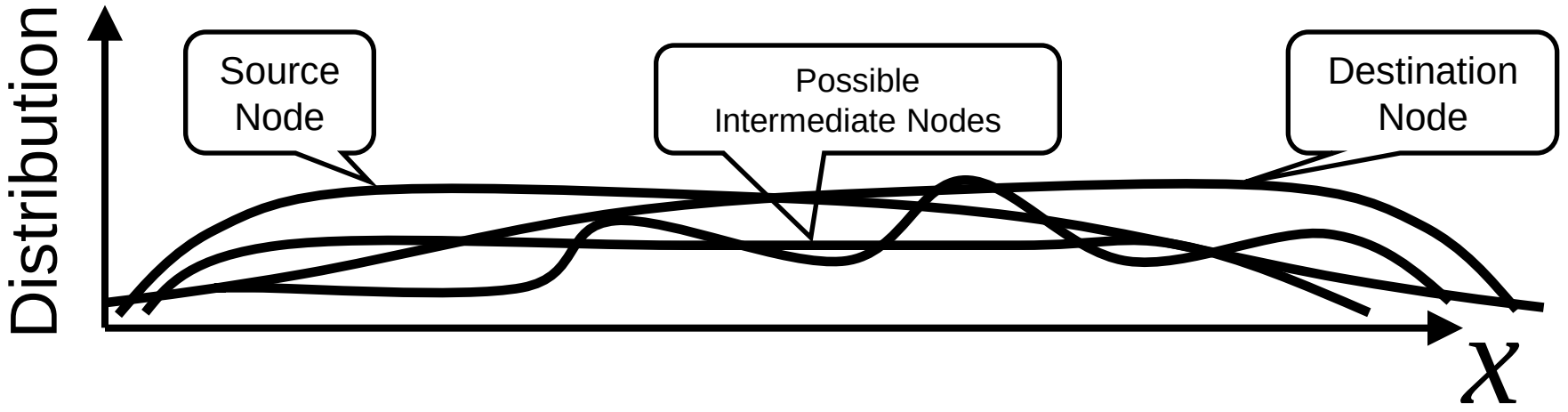




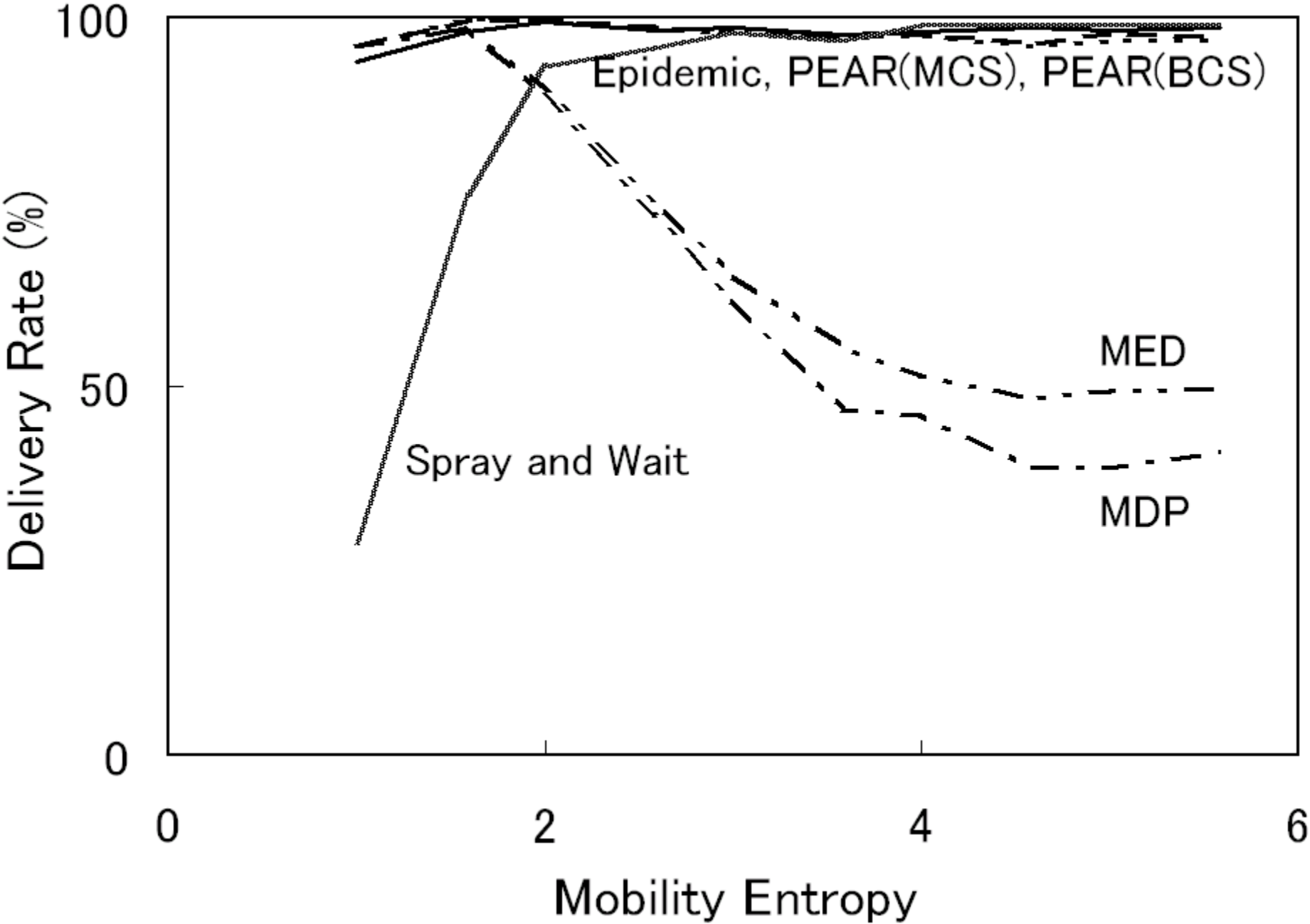
Potential and Message Routing

Large Entropy Case

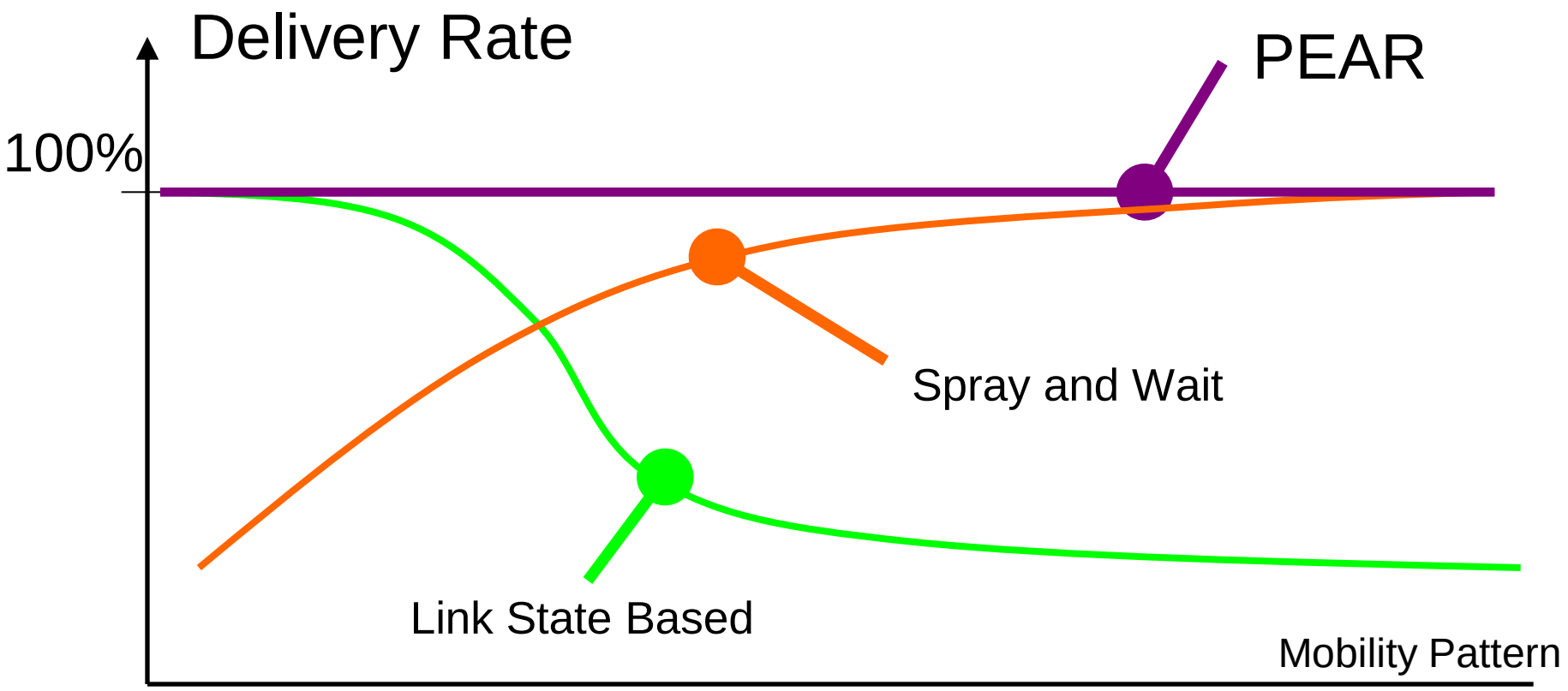


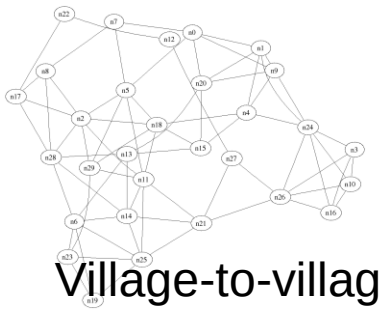


Rough Simulation-Based Evaluation

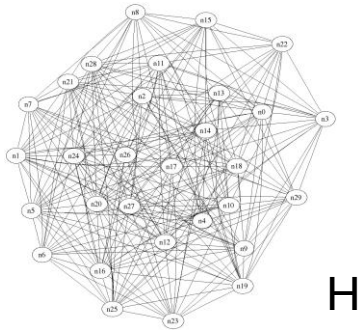


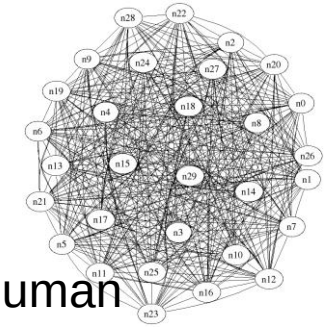
Rough Simulation-Based Evaluation (Summary)





Village-to-village





Human-to-human

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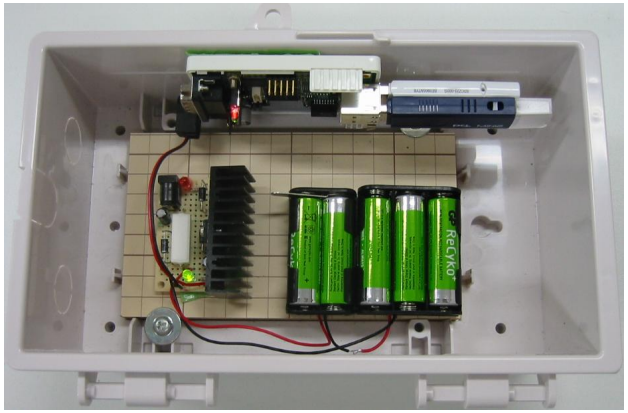
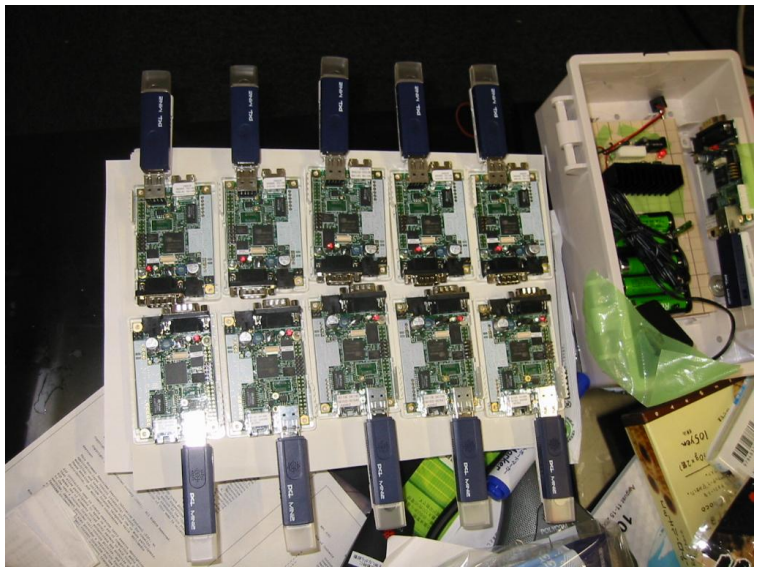
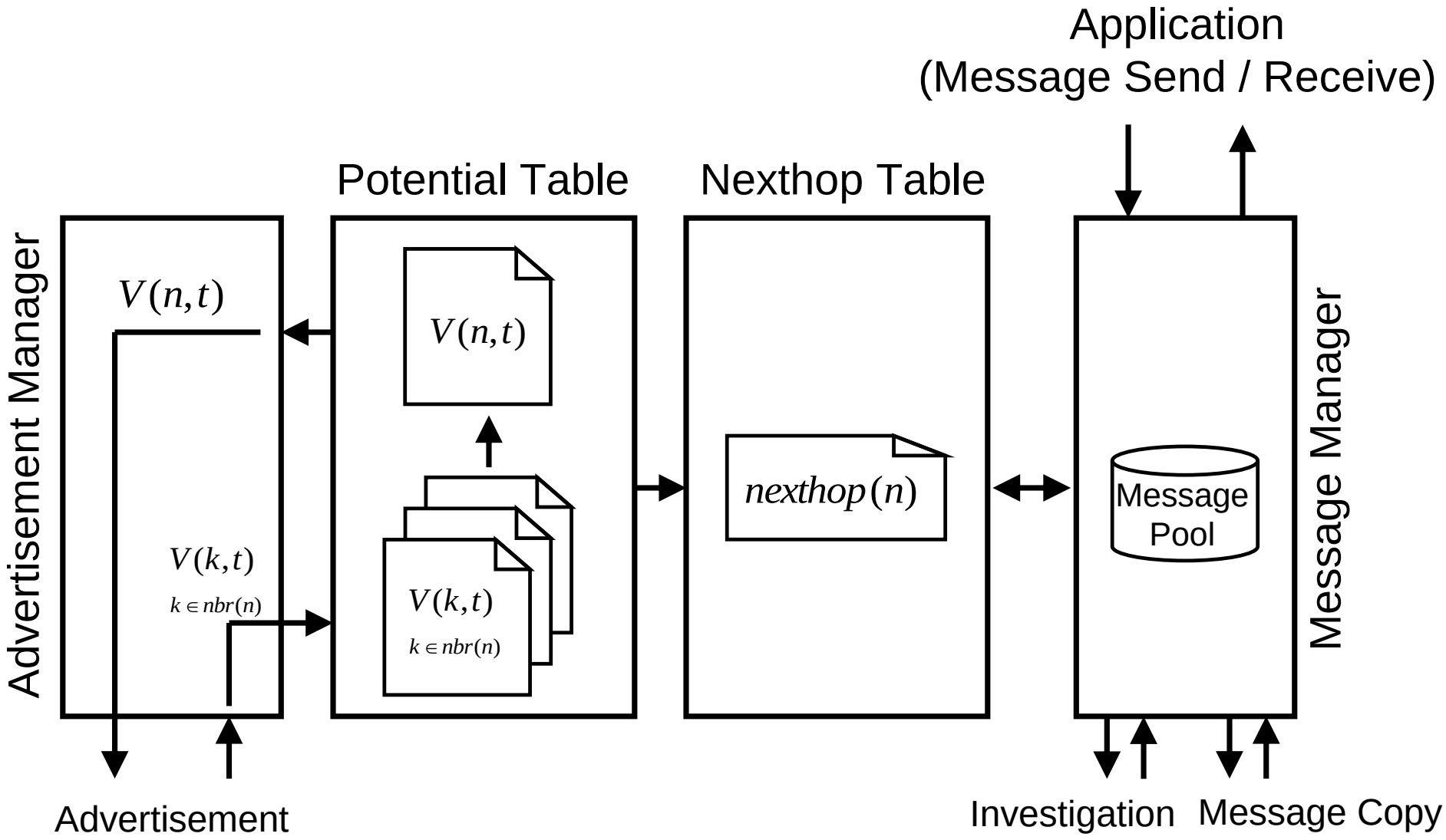
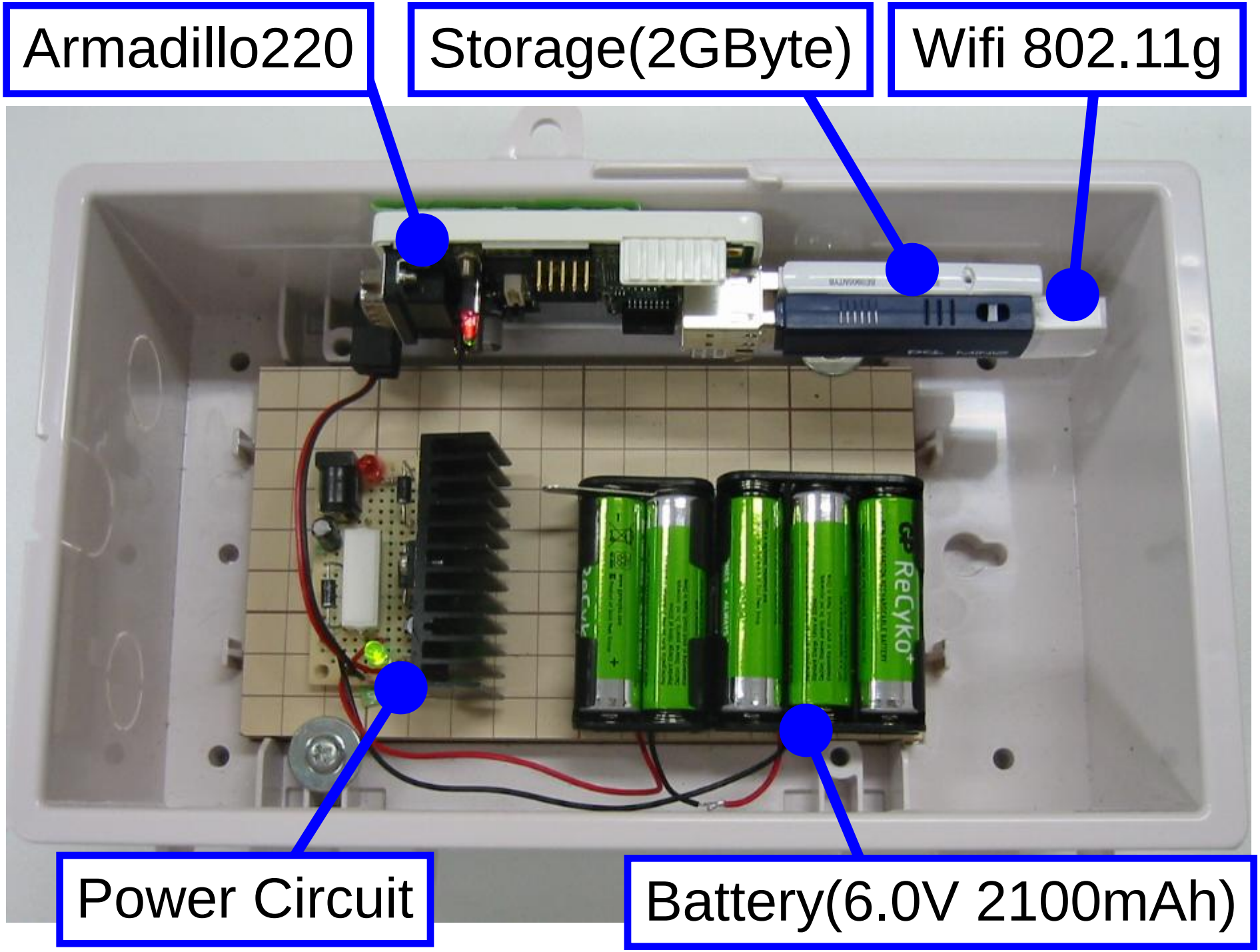


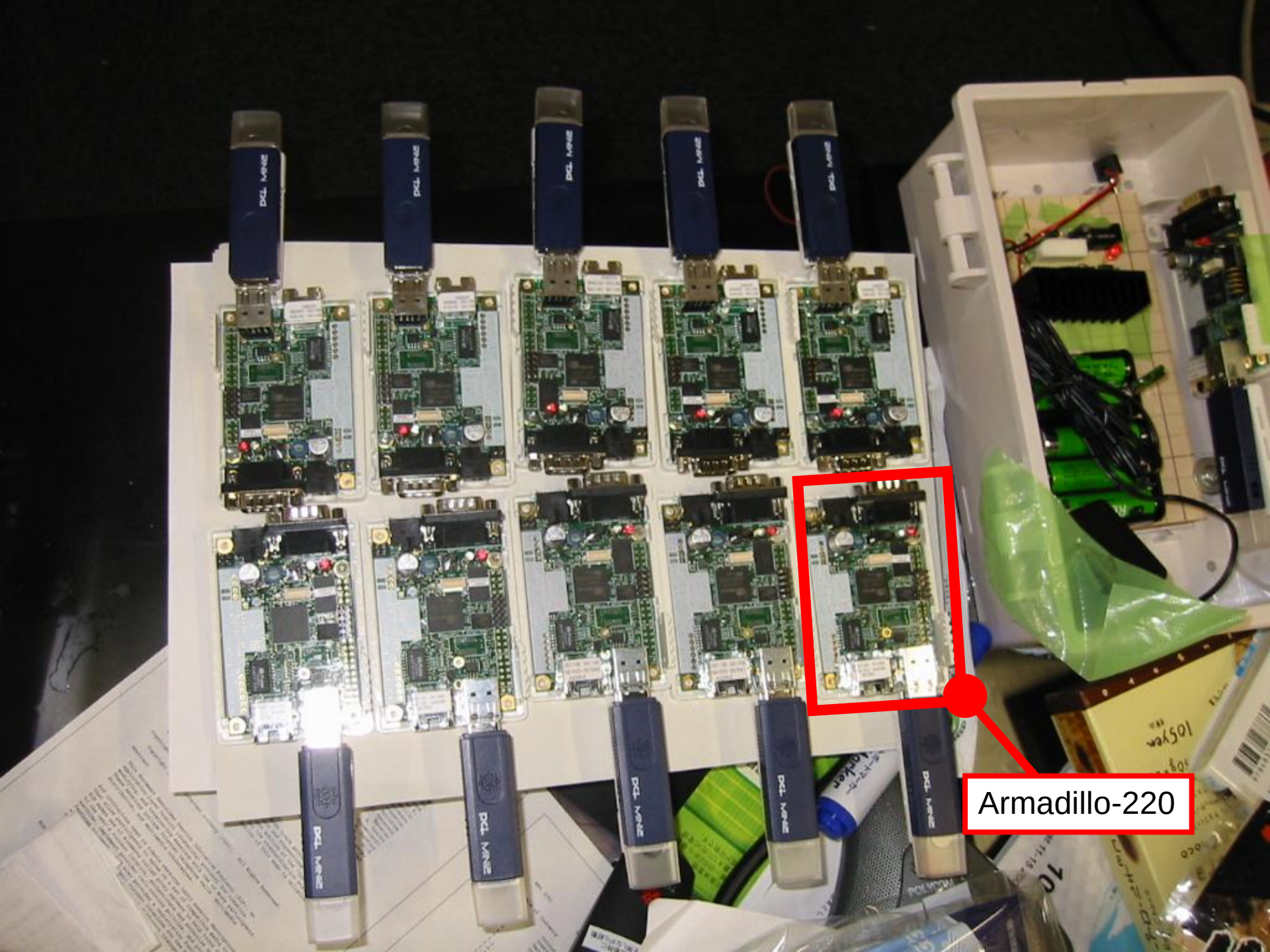


Software Design of PEAR

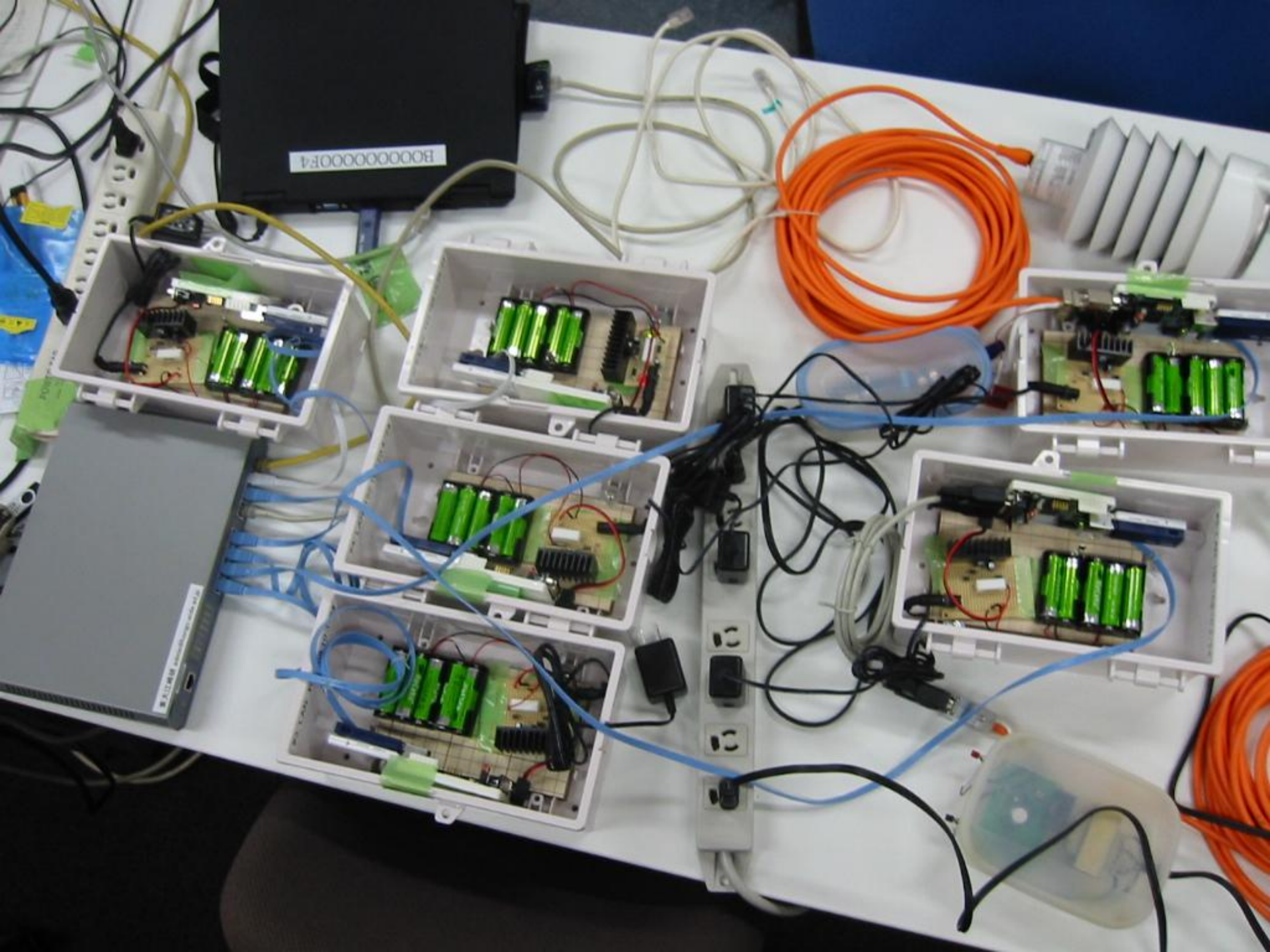


About 3000 lines in C.
Footprint is 34k byte in object code.


Armadillo220
Storage(2GByte)
Wifi 802.11g
Power Circuit
Battery(6.0V 2100mAh)


Armadillo-220


Recyko
Recyko+



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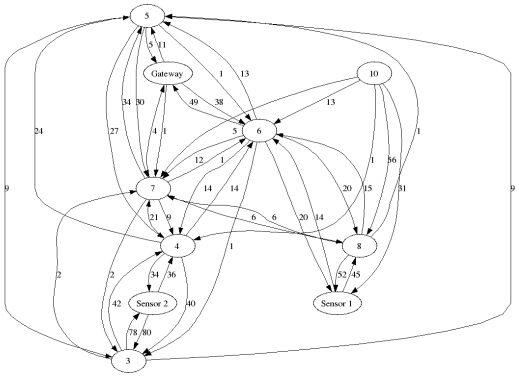
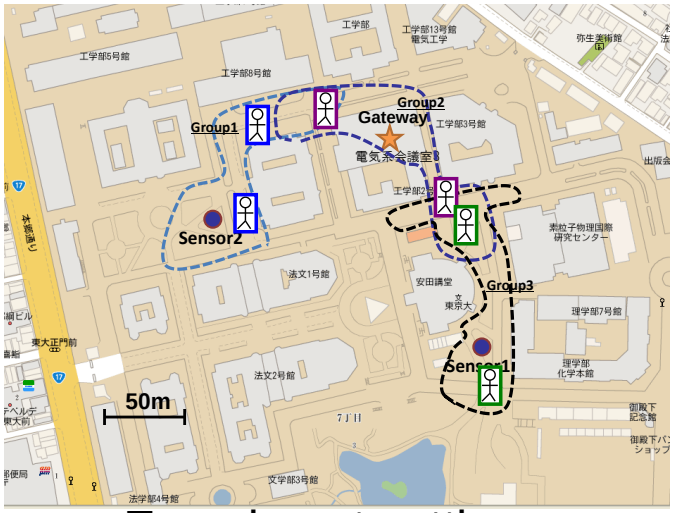
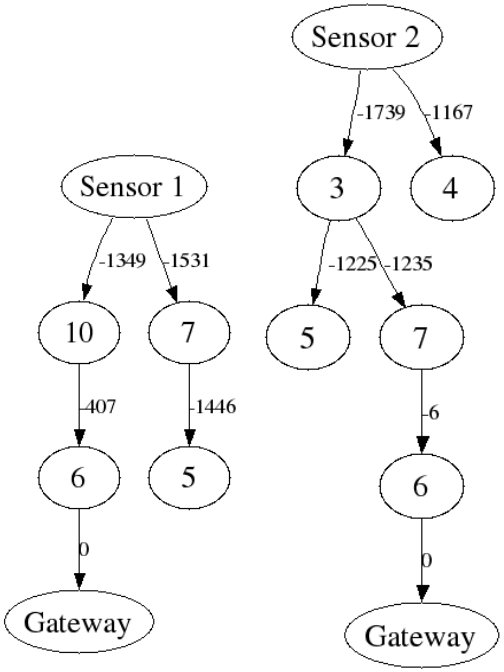


Contact graph



Experiment settings

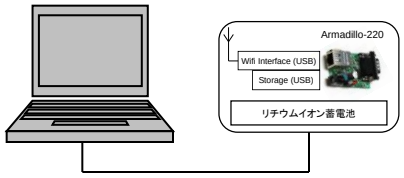


Delivery pattern

Members for the experiment

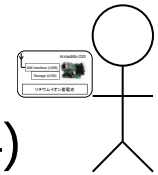
- The University of Tokyo
  - Ochiai, Shimotada, Fujita, Kawakami, Himura, Sugita, Lert, Wan, Minshin, Motodate, Kure, Kawaguchi, Ishizuka
- Nara Institute of Science and Technology
  - Dr. Matsuura
- Keio University
  - Dr. Miyakawa, Yamanouchi
- Cisco Systems, Inc.
  - Momose

Scenario Overview

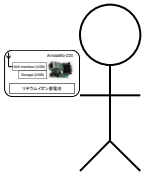


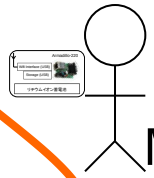
InternetGW (#99)

1. **Deploy sensors in remote sites.**
2. **Sensors periodically transmit data to the GW**
3. **Mobility of nodes enables delivery of data from sensors to the GW.**

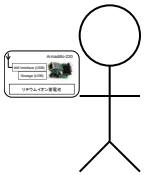


Mobile Node (#4)

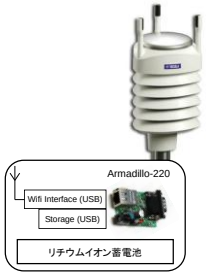




Mobile Node (#3)

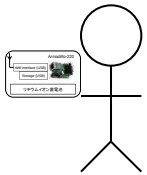


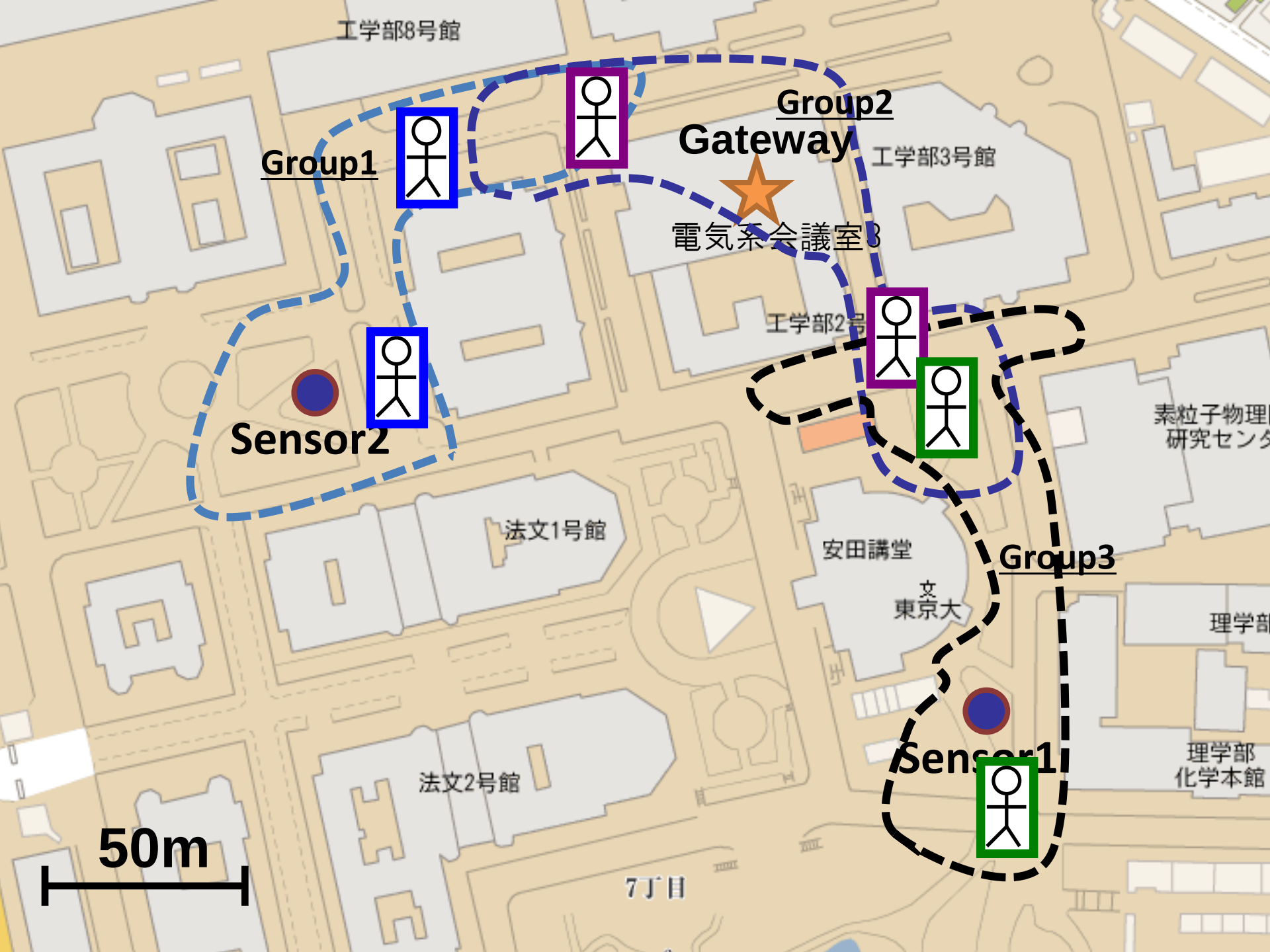
Mobile Node (#5)



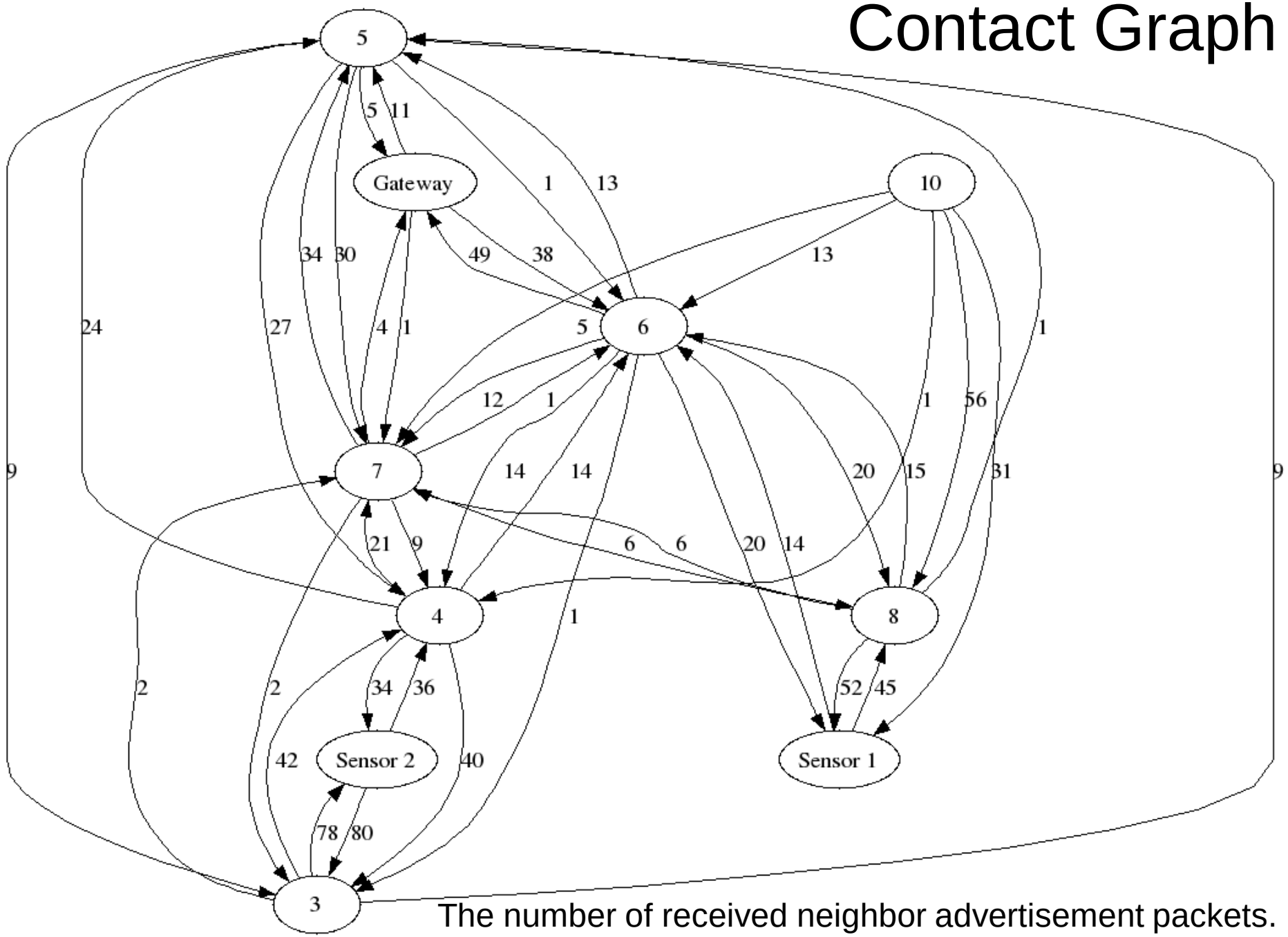
Sensor Static (#1)

Sensor Static (#2)




工学部8号館
Group1
Group2
Gateway
工学部3号館
電気系会議室3
工学部2号
Sensor2
法文1号館
安田講堂
Group3
文
東京大
素粒子物理
研究センタ
理学部
Sensor1
理学部
化学本館
法文2号館
7丁目
50m

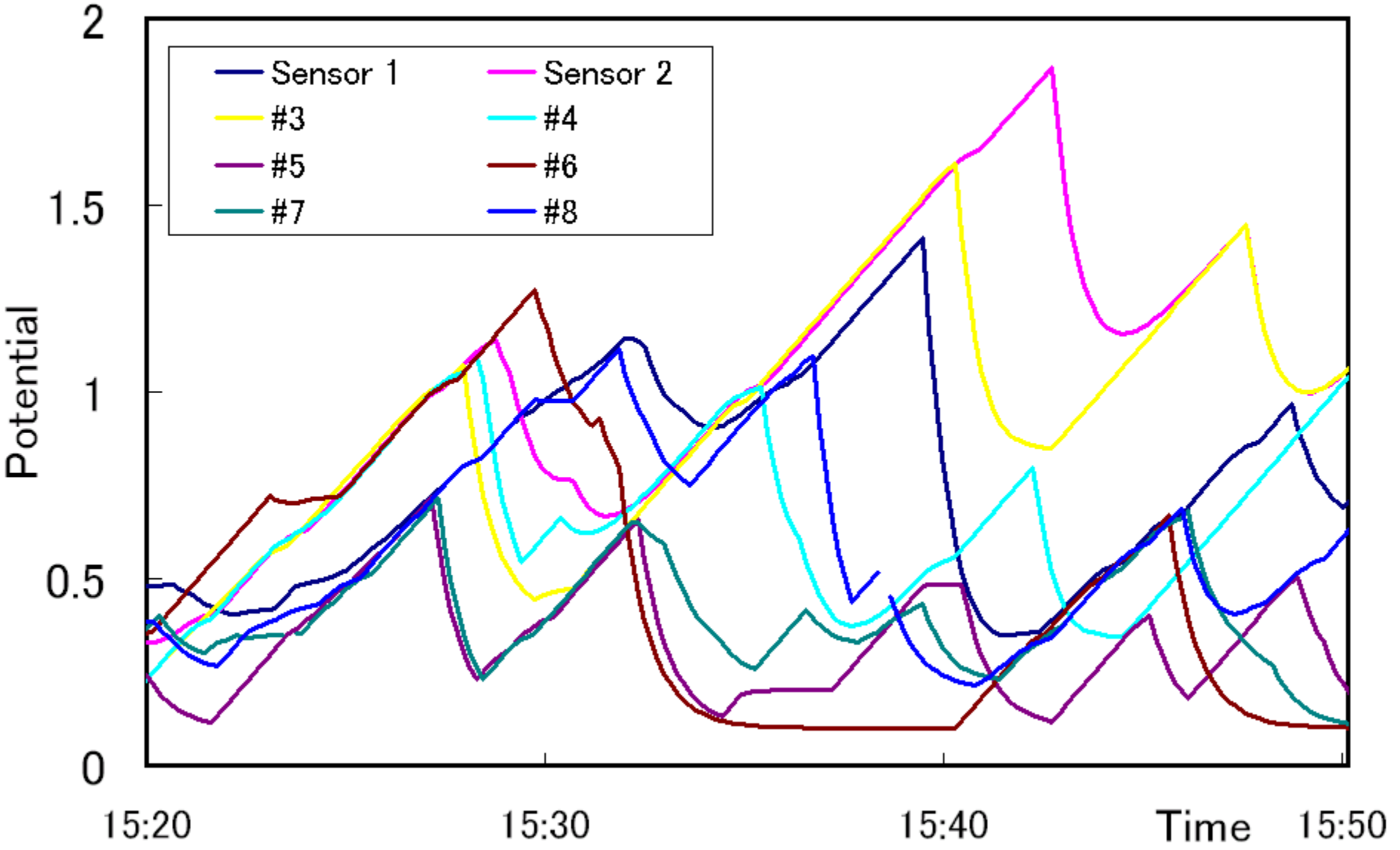
Contact Graph



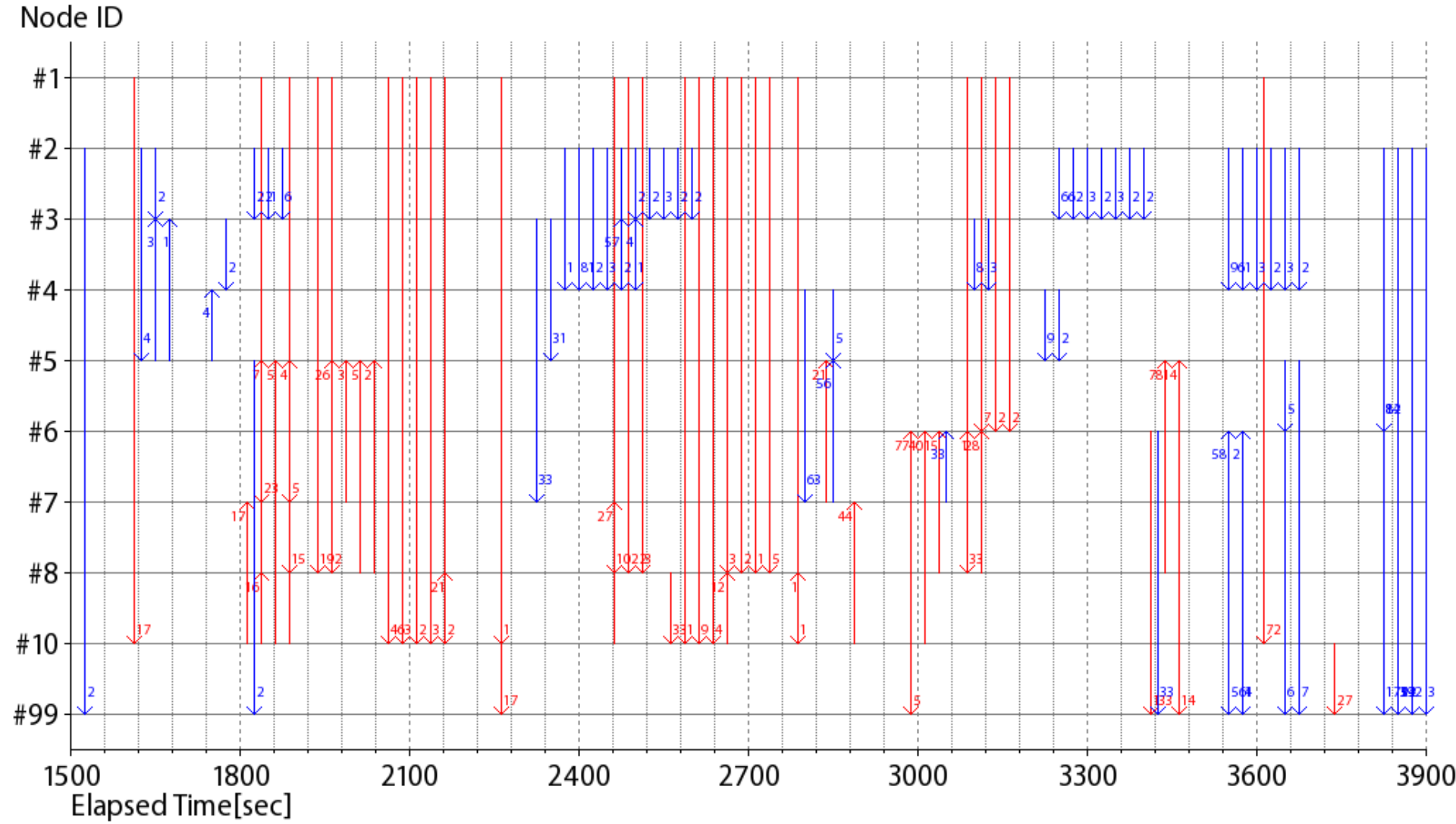
Mobility Entropy≒2.1

The number of received neighbor advertisement packets.
e.g., node 8 received 45 advertisements from sensor 1.

Potential for the Gateway



Message Flow (1/2)

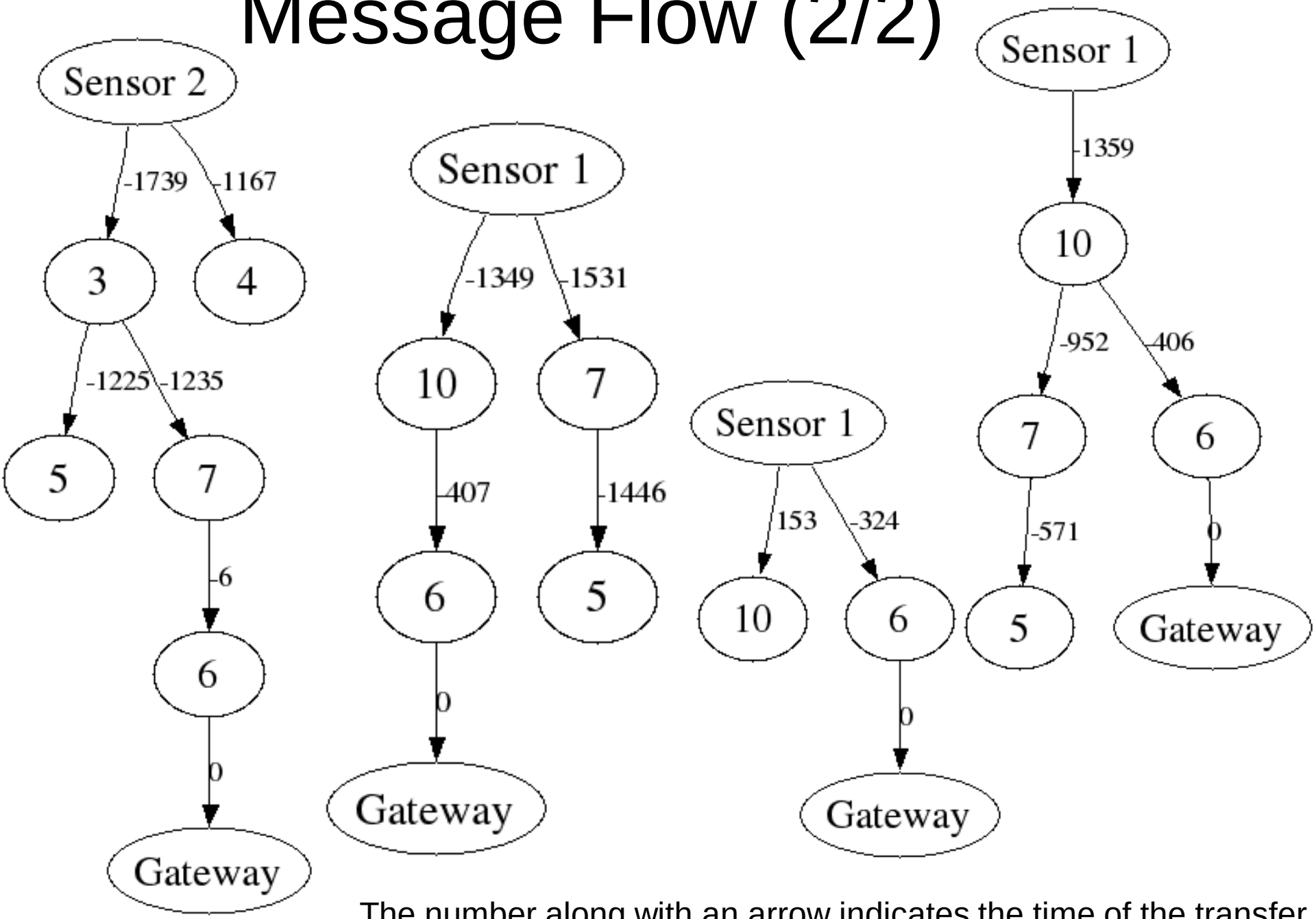


GW: #99

Red arrow: messages from sensor 1 (#1)

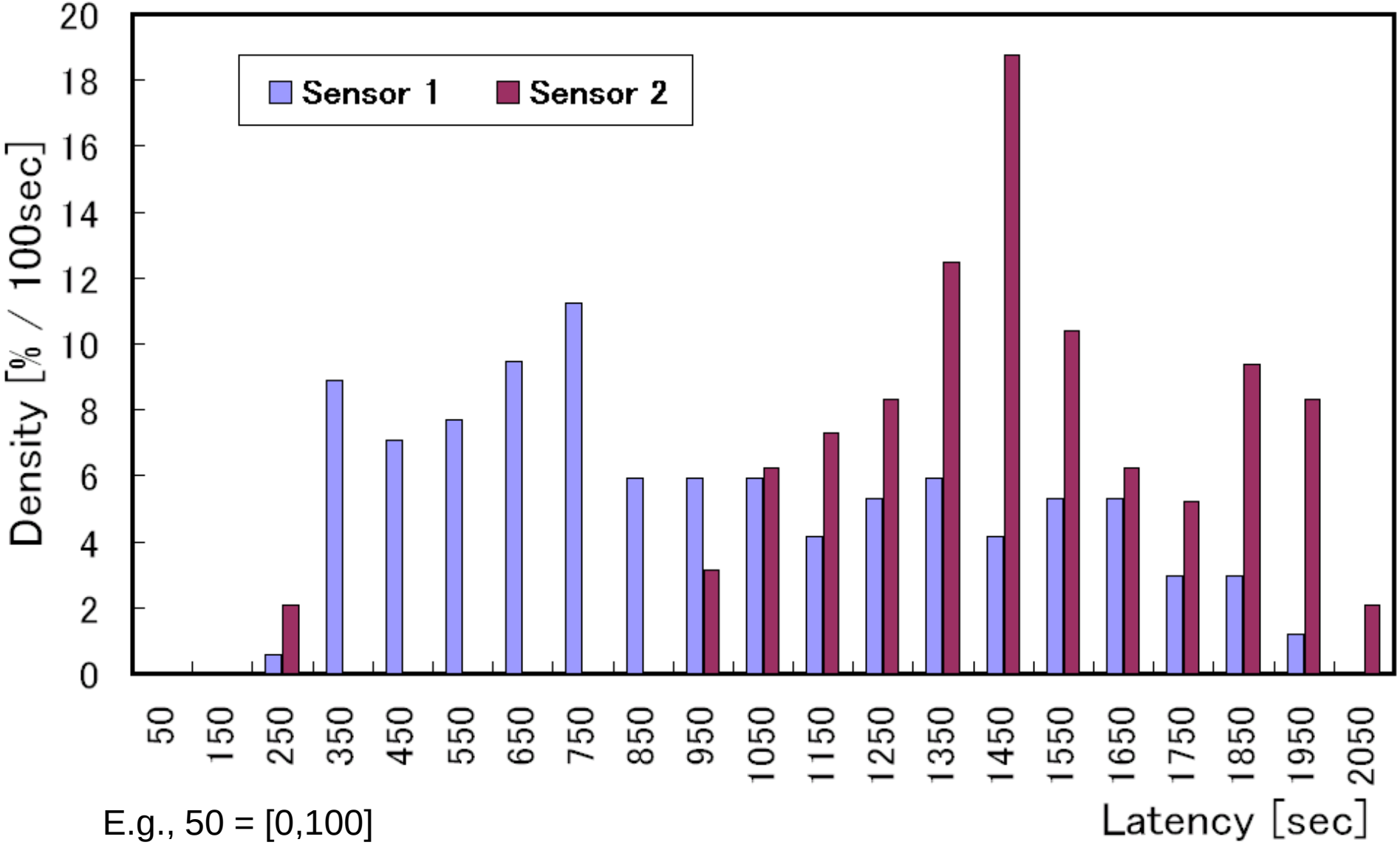
Blue arrow: messages from sensor 2 (#2)

Message Flow (2/2)



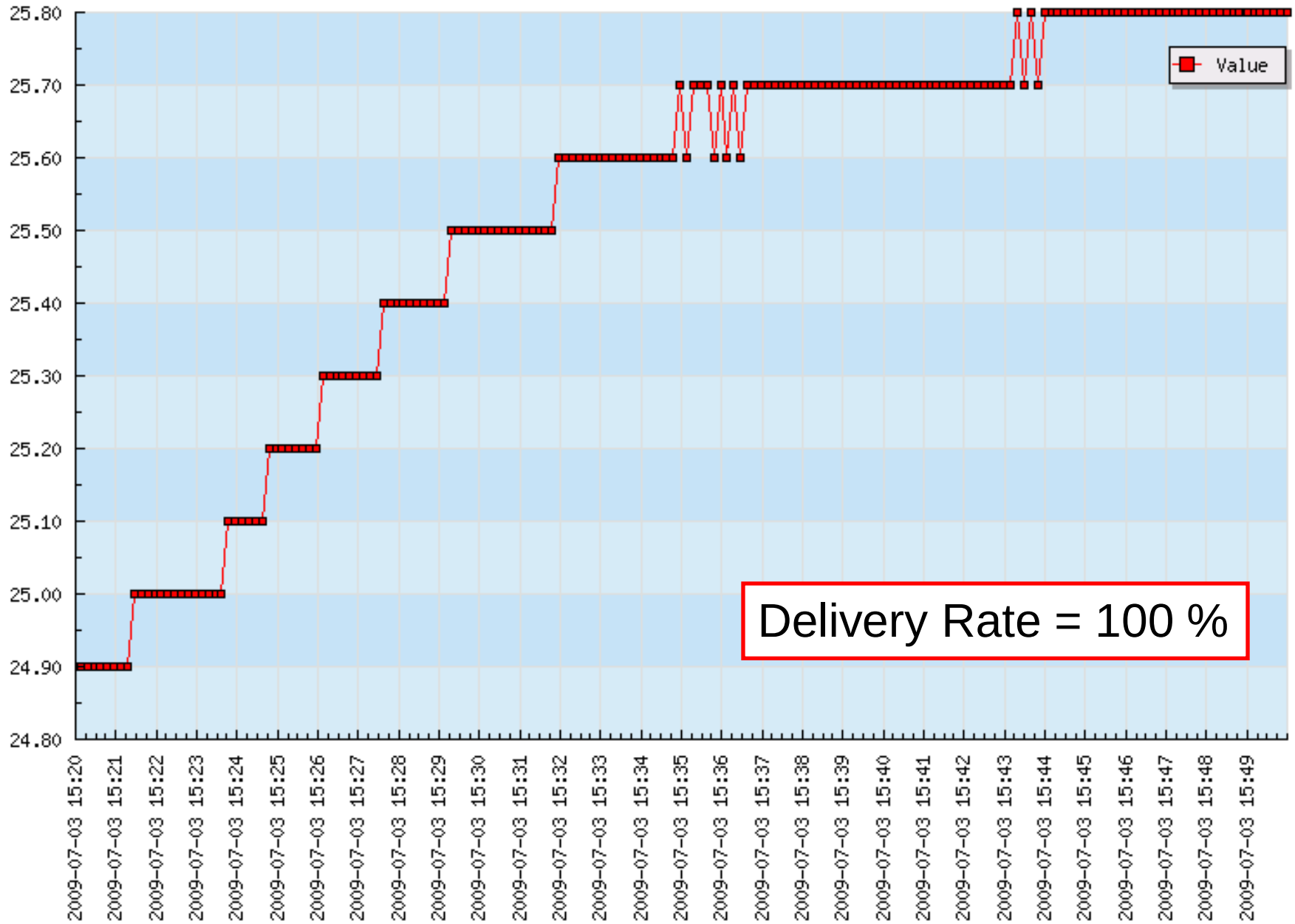
The number along with an arrow indicates the time of the transfer

Distribution of Delivery Latency

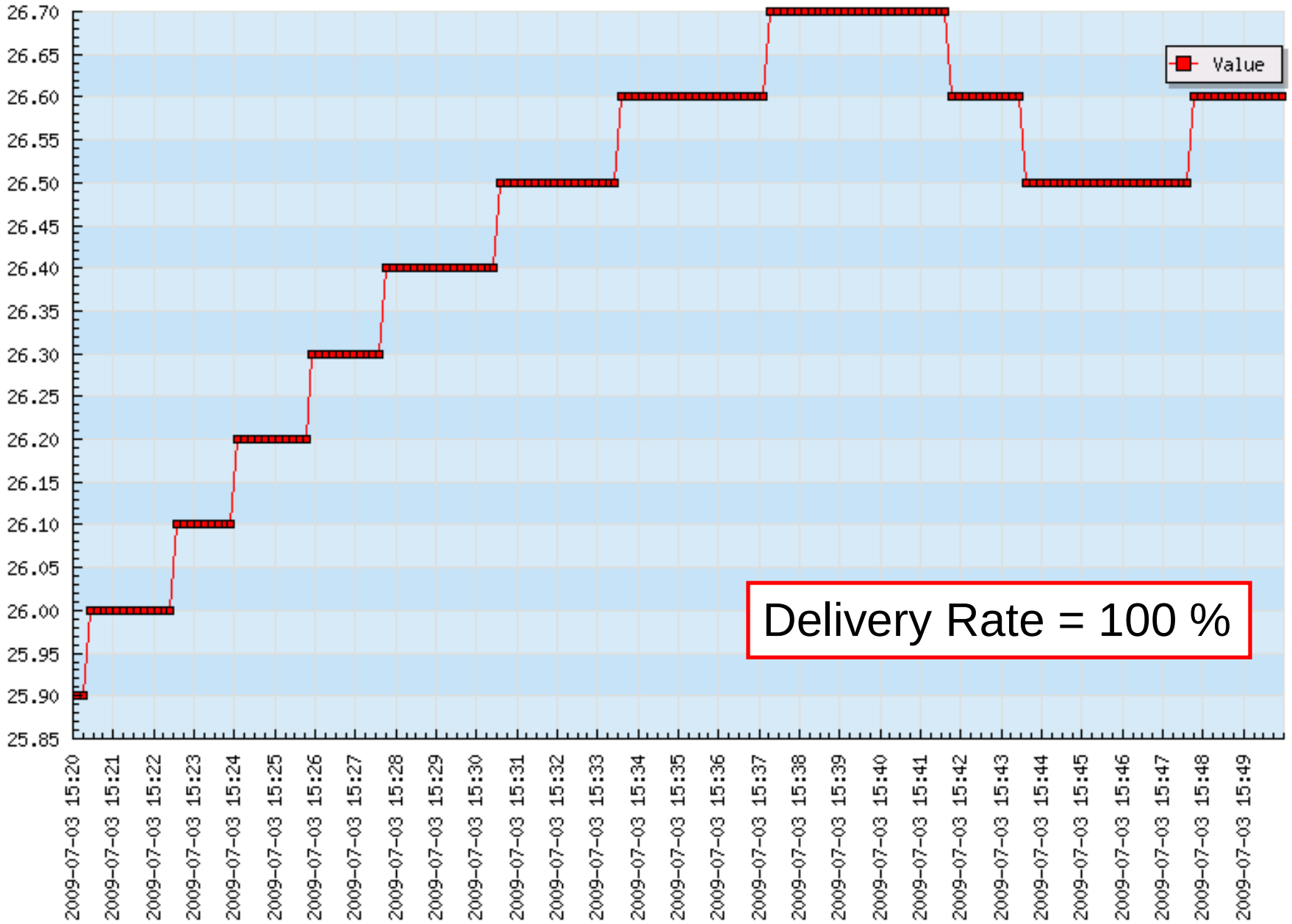


E.g., 50 = [0,100]

Collected Temperature Data from Sensor 1



Collected Temperature Data from Sensor 2



Outline

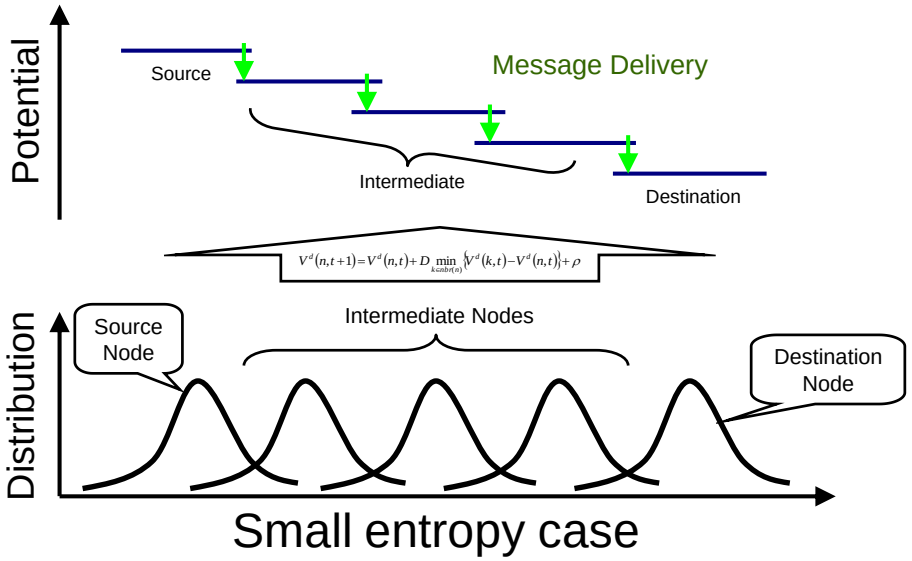
- Introduction
- Potential-based entropy adaptive routing
- Prototype implementation
- Campus-wide experiment
- Conclusion

Conclusion

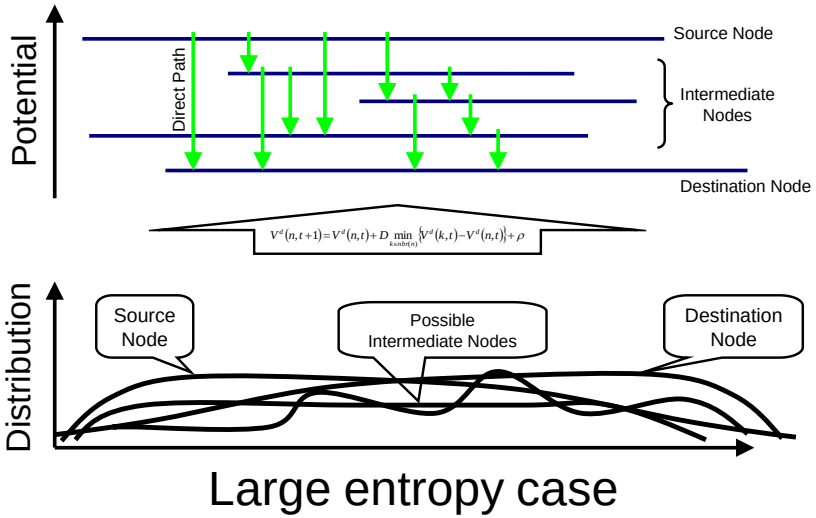
- We proposed PEAR for opportunistic networking
  - It directly forwards a message at small entropy cases
  - It replicates a message to improve delivery latency at large entropy cases
- Implementation and deployment of PEAR
  - Prototype system with embedded computers
  - 10-node scale campus wide experiment
- PEAR has achieved 100% delivery rate with reasonable delay on the experiment settings.

Thank you...

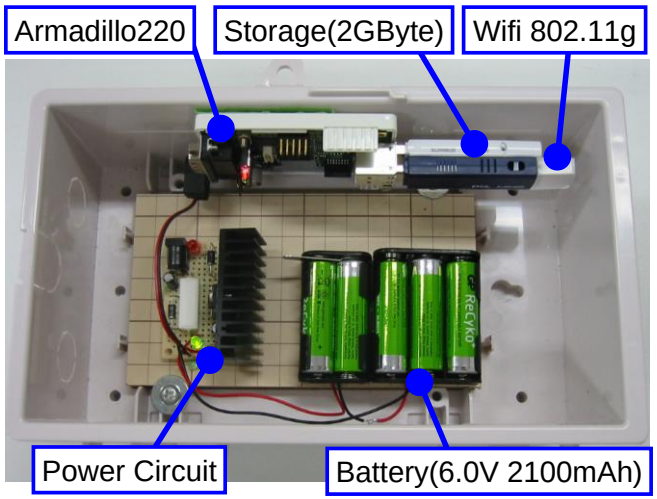
Google by "Mobility Entropy and Message Routing"



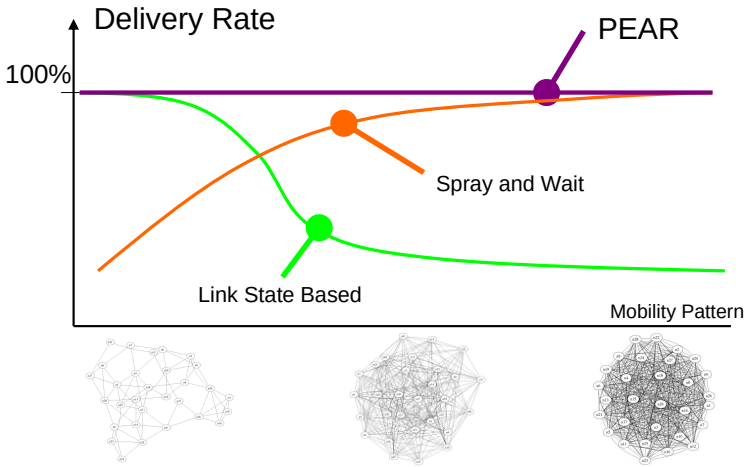
Small entropy case



Large entropy case



Prototype implementation



PEAR maintains high delivery rate over wide-range of mobility patterns