Potential-Based Entropy Adaptive Routing for Disruption Tolerant Networks

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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

**Small Entropy Case**

- Biased contact

  It should choose the best path

**Large Entropy Case**

- Uniform contact

  It should improve delivery rate by increasing redundancy.

A bolder link indicates larger contact time.
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

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

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

\[ D(> 0), \rho(> 0) \quad \text{const.} \]

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

Diffusion Equation

\[ V^d(n, t + 1) = V^d(n, t) + D \sum_{k \in \text{nbr}(n)} \left\{ V^d(k, t) - V^d(n, t) \right\} \]
Potential-Field Construction

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

\[ \forall t, (V^d(d, t) = 0) \]
Transfer-Based v.s. Copy-Based Message Delivery

Transfer-Based Message Delivery

Copy-Based Message Delivery
Copy-Based Message Transfer in PEAR

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

Do you have any information about msg_id= XXXX ??

- NOT_HAVE
- ALREADY_HAVE
- DELIVERED
Potential and Message Routing
Small Entropy Case

\[ V^d(n+1,t) = V^d(n,t) + D \min_{k \in \text{nbr}(n)} [V^d(k,t) - V^d(n,t)] + \rho \]
Potential and Message Routing
Large Entropy Case

\[ V^d(n,t+1) = V^d(n,t) + D \min_{k \in \text{nbr}(n)} \left( V^d(k,t) - V^d(n,t) \right) + \rho \]
Rough Simulation-Based Evaluation

![Graph showing delivery rate vs. mobility entropy with lines for Epidemic, PEAR (MCS), PEAR (BCS), Spray and Wait, MED, and MDP.](image-url)
Rough Simulation-Based Evaluation (Summary)

- Delivery Rate
- Mobility Pattern
- PEAR
- Spray and Wait
- Link State Based
- Village-to-village
- Human-to-human
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Software Design of PEAR

Advertisement Manager

Potential Table

Nexthop Table

Application (Message Send / Receive)

Advertisement

Message Manager

Message Pool

Investigation

Message Copy

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
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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

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

Mobility Entropy $\approx 2.1$
Potential for the Gateway

The graph shows the potential over time for different sensors indicated by the legend:
- Sensor 1
- Sensor 2
- #3
- #4
- #5
- #6
- #7
- #8

The x-axis represents time from 15:20 to 15:50, and the y-axis represents potential on a scale from 0 to 2.
Message Flow (1/2)

Node ID

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

Delivery Rate = 100 %
Collected Temperature Data from Sensor 2

Delivery Rate = 100 %
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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"

Potential

Source

Intermediate

Destination

Small entropy case

Potential

Source Node

Intermediate Nodes

Destination Node

Large entropy case

Potential

Source Node

Possible Intermediate Nodes

Destination Node

Delivery Rate

100%

PEAR

Spray and Wait

Link State Based

Mobility Pattern

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