Fast Data Dissemination in Wireless Sensor Network

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Paper Introduction

Overview of paper

- Topic
  - Introduce Pando, a completely contention-free data dissemination protocol for wireless sensor networks.
- Goal
  - Improve reliability in data dissemination
  - Reduce dissemination time

Pando

Abstract

- Pando encodes data by Fountain codes and disseminates the rateless stream of encoded packets along the fast and parallel pipelines built on constructive interference and channel diversity

Main feature

- Fountain coding
- Silence based feedback scheme
- Packet level adaptation

Background

Keywords [1/2]

- Data dissemination
  - Deliver a bulk of data to all the nodes in a network
  - Provide a fundamental service for many application such as on-the-air reprogramming and application updating

- Pipeline transmission
  - Recent advanced physical layer technique for cooperative broadcasting

  - Constructive interference : remove unnecessary channel contention and improve the flooding performance (Glossy)
  - Pipelining : enable adjacent links in a multi-hop path to operate concurrently with multi-channel (PIP)

  - The combination of constructive interference and pipelining is Pipeline transmission

Keywords [2/2]

- Pipelined tree topology
  - One packet is forwarded simultaneously by all nodes at a same layer

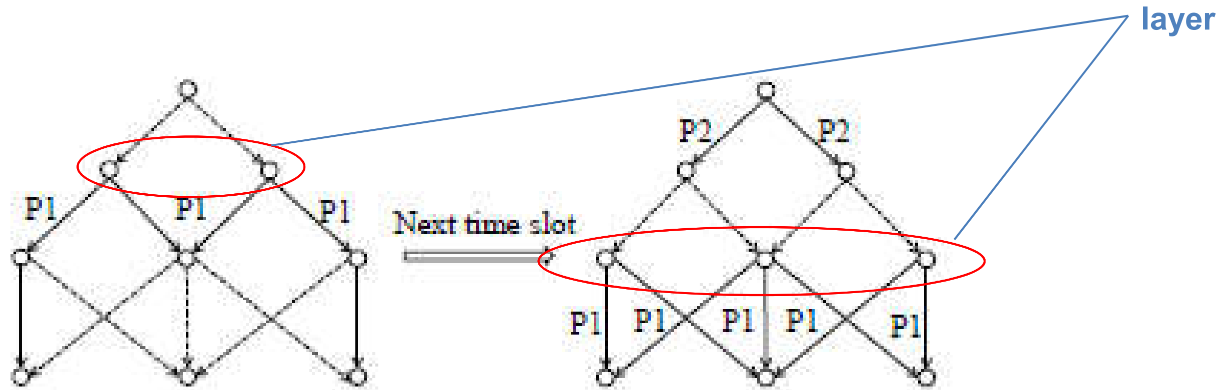


Figure 1: The pipelined tree built on constructive interference and pipelining. 'P1' and 'P2' represent the first packet and the second packet respectively.

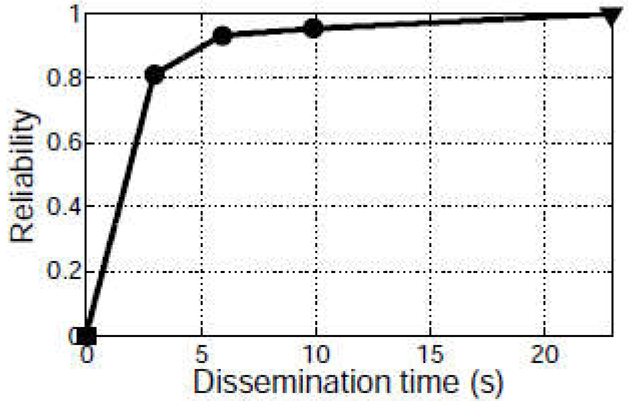
- Fountain code
  - Original source can be recovered from any subset of the encoding symbols of size equal to or only slightly larger than the number of source symbols.

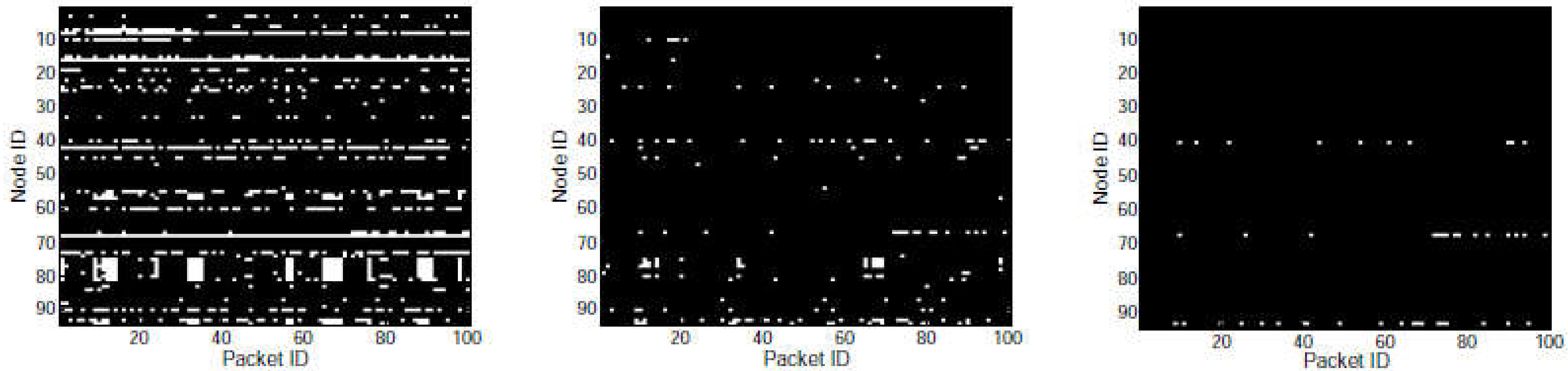
Splash [1/2]

- The state of art protocol in data dissemination
- Disseminates the data object multiple times and relies on a local recovery phase to achieve high reliability
  - First two round : Disseminate same data object twice
  - Third round : Disseminate 500 XOR-encoded packets that combination of 20 randomly-selected original packets. If node has 19 original packets, then it can recover a missing original packet
  - Local recovery : request missing packets from their neighbors using CSMA/CA based multiple access.

Splash [2/2]

- Long tail problem
  - The local recovery phase is much longer than the total transmission time of three dissemination rounds





(a) First round (85% reliability). (b) Second round (96.8% reliability). (c) Third round (99% reliability).

Pando

Preliminaries on Fountain codes

- LT code (Luby Transform code) – simple design
- Every encoded packet is calculated by performing XOR operation of d packets that are randomly chosen from k original packets. (d = 1,2,3,…,k)

Radio-driven coding scheme [1/3]

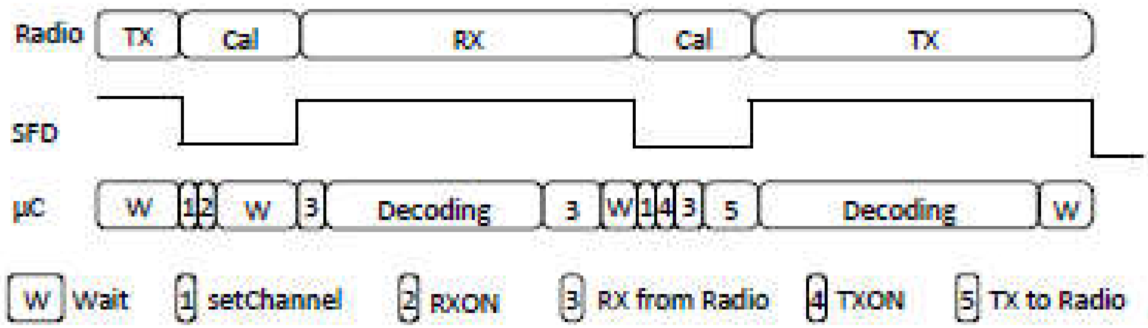
- Pando needs highly synchronized environment because constructive interference and pipelining.
- Since CPU is mostly in idle mode while the radio is receiving or transmitting, the CPU can execute the coding computation that time.

Radio-driven coding scheme [2/3]

- Constant interval of idle CPU
  - While Rx and Tx time on Glossy and PIP protocol, there is constant idle interval for every packet transmission
- Deterministic coding time
  - Using Accumulative Gaussian Elimination (AGE) algorithm, limit the coding time up to 64 μs (smaller than guard interval 256 μs)

Radio-driven coding scheme [3/3]

- Timing process
  - After end of TX , there is short calibration time(192 μs) and RX time
  - Receiving a first two bytes of packet, it begins to decode the previously-received encoded packet



Silence-based feedback

- Since source continuously flood the encoded packets to the network, source don’t know when terminate the dissemination
- A feedback scheme is needed to terminate the dissemination at time
- Acknowledgment transmission could harm completely contention free protocol, so that silence based feedback scheme is selected

Silence-based feedback

- If node successfully receive encoded packet and recover original packet, it generate the encoded packet and transmitting to its child nodes without receiving new packets form its parent nodes

- Parent node detect the child nodes successful recover by listening the child node's channel

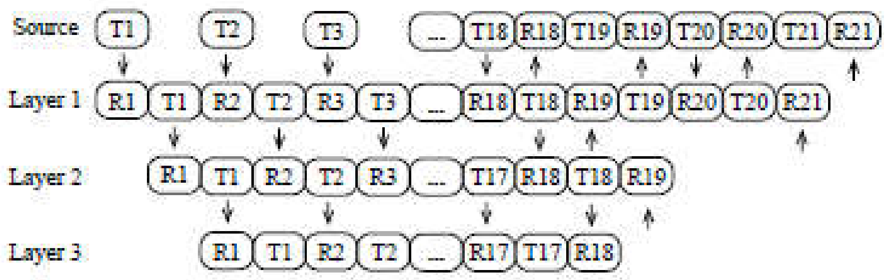


Figure 5: Dissemination process of a 16-packet data object in Pando. 'T1' refers to the first TX slot. 'R1' represents the first RX slot. The arrow indicates the signal transmission direction.

Silence-based feedback

- RSSI value is used to detect silence

- False negative of channel silence
  - Due to ambient noise or interference, a node may not be able to detect the channel silence
  - Measure the channel state to 10 time slot and Setting threshold refer these values

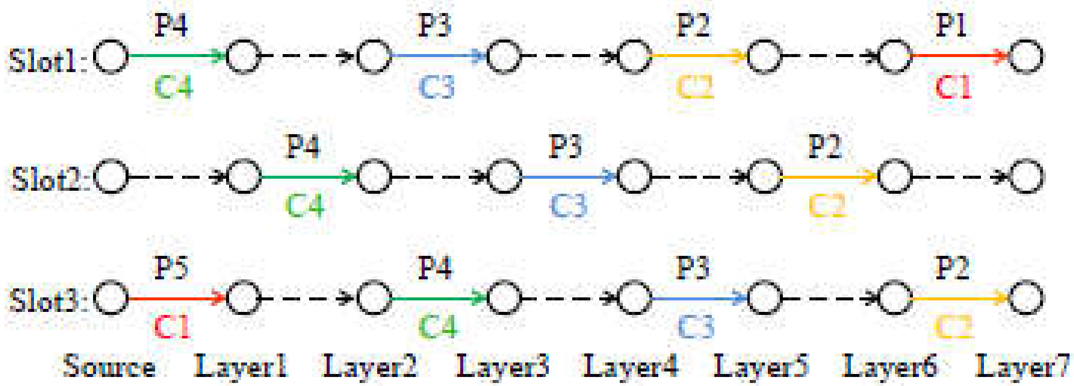
- False positive of channel silence
  - When node fails to receive a packet, it cannot forward that packet.
  - Parent node only infer that all child node complete the reception When M (M is constant value) consecutive silent slot are detected

Packet-level adaptation

- Some channels may have bad quality or some nodes may have poor packet reception
- To solve theses problem, Pando select Packet level adaptation
- Packet-level adaptation can only be enabled in the data dissemination of Fountain-encoded packets because the encoded packets are independent to each other

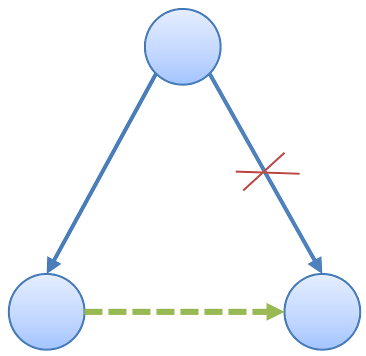
Packet-level adaptation

- Channel diversity
  - At first, a node is set to a default channel to receive the first packet
  - After forwarding the received packet to their child nodes, they immediately switch to the channel allocated for the next packet
  - The minimum distance between two packets using a same channel is at least eight hops
  - Next packet's channel is calculated according to the sequence number of the last received packet



Packet-level adaptation

- Overhear
  - If node misses a packet because the signal is not detected, it tries to overhear the packet from same layer by increasing RX time



- Network density
  - To adapt the network density, the leaf nodes transmit a received packet only when the sequence number of that packet is even

Evaluation

Evaluation setting

- Topology : pipelined tree
- Metrics : reliability, dissemination time, energy consumption, memory cost
- Environment
  - two large-scale open testbed of wireless sensor network, Indriya and Flocklab
  - Operate on 2.4 GHz
  - Packet size if 64 bytes and data object is 35 Kbytes (500 packets)
  - Indriya has 99 nodes and Flocklab has 31 nodes

Evaluation - time

- All three protocol can achieve 100% network reliability

- Pando reduce the dissemination time of Splash by an average factor of 3.5 and 6.4 on Indriya and Flocklab

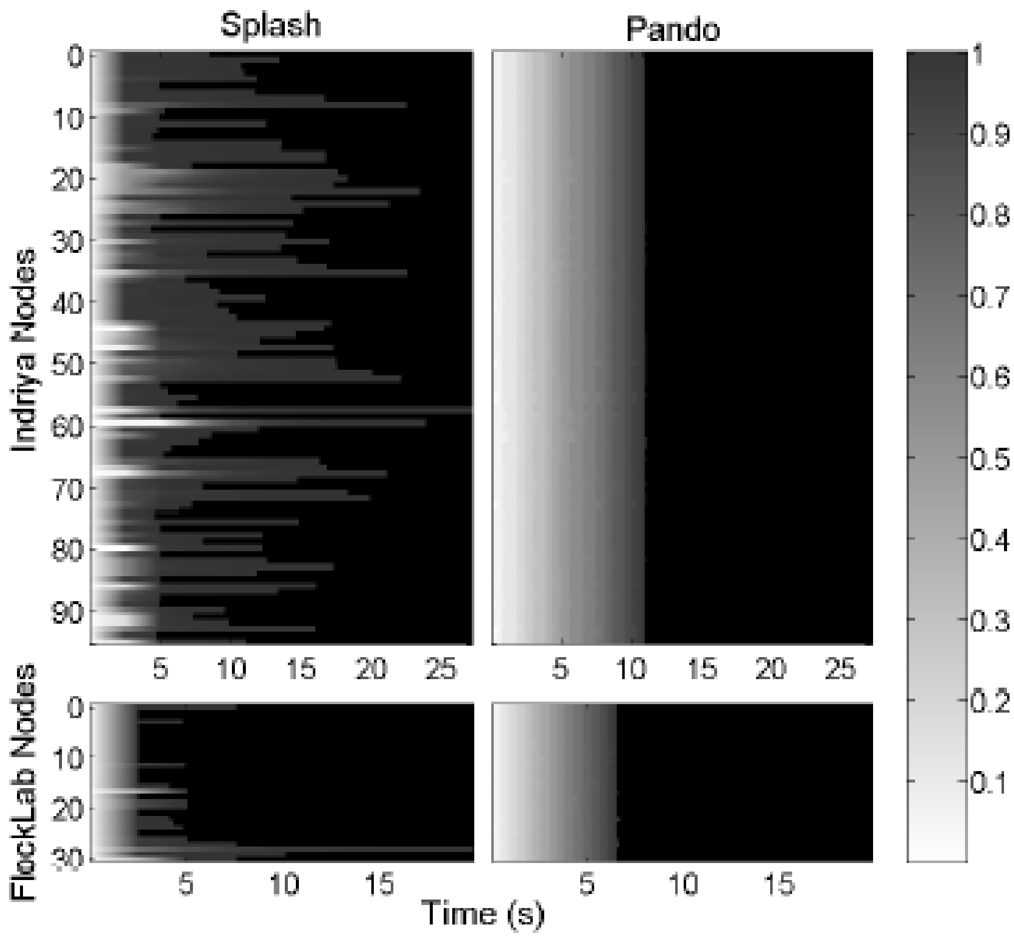
Table 1: Dissemination time (second) on Indriya[1].

Test #	Size (hops)	Pando	Splash	Splash w/o encoding
1	7	9.7	40.2	22.3
2	8	13.3	40.4	22.5
3	9	10.4	39.4	21.6
4	8	12.4	39.7	21.9
5	7	11.0	40.8	22.9
Average	8	11.4	40.1	22.3

Table 2: Dissemination time (second) on Flocklab.

Test #	Size (hops)	Pando	Splash	Splash w/o encoding	Deluge (2 kBytes)
1	6	5.7	36.4	18.4	481.4
2	5	4.3	36.3	18.3	471.7
3	9	7.7	36.4	18.4	481.4
4	6	6.4	36.3	18.3	481.4
5	5	4.4	36.5	18.6	466.9
Average	6	5.7	36.5	18.7	476.6

Evaluation – individual node



Evaluation – reliability

- Splash has high XOR encoding overhead and long tail problem

- Pando reduce the time of Splash by 2.0 and 3.3 on Indriya and Flocklab respectively

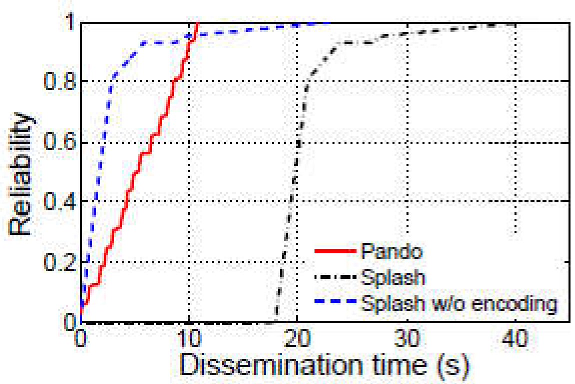


Figure 9: Network reliability progress on Indriya.

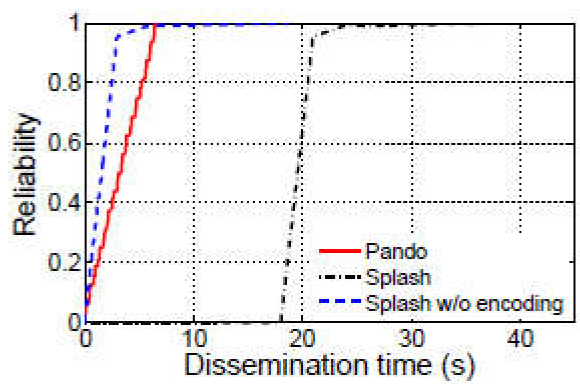


Figure 10: Network reliability progress on FlockLab.

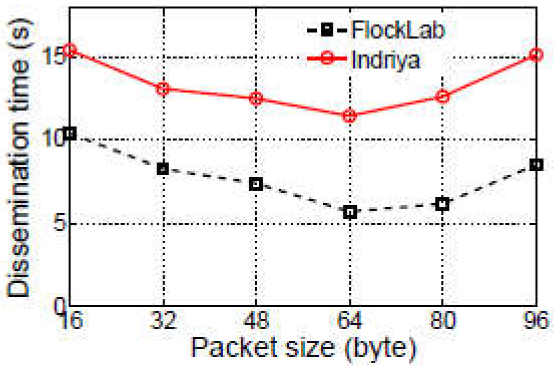
Evaluation – energy & memory

- Pando utilize CPU at idle time but it increase only 5.2% of energy, But by reducing dissemination time node can save 69.5% energy compare to Splash

- Pando uses 6.24 Kbytes of RAM (10 Kbytes), 32 Kbytes of data flash memory (1 Mbytes), 31.49 Kbytes of ROM (48 Kbytes) (in brace value is resource in TelosB node)

Effect of packet size

- When the packet size is small, the preamble of the physical and MAC layer introduces high percentage of overhead and occupies a large portion of the dissemination time.
- When the packet size is large, the performance of constructive interference decreases.
- 64 bytes is optimal in current pipeline transmission



Thank you for your attention!

Any Questions ?