Topology Control and Channel Assignment in Lossy Wireless Sensor Networks

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Outline

- Background and Introduction
- Network Model and Problem Formulation
- Centralized Algorithm
- Distributed Algorithm
- Performance Evaluations
- Conclusion

Background

- Lossy property of Wireless Sensor Networks
  - A large amount of links are unreliable
  - One packet needs multiple retransmissions.
  - Described by packet reception ratio (PRR)
- PRR has been used as a link metric for clustering and routing algorithms in WSNs
  - Improves network performance
  - Enhances energy efficiency

Background

- PRR of a link is highly related to the signal to interference noise ratio (SINR)
- To boost SINR of links
  - Enhancing received power
  - Mitigating interference
    - Scheduling interfering links
    - Topology control
    - Multiple channel schemes

Introduction

- We use a weighted undirected graph G= (V, E, P, C, M, W) to model a Lossy WSN.

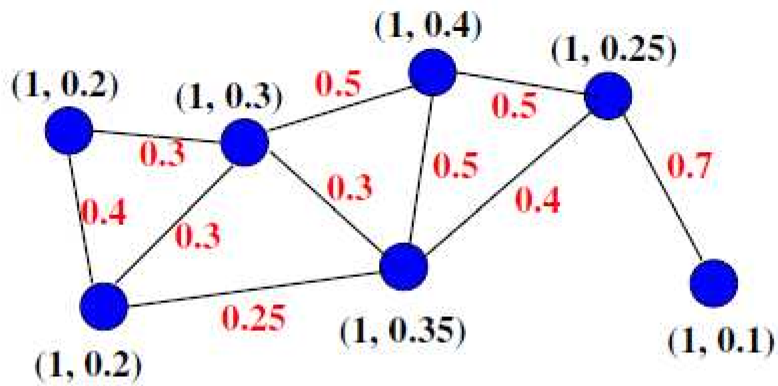


Fig. 1. An example of network graph for WSNs. In the graph, blue dots denote sensor nodes and the lines among them stand for the links. The transmission power and traffic demand of each node are given in the bracket above it and the PRR of each link is the red number nearby.

Introduction

- We investigate how to achieve optimal performance in Lossy WSNs by jointly exploring topology control and multiple channels.
  - Finding a spanning tree on which the packet reception ratio (PRR) of every link is maximized
  - Maximizing PRR by regulating following parameters for every node
    - Transmitter power levels
    - Channels

Network Model

- We assume the received power of a link is determined by the transmitting power and the propagation model
  - We use Log-normal shadowing model as the propagation model
  - $r_{(i,j)} = p_i - PL(d_0) - 10n \log \frac{d_{(i,j)}}{d_0} + X\_\sigma$
- We assume the interference of a link is related to both traffic load and received power of external nodes
  - $SINR_c^{(i,j)} = \frac{r_{(i,j)}}{\sum_{k \in V, k \neq i}^{c_i = c_k} m_k \cdot r_{(k,j)} + N_j}$
- We assume PRR of a link is limited by the smaller SINR of both directions.
  - $PRR_{(i,j)} = \lambda \cdot \min\{ SINR_{(i,j)}, SINR_{(j,i)} \}$

Problem Formulation

- Problem: Find a spanning tree T on G, in which the weight of each link is maximized.
  - Problem Formulation
  - Constraints:
    - Transmission power
    - Channel
    - PRR
    - Spanning tree
  - NP-hard

Maximize

$$\min\{PRR_{(i,j)}, \forall (i,j) \in T\}$$

Subject to

$$p_{\min} \le p_i \le p_{\max}, \forall i \in V \quad (1)$$

$$1 \le c_i \le |C|, \forall i \in V \quad (2)$$

$$r_{(i,j)} = p_i - PL(d_0) - 10n \log \frac{d_{(i,j)}}{d_0} + X_\sigma \quad (3)$$

$$t_{(i,j)} = 1, \forall (i,j) \in T \quad (4)$$

$$\sum_{\forall (i,j) \in E} t_{(i,j)} = |V| - 1 \quad (5)$$

$$\sum_{i \in S, j \in S} t_{(i,j)} \le |S| - 1, \forall S \subset V, |S| \ge 3 \quad (6)$$

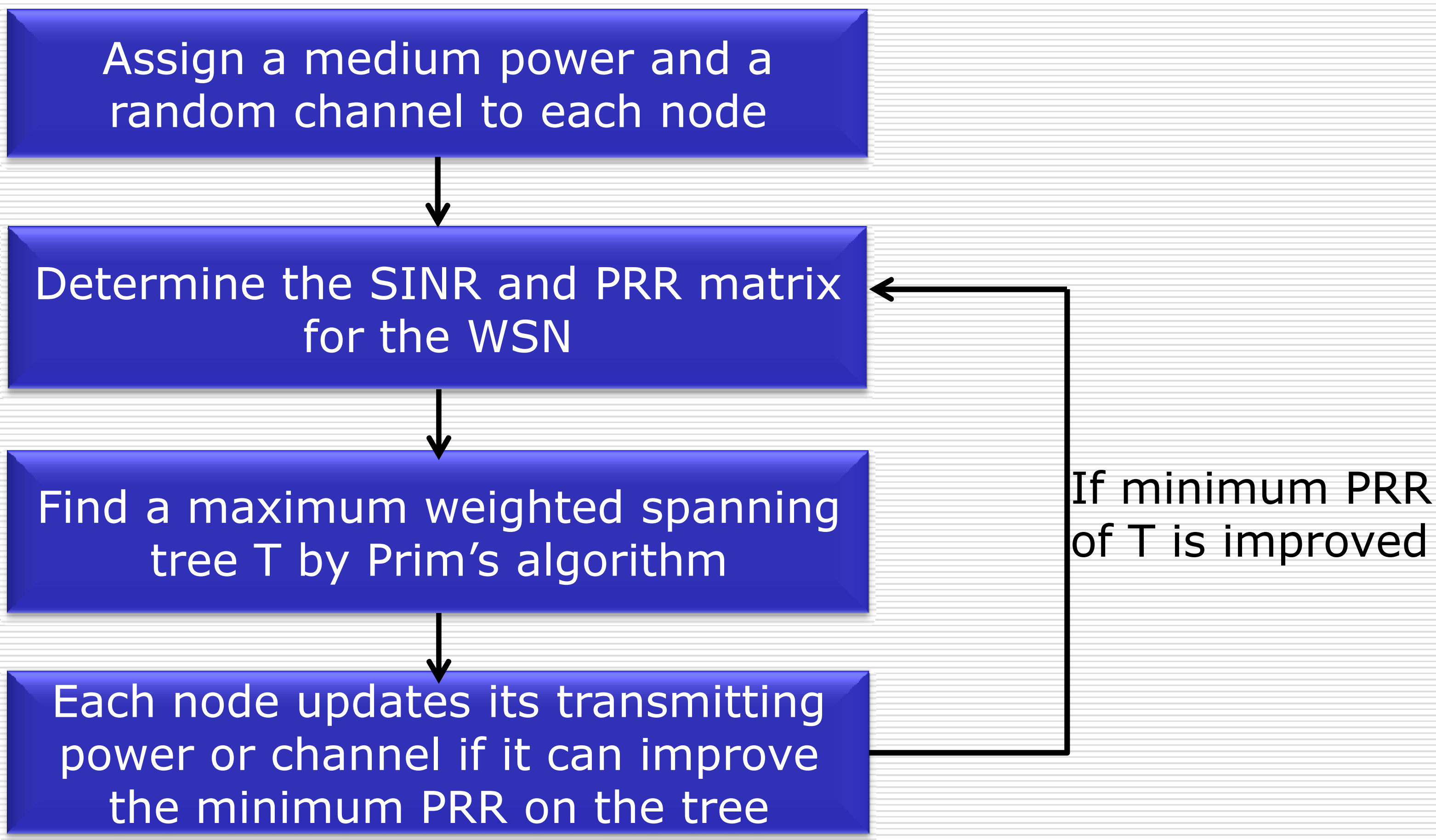
$$SINR_c^{(i,j)} = \frac{r_{(i,j)}}{\sum_{k \in V, k \ne i}^{c_k = c_i} m_k \cdot r_{(k,j)} + N_j} \quad (7)$$

$$PRR_{(i,j)} = \lambda \cdot \min\{SINR_c^{(i,j)}, SINR_c^{(j,i)}\} \quad (8)$$

Centralized PRR Maximization Algorithm

- Motivations
  - Given PRR of every link, a maximum PRR tree can be derived using Prim's algorithm
  - Given a spanning tree, the minimum PRR can be improved by adjusting transmitting power and channel of nodes
  - Iteratively performing these two steps to maximize the minimum PRR of the network

Centralized PRR Maximization Algorithm



Distributed PRR Maximization Algorithm

- Definition and assumption
  - 1-hop neighbors: all reachable nodes if a node transmits at the maximum power level
  - Interference from nodes more than 2-hops away can be neglected
- Distributed Algorithm
  - Discovery of 2-hop neighbors
  - Measurement of received power level
  - Calculation and exchange of SINR
  - Construction of the spanning tree
  - Adjustment of transmitting power and channel

Phase 1: Discovery of 2-hop Neighbors

Backoff timer expires → Broadcast a *hello1* message Including its node ID and traffic load

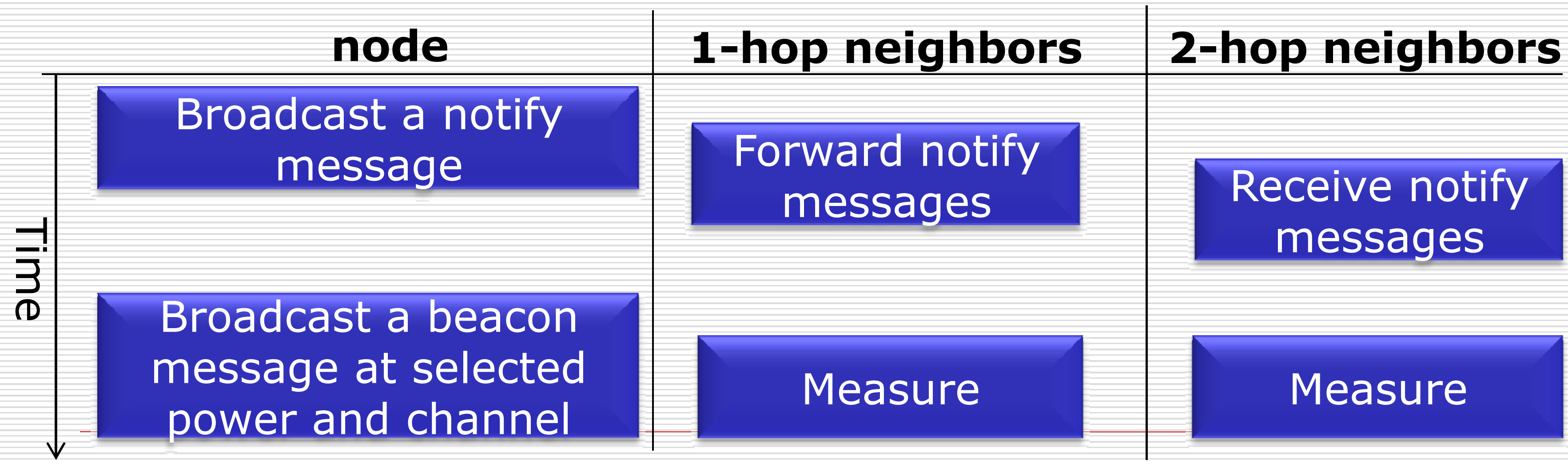
Reception of hello1 messages → Update 1-hop neighbor list

Idle timer expires → Broadcast a *hello2* message including 1-hop neighbor list

Reception of hello2 messages → Update 2-hop neighbor list

Phase 2: Measurement of Received Power Level

- Each node broadcasts a *beacon* message so 2-hop neighbors can measure the received power.
  - 2-hop neighbors may not be able to decode a message and determine the source of the message.
    - Introduce a *notify* message, including the time, transmitting power and channel of the beacon message.



Phase 3: Calculation and Exchange of SINR

- Calculate the SINR of link (i,j) at node j for all 1-hop neighbors.
  - $$SINR_c^{(i,j)} = \frac{r_{(i,j)}}{\sum_{\forall k \in \mathrm{N}_2^{\mathrm{j}}, k \neq i}^{c_i = c_k} m_k \cdot r_{(k,j)} + N_j}$$
- Broadcast a *candidate* message including the SINR of all adjacent links, so that all 1-hop neighbors can obtain the SINR in the reverse direction.
- Calculate the PRR of all adjacent links

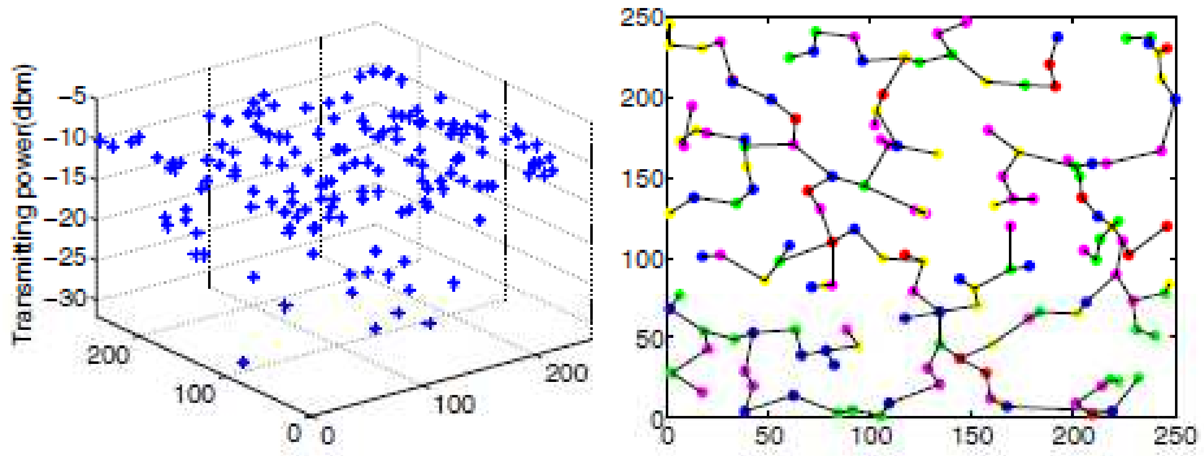
Phase 4: Construction of the Spanning Tree

- Nearest Neighbor Tree (NNT) is a distributed algorithm to construct spanning tree.
  - A unique rank is assigned to each node
  - Each node connects with the nearest node with higher rank
- We use the reciprocal of the PRR as the distance in the spanning tree construction, to get a maximum PRR spanning tree
- The PRR of every link is disseminated to 2-hop neighbors for future adjustment of transmitting power and channel
  - By broadcasting and forwarding a PRR message

Phase 5: Adjustment of Transmitting Power and Channel

- A node checks whether the minimum PRR of the spanning tree in its 2-hop neighbors can be improved by updating its transmitting power
- A node checks whether the minimum PRR of the spanning tree in its 2-hop neighbors can be improved by updating its channel
- A node disseminate an *update* message to 2-hop neighbors so that they can update their PRR and SINR records
- Phase 3 to 5 are executed iteratively to maximize the minimum PRR of the spanning tree

An Example Result



(a) (b)

Fig. 2. An example WSN after running the distributed algorithm. (a) Transmitting power of sensor nodes; (b) Channel assignment and the spanning tree of the WSN, in which dots denote sensor nodes, lines stand for links on the spanning tree and the color of each node represents the assigned channel for the node.

Performance Evaluations

- We implement our algorithms in NS-2, and compare them with the local minimum spanning tree (LMST) algorithm in the literature.
- Network Settings
  - All sensor nodes randomly distributed in a 250mx250m field
  - Normalized traffic load from 0.4 to 1
  - 1-hop Poisson traffic pattern
  - Transmitting power ranges from -32dbm to 0dbm
  - Link bandwidth is 2Mbps

Performance Evaluations

- SINR and system throughput
  - Proposed algorithms outperform other algorithms in both SINR and system throughput
  - Adopting multiple channels can greatly improve performance

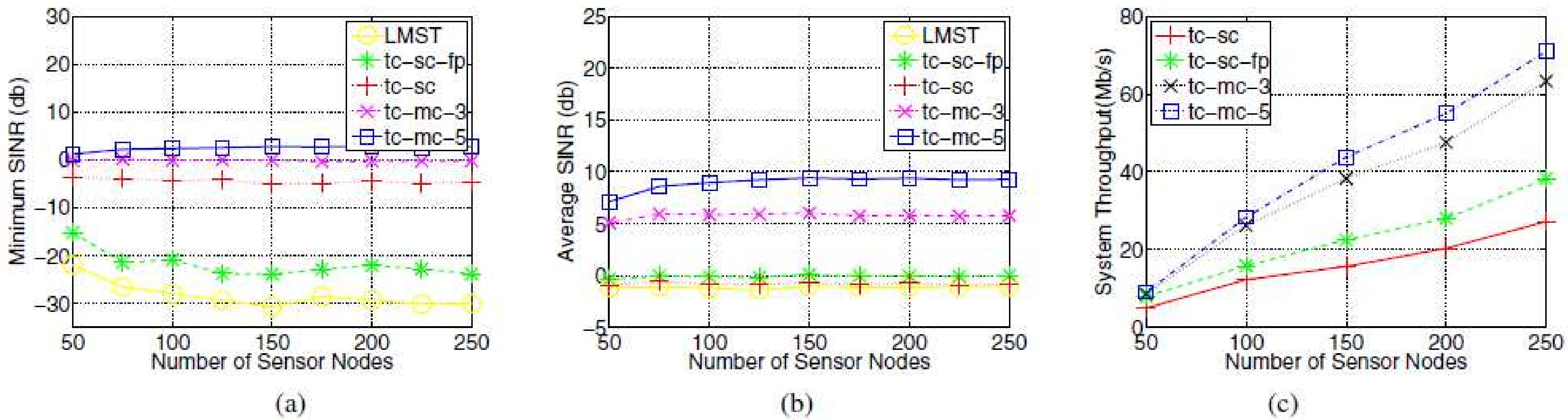


Fig. 3. The SINR and system throughput for the spanning tree generated for WSNs. (a) Minimum SINR. (b) Average SINR. (c) System throughput.

Performance Evaluations

- Energy efficiency
  - Adjusting transmitting power can significantly save energy
  - Applying multiple channels notably improve PRR.

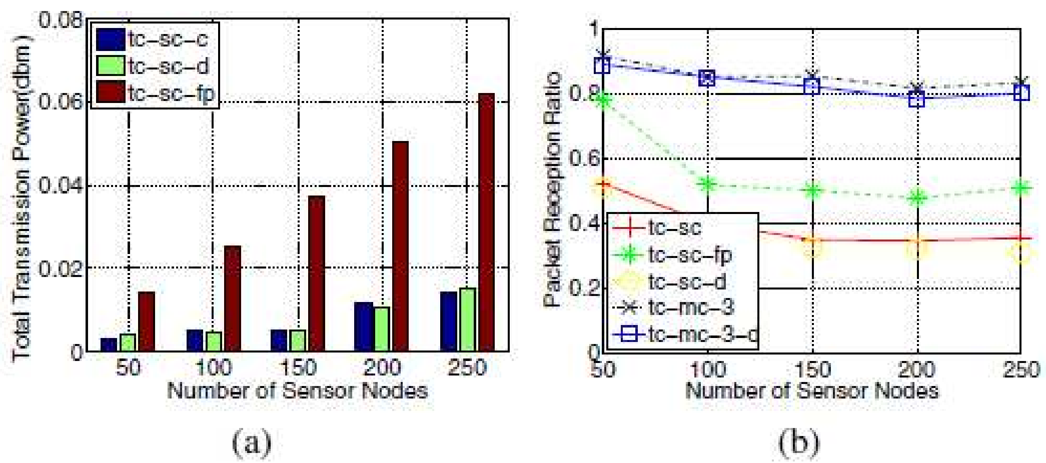


Fig. 4. Energy efficiency of the proposed algorithms. (a) Transmission power consumption. (b) Average PRR.

Performance Evaluations

- Impact of available channels
  - Multiple channels can reduce packet dropped by interference.
  - Multiple channels cannot mitigate packet drops due to multi-path effect and burst noise.

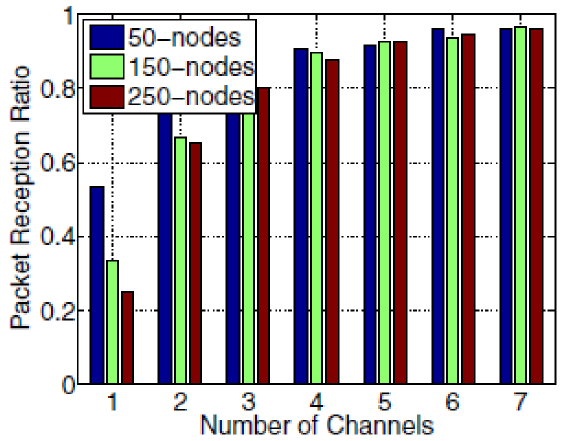


Fig. 5. Average PRR for varying number of available channels.

Conclusion

- We studied the problem of joint topology control and channel assignment in Lossy WSNs, aiming at finding a maximum PRR spanning tree.
- We formulated the problem into an optimization problem and proved the problem is NP-hard.
- We provided both a centralized and a distributed PRR maximization algorithm.
- Simulation results show that our algorithms can improve both network performance and energy efficiency.

Thank you & Questions?