A Power Assignment Method for Multi-Sink WSN with Outage Probability Constraints

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Outline

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Introduction

- Wireless Sensor Networks (WSNs) for monitoring areas.
- Multi-hop networks
- Sinks for data aggregation
- Smart Grids and Smart Cities
- Energy efficiency, reliability, and network capacity are important for WSNs.
- Planning cluster-based WSNs under using the aforementioned properties as constraints.

Related Work

- Sinks and clustering reduce energy consumption at each node in a WSN
- The k-means algorithm has been used to plan WSNs to meet a given network lifetime.
- Minimizing average distance of nodes to sinks based on distance info of neighbors.
- Cost models based on hops.
- Routing topology.

Related Work (cont.)

- Divide network into k-clusters for minimal hops and maximal average degree of sink nodes.
- Maximize network reachability measured by info at sinks.
- Model influence of fading effects due to wireless propagation.
- Account for wireless interference for capacity

Power & Outage-Based Capacity Model

- Wireless channel capacity function of radio channel impairments
- Channel outage probability is a good predictor of packet error rate
- *Nakagami-m* distribution models fading effects of wireless propagation environment.
- Fading severity controlled through parameter *m*

Nakagami-m Fading Outage Probability Model

$$\mathcal{O}_{P,d,m} = \mathbb{P}\left[\gamma_{P,d,m} < \beta\right] = \frac{\Psi\left(m, \frac{m \cdot \beta}{\overline{\gamma}_{P,d}}\right)}{\Gamma(m)}, \qquad (1)$$

- *P* = Power of a transmitting WSN node
- *d* = Distance to the receiver from the WSN node
- *m* = Severity of fading in the Nakagami-m distrib.
- *B* = The threshold for error-free decoding

Increasing Transmission Power

- In the previous model, the outage probability can be reduced by increasing the transmission power

- Increasing this power, however, increases wireless interference in the WSN.

- The range of interference is as far as the receiver sensitivity.

- The author’s model assumes 100% interference within this sensitivity-gauged range.

Affect of Transmission Power on Outage Probability

- Modeled typical Zigbee radio for a single hop transmission.
- Entered parameters for Zigbee radio into Nakagami-m fading outage probability model.

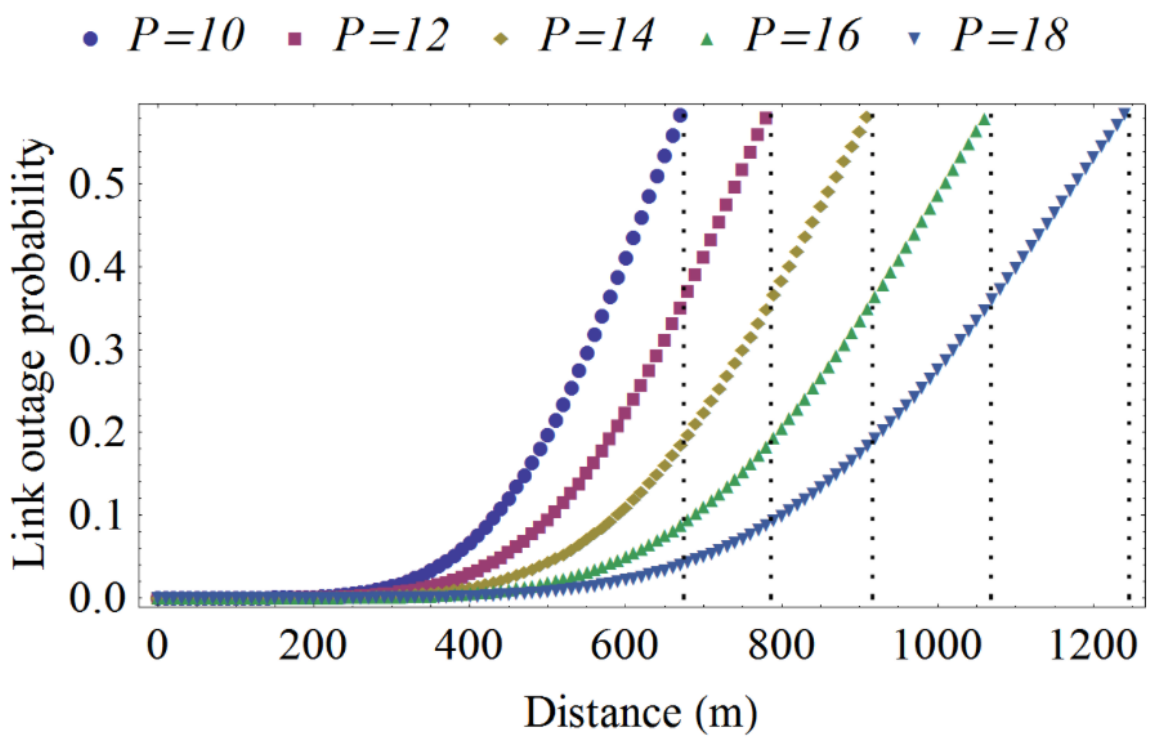


Figure 1. Outage with respect to the distance between sensor nodes.

Estimating the Number of Transmissions

$$T_{P,d,m} = \frac{1}{1 - \mathcal{O}_{P,d,m}}.$$

- Assumes message re-transmission
- Assumes channel gain remains constant during packet transmission
- Can consequently estimate retransmissions from the outage probability of the WSN.

Node Transmission Distance

$$E_c = \{ \ (v_i, v_j) \mid v_i, v_j \in V_c \wedge \mathrm{ED}_{\mathrm{ij}} \leq D_{P_i, \mathcal{O}} \ \},$$

- Depends on transmission power of the node
- Depends on maximum acceptable outage
- Is used by the authors to determine interference influence of a node in a WSN and traffic load.

Communication Interference

- Total task load on path from transmitter node to receiver node (without interference).

$$TEL_{xy} = \sum_{l_{ij} \in TM \wedge (v_x, v_y) \in p_{ij}} l_{ij},$$

Traffic load (no interference)

- All nodes within the transmission distance of a given node can cause interference.

$$CDS_{c,ij} = \left\{ \begin{array}{c} (v_x, v_y) \mid (v_x, v_y) \in E_c \wedge \\ \mathrm{ED}_{xi} \leq I_{P_x} \vee \mathrm{ED}_{xj} \leq I_{P_j} \end{array} \right\}.$$

Collision Domain for nodes i and j

- The total traffic load in the collision domain of an edge.

$$CDL_{c,ij} = \sum_{(v_i, v_j) \in CDS_{c,xy}} \frac{TEL_{xy}}{1 - \mathcal{O}_{xy}},$$

Collision Traffic load (Interference)

Node Transmission Capacity

- Assume all demands made (i.e., tasks) are uniformly weighted.
- The maximum transmission capacity of a node can be calculated as the maximum throughput capacity of the wireless channel divided by the traffic load of the most congested edge.

Node Power Consumption

$$\mathcal{P}_i = \frac{\sum\limits_{\forall x \in V_c} TEL_{ix}/(1 - \mathcal{O}_{ix})}{MCE} \cdot P_i.$$

- With retransmission considered, the power for a node is modeled by the equation above.

$$\mathcal{O}_{p_{ij}} = 1 - \prod_{(v_x, v_y) \in p_{ij}} (1 - \mathcal{O}_{xy}).$$ Without re-transmission

Geometry-Based Clustering (GBC)

- Built using Wolfram Mathematica as a modeling tool.
- Cannot account for interference effect of clusters operating on the same channel.

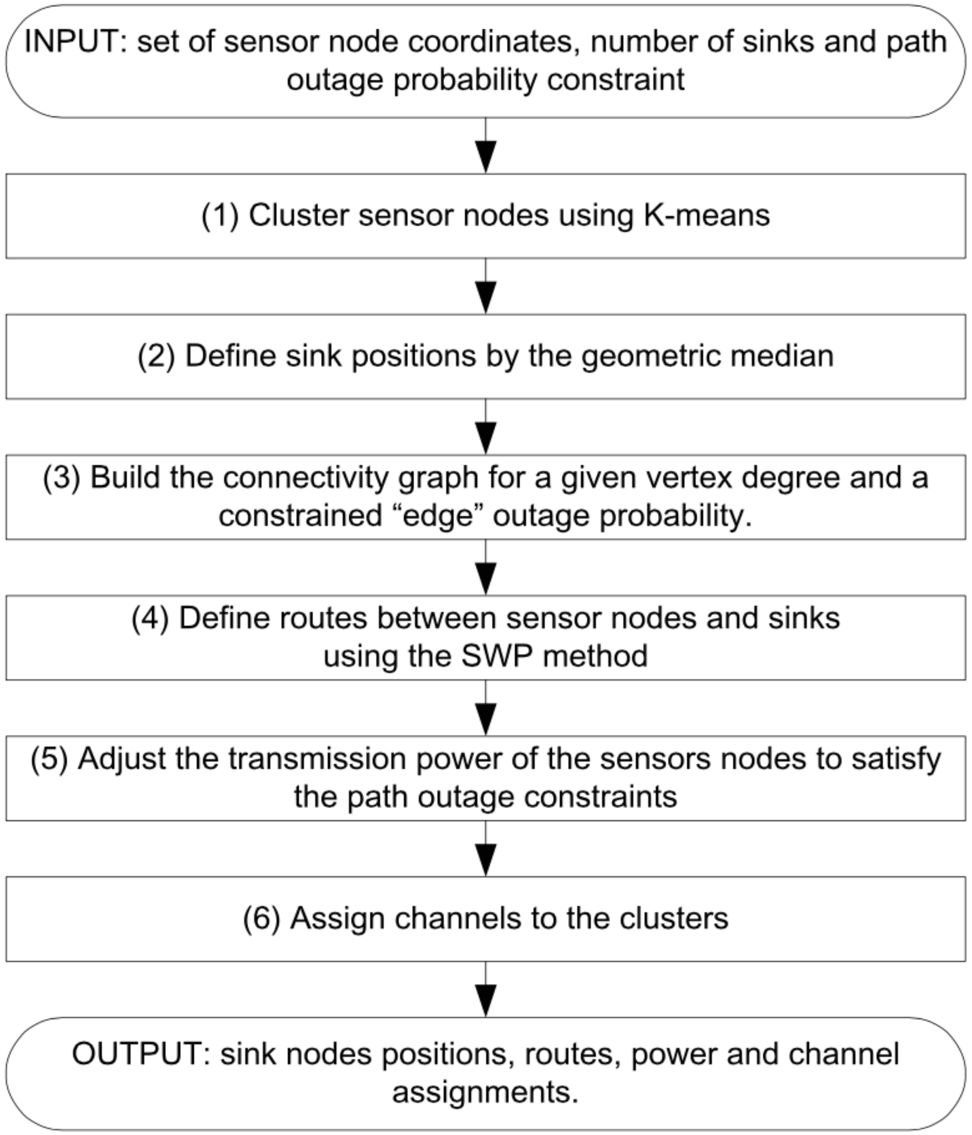


Figure 3. Main steps of the GBC planning algorithm.

Path-Based Clustering

- Focuses on maximizing the network capacity, which accounts for interference.
- Less-energy efficient than GBC approach.
- Better balancing of traffic in each channel when the number of clusters is higher than the number of channels.

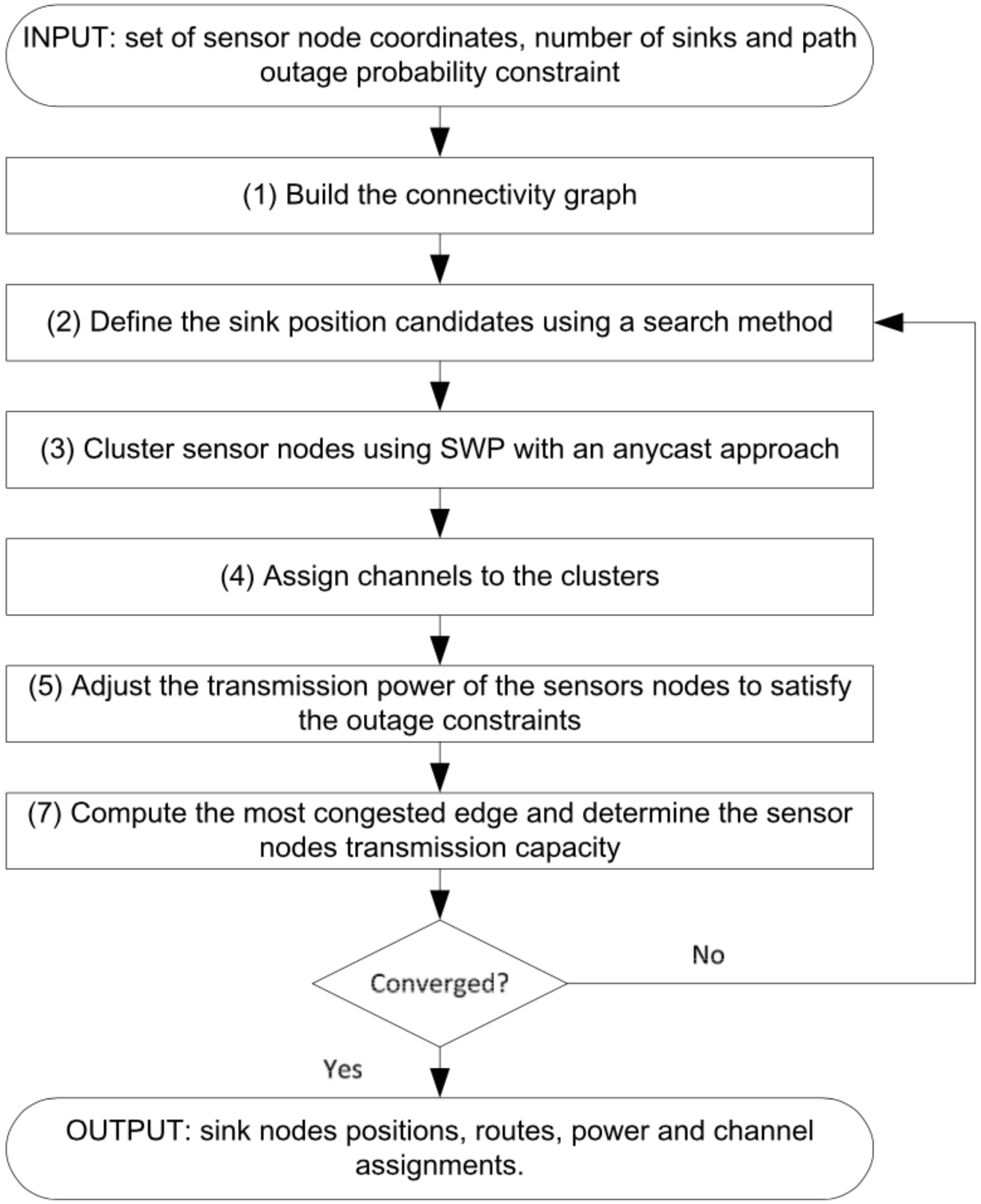
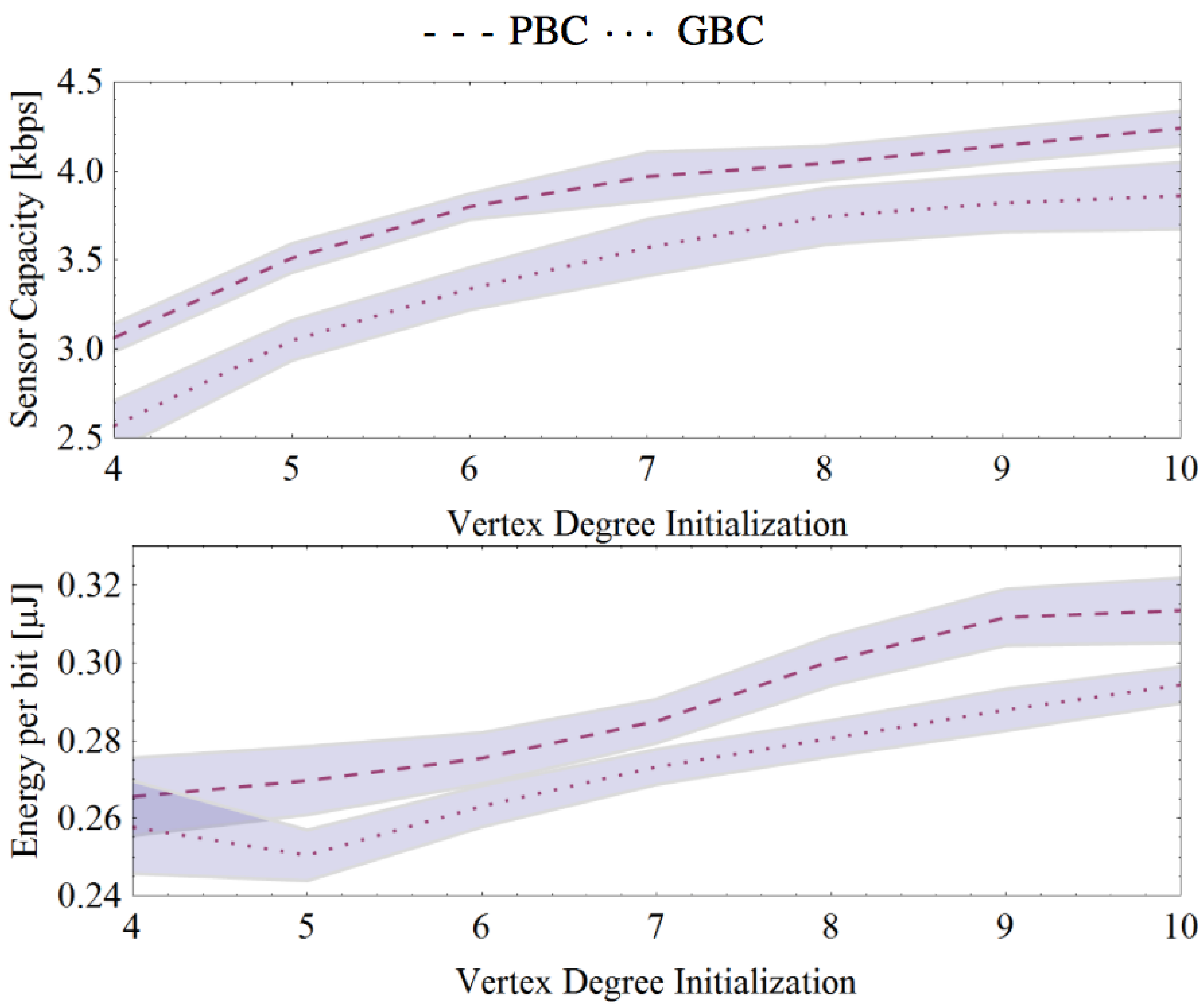


Figure 6. Main steps of the PBC planning algorithm.

Model Assumptions

- Wireless channel in quasi-static fading.
- WSN nodes operate in half-duplex mode.
- Packet retransmission is being used in the WSN.
- 100% wireless interference of a given channel if within range of a transmitting node.
- Node power consumption is an over-estimate.

Evaluation



PBC
GBC
Sensor Capacity [kbps]
4.5
4.0
3.5
3.0
2.5
4
5
6
7
8
9
10
Vertex Degree Initialization
Energy per bit [μJ]
0.32
0.30
0.28
0.26
0.24
4
5
6
7
8
9
10
Vertex Degree Initialization

Conclusion

- Planning large scale WSNs is a complex problem.
- Power levels and channel assignment for nodes needs to be considered.
- Sink placement is also important.
- Using multiple stages to solve the problem can help.
- The GBC approach is more energy efficient.
- The PBC approach minimizes interference and maximizes capacity.

Critique

- The paper was very thorough when it came to the describing the reasoning behind the selection of the models used.
- The paper makes it clear that this is only progress made, but not a full solution.
- The paper only models the situation for a real device mathematically and not through testing.

Questions?

Sources

- All figures and equations mentioned in these slides were collected from the research paper mentioned in the title slide.