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

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Outline

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• Related Work

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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

\[ O_{P,d,m} = P[\gamma_{P,d,m} < \beta] = \frac{\Psi \left( m, \frac{m \cdot \beta}{\gamma_{P,d}} \right)}{\Gamma(m)}, \quad (1) \]

- \( P \) = 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.

![Graph showing outage probability with different transmission powers](image)
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

\[ E_c = \{ (v_i, v_j) \mid v_i, v_j \in V_c \land ED_{ij} \leq D_{P_i,0} \} , \]

- 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).

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

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

\[
TEL_{xy} = \sum_{l_{ij} \in TM \land (v_x, v_y) \in p_{ij}} l_{ij},
\]

Traffic load (no interference)

\[
CDS_{c,ij} = \left\{ (v_x, v_y) \mid (v_x, v_y) \in E_c \land ED_{xi} \leq I_{P_x} \lor ED_{xj} \leq I_{P_j} \right\}.
\]

Collision Domain for nodes i and j

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

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

\[ P_i = \sum_{\forall x \in V_c} \frac{TEL_{ix}}{(1 - O_{ix})} \cdot \frac{MCE}{MCE} \cdot P_i. \]

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

\[ O_{p_{ij}} = 1 - \prod_{(v_x, v_y) \in p_{ij}} (1 - O_{xy}). \]  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]

Vertex Degree Initialization

Energy per bit [μJ]

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.