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Design and Accuracy Analysis of a Power-Efficient TOA-based Location Scheme for Wireless Networks

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Introduction

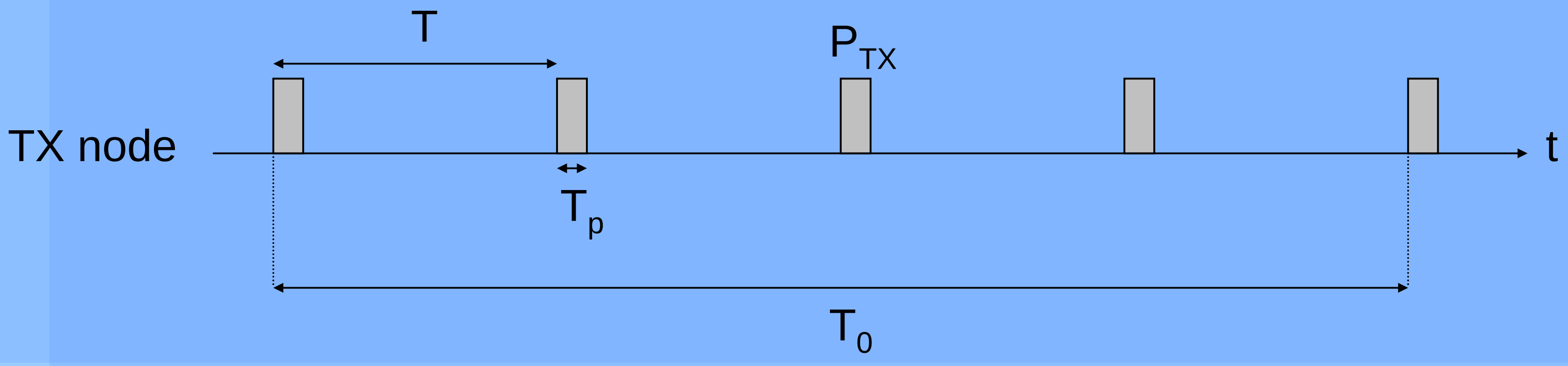
- Crucial issues in wireless ad hoc and sensor networks:
  - Energy management
    - Nodes must have autonomous performance
    - The endurance of the network depends on its capacity to manage energy
  - Automatic localization of nodes
    - Contextualize gathered sensor data
    - Provide location based services
    - Optimize some network aspects
- Objective: evaluate the energy consumption when developing a TOA-based localization technique in a wireless network and find the strategy that, ensuring a certain accuracy in the localization results, minimizes the total consumed energy of the network.

Assumptions

- N nodes which can change their position
- R reference nodes (known position)
- TOA measurements
- The accuracy of the localization depends on the accuracy of the TOA measurements
- To obtain an accurate value -> average the TOA of several packets
- Periodical localization
- Each node will average the TOA of all packets received during a period of time T_0
- Network synchronization

Objective

- Find the transmission strategy
  - Transmit power (P_{TX})
  - Time between transmitted packets (T)
- that achieves a desired accuracy in the averaged value of the TOA
- with minimum consumed energy



Energy consumption analysis

- During T0, *k* packets are transmitted, *n* packets are received
- Average number of received packets:

$$n = k \cdot PRP = \frac{T_0}{T} \cdot PRP \qquad PRP = \textit{Packet reception probability}$$

- Energy consumption during T_0:

$$P = \frac{k \cdot E}{T_0} = \frac{E}{T} = \frac{P_{TX} \cdot T_p}{\frac{T_0}{n} \cdot PRP} = \frac{P_{TX} \cdot T_p \cdot n}{T_0 \cdot PRP}$$

$E = \textit{Consumed energy for one packet}$

$T_p = \textit{Packet length}$

$n = \textit{Received packets}$

- The desired accuracy imposes the value of *n*:

$$\Delta TOA = t_{n-1} \frac{\sigma_{n-1}}{\sqrt{n}}$$

Energy consumption analysis

- Average number of received packets:

$$n = k \cdot PRP = \frac{T_0}{T} \cdot PRP$$

- Relationship between PRP and *T* for a given desired accuracy.
- PRP depends on the SNR
- SNR depends on the transmit power (P_{TX}) and the distance (d)
- Relationship between P_{TX} and *T* for a given desired accuracy.
- Objective: find the pair P_{TX} -*T* that ensure the required number of received packets, with the lowest energy consumption.

Channel models

- Sensor network with MICAz motes:
- Relation between PRP and SNR:

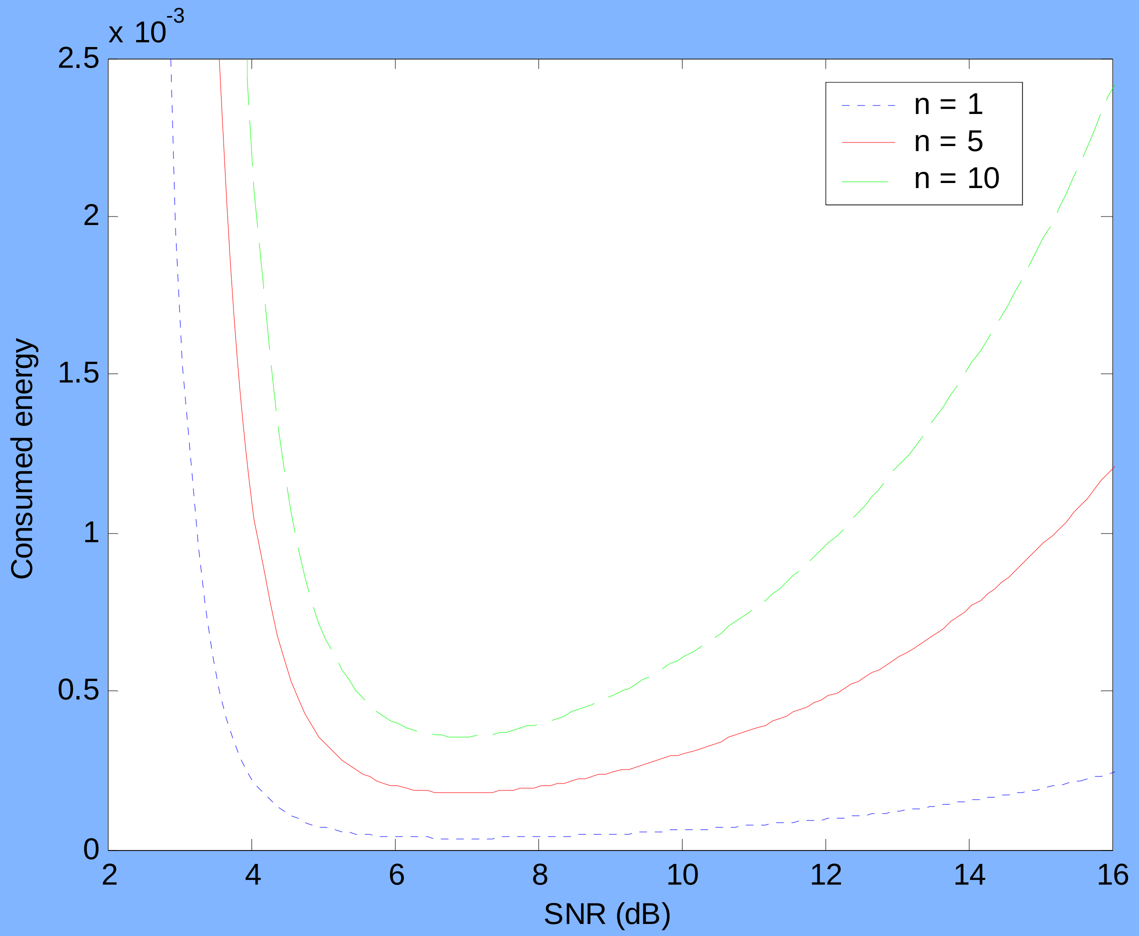
$$PRP = (1 - BER)^{8 \cdot l} = \left(1 - Q\left(\sqrt{2SNR}\right)\right)^{8 \cdot l}$$

- Path loss model:

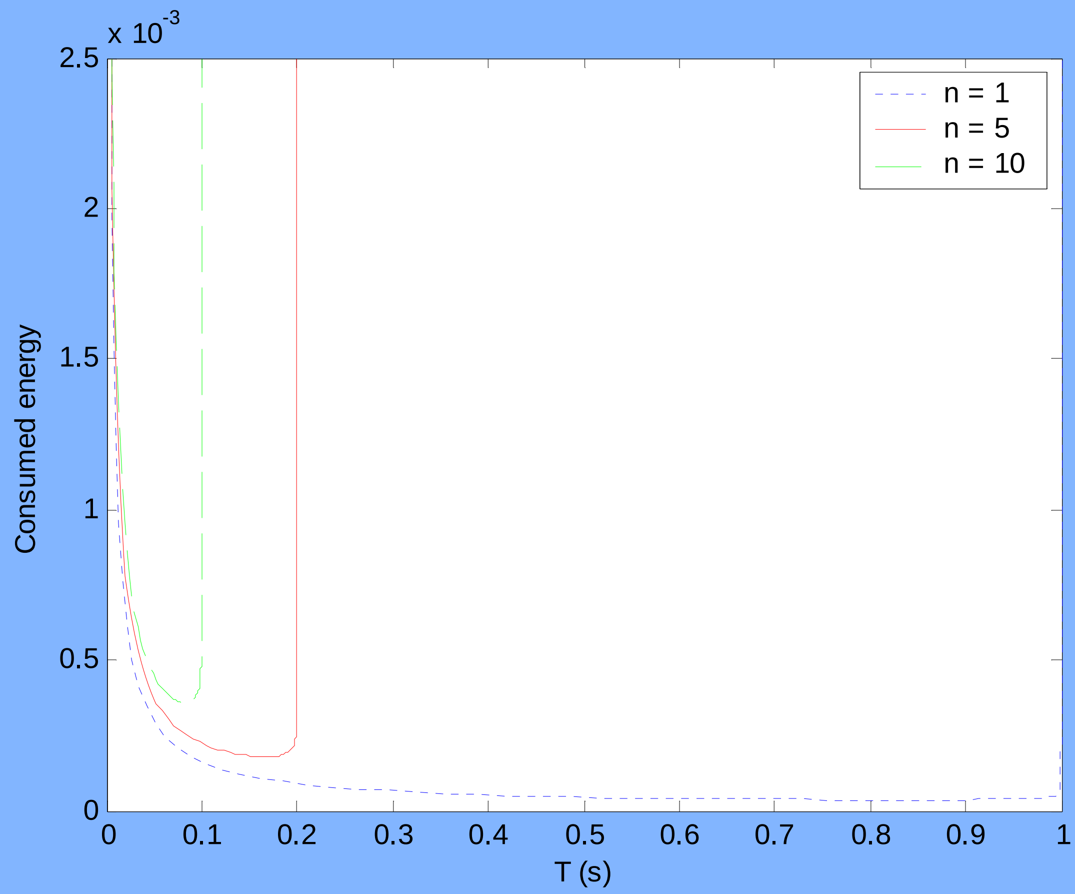
$$P_{RX}(dBm) = P_{TX}(dBm) + A - 10\eta \log \frac{d}{d_0}$$

$$SNR(dB) = P_{RX}(dBm) - N(dBm) = P_{TX}(dBm) + A - 10\eta \log \frac{d}{d_0} - N(dBm)$$

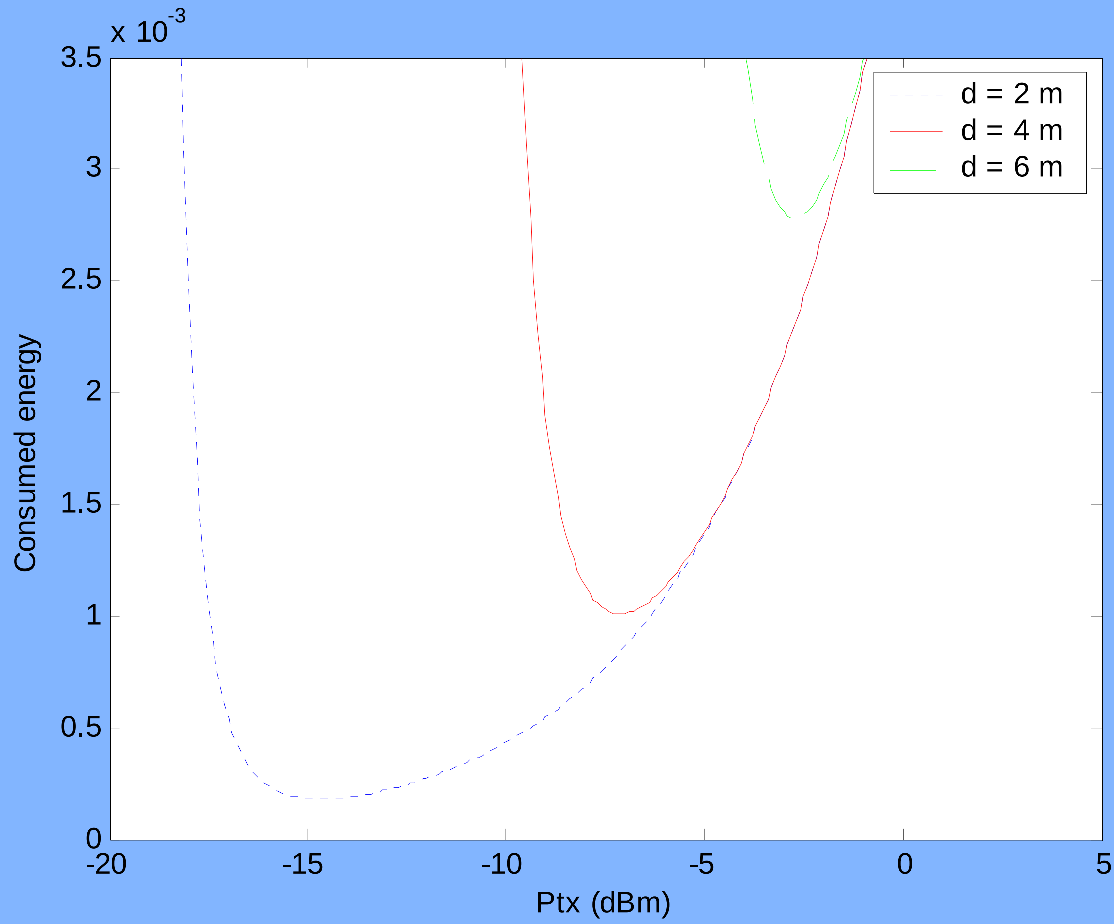
Consumed energy - SNR



Consumed energy - T



Consumed energy - P_{TX}



Best transmission strategy

- Each transmitter node should send packets to its neighbor nodes with:
  - P_{TX} such that the SNR at its furthest neighbor is the optimum
  - The optimum T for its furthest neighbor

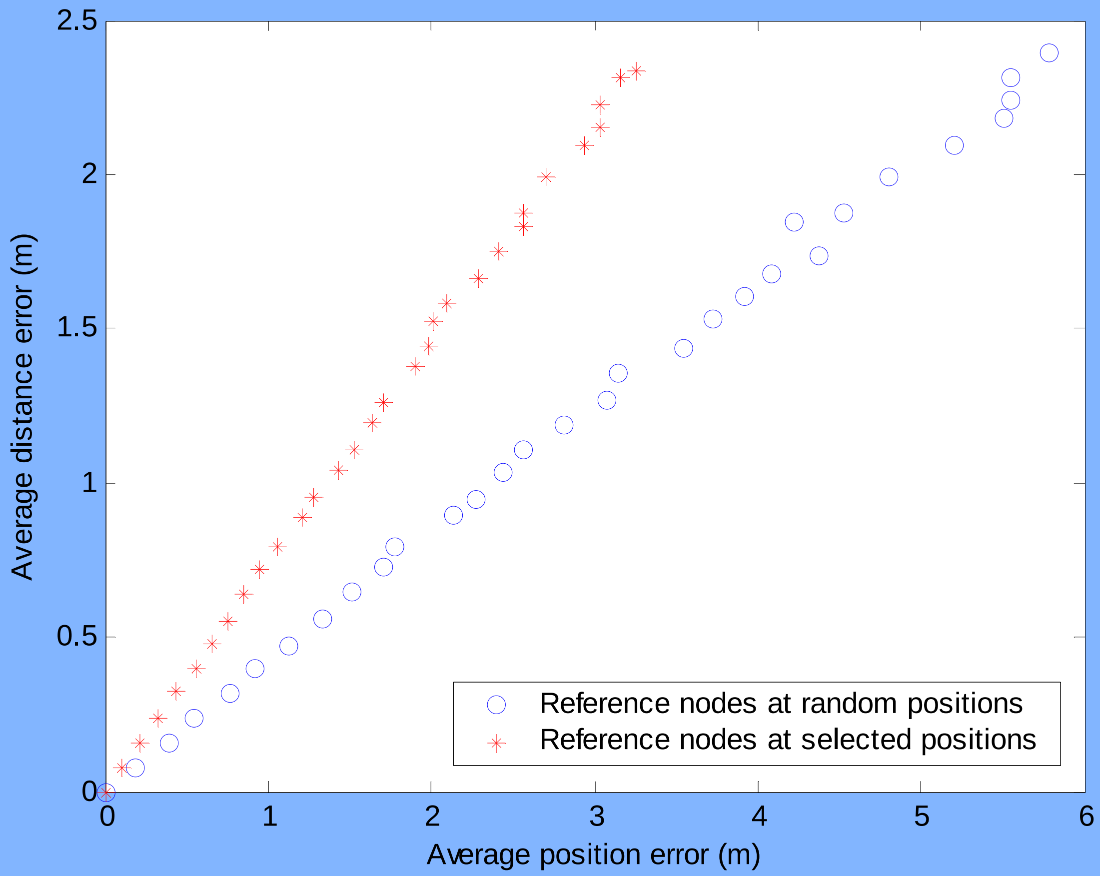
$$n = k \cdot PRP = \frac{T_0}{T} \cdot PRP \quad \rightarrow \quad T = \frac{T_0}{n} \cdot PRP$$

Error propagation analysis

- How to decide the value of n?
- TOA measurement errors -> distance estimation errors -> position estimation errors
- TOA measurement: $\tilde{t} = t + N(0, \sigma_t)$
- Distance estimation: $\tilde{d} = d + \Delta d = d + N(0, \sigma)$
    - For one way TOA measurements: $\sigma = c \cdot \sigma_t / \sqrt{n}$
    - For two way TOA measurements: $\sigma = c \cdot \sigma_t / 2\sqrt{n}$
- Position estimation error:

$$\Delta \bar{x} = \left(H^T H\right)^{-1} H^T \begin{bmatrix} 2d_2 \Delta d_2 + 2d_1 \Delta d_1 \\ \vdots \\ 2d_V \Delta d_V + 2d_1 \Delta d_1 \end{bmatrix} \qquad H = \begin{bmatrix} 2x_2 & 2y_2 & 2z_2 \\ \vdots & \vdots & \vdots \\ 2x_V & 2y_V & 2z_V \end{bmatrix}$$

Position errors – distance errors



Conclusions and further work

- Conclusions:
  - Position estimation accuracy → Distance estimation accuracy → → Number of packets (n) that should be averaged during T_0
  - Using the proposed transmission strategy, it is assured that at least n packets will be received in average at each node during T_0, while consuming the minimum energy
  - The accuracy required for the application is achieved and the total energy consumption of the network is reduced to a minimum value
- Further work:
  - Experimental tests to measure the consumed energy in real sensor networks
  - Comparison with other strategies

Thank you for your attention