Position Estimation of Nodes Moving in a Wireless Sensor Network

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Motivation

Investigate a method with high accuracy but lower cost for positioning object in indoor environments.

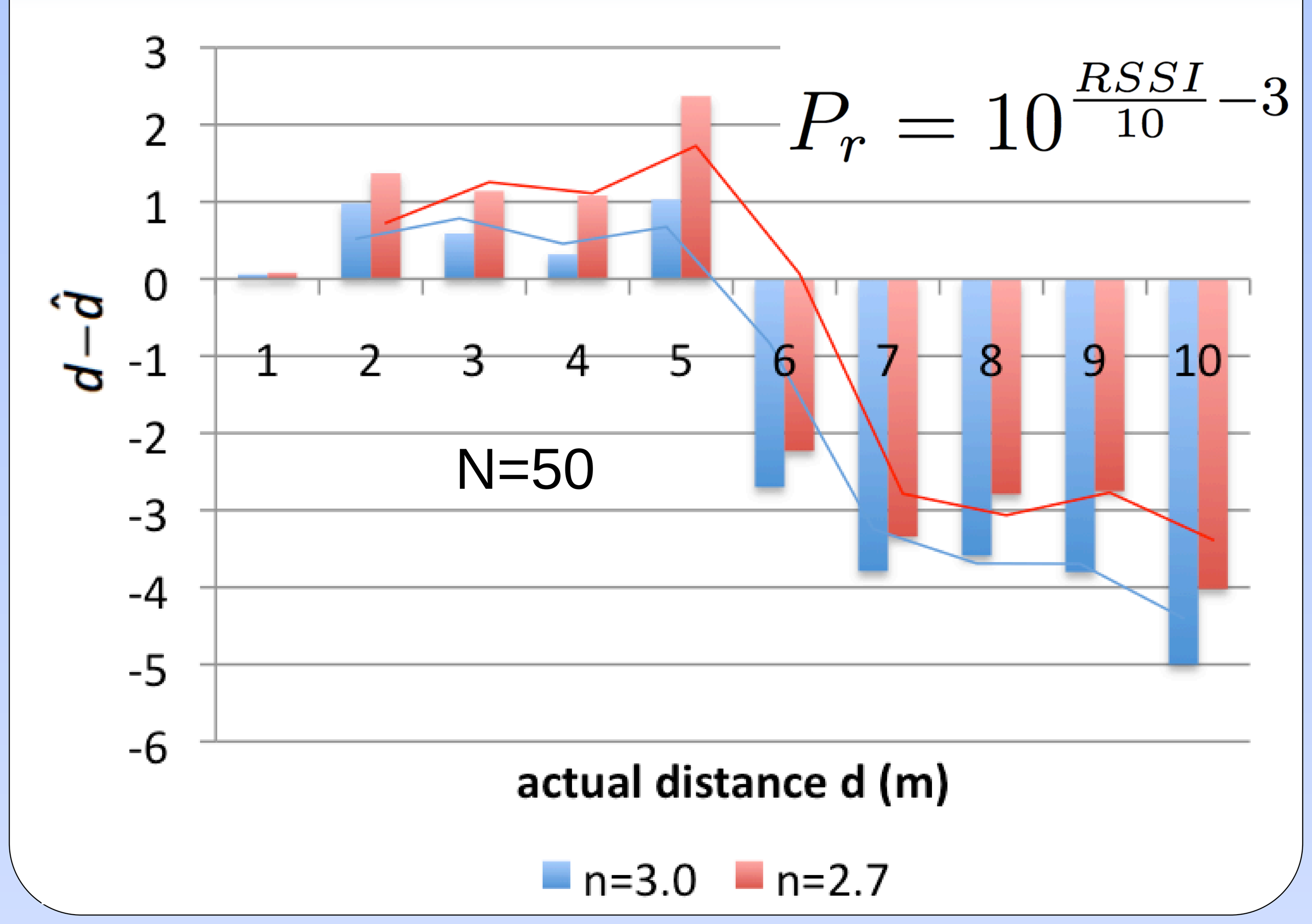
Received Signal Strength Indicator (RSSI), in dBm

- Less communication overhead – 8 bits
- Simpler
- Output by most single-chip transceivers
- Lower cost
- Tradeoff with lower distance accuracy

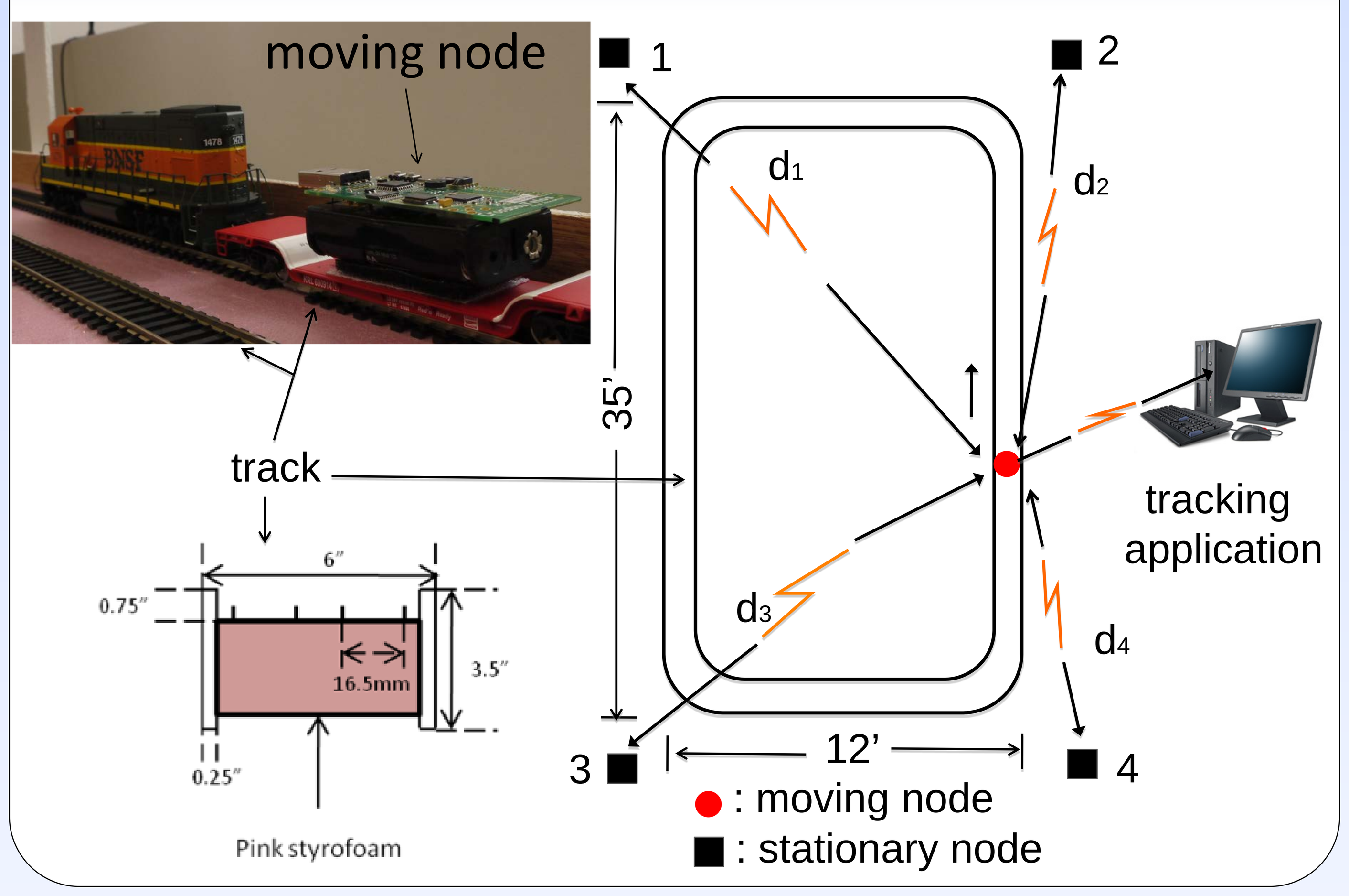
Indoor Position Estimation

Method	Range of Use	Accuracy
Signal Strength Difference of Arrival	20m (simulated)	below 2.4m for the lower noise below 4.2m for the high noise
Angle of Arrival	30m x 30m square (simulated)	better than 2m
Received Signal Strength Indicator	30m	distance error of 10% of range
Time of Flight	30m	at worst 9m, 3m average
Time Difference of Arrival (e.g.: Cricket)	indoor area	1cm to 3cm
Ultra-Wideband (e.g.: Ubisense)	400m² for 4 stationary nodes	tens of centimeters
Mobile Phone Location (e.g.: My Location Indoor)	indoor area	several meters

Distance Estimate Using RSSI



Test Platform



Distance Estimation Method

- **Free Space Propagation Model**

$$P_r = \frac{\lambda^2}{4\pi} G_r \frac{1}{4\pi d^n} G_t P_t$$

where d is defined as

$$d = \sqrt[n]{\frac{\lambda^2 G_r G_t P_t}{16\pi^2 P_r}}$$

P_r = received power (W),
λ = carrier wave length,
G_r = gain of the receiver antenna,
G_t = gain of transmitter antenna,
P_t = transmitter power (W),
d = distance between transmitter and receiver (m),
n = propagation exponent.

- **Log-Normal Shadowing Model (LNSM)**

$$PL(d) = \overline{PL(d_0)} + 10n\log_{10}\frac{d}{d_0} + X_\sigma (or \quad +\sigma(d)X)$$

LNSM-DV

where *d* is defined as

$$d = 10^{\frac{PL(d) - \overline{PL(d_0)} - X_\sigma}{10n}} d_0$$

PL = path loss (dB),
d_0 = near-earth reference distance (m),
n = a path loss exponent depending on the surroundings,
X_σ = zero-mean Gaussian random variable (dB).

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Least Squares Method

$$F(\mathbf{x}, \mathbf{l}) = \sqrt{(x_a - x_i)^2 + (y_a - y_i)^2 + (z_a - z_i)^2} - d_i = 0 \quad i = 1, 2, \ldots, k$$

$$A_{4,3} = \begin{pmatrix} \frac{\hat{x}_a - x_1}{d_1} & \frac{\hat{y}_a - y_1}{d_1} & \frac{\hat{z}_a - z_1}{d_1} \\ \vdots & \vdots & \vdots \\ \frac{\hat{x}_a - x_4}{d_4} & \frac{\hat{y}_a - y_4}{d_4} & \frac{\hat{z}_a - z_4}{d_4} \end{pmatrix} \qquad \mathbf{P}_{k,k} = \begin{pmatrix} 1/\sigma_1^2 & 0 & \cdots & 0 \\ 0 & 1/\sigma_2^2 & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1/\sigma_k^2 \end{pmatrix}$$

$$\hat{d}_i = \sqrt{(\hat{x}_a - x_i)^2 + (\hat{y}_a - y_i)^2 + (\hat{z}_a - z_i)^2}$$

$$\mathbf{w}_{k,1} = \hat{\mathbf{d}} - \mathbf{l} = \begin{pmatrix} \hat{d}_1 \\ \hat{d}_2 \\ \vdots \\ \hat{d}_k \end{pmatrix} - \begin{pmatrix} d_1 \\ d_2 \\ \vdots \\ d_k \end{pmatrix}$$

$$\Delta\mathbf{x} = (\mathbf{A}^T\mathbf{P}\mathbf{A})^{-1}\mathbf{A}^T\mathbf{P}\mathbf{w}$$

$$\hat{\mathbf{x}}^j = \hat{\mathbf{x}}^{j-1} + \Delta\mathbf{x}$$

repeat until $|\Delta x| \le \varepsilon$

$$\mathbf{C}_{\hat{\mathbf{x}}} = \hat{\sigma}_0^2 (\mathbf{A}^T\mathbf{P}\mathbf{A})^{-1}$$

$$\hat{\sigma}_0^2 = \frac{\hat{\mathbf{r}}^T\mathbf{P}\hat{\mathbf{r}}}{df}$$

Proposed Sequence Diagram