Indoors object locating with RSSI

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Why to locate objects

Sailors all over the time have tried to locate themself using stars

It would be nice to know where valuable items were

Apple Airtag

US military might start to locating their planes

https://www.bbc.com/news/world-us-canada-66841194

BBC

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Missing F-35: US military asks for public's help to find jet

18 September 2023

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Megan Fisher
BBC News

Watch: This is what the missing F-35 US military jet looks like

The US military has asked for the public's help to locate one of its $100m (£80m) F-35B fighter jets after the pilot ejected from the aircraft.

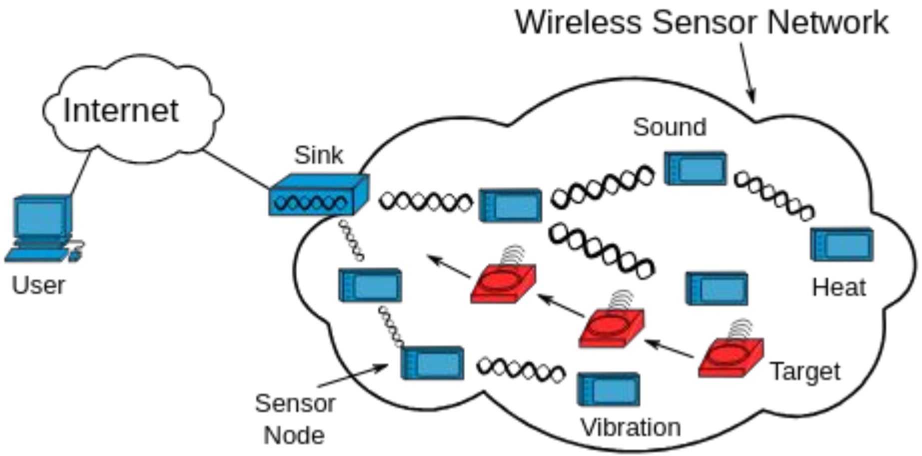
Wireless sensor network (WSN)

Network of *nodes*

Sink is a more powerful computer used to connect the WSN to the internet

Use cases

- Forest fire detecting
- Earthquake detecting
- Research



https://commons.wikimedia.org/wiki/File:Wireless_Sensor_Network_General_Structure.svg

A node

Small -- About size of a coin

Required component

- Central Processing Unit (CPU)
- Communicating unit
- Battery

Measurement nodes (Node)

- Lot of sensors
- Unknown position

Anchor nodes (Anchors)

- Specialize on measuring own position
- Specialized locating chip
- Mounted on known location

Time of Arrival (ToA)

Known speed of radio waves

Two very accurate clocks

CPU has a built in clock, but it is very inaccurate

External clock is required

$$d = v \cdot t$$

d is distance

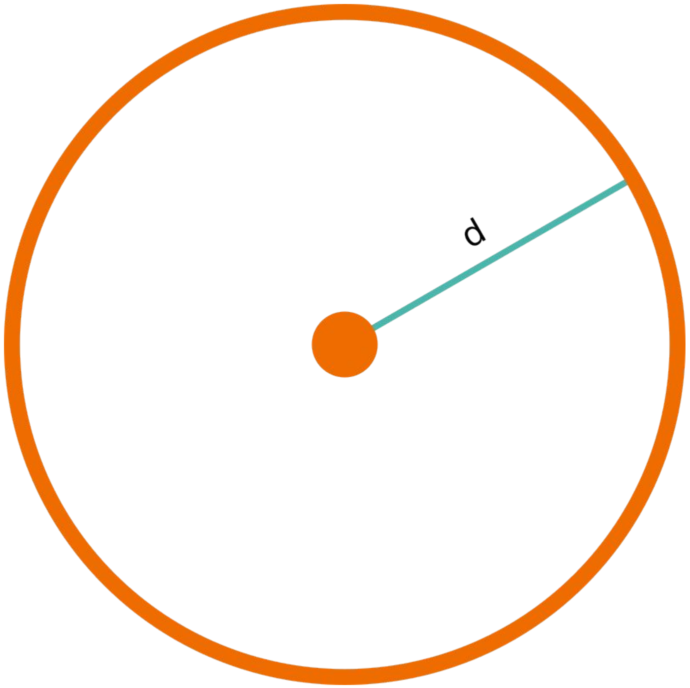
v is velocity of the radio wave

t is the time it took

Received Signal Strength Indicator (RSSI)

One can calculate the distance between the node and anchor

Strength is inverse proportionality to the distances square



Friis equation

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2$$

P_r is received power

P_t is transmitted power

G_t is transmitter gain

G_r is receiver gain

λ is wavelength of signal

d is distance between the nodes

Usually power are given in decibels

$$P_r^{[dB]} - P_t^{[dB]} = G_t^{[dB]} + G_r^{[dB]} + 20\log_{10}\left(\frac{\lambda}{4\pi d}\right)$$

Solve the distance

$$d = \frac{\lambda}{4\pi} 10^{-\frac{P_r^{[dB]} - P_t^{[dB]} - G_t^{[dB]} - G_r^{[dB]}}{20}}$$

Trilateration

Three points

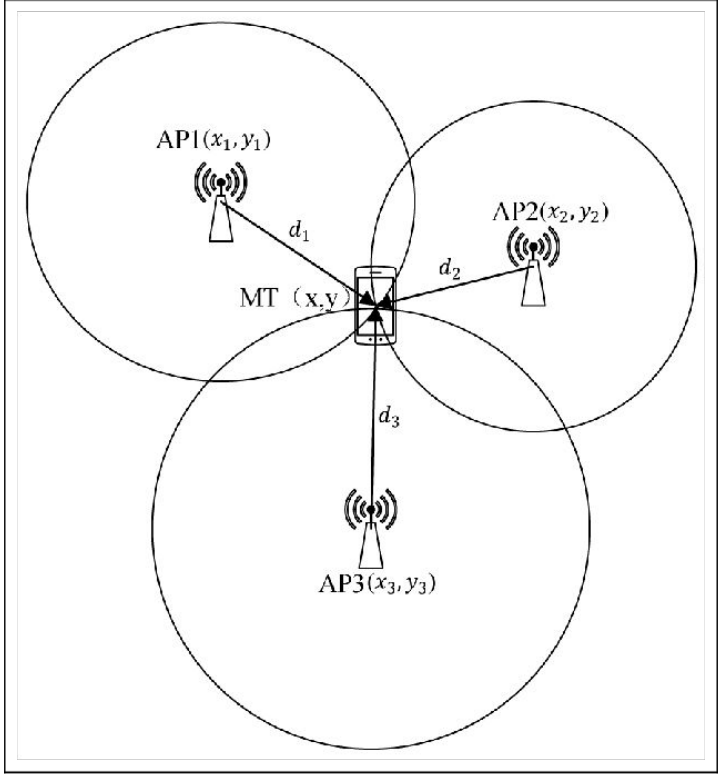
Compute the intersecting point

$$x = \frac{AY_{32} + BY_{13} + CY_{21}}{2\left(x_1Y_{32} + x_2Y_{13} + x_3Y_{21}\right)}, \quad y = \frac{AX_{32} + BX_{13} + CX_{21}}{2\left(y_1X_{32} + y_2X_{13} + y_3X_{21}\right)}$$

$$A = x_1^2 + y_1^2 - d_1^2, \quad B = x_2^2 + y_2^2 - d_2^2, \quad C = x_3^2 + y_3^2 - d_3^2$$

$$X_{32} = \left(x_3 - x_2\right), \quad X_{13} = \left(x_1 - x_3\right), \quad X_{21} = \left(x_2 - x_1\right),$$
$$Y_{32} = \left(y_3 - y_2\right), \quad Y_{13} = \left(y_1 - y_3\right), \quad Y_{21} = \left(y_2 - y_1\right).$$

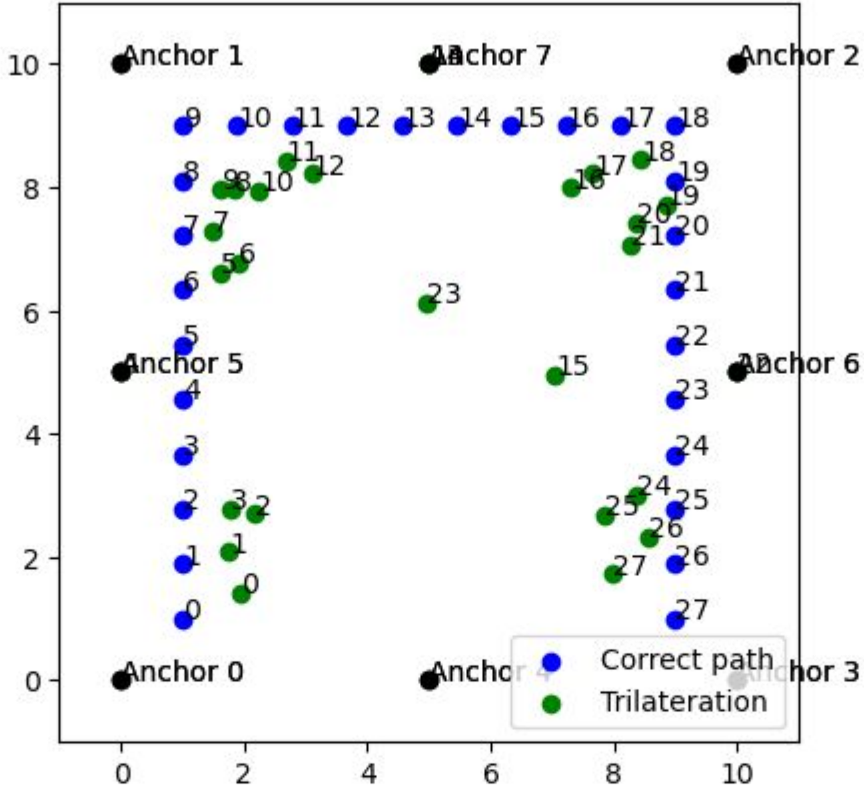
Jondhale, S & Maheswar, R & Lloret, J. "Received Signal Strength Based Target Localization and Tracking Using Wireless Sensor Networks" 1st ed. Cham, Switzerland: Springer. 2022. 201 s. ISBN 3-030-74061-7.



https://www.researchgate.net/figure/Illustration-of-trilateration_fig1_324061572

Point estimation with Trilateration -- 8 nodes

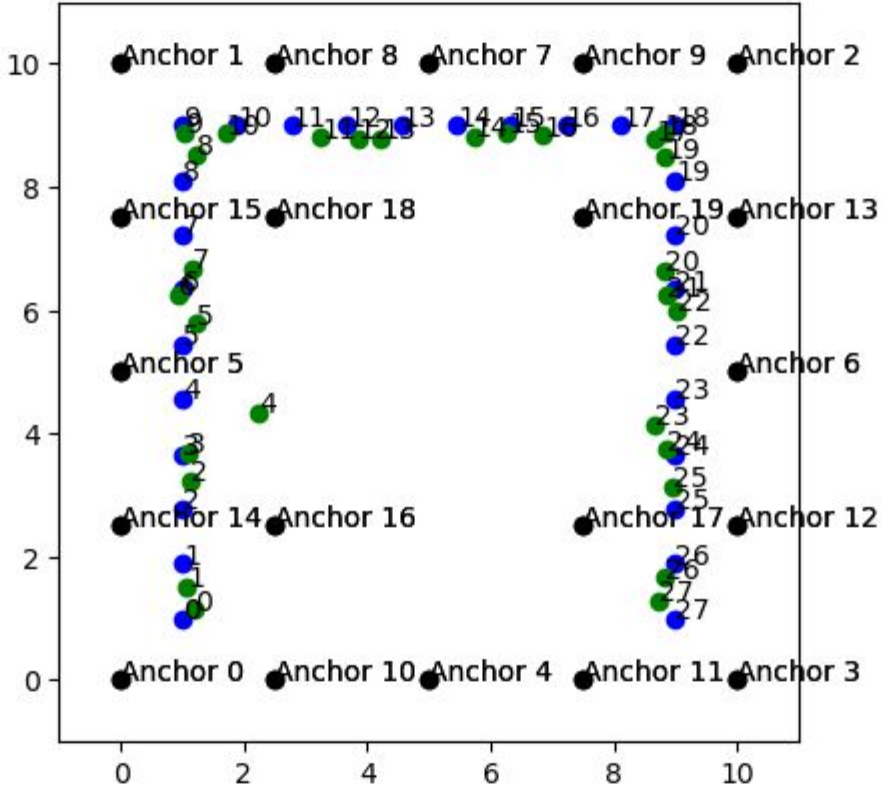
Root mean square error 1.474132706



Add more anchor nodes -- 20 nodes

Root mean square error 0.442750141

More anchors -> Less nodes



Kalman filter

R. Kalman published a revolutionary paper in 1960

Recursive solution to a discrete-time linear optimization problem

Recursive -> No huge memory consumption

Works in two part

First part is the so called prediction part

Second part is the so called update part

Kalman filter -- Prediction

The Prediction step, predicts a new state based on the state model

$$\bar{X}_k = A\hat{X}_{k-1}$$

$$P_k^- = AP_{k-1}A^T + Q_k$$

- A is state state-transition matrix
- $\bar{X}_k$ is the new state prediction
- $\bar{X}_{k-1}$ is the last updated state
- P_k^- is temporary covariance matrix
- P_{k-1} is covariance matrix
- Q_k is process noise matrix

$$P_k^- = AP_{k-1}A^T + Q_k$$

Kalman filter -- Update

The Update step, updates the new state based on the data available

$$K_k = P_k^- H^T \left(H P_k^- H^T + R \right)^{-1}$$

$$\hat{X}_k = \bar{X}_k + K_k \left(z_k - H \bar{X}_k \right)$$

$$P_k = (I - K_k H) P_k^-$$

K_k is kalman gain

H Measurement model matrix

$\hat{X}_k$ is the state estimation

R measurement noise matrix

P_k is covariance matrix

z_k is the measurement matrix

$$P_k^- = A P_{k-1} A^T + Q_k$$

Kalman filter -- In our case

$$A = \begin{bmatrix} 1 & 0 & T_s & 0 \\ 0 & 1 & 0 & T_s \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$X = \begin{bmatrix} x & y & \dot{x} & \dot{y} \end{bmatrix}^T$$

$$z = \begin{bmatrix} x & y \end{bmatrix}^T$$

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

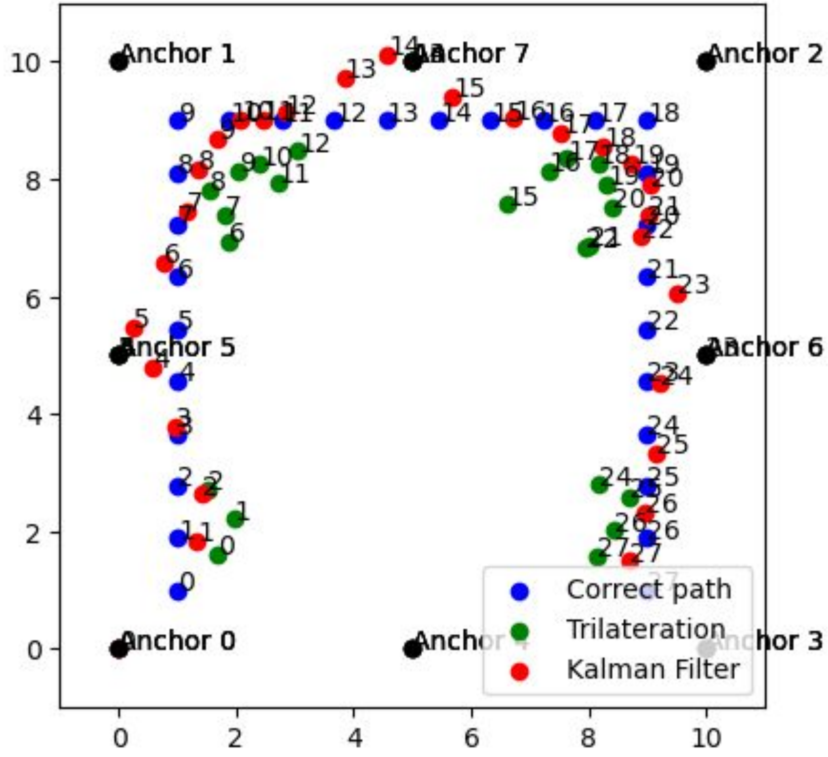
$$R = \begin{bmatrix} 0.5 & 0 \\ 0 & 0.5 \end{bmatrix}$$

$$P_k^- = AP_{k-1}A^T + Q_k$$

Point estimation with Kalman filter -- 8 nodes

Root mean square error without kalman filter 1.042912802

Root mean square error with kalman filter 0.8047597031



How produce data

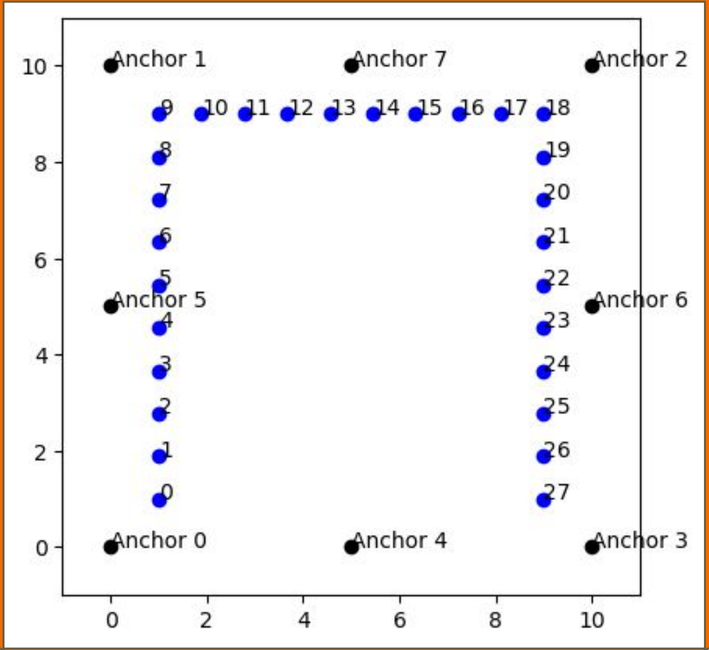
Hopefully a whole testing lab -- unfortunately not

Needed to produce it synthetically.

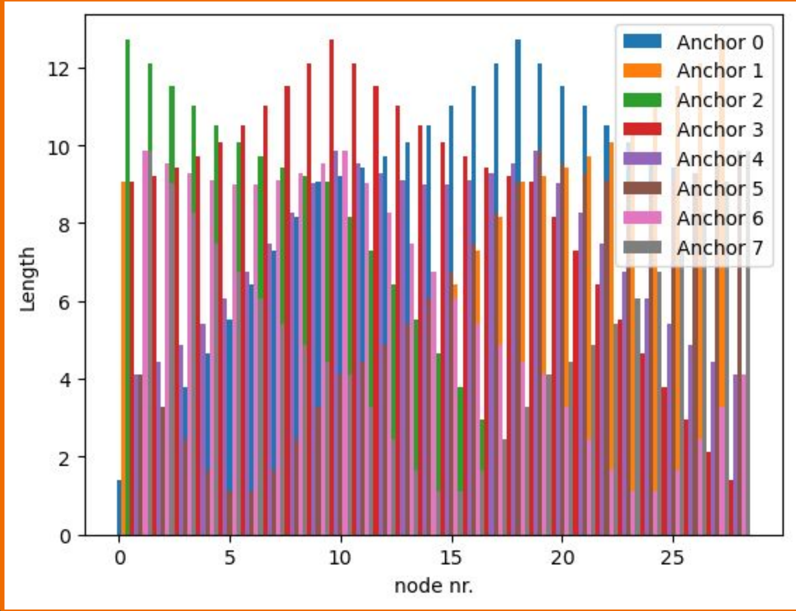
Five step process

Process of generating synthetic data

Create path

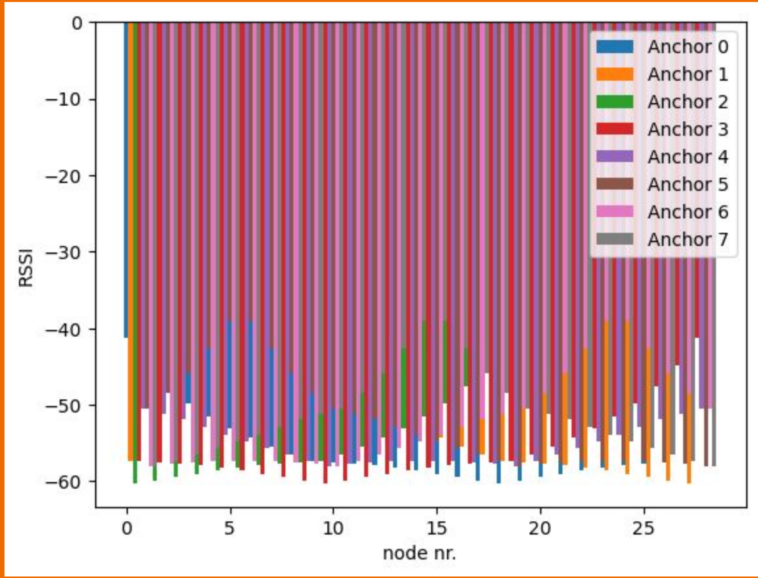


Calculate distances

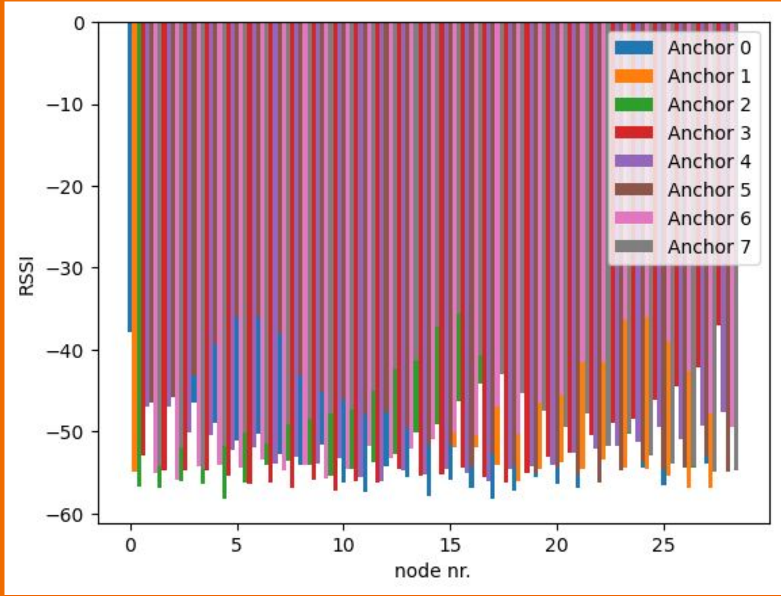


Process of generating synthetic data

Convert to RSSI

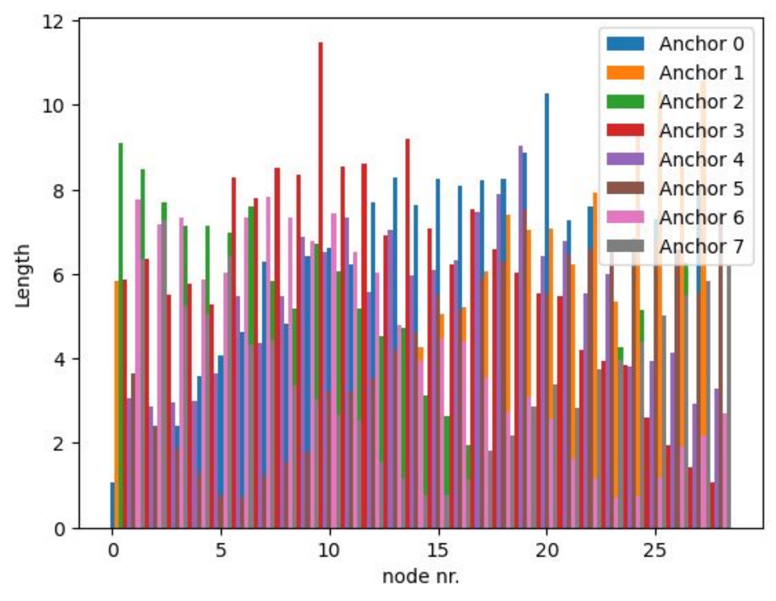


Add noise to RSSI

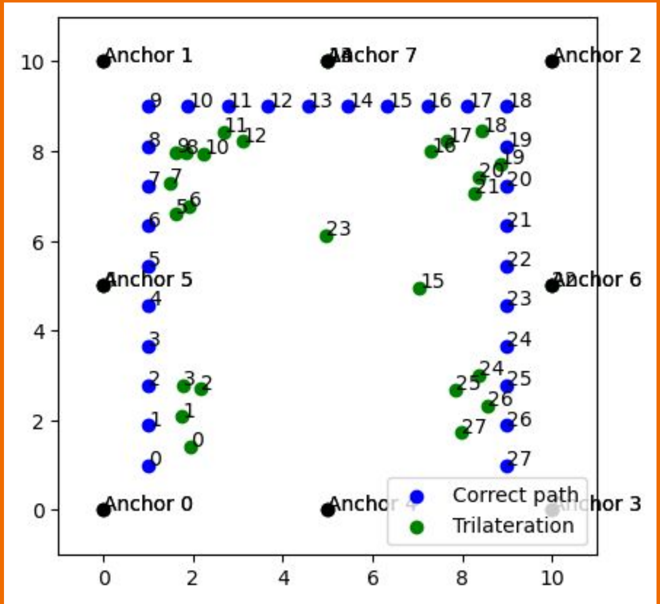


Process of generating synthetic data

Convert to Distance

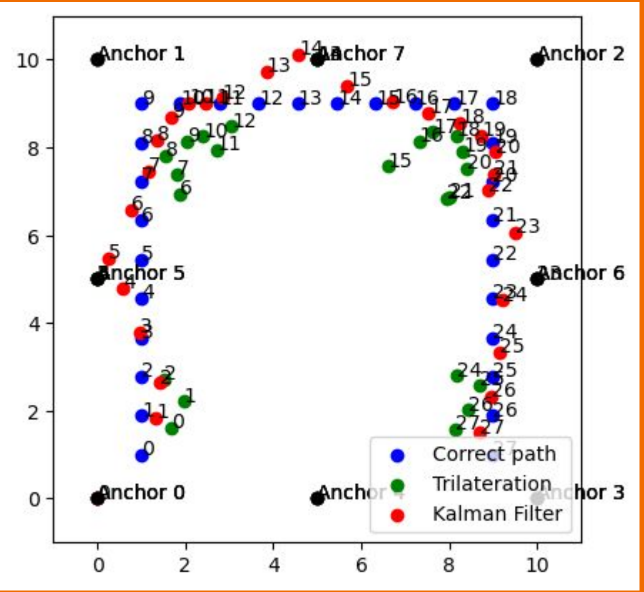


Trilaterate



Process of generating synthetic data

Kalman Filter



Conclusion

It is possible to locate and track objects indoors with RSSI.

Kalman filter can be utilized to improve measurements

Adding more anchors improves the accuracy on the cost of nodes

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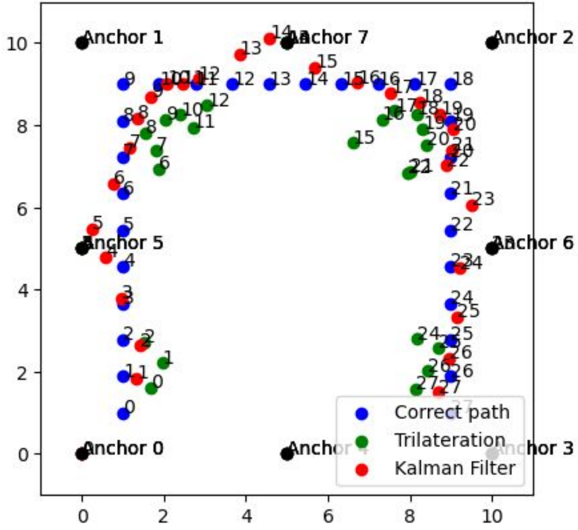
Root mean square error with kalman filter 0.8047597031



Questions and Sources

Jondhale, S & Maheswar, R & Lloret, J. “Received Signal Strength Based Target Localization and Tracking Using Wireless Sensor Networks” 1st ed. Cham, Switzerland: Springer. 2022. 201 s. ISBN 3-030-74061-7.

Patwari, N & Ash, J & Kyperountas, S & Hero III, A & Moses, R & Correal, N. “Locating the nodes: cooperative localization in wireless sensor networks”. IEEE Signal Processing Magazine 22 (2005): 54-69.

Kalman, E. “A new approach to linear filtering and prediction problems.”.Journal of basic Engineering 82.1 (1960): 35-45.

Särkkä & S, Svensson & L. ”Bayesian Filtering and Smoothing“. 2nd ed. Cambridge University Press; 2023.

Zhanwei, T & Huicheng, H & Yan, S. ”AOA and TDOA-Based a Novel Three Dimensional Location Algorithm in Wireless Sensor Network“ The Open Automation and Control Systems Journal, 7.1