ese
embedded systems
engineering

Localization of Wireless Sensor Networks with a Mobile Beacon

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Summary of the paper of

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Released on the First IEEE Conference on Mobile Ad-hoc and Sensor Systems
MASS, October 2004

Overview

- Introduction
  - Localization Problem
- Approach
  - Concept
  - RSSI
  - Gaussian
  - Bayesian Inference
  - Result
- Discussion

Introduction

Introduction

Introduction
Localization Problem

Localization Problem

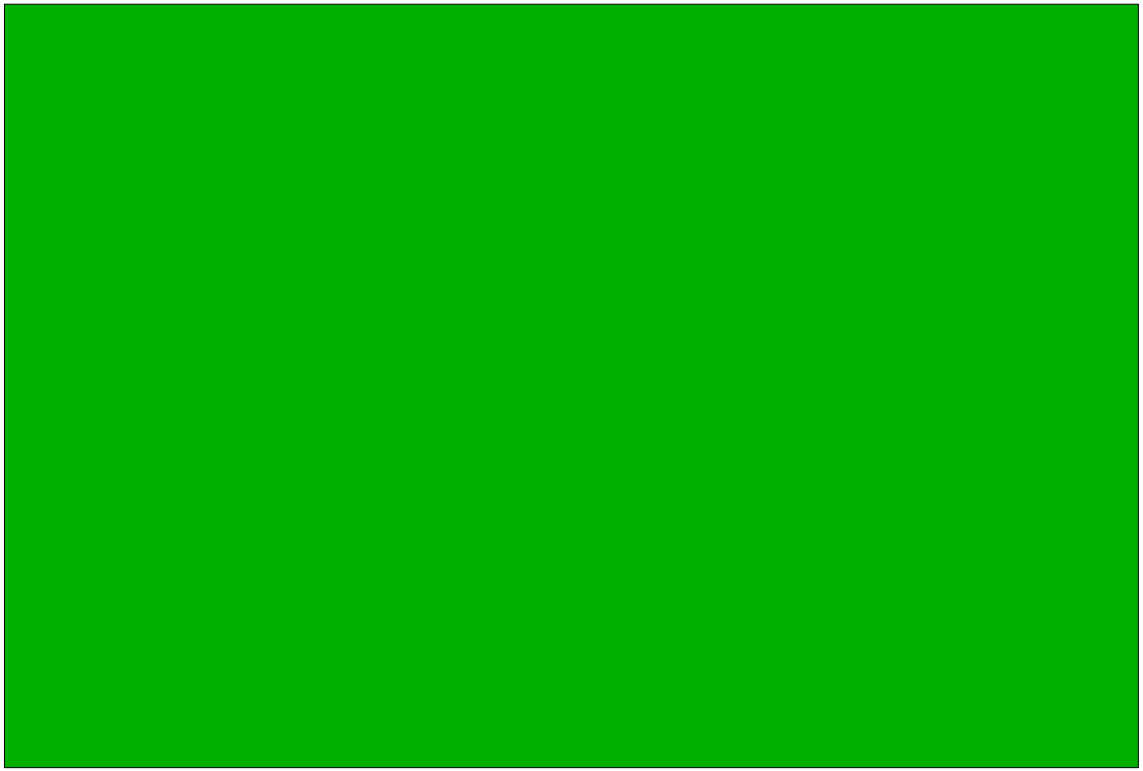
Introduction
Localization Problem

Imagine you are standing on a grassland ...

Introduction
Localization Problem

Source: http://www.indiatalkies.com/images/grassland5208d.JPG [10/06/2012]

Introduction
Localization Problem

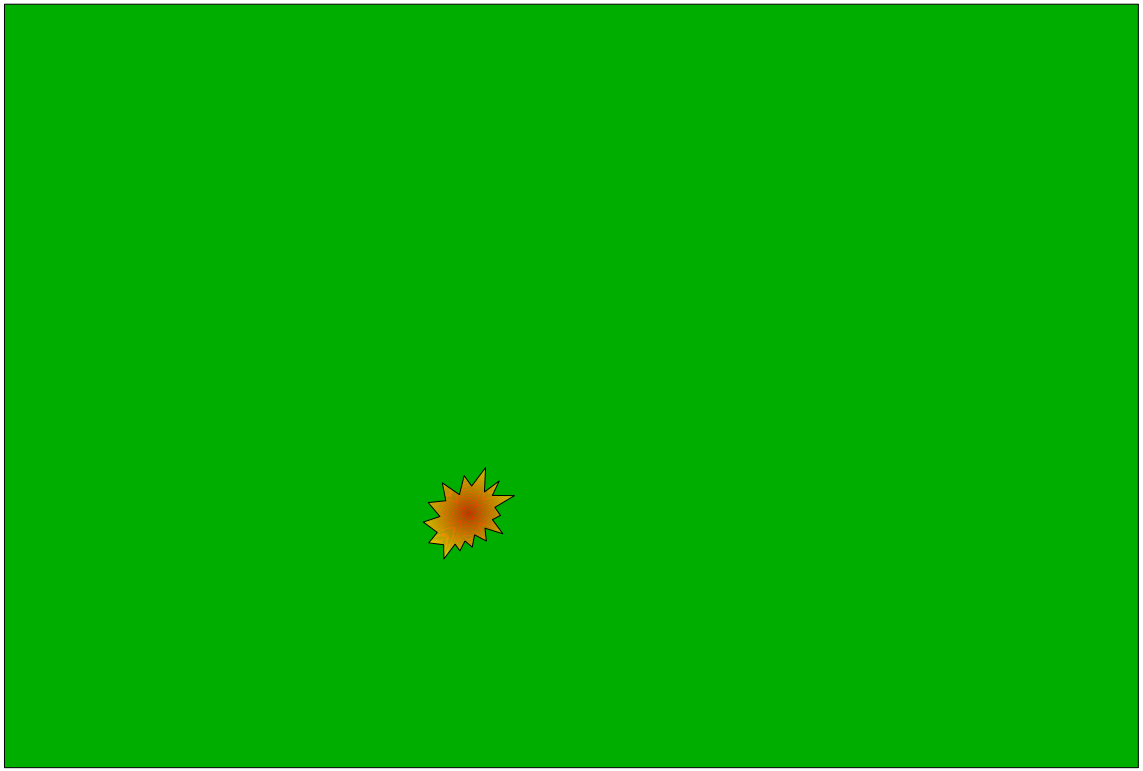


Abstracted ...

Introduction
Localization Problem

How to detect grassland fires?

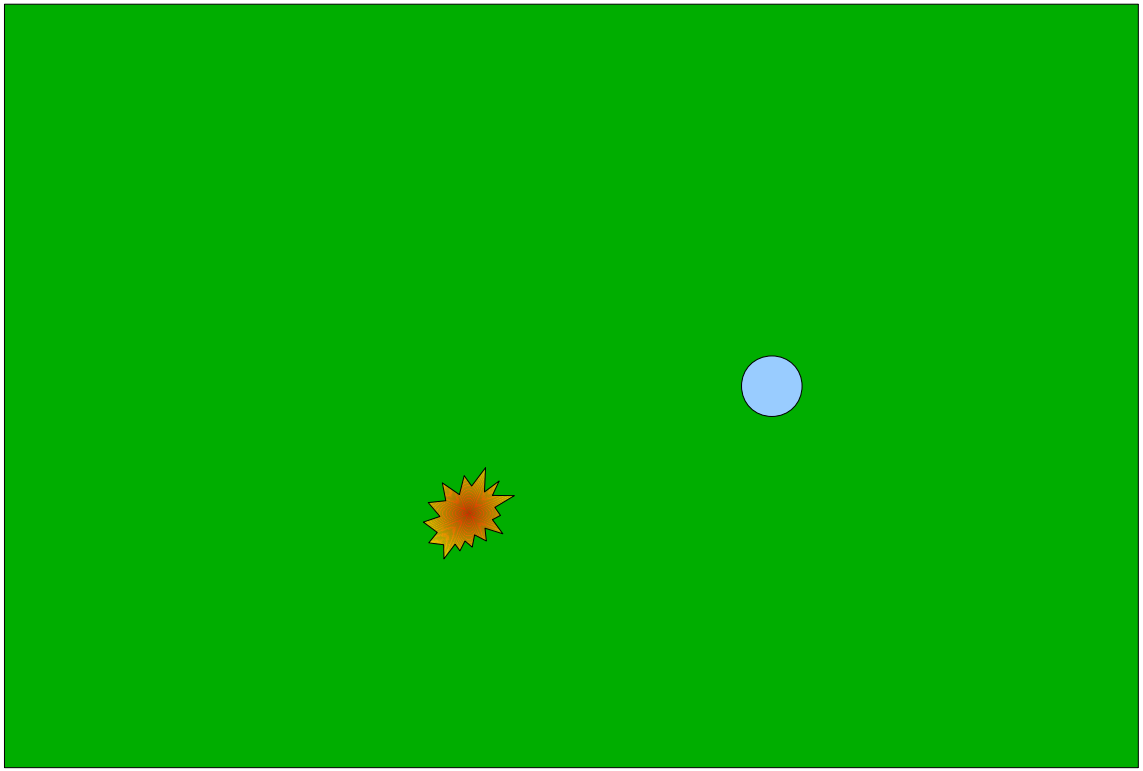
Introduction
Localization Problem



Introduction
Localization Problem

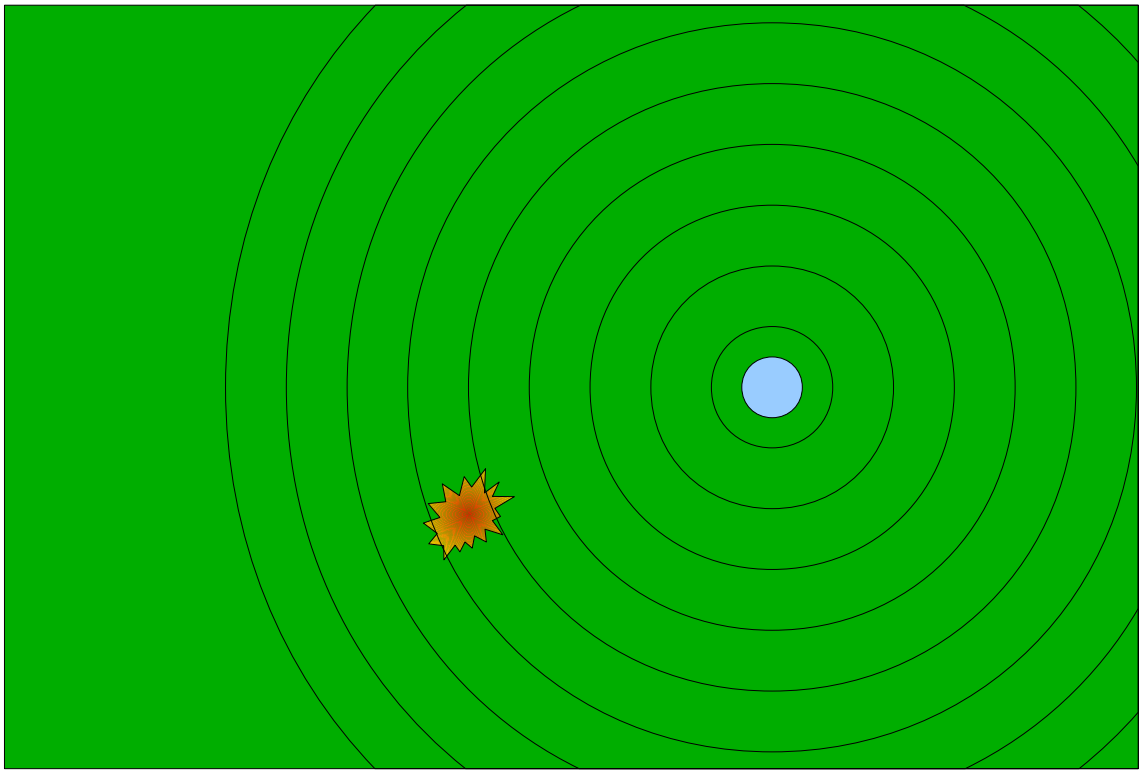
1st scenario

Introduction
Localization Problem



Using few sensors ...

Introduction
Localization Problem



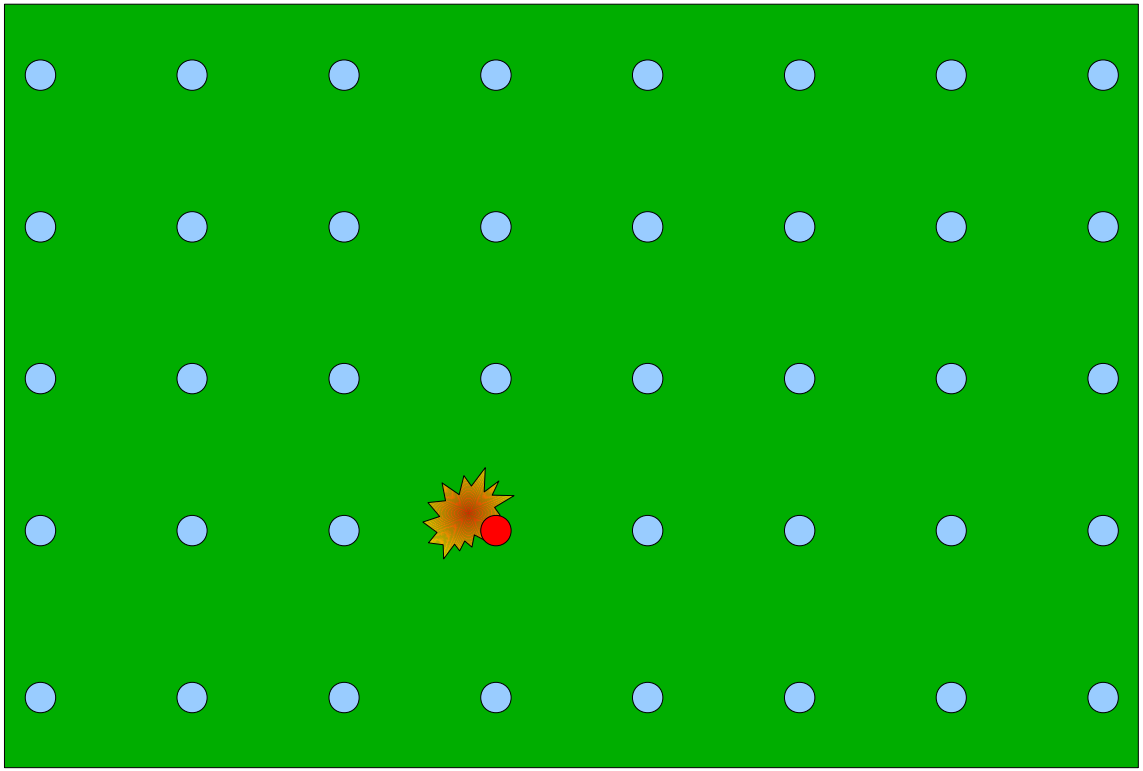
... with a wide range.

- Very expensive
- Hand-placed
- Mainly local or limited information

Introduction
Localization Problem

2nd scenario

Introduction
Localization Problem



Using numerous sensor nodes.

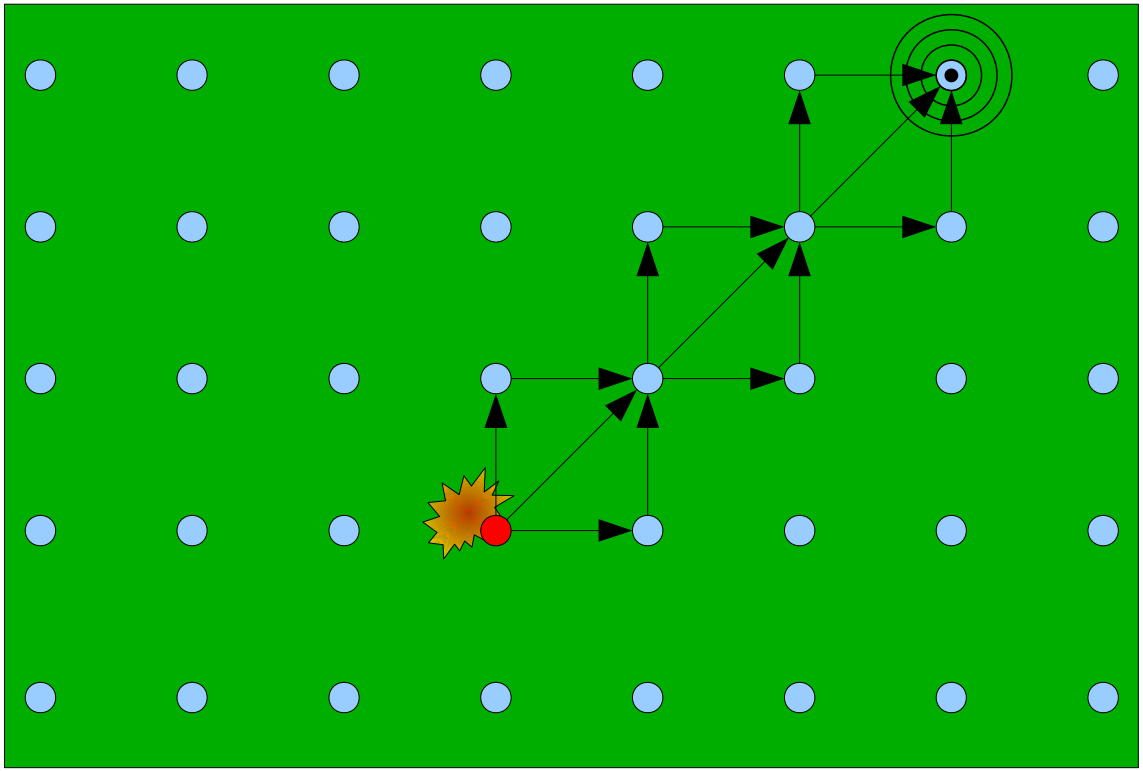
- Increasing accuracy
- Highly integrated
- Inexpensive
- Default RF-Unit

Introduction
Localization Problem

But how to transmit data to the relay station that forwards the measurements to the control station?

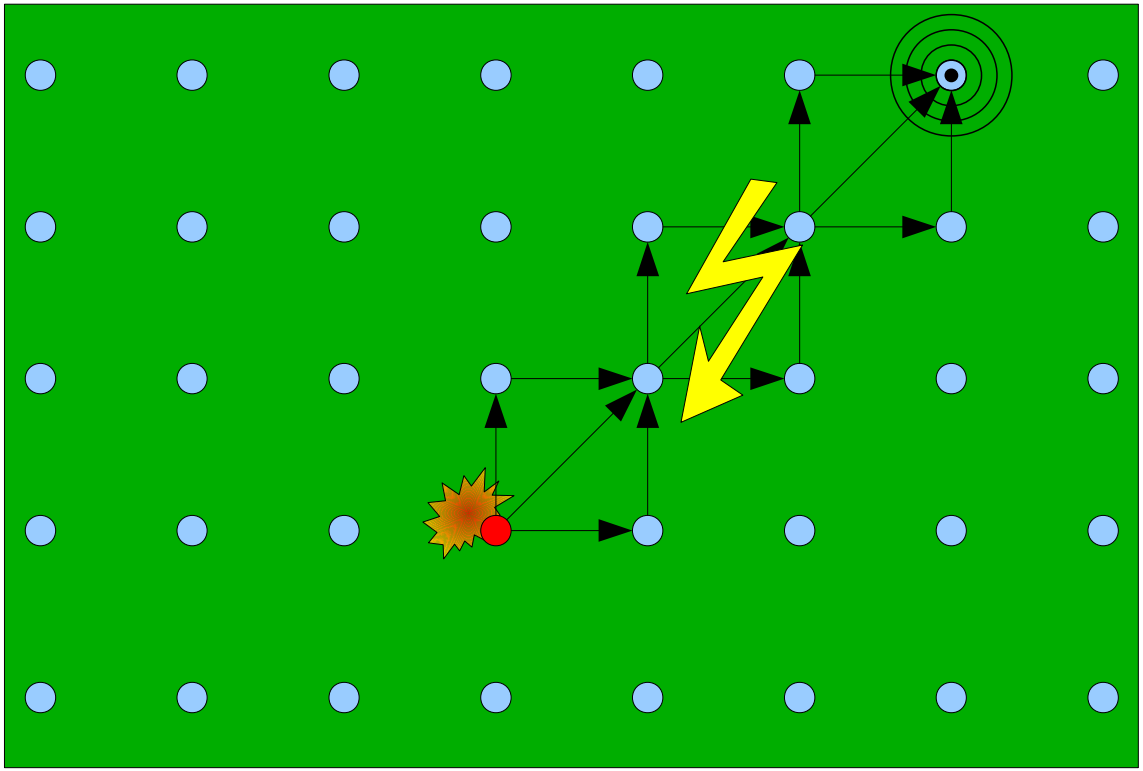
How to address repeater nodes
if the signal strength is not sufficient?

Introduction
Localization Problem



New challenges in the field of communication protocols are the consequence!

Introduction
Localization Problem



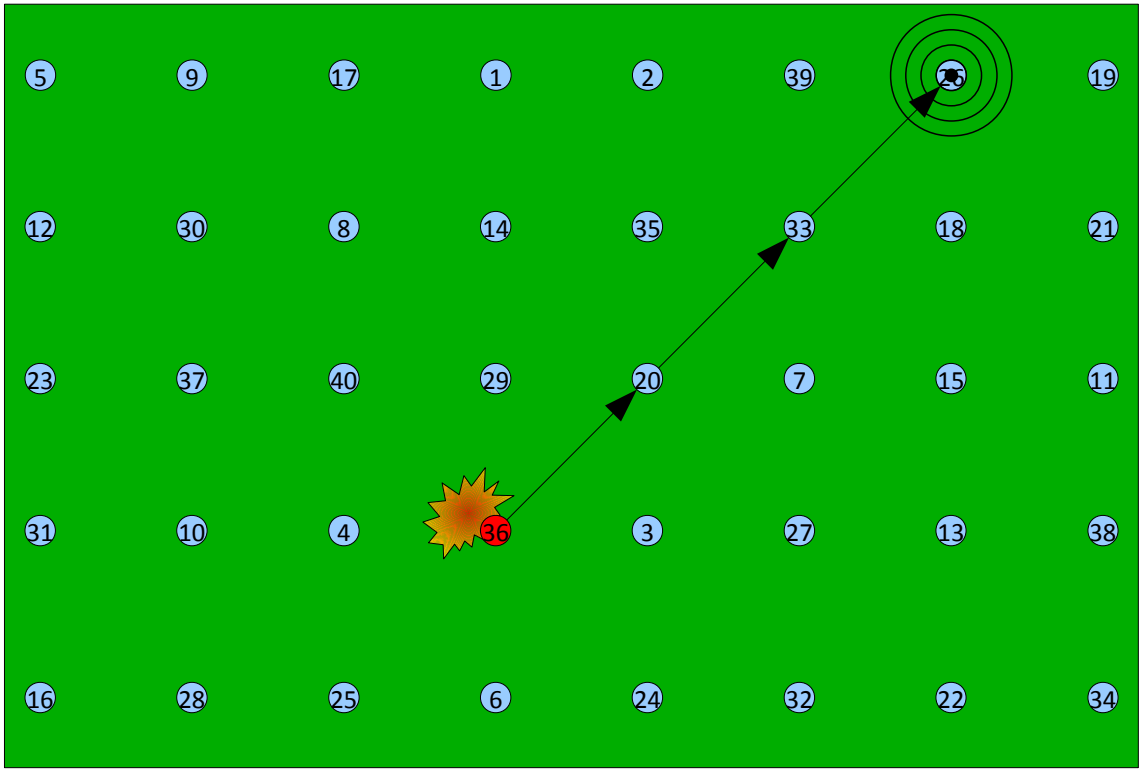
Especially when continuous data transfer is needed.

Increasing problems with data collisions and routing-efficiency.

Introduction
Localization Problem

1st solution

Introduction
Localization Problem



Every node gets an ID during its production process to make them unique and addressable.

- External mapping
- Self-organized mapping process

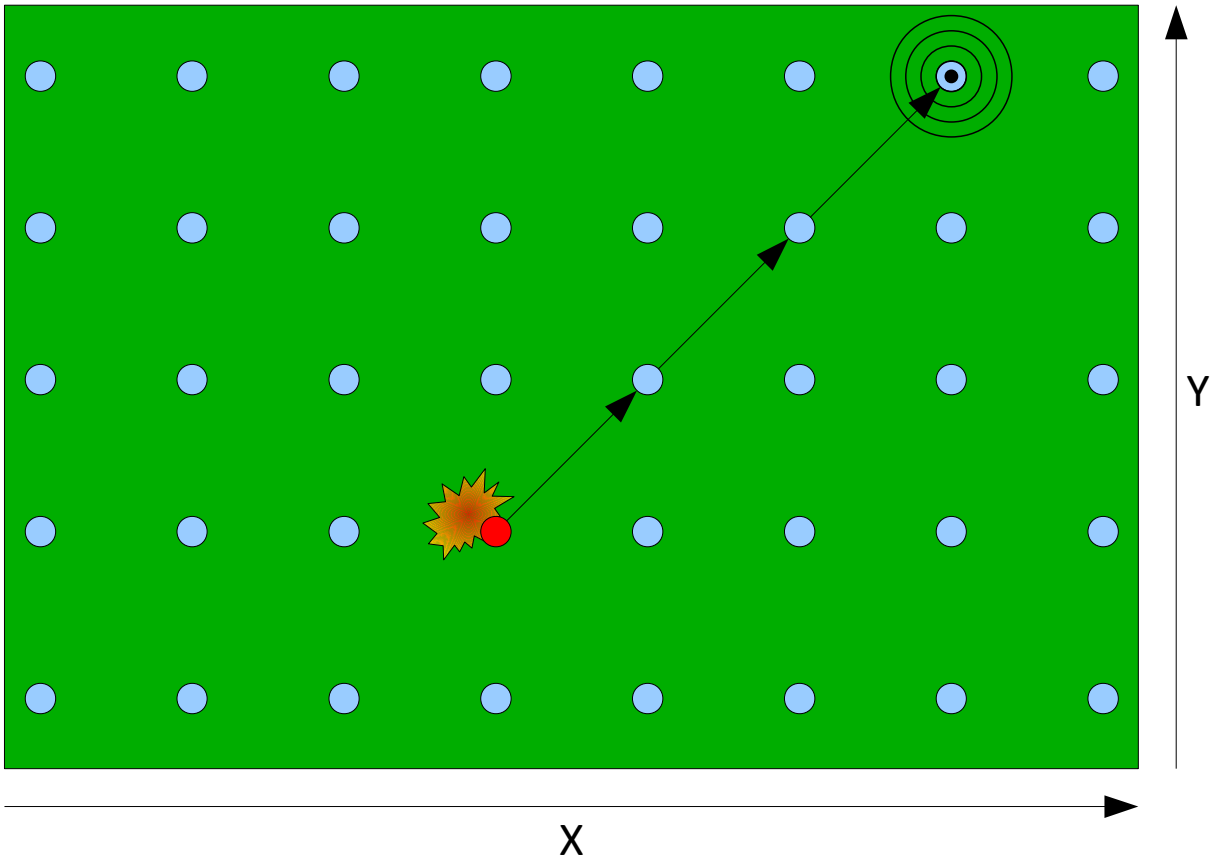
Expensive!

Introduction
Localization Problem

2nd solution

Introduction

Localization Problem



Every node is addressable by its geographical position as an explicit ID.

Introduction
Localization Problem

But where do the nodes get their position from?

Introduction
Localization Problem

Possible options

Introduction
Localization Problem

- Every node gets a GPS receiver
  - Very expensive!

Introduction
Localization Problem

- Every node gets a GPS receiver
  - Very expensive!
- External localization system
  - Using ultrasonic or radio-frequency
  - Complex infrastructure with multiple beacons
  - Inefficient in cost and afford

Introduction
Localization Problem

- Every node gets a GPS receiver
  - Very expensive!
- External localization system
  - Using ultrasonic or radio-frequency
  - Complex infrastructure with multiple beacons
  - Inefficient in cost and afford
- **Or this approach ...**

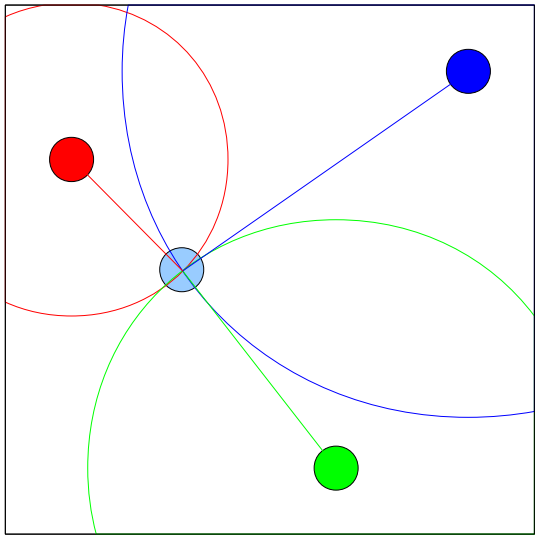
Approach

Approach

Approach
Concept

How to save cost and afford?

Approach
Concept



Traditional external localization systems

- Lateration / Multilateration
- Multiple beacons – at least three
- Estimates position with distances between beacons and nodes
- Accuracy increases with number of beacons

Approach
Concept

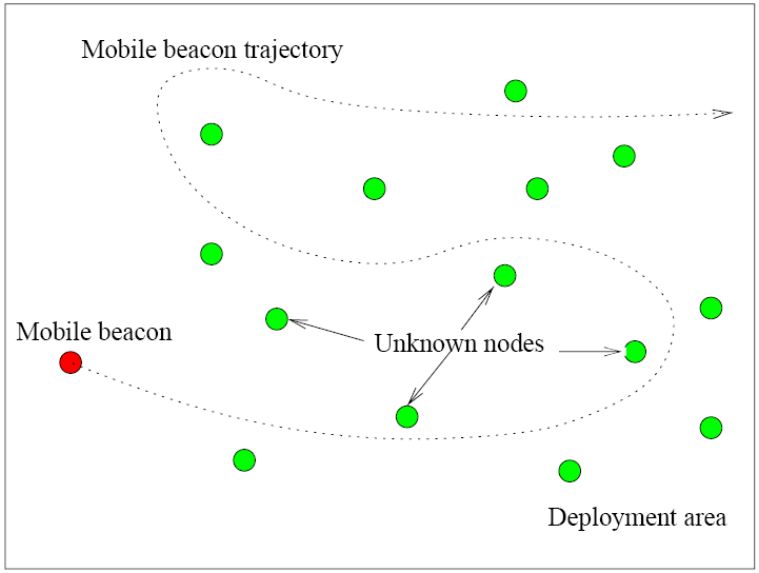
Occurring problems

- Beacons are much more expensive than sensor nodes
- Beacons become useless after ranging – waste of money

Approach
Concept

Why don't we reduce the number of beacons to one mobile?

Approach
Concept



[1]

- Numerous nodes deployed e.g. per plain
- Only one mobile beacon needed
- Each node computes its own position estimate locally
- Beacon knows its absolute position by an attached GPS receiver
- System provides localization with respect to a fixed coordinate system (GPS)
- Scalable to any number of unknown nodes

Approach
RSSI

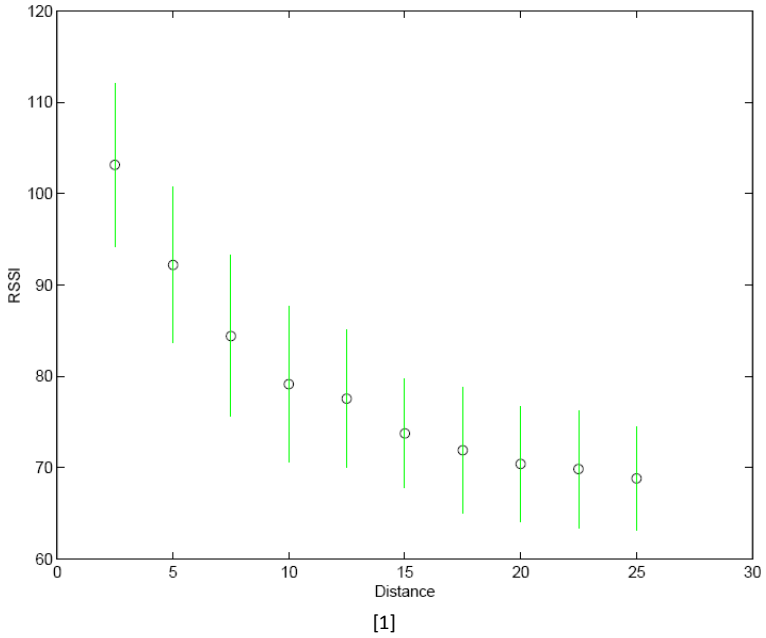
How to estimate the distance between node and beacon?

Approach
RSSI

RSSI

Received Signal Strength Indicator

Approach
RSSI



[1]

RSSI vs. distance
Standard deviation |

RSSI = Received Signal Strength Indicator

RSSI given by RF-units by default.

Optimal

- RSSI ~ 1 / distance

Reality

- Obstacles (e.g. walls) let signals become unpredictable
- No chance for indoor applications

Calibration: Measuring every 2.5 m

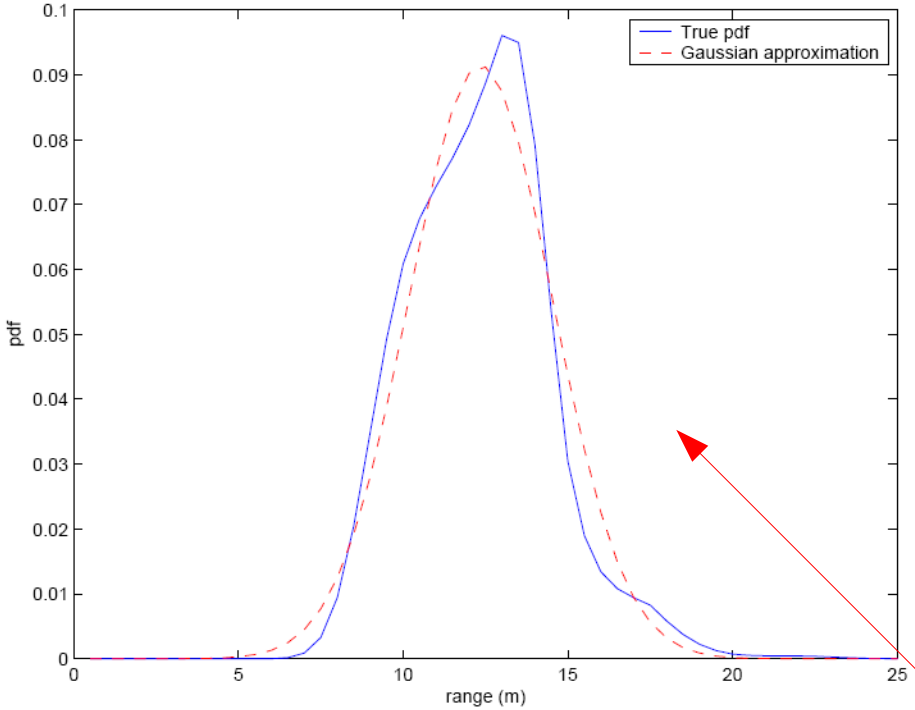
Approach
Gaussian

How to increase accuracy?

Approach
Gaussian

Gaussian

Approach
Gaussian



[1]

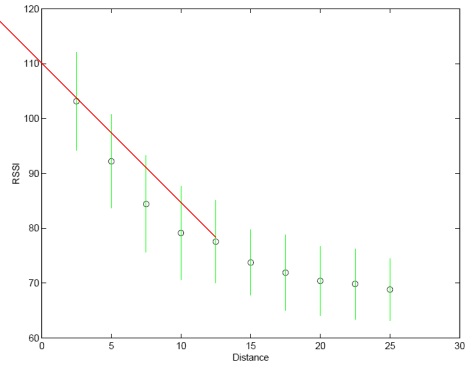
Looking at one point:

RSSI of 77

Distance ≈ 12.5 m

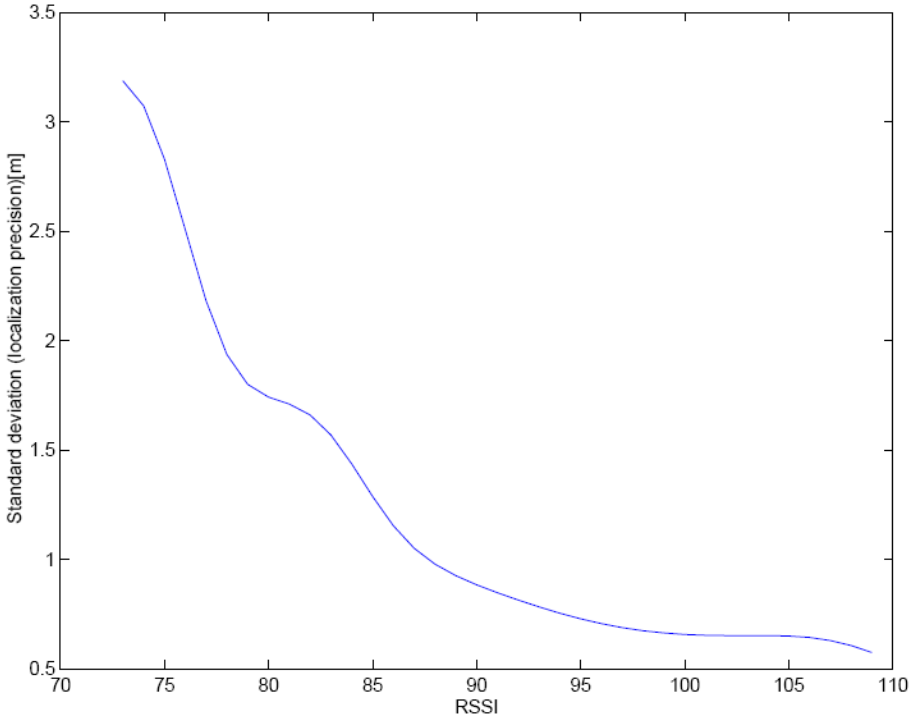
Probability distribution function pdf

Increasing accuracy by approximating the pdf with a Gaussian curve.



[1]

Approach
Gaussian



[1]

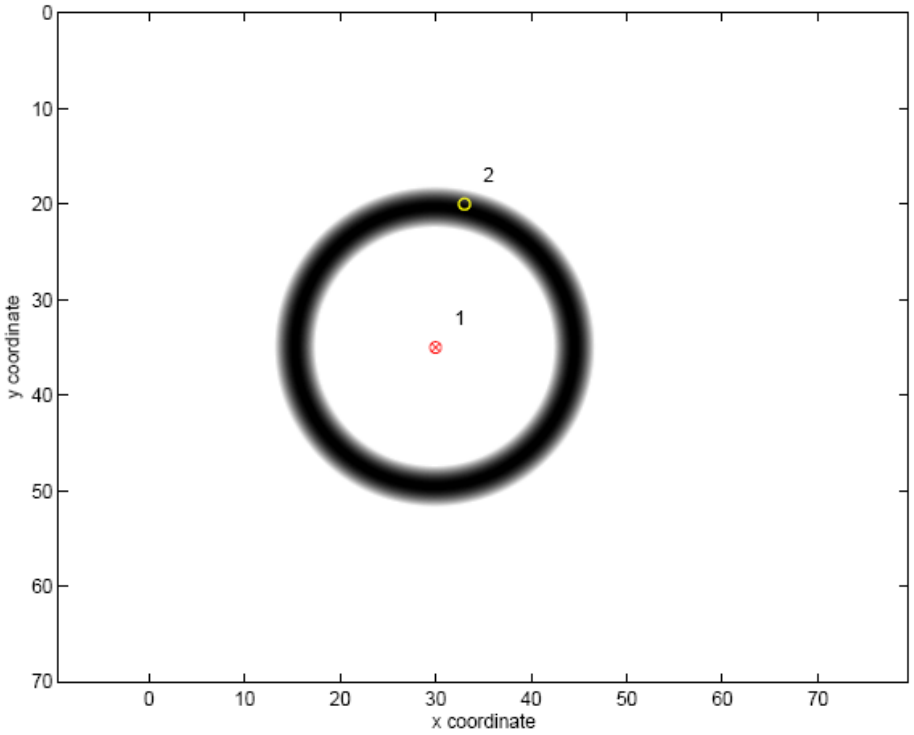
Standard deviation of the distances as a function of the RSSI value.

- High precision of under one meter in short ranges
- Decreasing precision with increasing distance

Approach
Bayesian Inference

But how to estimate the position?

Approach
Bayesian Inference



[1]

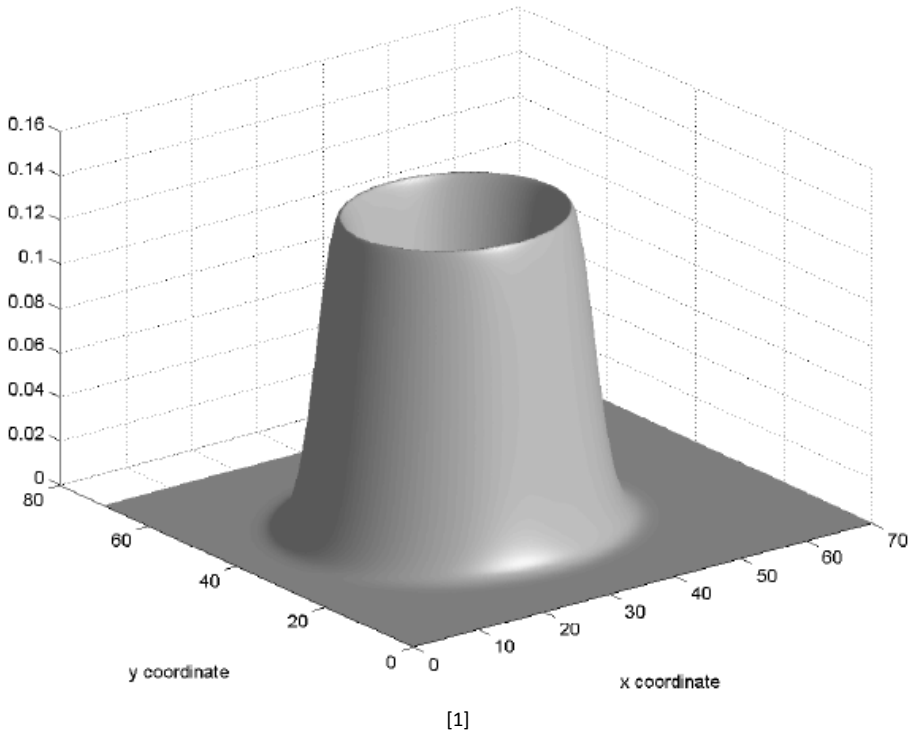
Position of beacon **1**

Position of unknown node **2**

Current position of beacon is given by GPS and transmitted via radio to nodes.

Circular probability space where node could be through combining beacon position and RSSI value.

Approach
Bayesian Inference



[1]

3D view of the circular probability space with Gaussian approximation.

No explicit result!

Approach
Bayesian Inference

How to estimate an explicit result?

Approach
Bayesian Inference

Bayesian Inference

Approach
Bayesian Inference

Statistical instrument to estimate occurring events by using the knowledge of previous events. [2]

- $P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B)}$
  Probability of the event A under the condition of event B – this is what we want to know!
- $P(A)$
  Probability of the event A
- $P(B)$
  Probability of the event B
- $P(B|A)$
  Probability of the event B under the condition of event A

Approach
Bayesian Inference

The Bayesian Inference helps to estimate the new position estimate **NPE** in assistance of the old position estimate **OPE**.

- $P(A) = PDF_{RSSI}(dist((x,y),(x_B,y_B)))$
- $P(B) = \int_{x_{min}}^{x_{max}} \int_{y_{min}}^{y_{max}} OPE(x,y) \times PDF_{RSSI}(dist((x,y),(x_B,y_B)))\,\mathrm{d}x\mathrm{d}y$
- $P(B|A) = OPE(x,y)$
- $P(A|B) = NPE(x,y) = \frac{P(B|A) \times P(A)}{P(B)}$

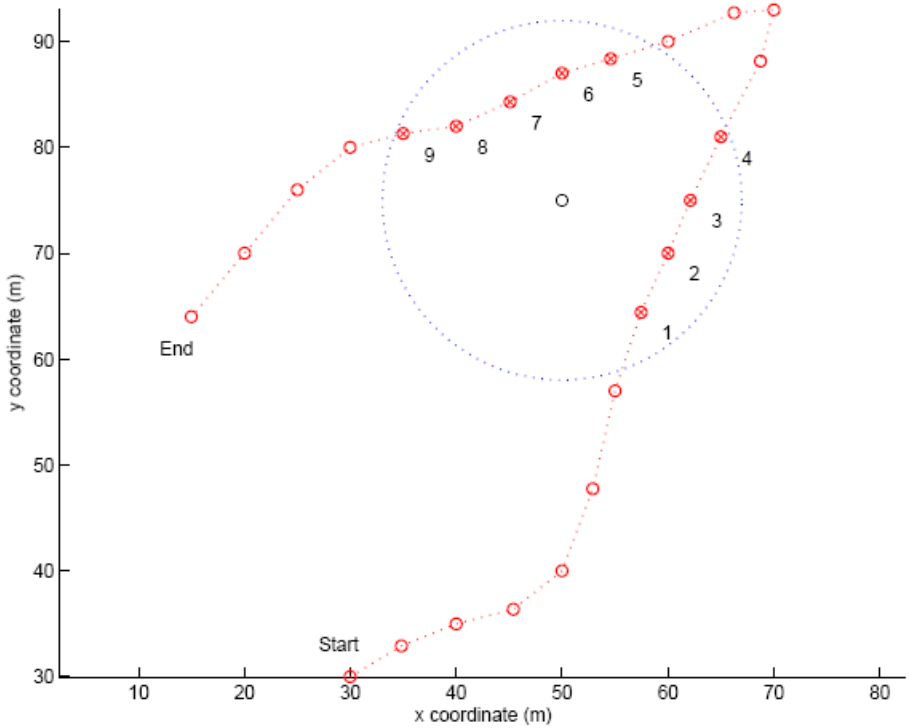
$$= \frac{OPE(x,y) \times PDF_{RSSI}(dist((x,y),(x_B,y_B))}{\int_{x_{min}}^{x_{max}} \int_{y_{min}}^{y_{max}} OPE(x,y) \times PDF_{RSSI}(dist((x,y),(x_B,y_B)))\,\mathrm{d}x\mathrm{d}y}$$

[1]

Approach
Bayesian Inference

No more theory!
What is the use of it?

Approach
Bayesian Inference



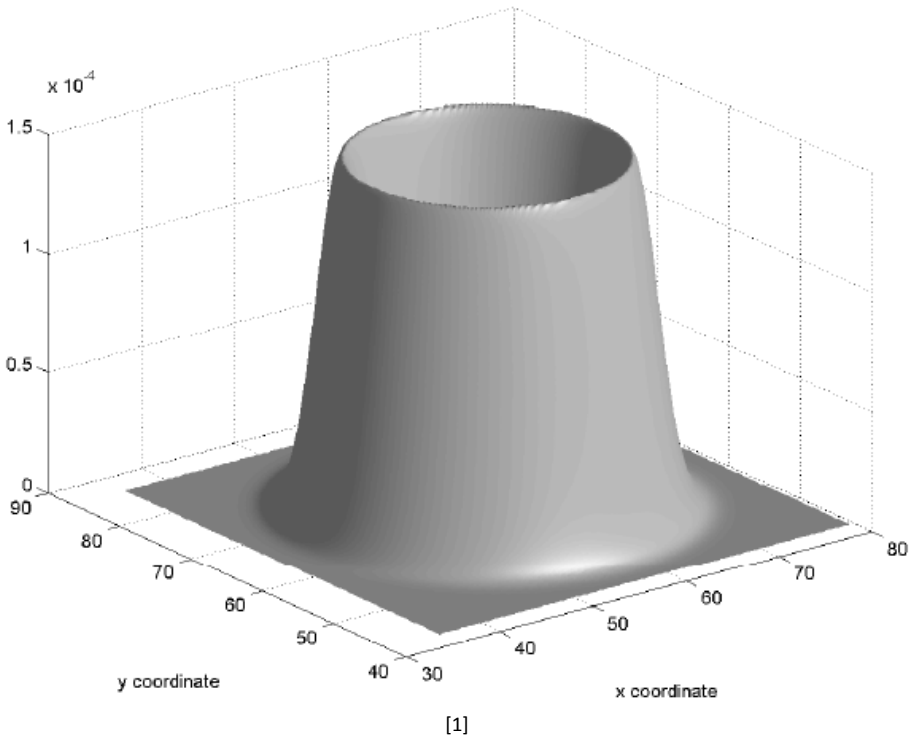
[1]

Showcase of a beacon trajectory along one single unknown node.

There are some spots where the beacon sends a data packet containing its absolute position but only nine of them are in reach of the node.

The accuracy of the estimated position increases with each received data packet.

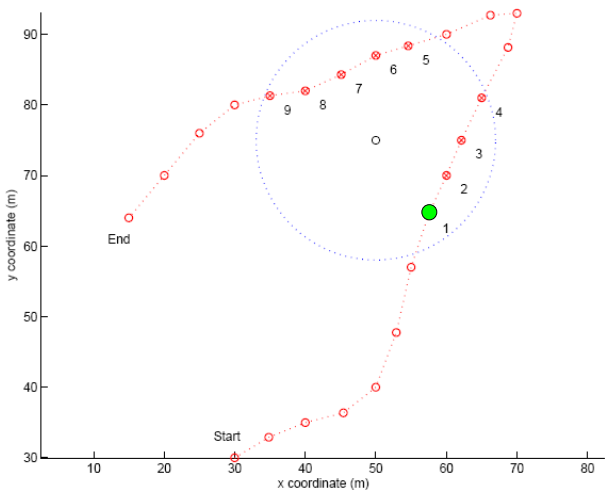
Approach
Bayesian Inference



[1]

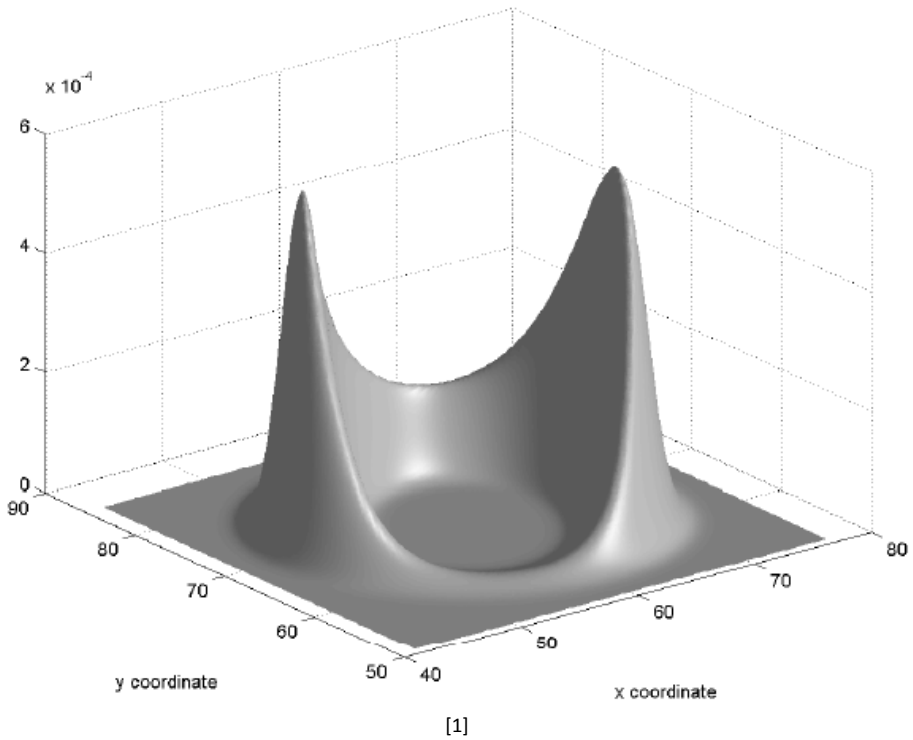
1st received beacon packet

3D probability space as shown before.



[1]

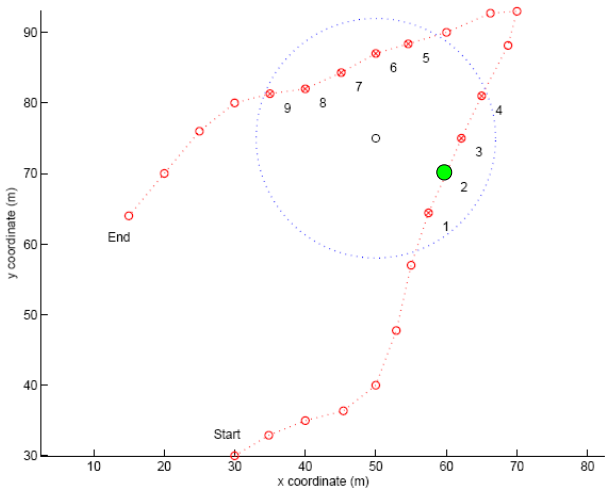
Approach
Bayesian Inference



[1]

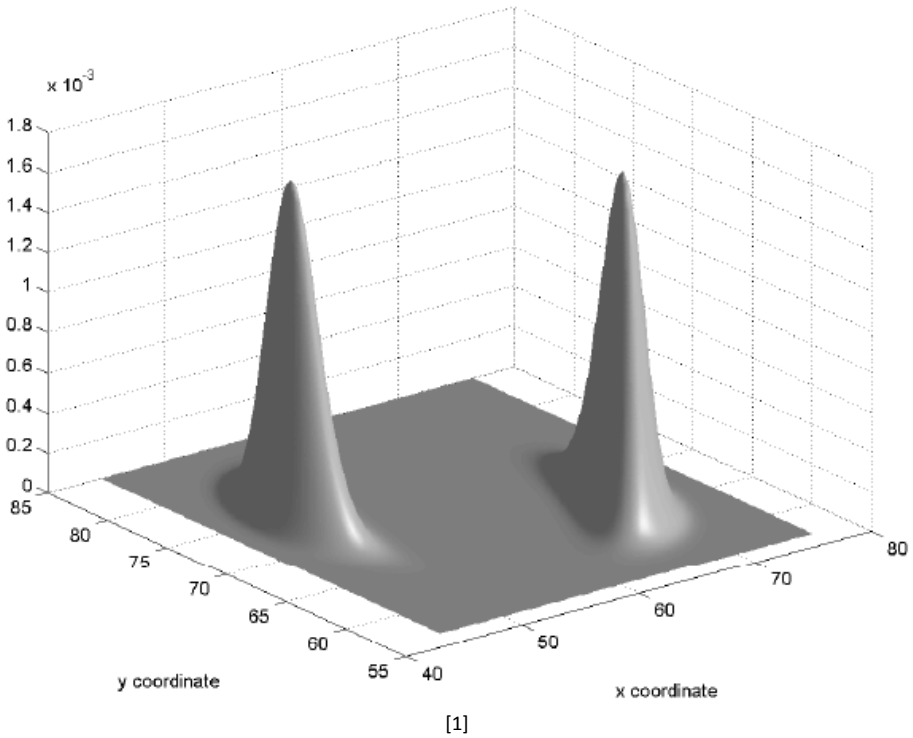
2nd received beacon packet

(1st packet) x (2nd packet)



[1]

Approach
Bayesian Inference

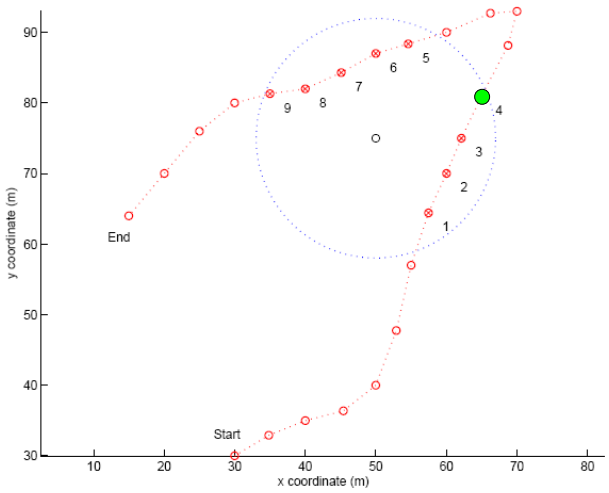


[1]

4th received beacon packet

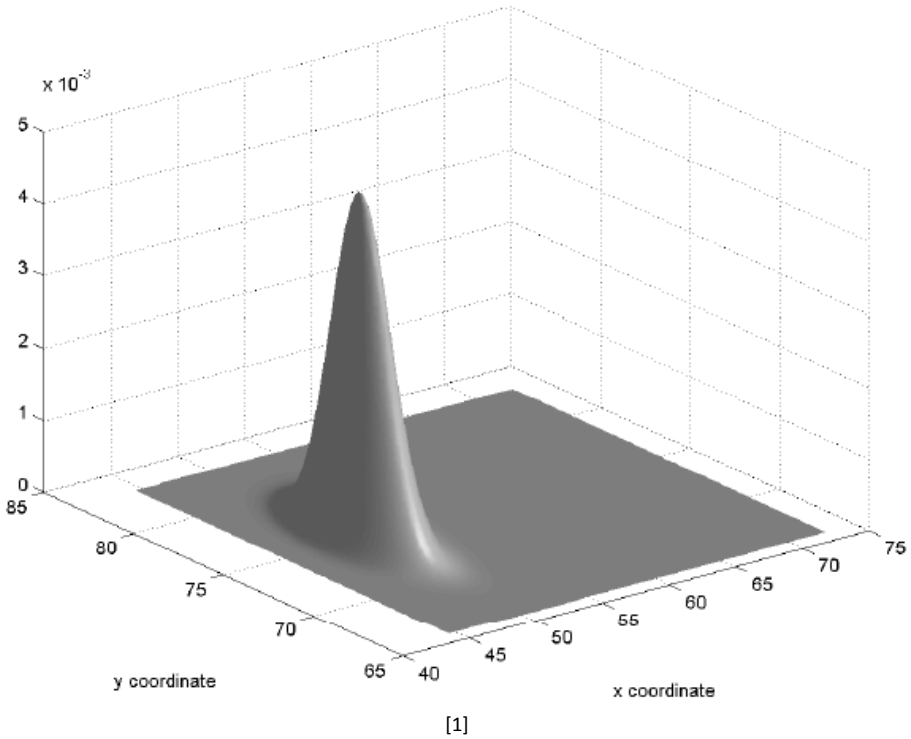
(prev. packets) x (4th packet)

Symmetric probability distribution caused of collinear waypoints.



[1]

Approach
Bayesian Inference

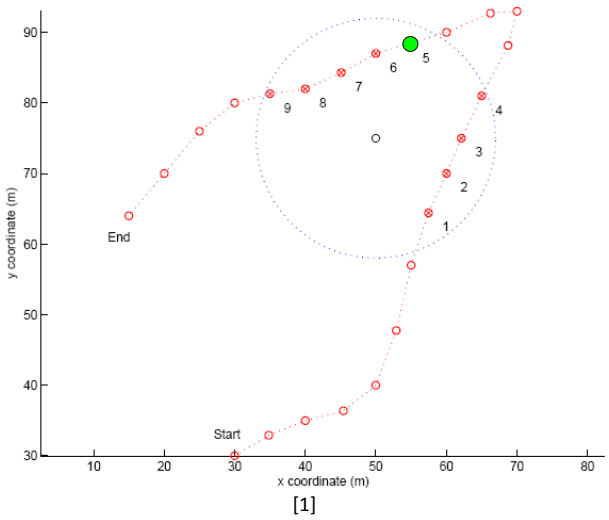


[1]

5th received beacon packet

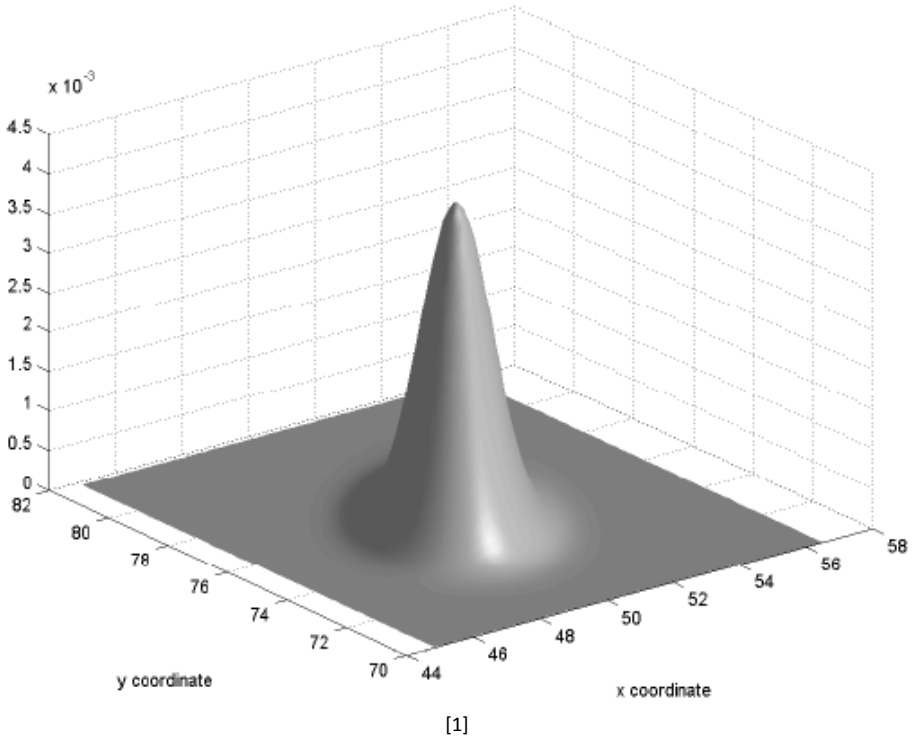
(prev. packets) x (5th packet)

Eliminating symmetric ratio.



[1]

Approach
Bayesian Inference

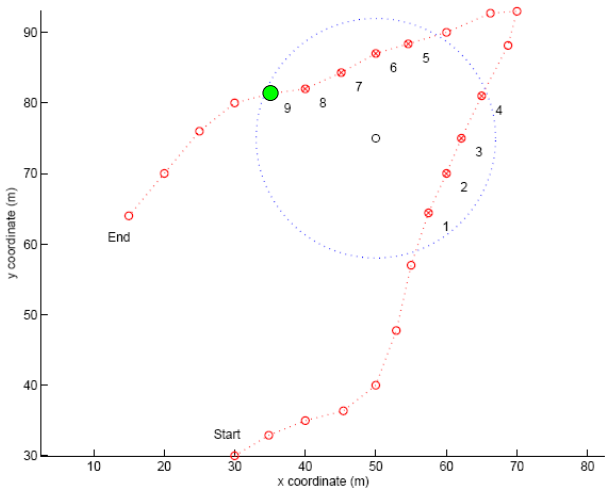


[1]

9th received beacon packet

(Prev. packets) x (9th packet)

The unknown node is now explicit localized!

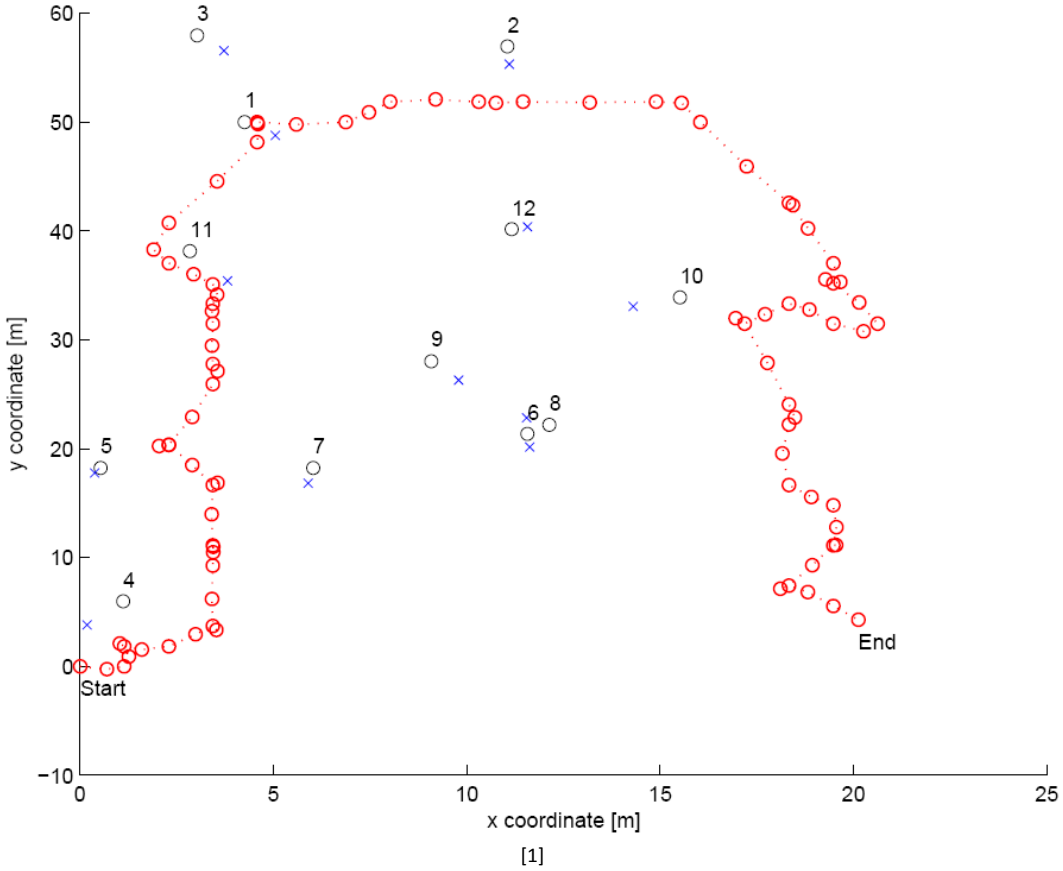


[1]

Approach
Result

Result

Approach
Result



[1]

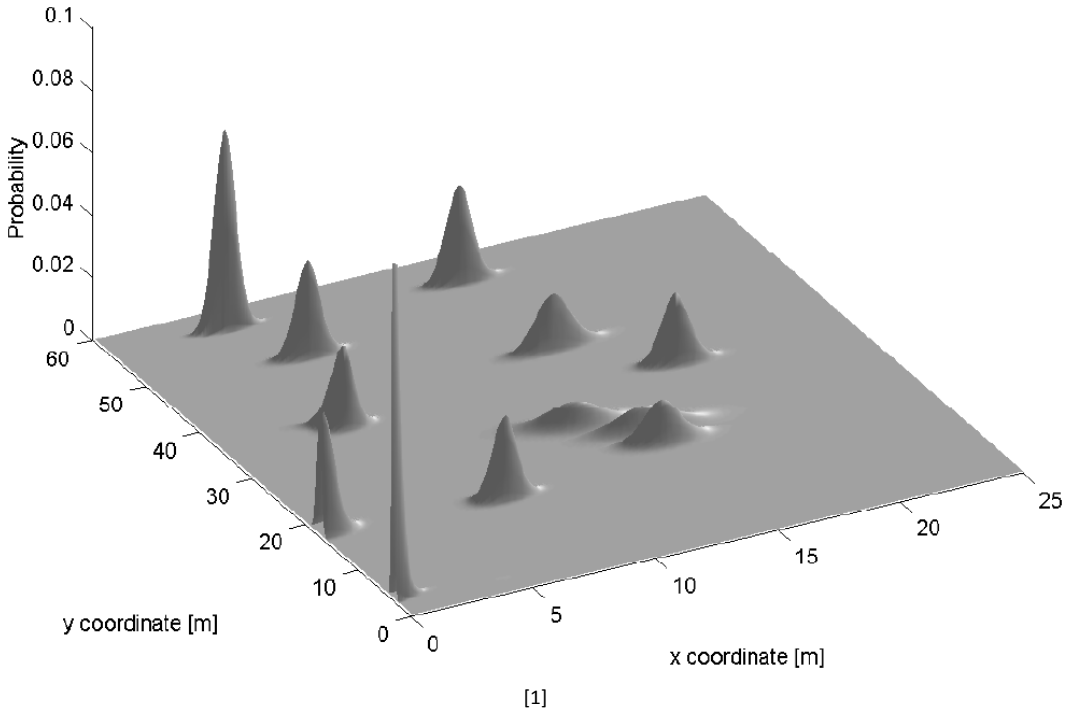
Nodes

- o real position
- x estimated position

Beacon

- o position where the beacon has send a packet

Approach
Result



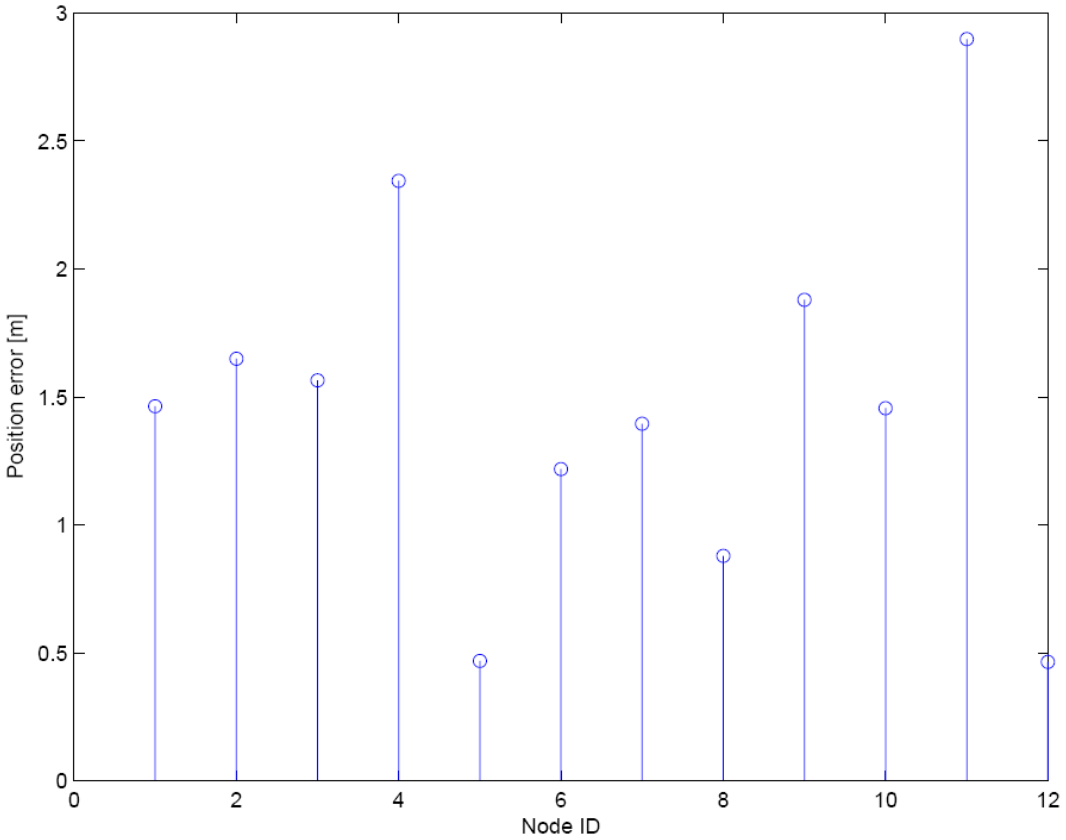
[1]

Map of the final position estimations.

High peak = high precision

Low peak = low precision

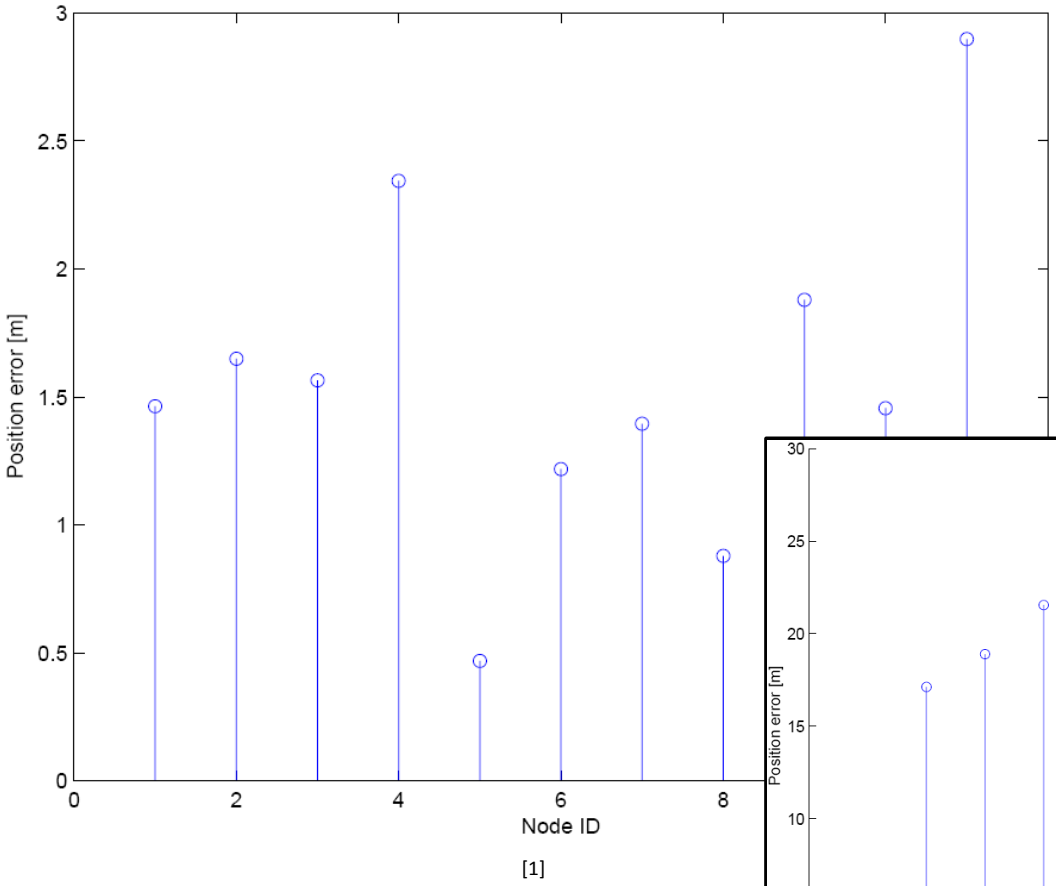
Approach
Result



[1]

Localization error

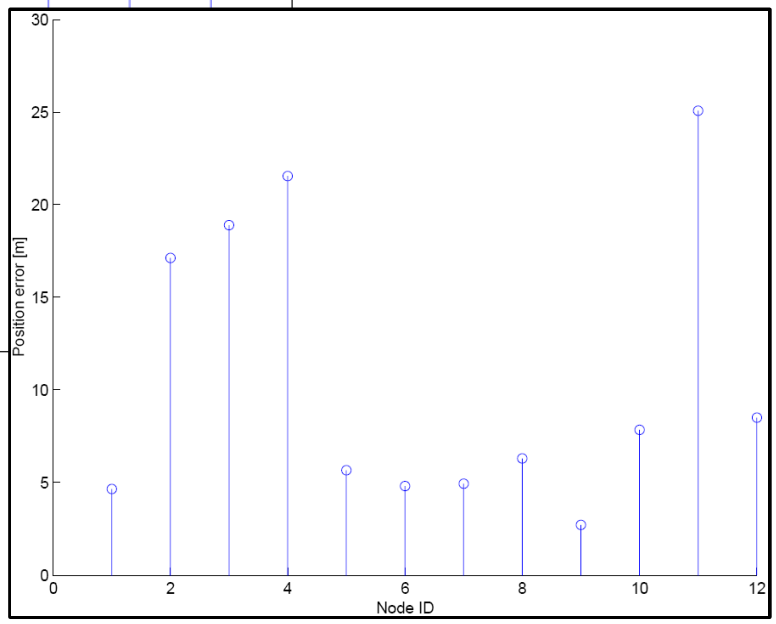
Approach
Result



[1]

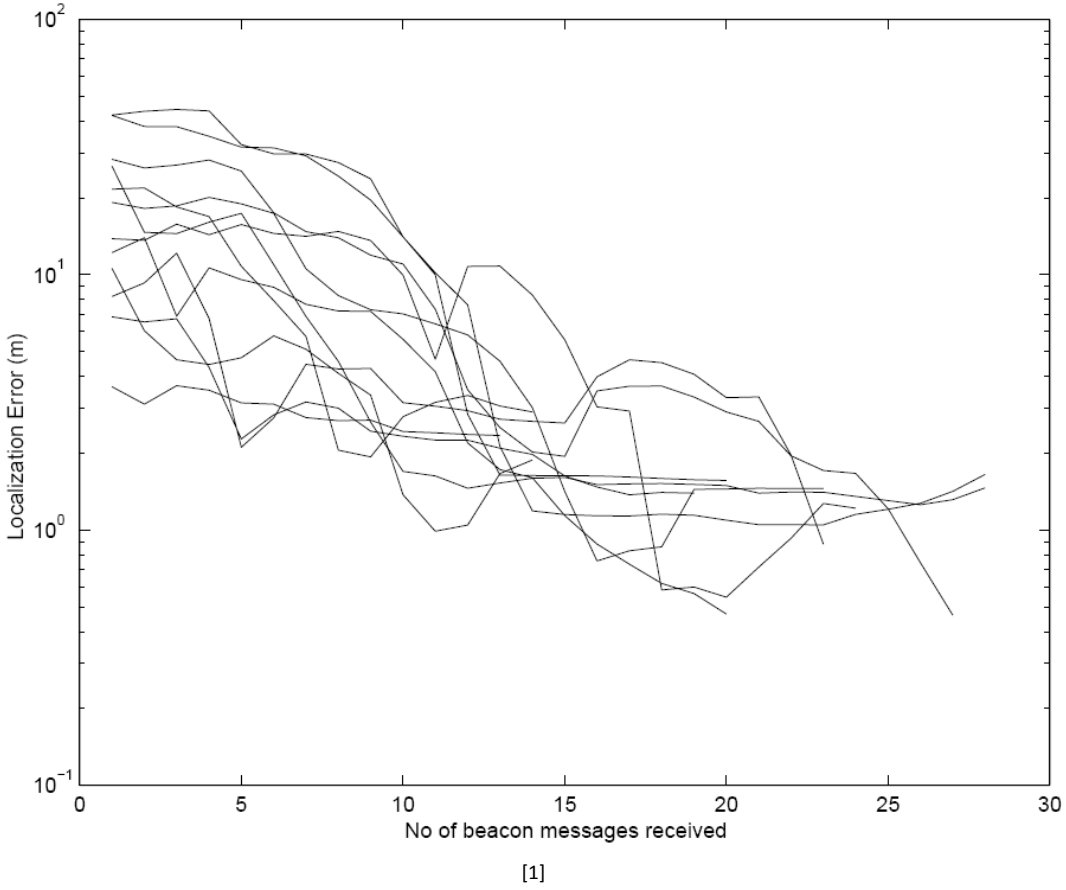
Localization error

Compared to the result of multilateration, it is a very good alternative!



[1]

Approach



[1]

Evolution of the localization error with increasing beacon packets.

Discussion

Discussion

Discussion

Pro

- Very precise compared to external systems
- Deployable and calibratable per plain
- Efficient in cost and afford

Contra

- Only practicable in outdoor applications
- Only for unmoving nodes
- Are there any reasonable applications?
  Except on battlefields?

The End

Thank you for your attention!

Questions?

Bibliographical References

[1] Mihail L. Sichitiu and Vaidyanathan Ramadurai. Localization of wireless sensor networks with a mobile beacon. First IEEE Conference on Mobile Ad-hoc and SensorSystems (MASS 2004), October 2004.

[2] http://de.wikipedia.org/wiki/Bayestheorem, Wikimedia Foundation Inc., 12/06/2012