Moving Baseline Localization

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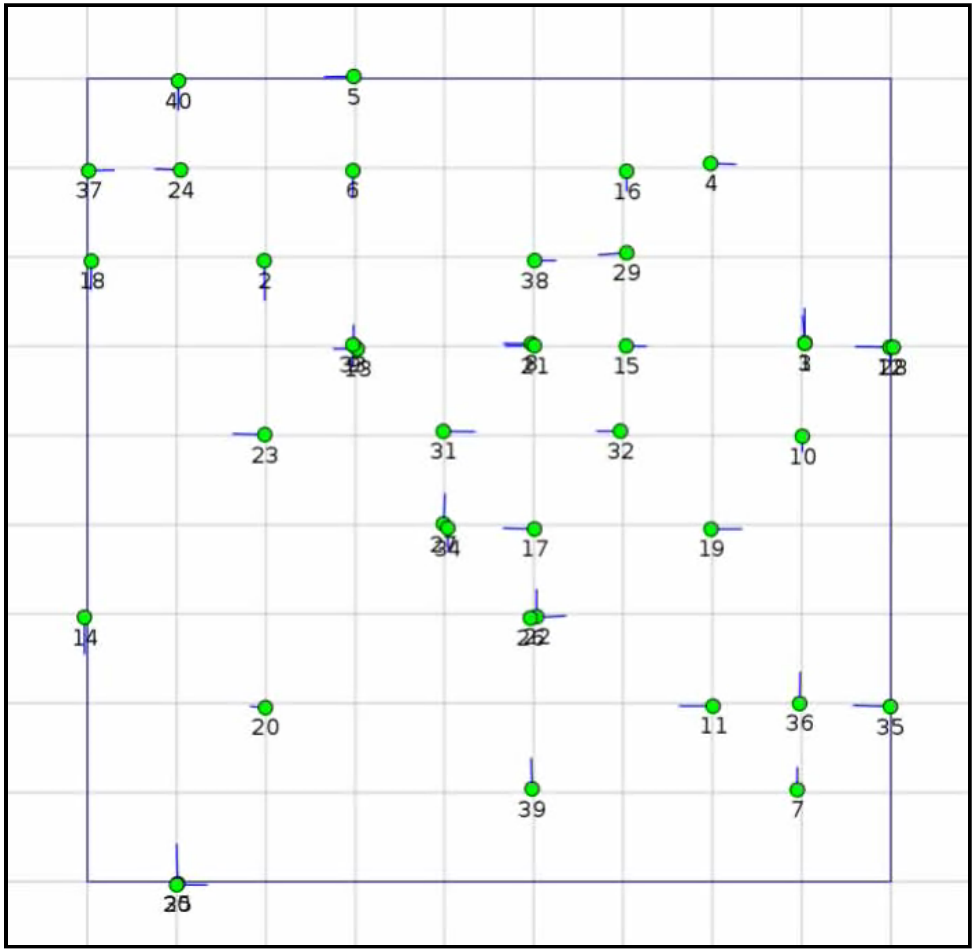

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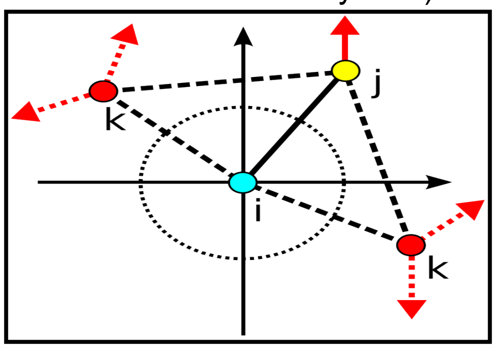
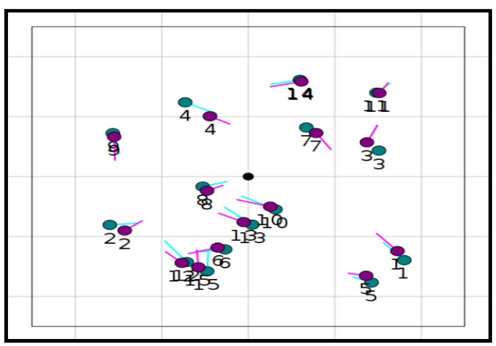
A localization method for mobile networks without an external coordinate reference

(Picture from Cricket location system)

Motivation and statement of the problem



Description of the Moving-Baseline Localization method



Results and discussion

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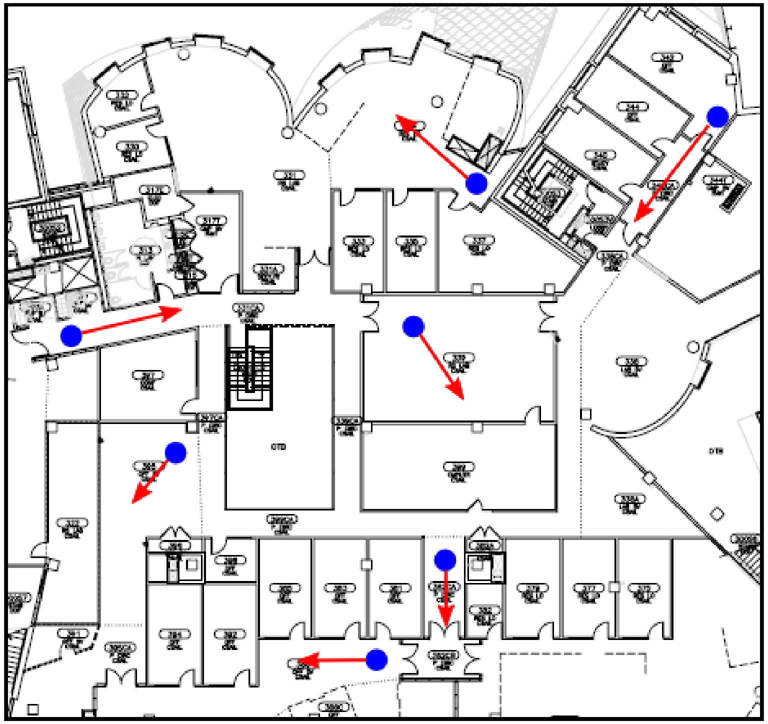
Localization enables situational awareness

No GPS

No deployed infrastructure



(Picture from Cricket location system)

Determine, for each node, the relative positions and velocities of all other nodes moving within a GPS-denied environment without previously deployed infrastructure

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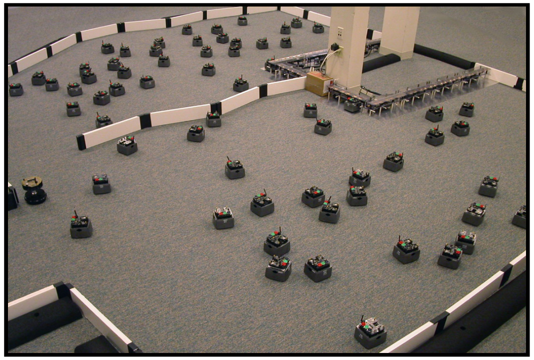
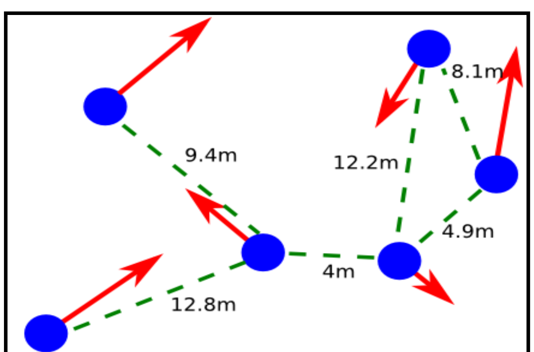
Moving-Baseline Localization (MBL) problem



(Picture from Robotic Swarm project)

Many mobile nodes

No external coordinate reference



Ranging and communication only between nearby nodes

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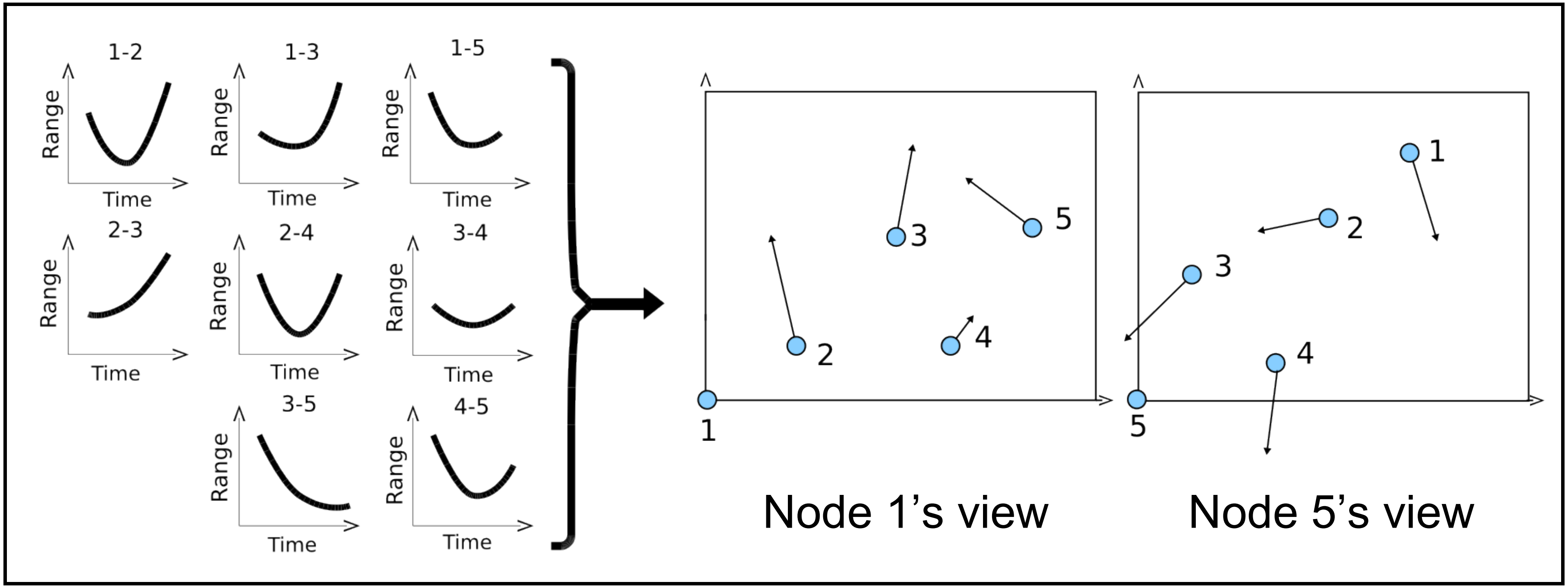
Related work

	Anchor-based	Anchor-free
Static network	Bulusu et al., ***GPS-Less Low-Cost Outdoor Localization for Very Small Devices***, 2000 Savarese et al., ***Robust Positioning Algorithms for Distributed Ad-Hoc Wireless Sensor Networks***, 2002 Niculescu and Nath, ***DV Based Positioning in Ad Hoc Networks***, 2003 He et al., ***Range-Free Localization Schemes for Large Scale Sensor Networks***, 2003 Savvides et al., ***The n-Hop Multilateration Primitive for Node Localization Problems***, 2003 Goldenberg et al., ***Localization in Sparse Networks using Sweeps***, 2006 Biswas et al., ***Semidefinite Programming Approaches for Sensor Network Localization with Noisy Distance Measurements***, 2006	Capkun et al. ***GPS-Free Positioning in Mobile Ad Hoc Networks***, 2002 Priyantha et al., ***Anchor-Free Distributed Localization in Sensor Networks***, 2002 Shang et al., ***Localization from Mere Connectivity***, 2003 Shang et al., ***Improved MDS-Based Localization***, 2004 Moore et al., ***Robust Distributed Network Localization with Noisy Range Measurements***, 2004 Ahmed et al., ***SHARP: A New Approach to Relative Localization in Wireless Sensor Networks***, 2005 Giorgetti et al., ***Wireless Localization Using Self-Organizing Maps***, 2007 Ash and Potter, ***Robust System Multiangulation Using Subspace Methods***, 2007
Mobile network	Hu and Evans, ***Localization for Mobile Sensor Networks***, 2004 Datta et al., ***Distributed Localization in Static and Mobile Sensor Networks***, 2006 Baggio and Langendoen, ***Monte-Carlo Localization for Mobile Wireless Sensor Networks***, 2006 Dil et al., ***Range-Based Localization in Mobile Sensor Networks,*** 2006	Akcan et al., ***GPS-Free Localization in Mobile Wireless Sensor Networks***, 2006 Xu et al., ***Mobile Anchor-Free Localization for Wireless Sensor Networks***, 2007

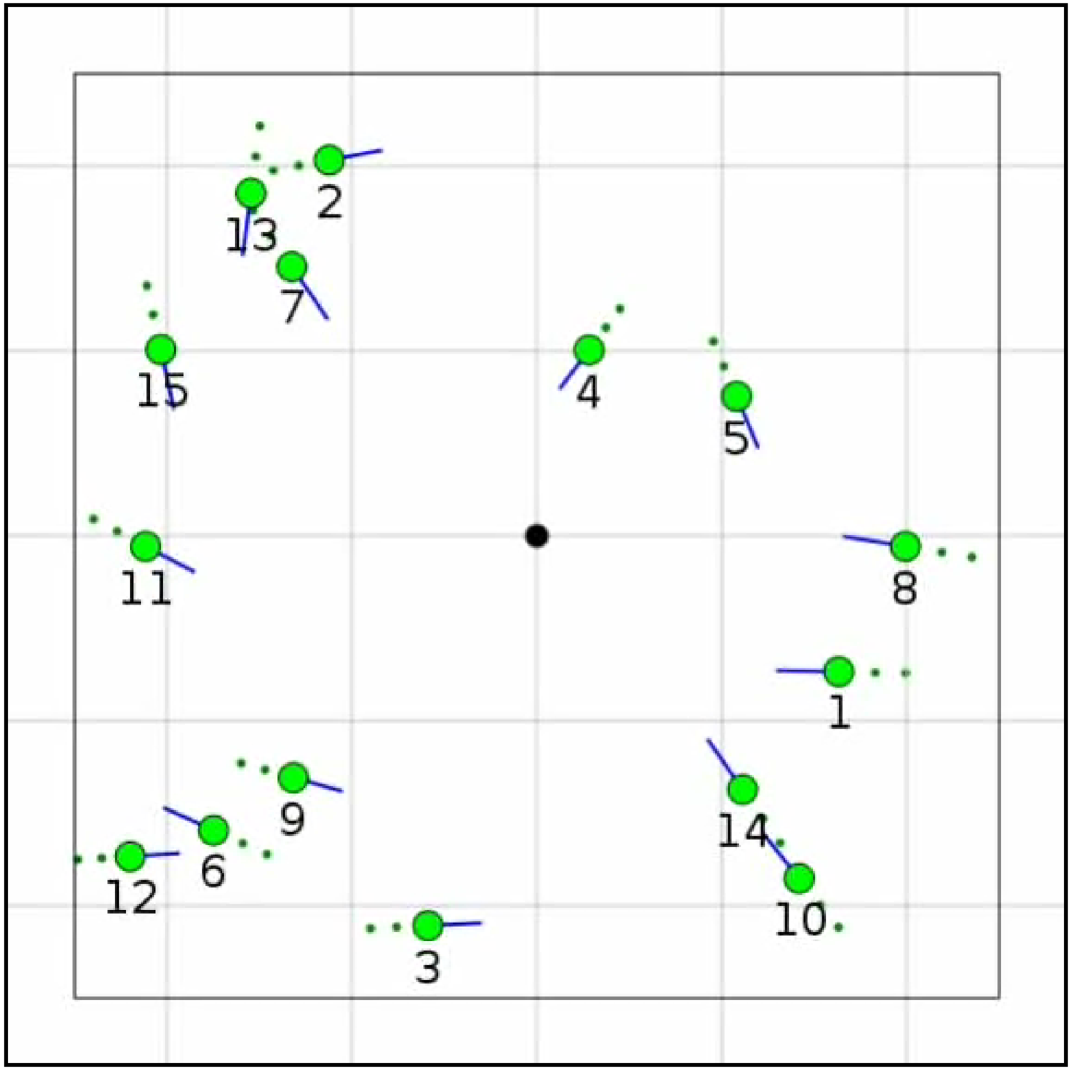
Problem statement



Input is a set of time series of range measurements acquired at each node

Solution consists, for each node, of a motion estimate for all *other* nodes in that node's local coordinate system

Assume planar motion
Model trajectories as piecewise-linear



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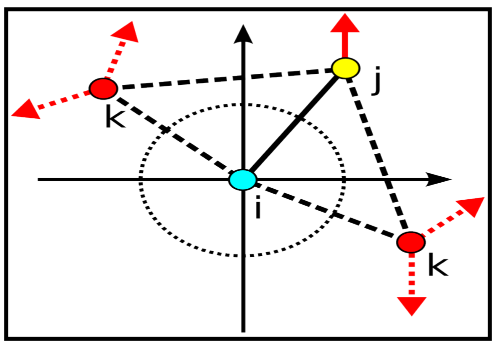
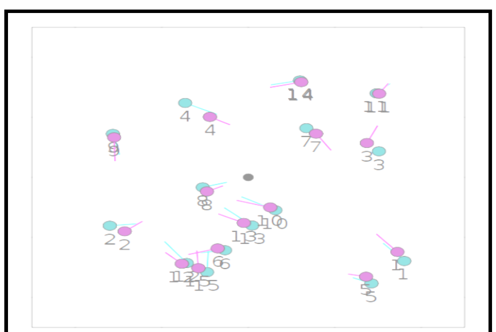
Outline

Motivation and statement of the problem



Description of the Moving-Baseline Localization method



Results and discussion

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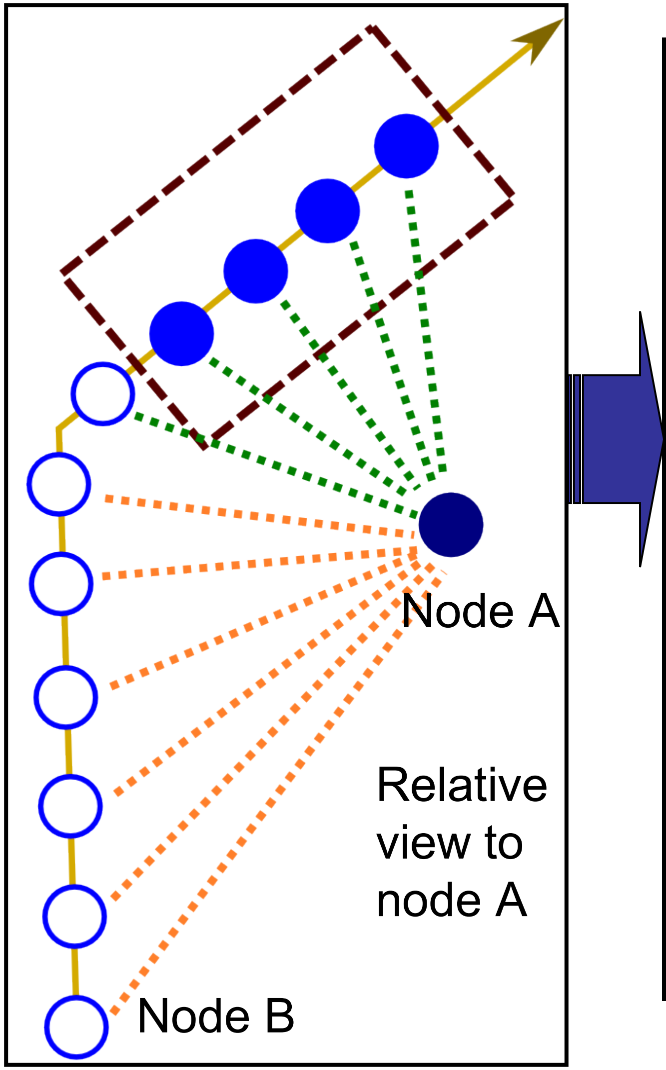
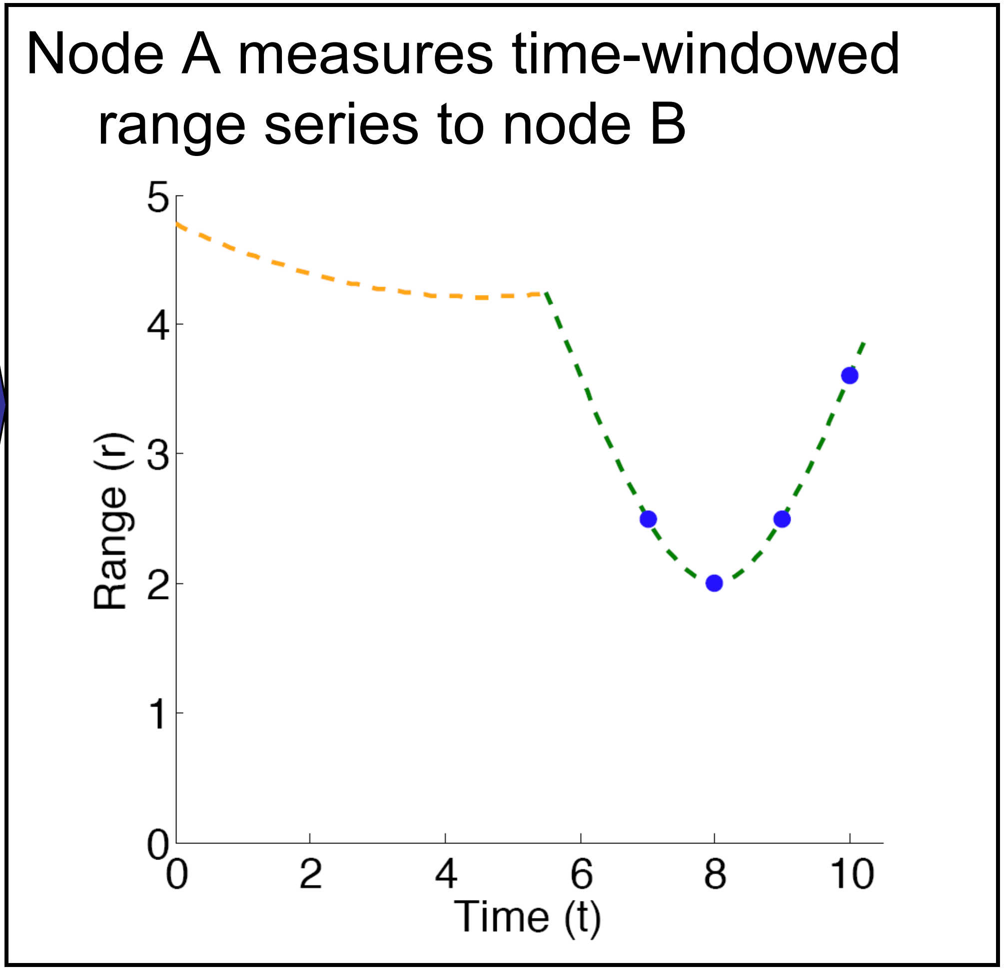
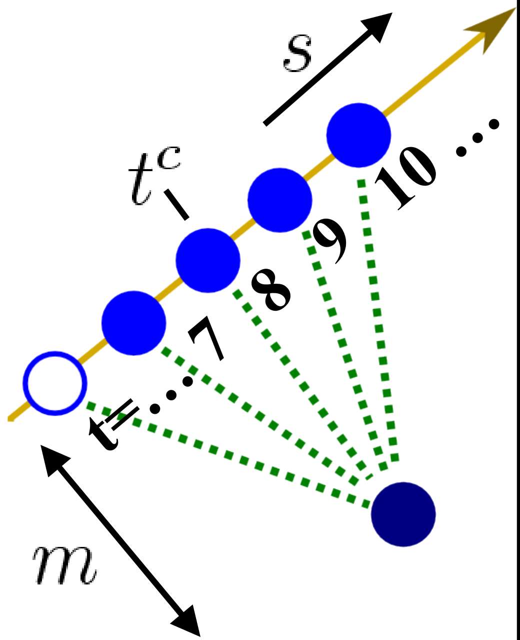
Basic ideas: Dimensionality reduction and convenient change of variables





Basic ideas: Dimensionality reduction and convenient change of variables

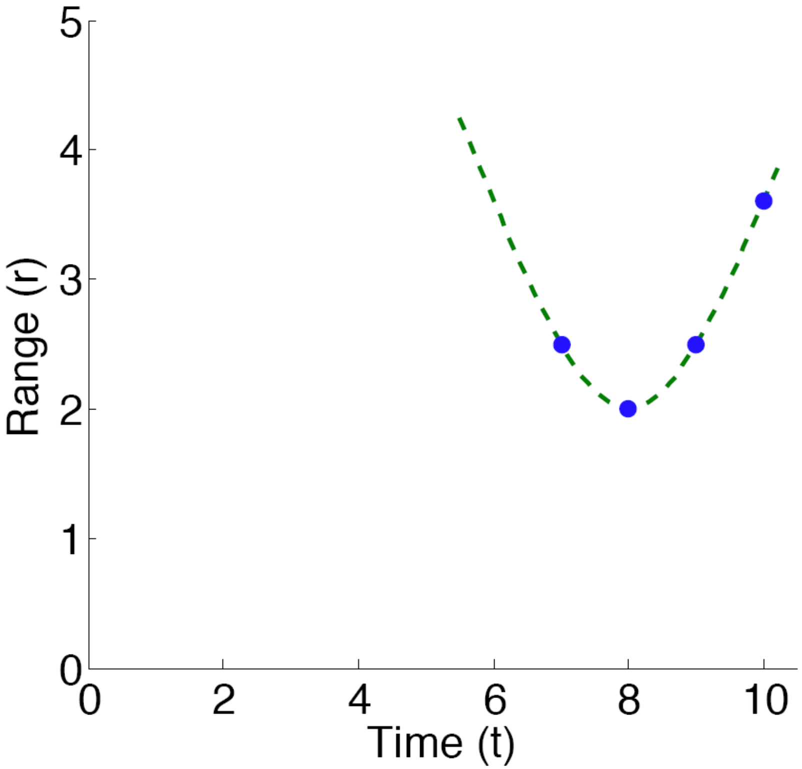


s Relative speed

m Closest distance

t^c Time at closest approach

$$r^2 = s^2(t - t^c)^2 + m^2$$



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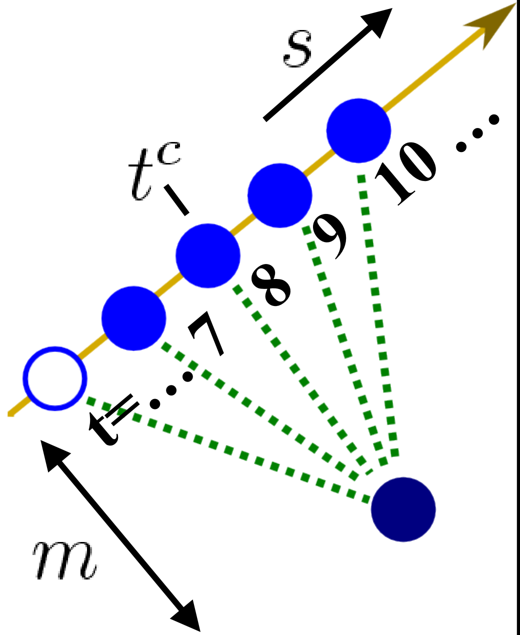
Basic ideas: Dimensionality reduction and convenient change of variables



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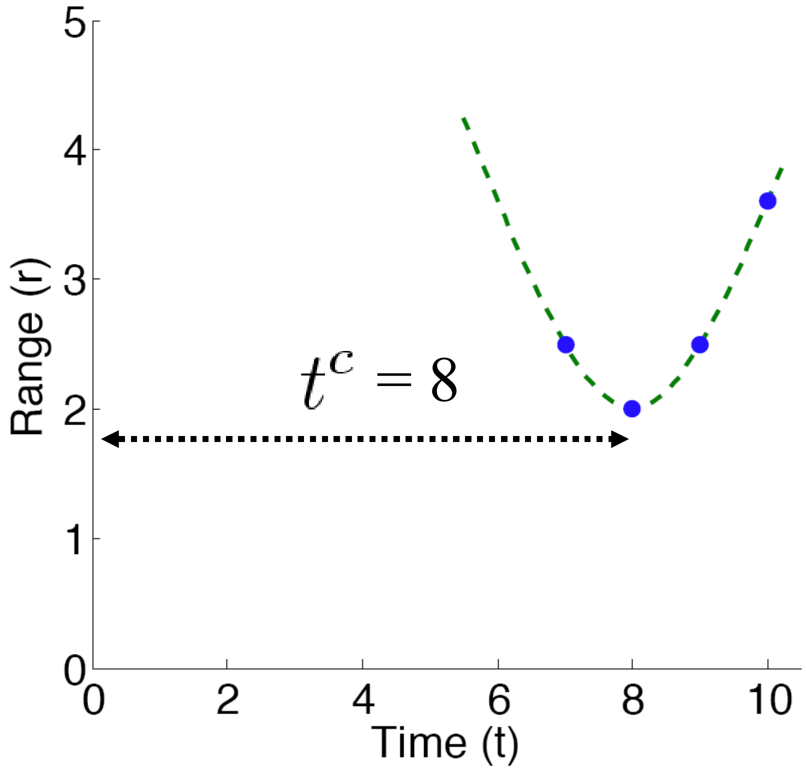
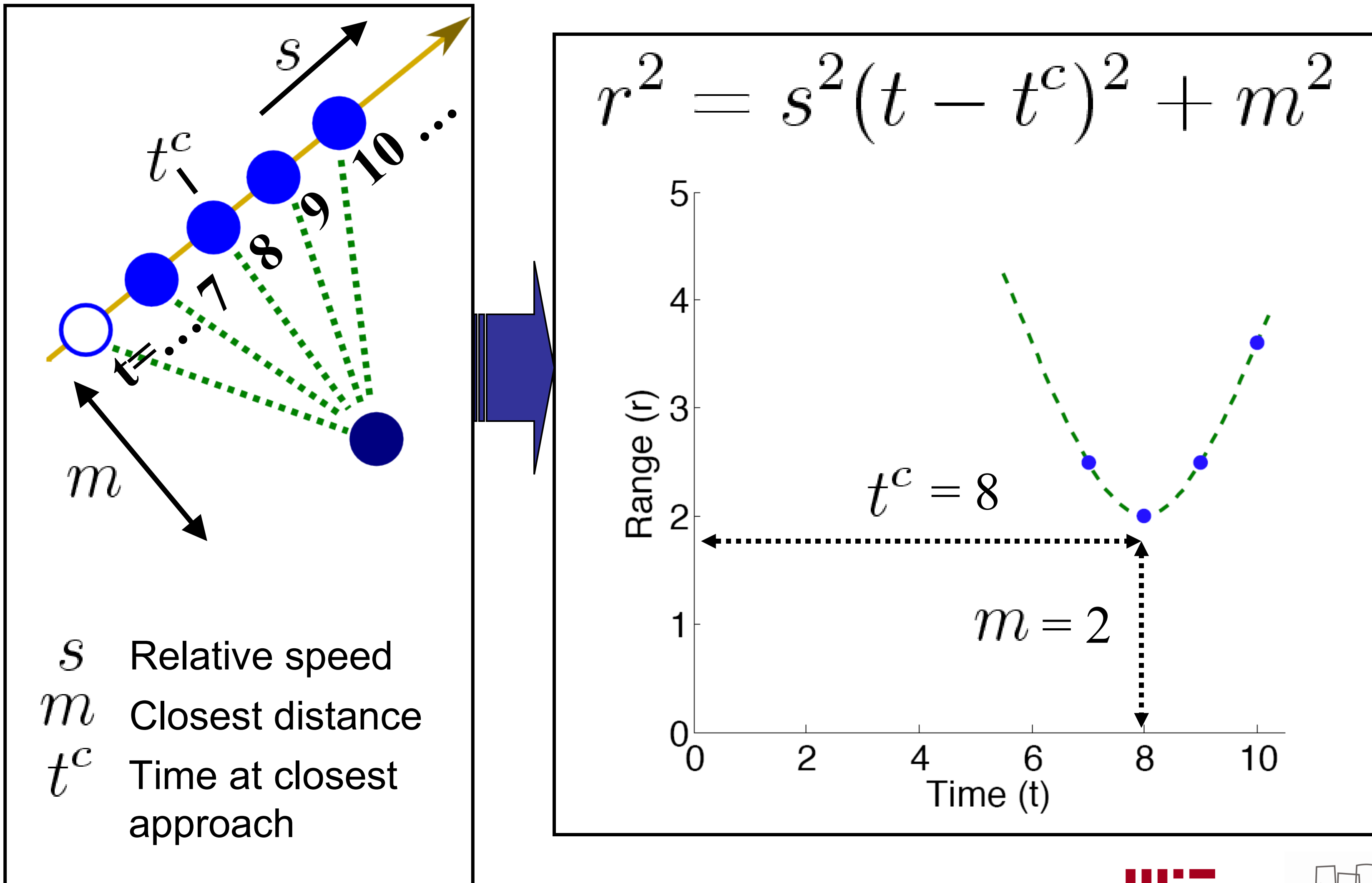


Basic ideas: Dimensionality reduction and convenient change of variables



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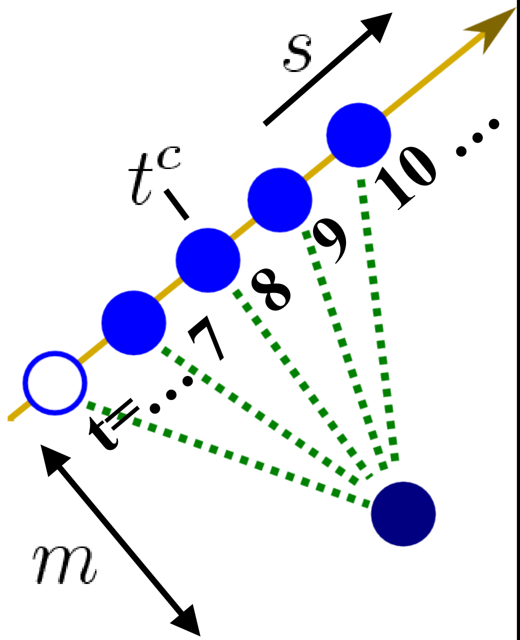
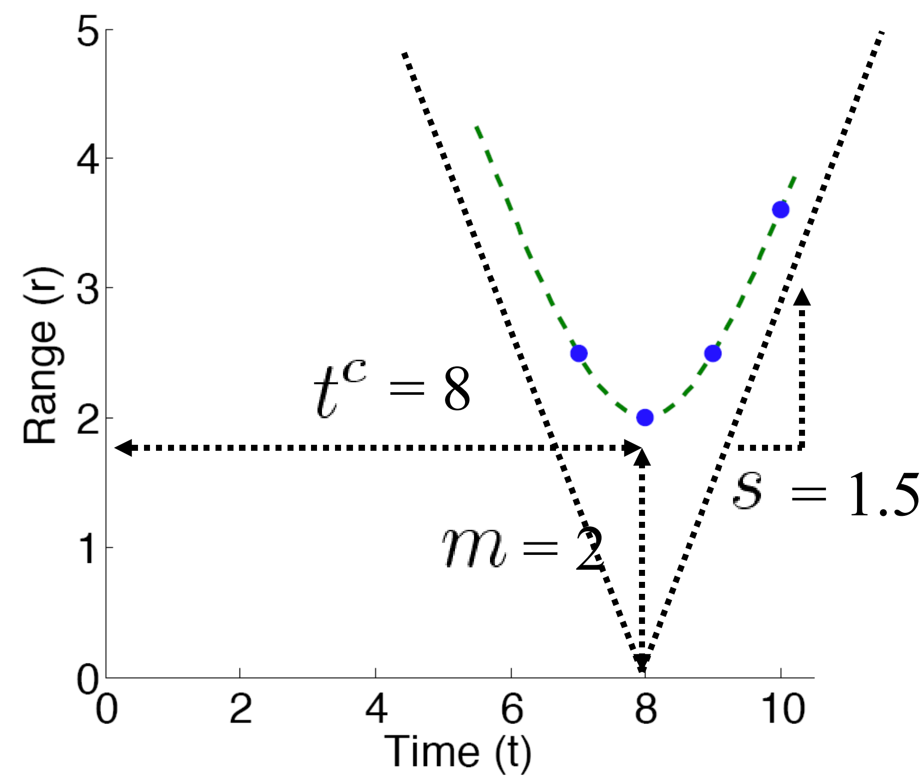
Basic ideas: Dimensionality reduction and convenient change of variables

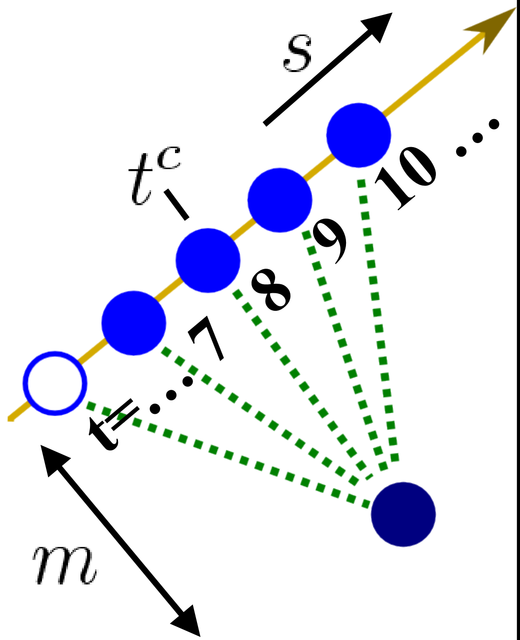


- s Relative speed
- m Closest distance
- t^c Time at closest approach

$$r^2 = s^2(t - t^c)^2 + m^2$$



Why recover trajectories, not positions?



s Relative speed

m Closest distance

t^c Time at closest approach

- Recovers fewer parameters
  - N nodes, M measurements
  - M >> N
  - 2NM parameters (position) model M instants of time
  - 4N parameters (trajectory) model entire motion
- Used for prediction and high-level reasoning
  - Saves computation
  - Saves communication
  - Improves user's situational awareness

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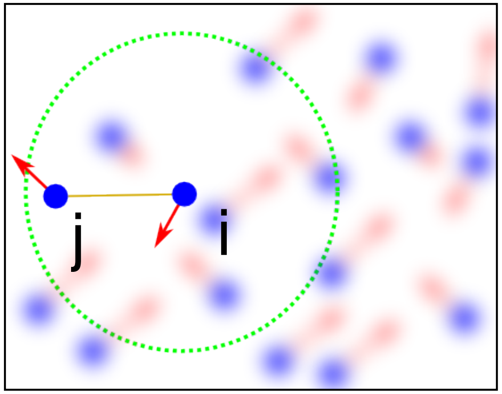
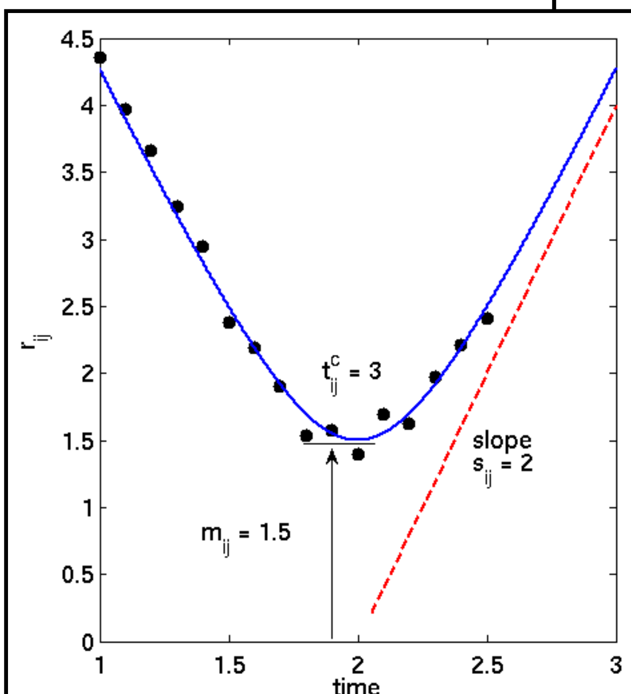
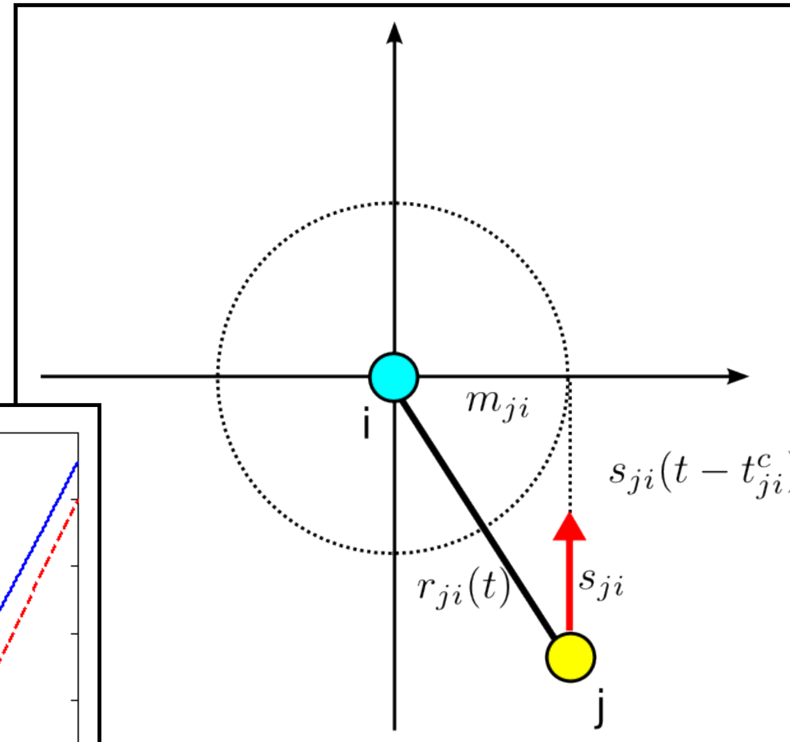
MBL (step 1): From the hyperbola parameters, we can recover pairwise geometry



Linear relative motion produces a hyperbola with three parameters





Relative path must be tangential at time of closest approach

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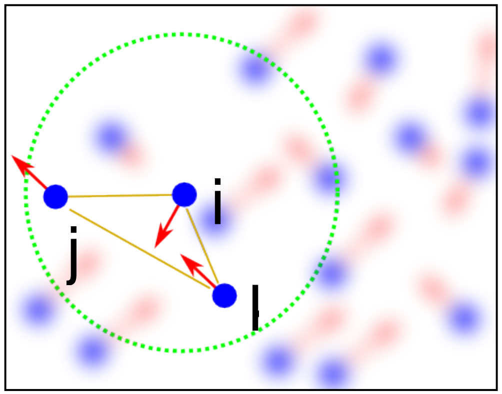
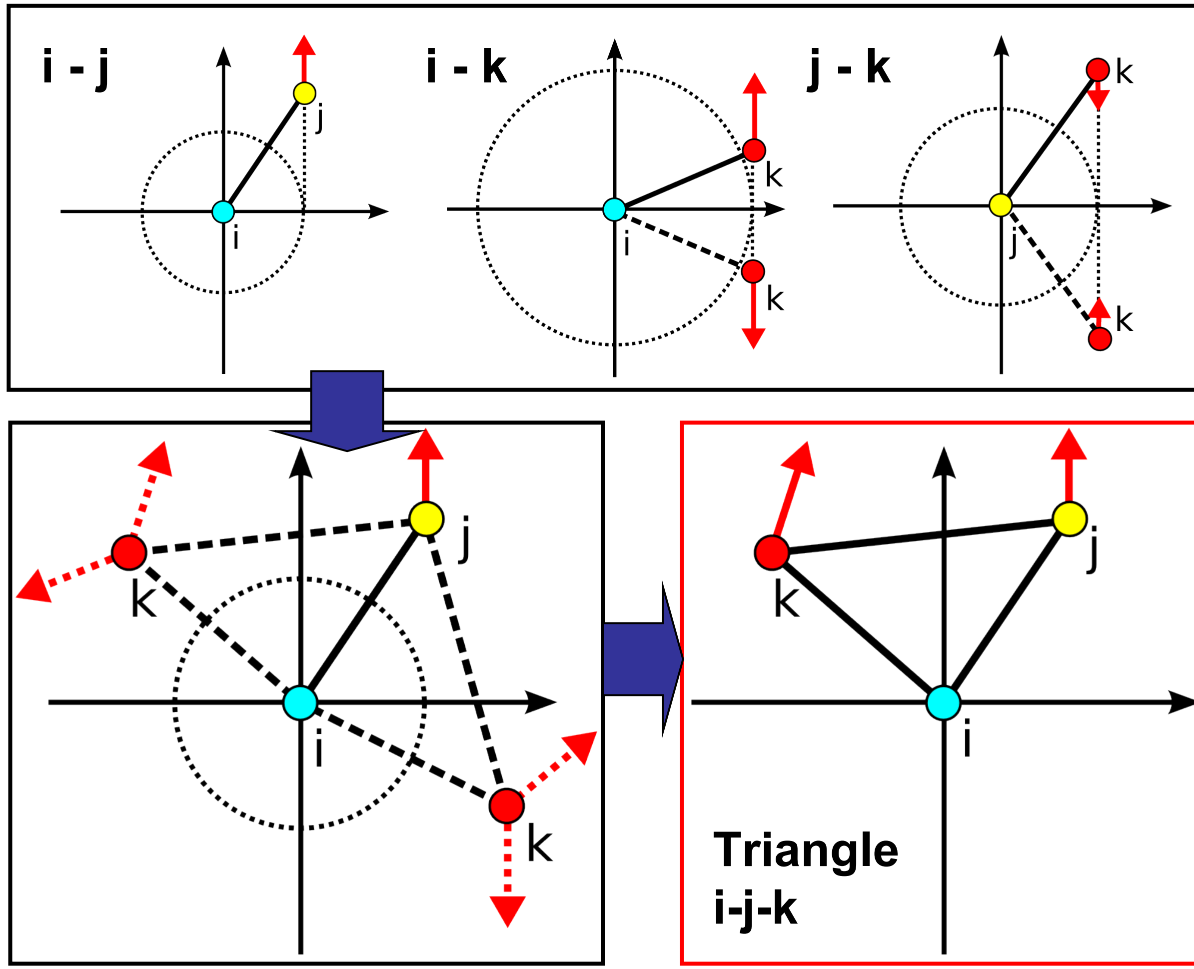
MBL (step 2): Three node pairs make a triangle with velocity vectors





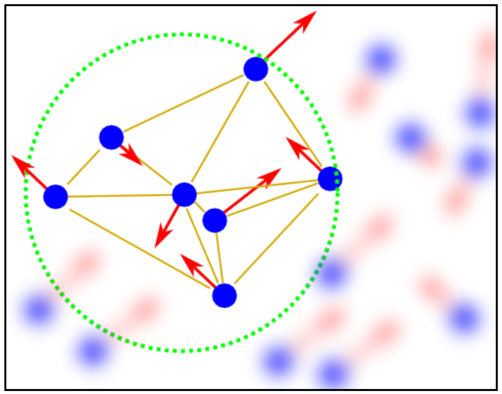
Input :

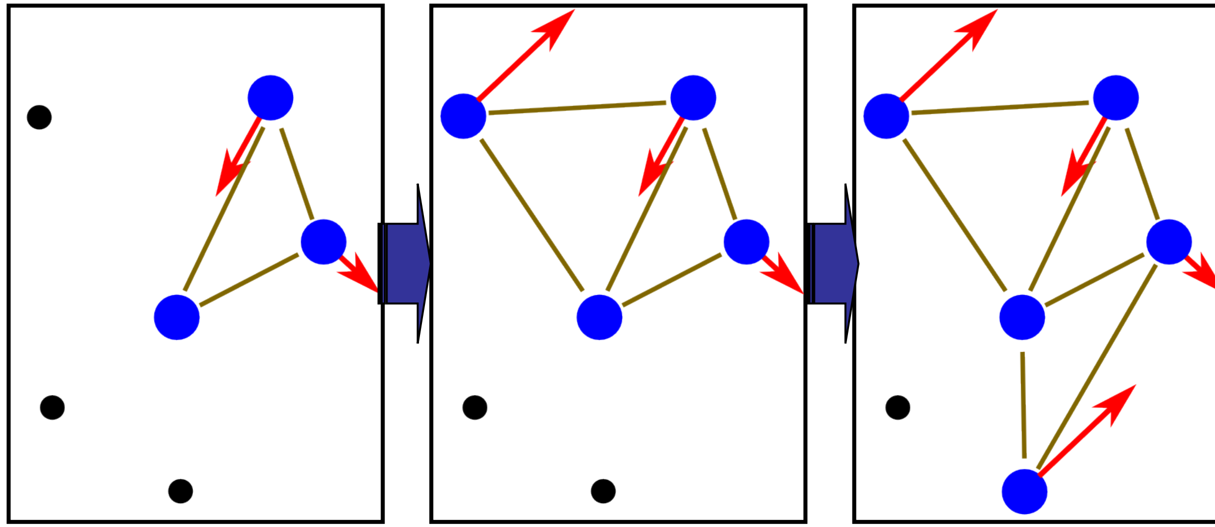
Three node pairs i-j, i-k & j-k

Output :

Triangle i-j-k with velocity vectors

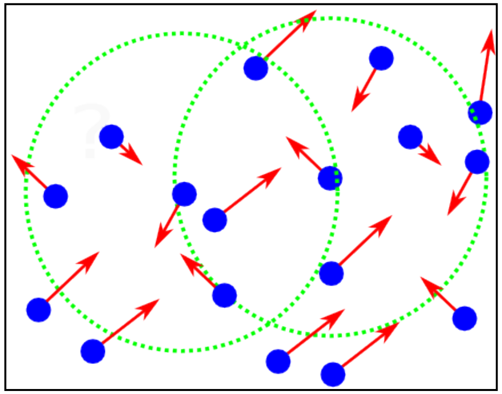
MBL (step 3): Each node computes motion estimates of one-hop neighbors using triangles

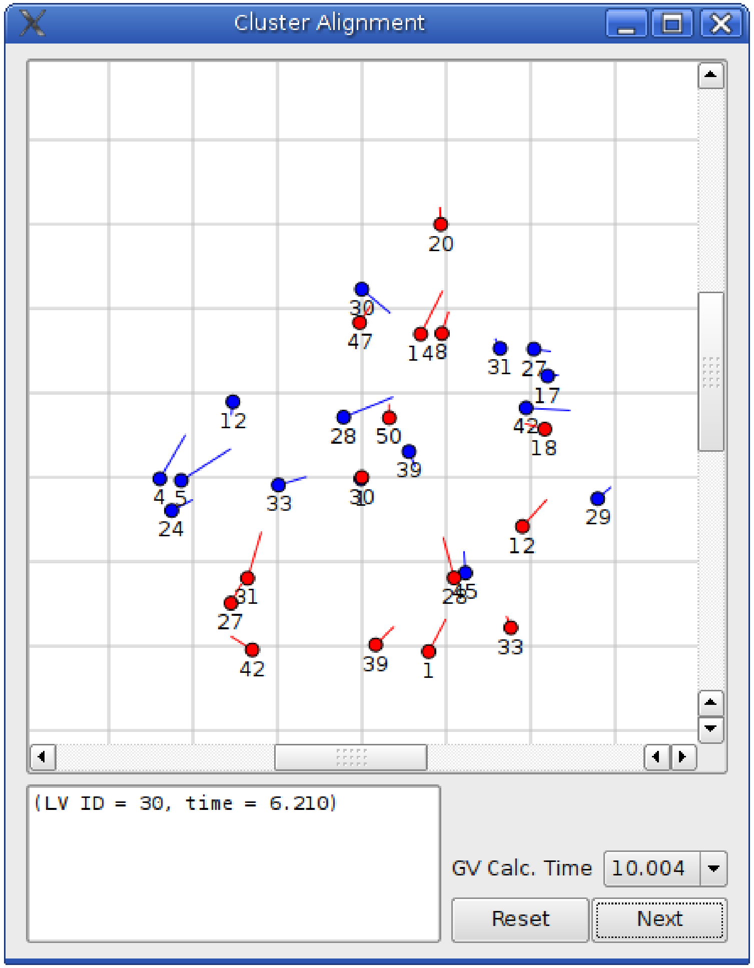




- Iterative trilateration, starting from an arbitrary triangle
- A local cluster consisting of a node and its one-hop neighbors is localized in the node's body frame
- The localized cluster is then broadcast to the network

MBL (step 4): Aligning local clusters constructs a global view of the network *from one node*

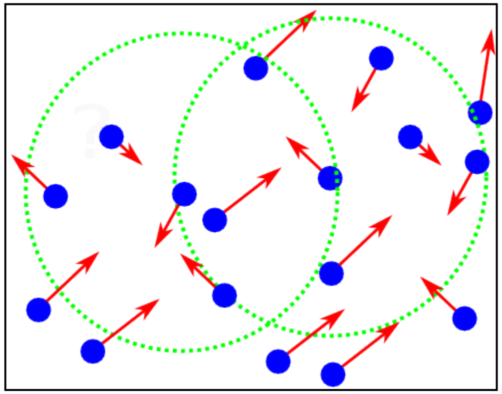


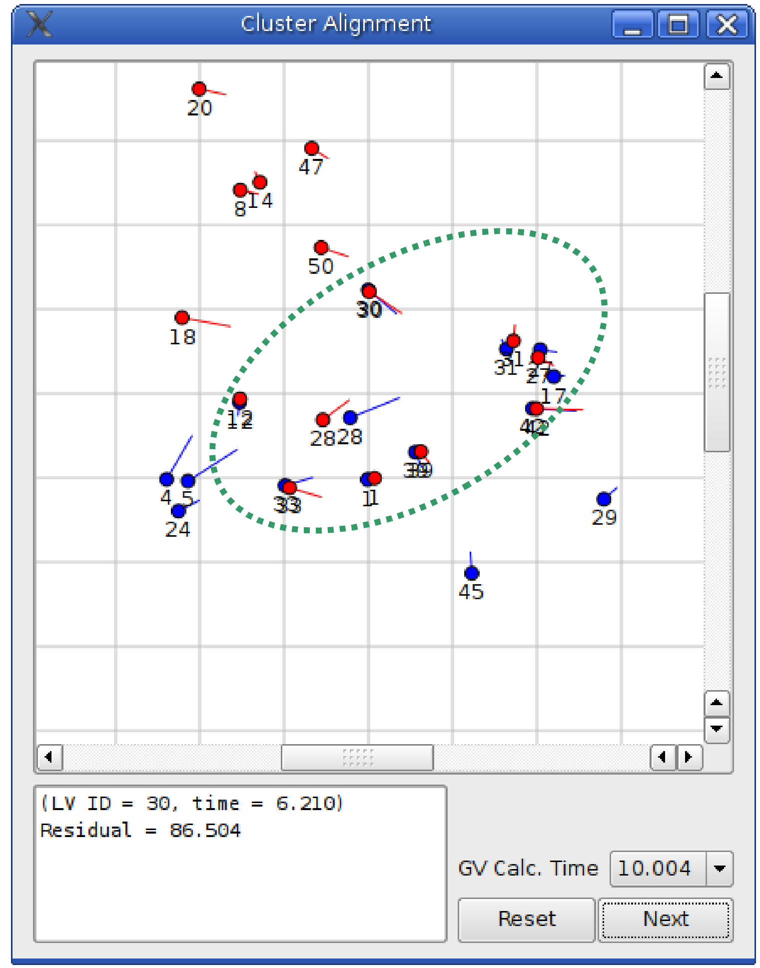


Node-centered view

New local cluster

MBL (step 4): Aligning local clusters constructs a global view of the network *from one node*





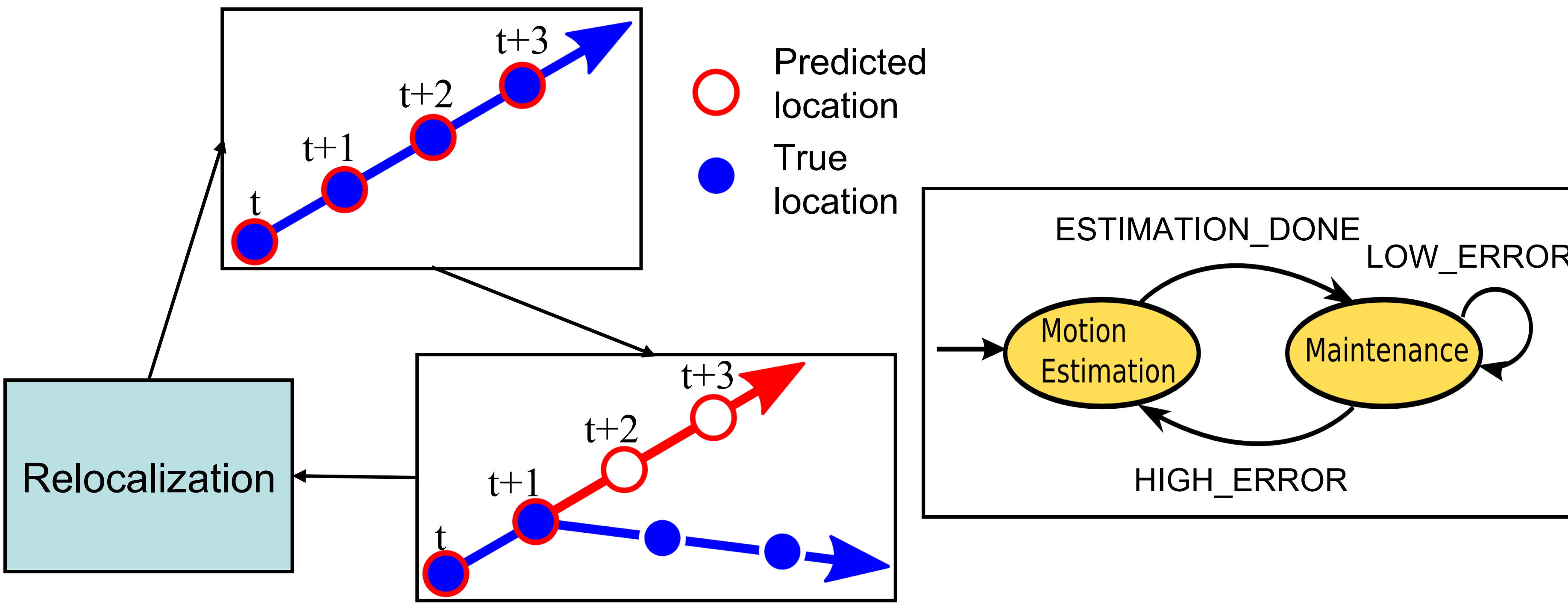
Node-centered view

New local cluster

Common nodes are aligned

(Linear time-complexity in the number of common nodes, Horn et. al., “Closed form solution of absolute orientation using orthonormal matrices”)

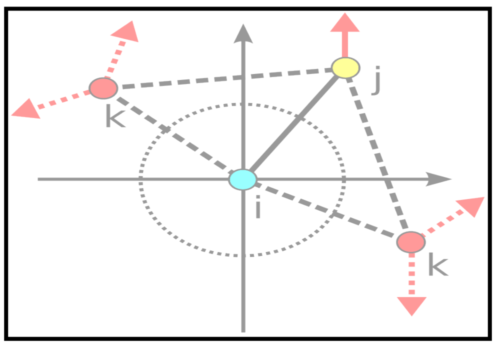
MBL (maintenance): Each node updates its own local cluster when needed



If error between predicted and observed distance goes beyond predefined threshold, a node triggers relocalization

Outline

Motivation and statement of the problem



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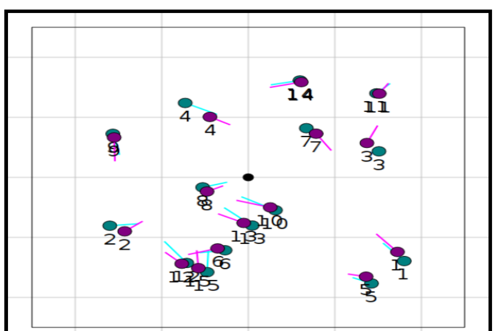
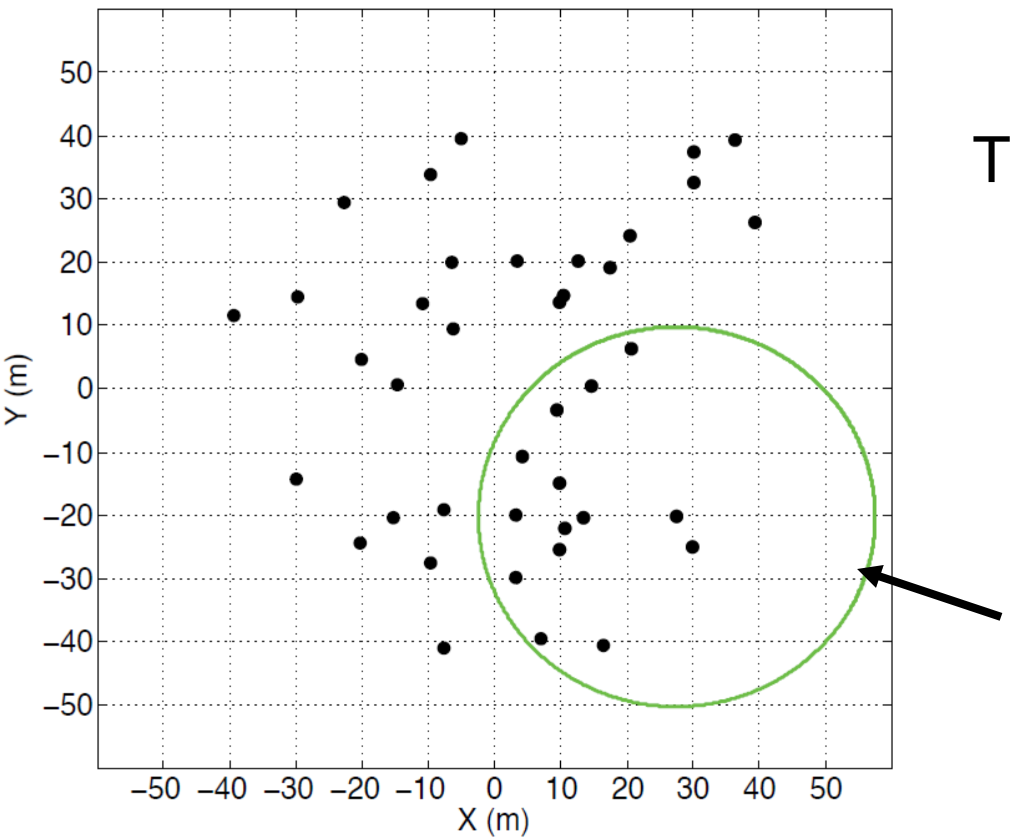


Results and discussion

Result: Simulated network example

- 40 UWB nodes, moving at about 1m/s for 100 seconds
- Random motion on 100 x 100 m grid, 10 m spacing



True node positions at t = 75 sec.

Comm. radius: 30 m

Ranging rate: 5 Hz

Result: Simulated network example

- 40 UWB nodes, moving at about 1m/s for 100 seconds
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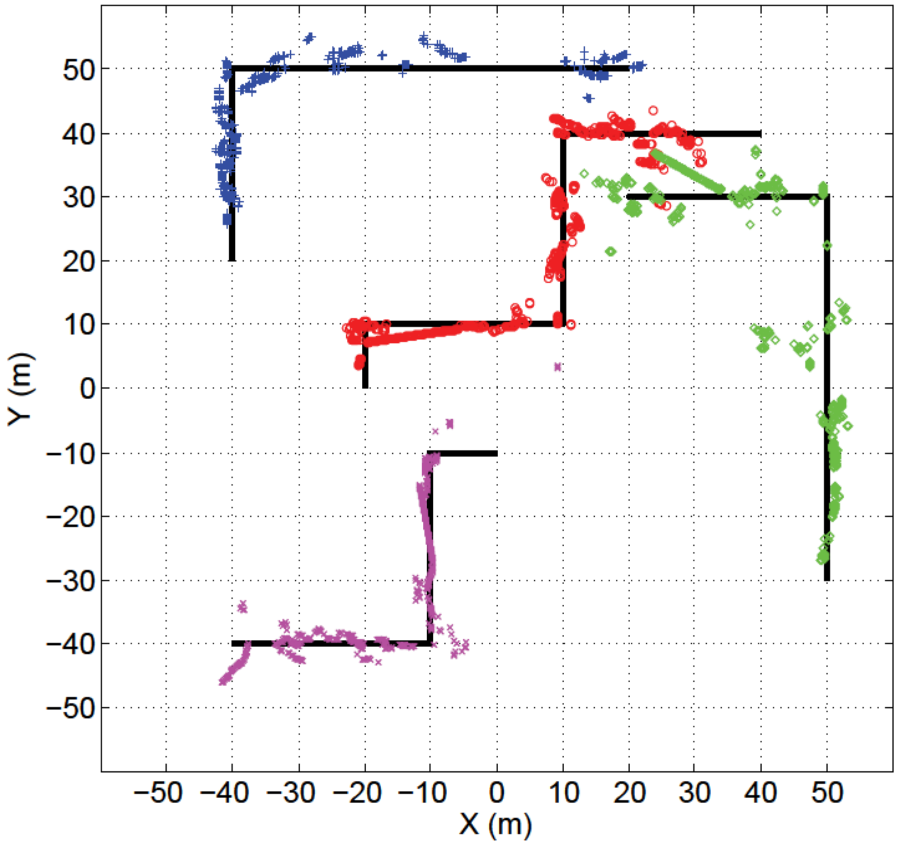

True (black line) and estimated (colored) for four nodes

MBL solution is in node-centered frame, but matched for comparison here

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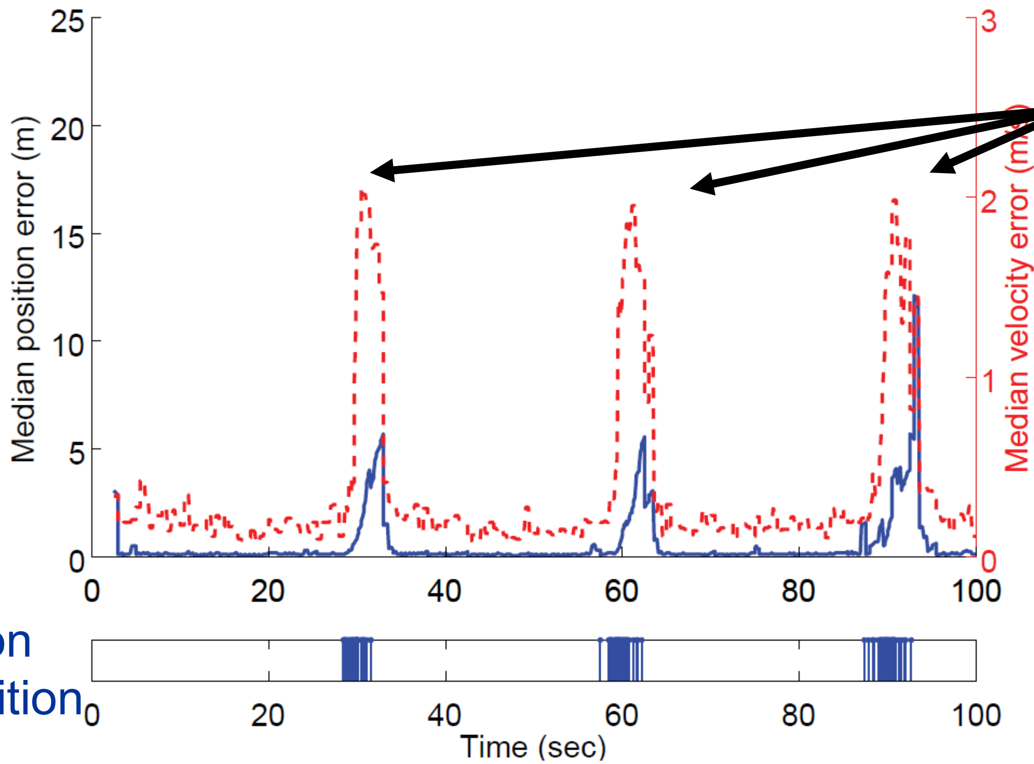
Result: Simulated network example

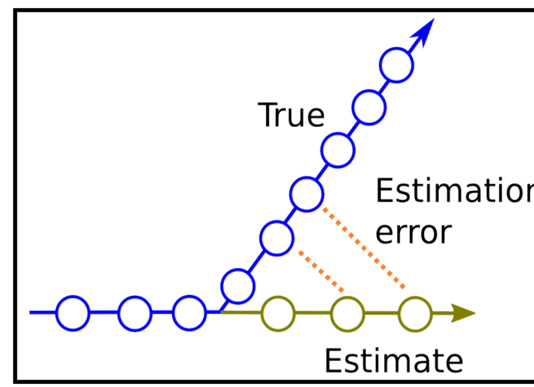
- 40 UWB nodes, moving at about 1m/s for 100 seconds
- Random motion on 100 x 100 m grid, 10 m spacing

~ 30-second transition-free intervals

Transient errors trigger relocalization.



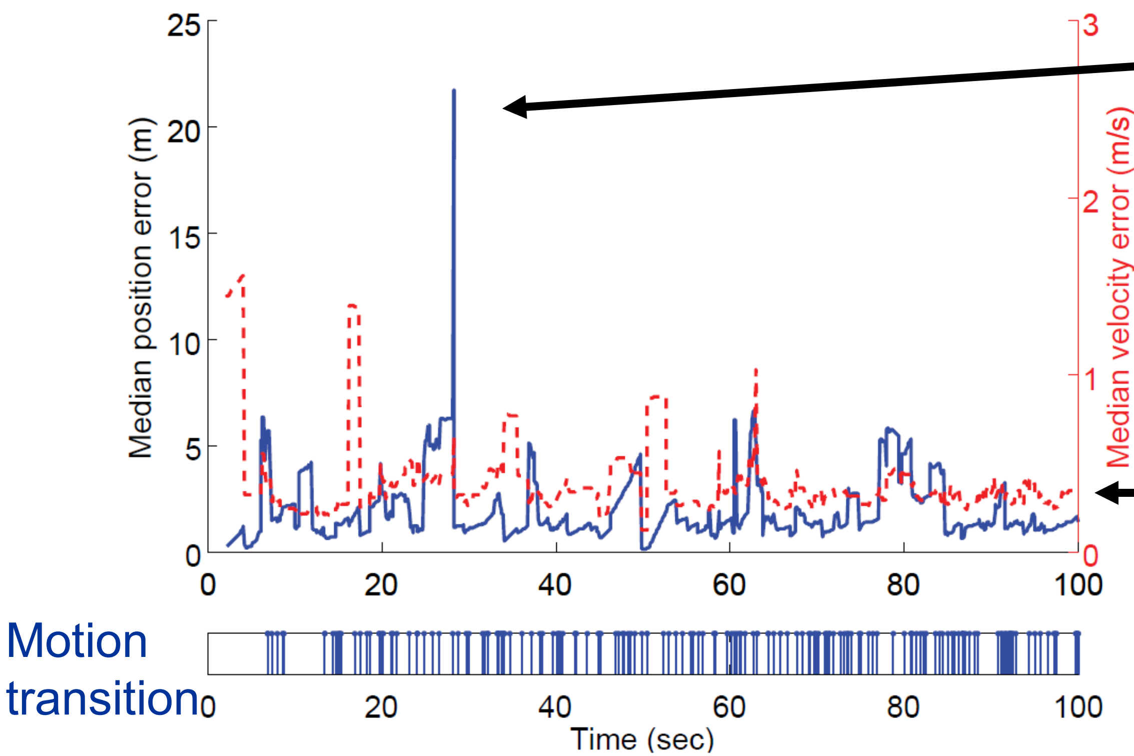
Motion transition



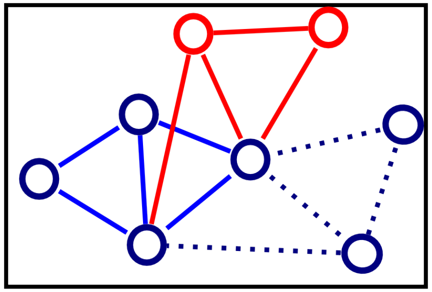
Result: Simulated network example

- 40 UWB nodes, moving at about 1m/s for 100 seconds
- Random motion on 100 x 100 m grid, 10 m spacing

~ 3-second transition-free intervals



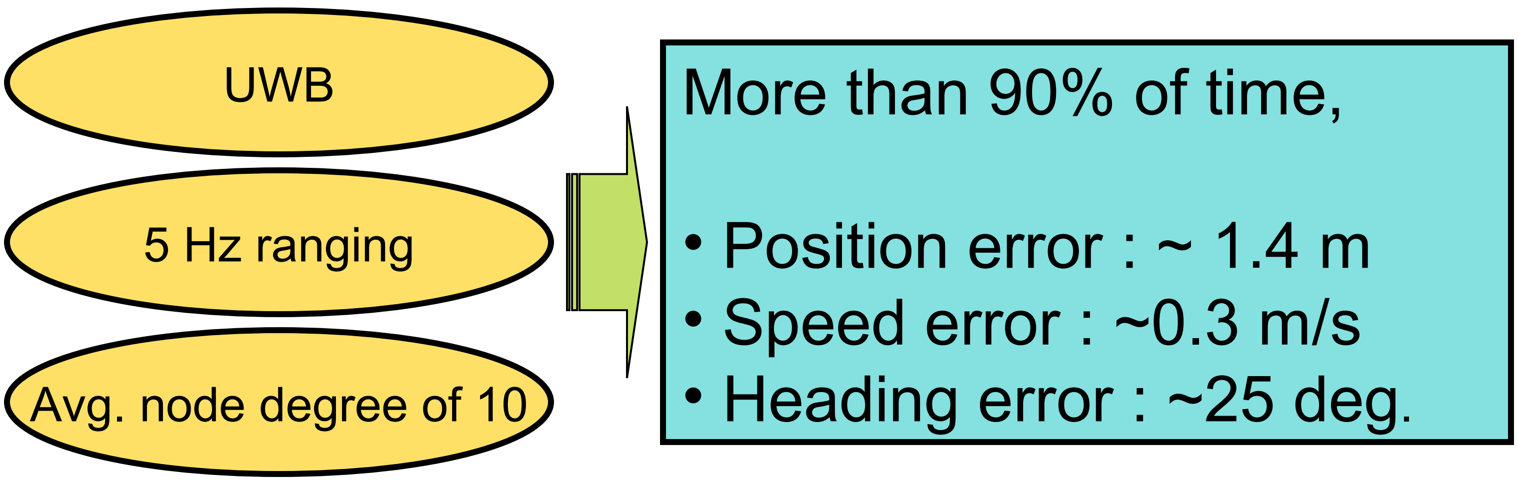
Flip configuration



Each node relocalizes the network more frequently to combat growing transient error

Discussion

- Our method estimates position and velocity of nodes together, thus localizes persistent node trajectories
- Performance of the method



- Recovered trajectories are used for prediction, reducing computation 6x (compared to repeated network solving)

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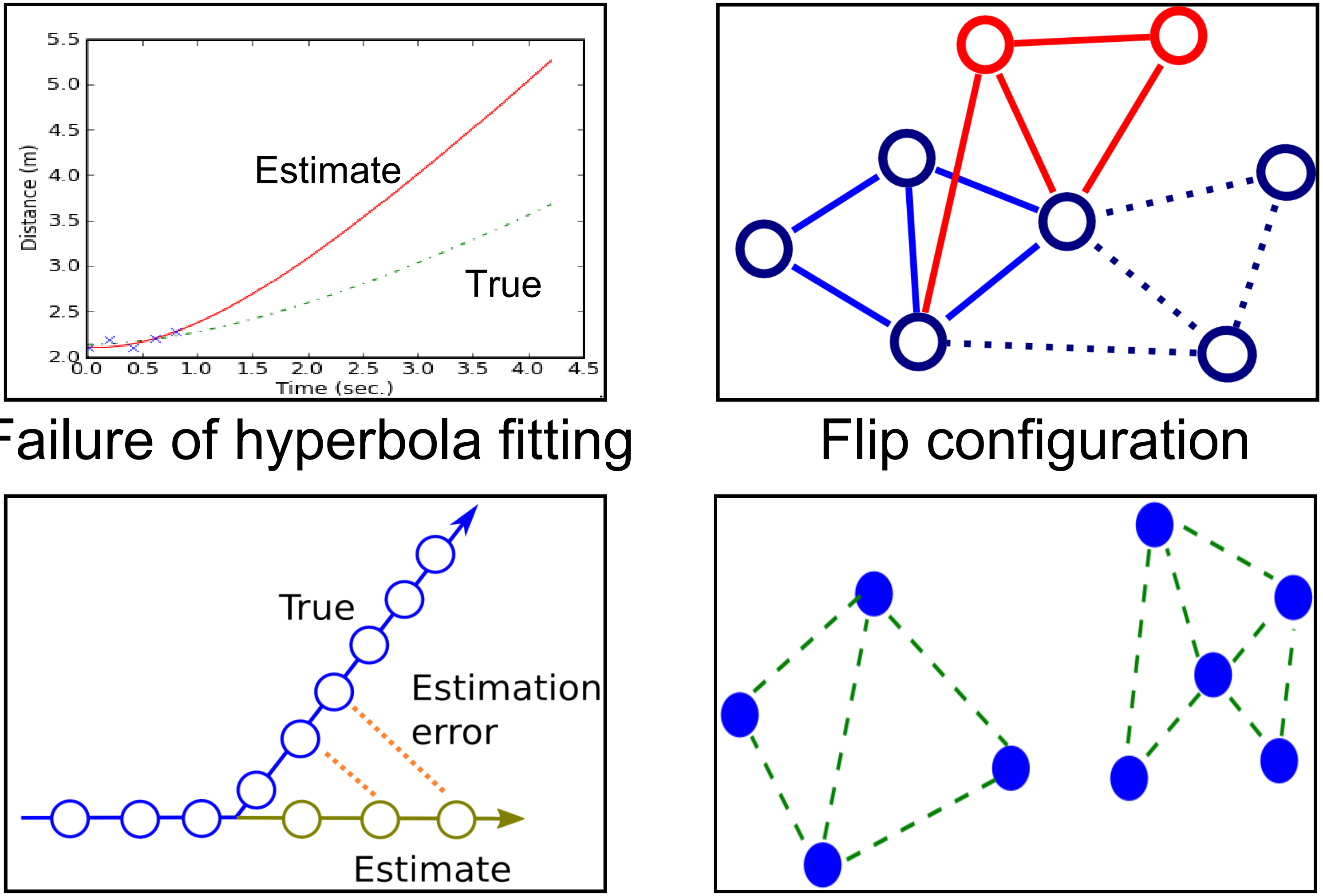
Discussion: Failure modes



Failure of hyperbola fitting

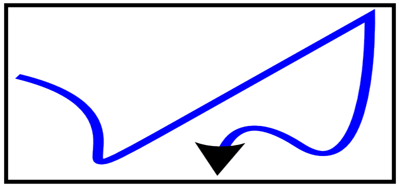
Flip configuration

Transient error

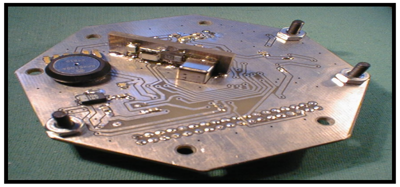
Disconnection

Future work

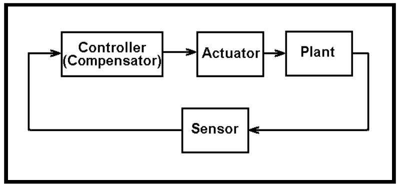
Evaluate the method using actual UWB devices



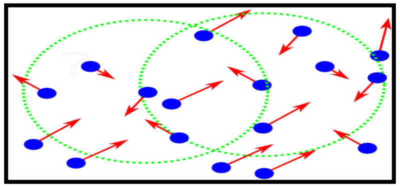
More complex motion paths & velocity profiles



Integration of additional sensors such as MEMS inertial sensors, compasses, and cameras



Feedback for QoS, guidance to movers



Establish quantitative relationship among fundamental parameters: e.g. ranging rate, ranging radius, density, velocity, etc.

Questions?