Testbed Design and Localization in MiNT-2: A Miniaturized Robotic Platform for Wireless Protocol Development and Emulation

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Outline

- Introduction
- The MiNT-2 Node Architecture
- RFID-based Localization
- Experimental Evaluation
- Conclusion & Future Work

Introduction

- Two predominant techniques for wireless protocols development and evaluation:
  - Simulations (NS2, QualNet, GlomoSim)
    - Difficult to capture real-world RF propagation characteristics such as: *Non-uniform path loss, interference, multipath fading*
  - Large-scale, custom-built testbeds (Roofnet, CMU Network)
    - *Limited scenarios, large physical-space requirement, expensive for setup and routine maintenance*

Small-scale testbeds

- MiNT (Miniaturized Network Testbed):
  - Originally developed at the *Stony Brook University*
  - Combines benefits of both simulations and large-scale testbeds
- Architectural Features:
  - **Mobility:** by mounting embedded computing boards on robots
  - **Miniaturization:** using RF attenuation & Tx-power control

Small-scale testbeds

- ORBIT
  - Topology formation: Explicit noise-injection to control pair-wise SNR
  - Mobility: based on migration of execution state
- Mobile Emulab
  - Motes mounted on robotic platforms
  - Needs manual recharging of robots
- CMU Wireless Emulator
  - Emulation of RF propagation (FPGA based DSP Engine)
  - Performance depends on accuracy of models

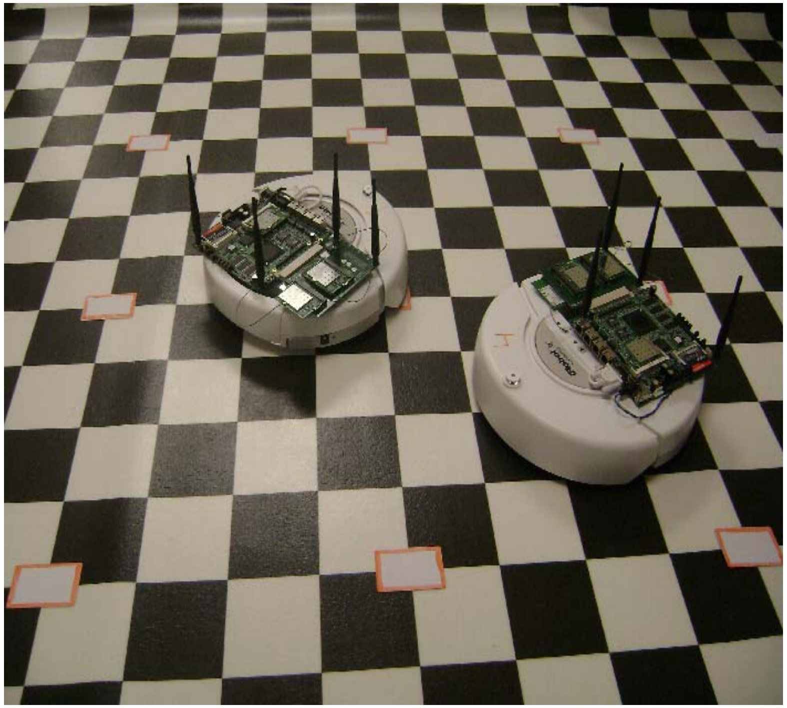
Localization Techniques

- To accurately estimate the nodes positions for:
  - Automatic topology formation & reconfiguration
  - Providing fairly accurate node mobility
- Vision based localization
  - Cameras mounted on ceiling
  - High accuracy when calibrated
  - However, inaccuracy may grow over time due to
    - Slight camera movements
    - Fading of color patterns
- Infrared/Ultrasonic localization
  - Expensive in terms of the cost and processing capacity required
  - Needs line-of-sight

Contributions

MiNT-2: The next generation of the original MiNT testbed.

- **Node design:** Reproducing the testbed using efficient but inexpensive hardware
- **Decentralized localization:** RFID-based localization mechanism



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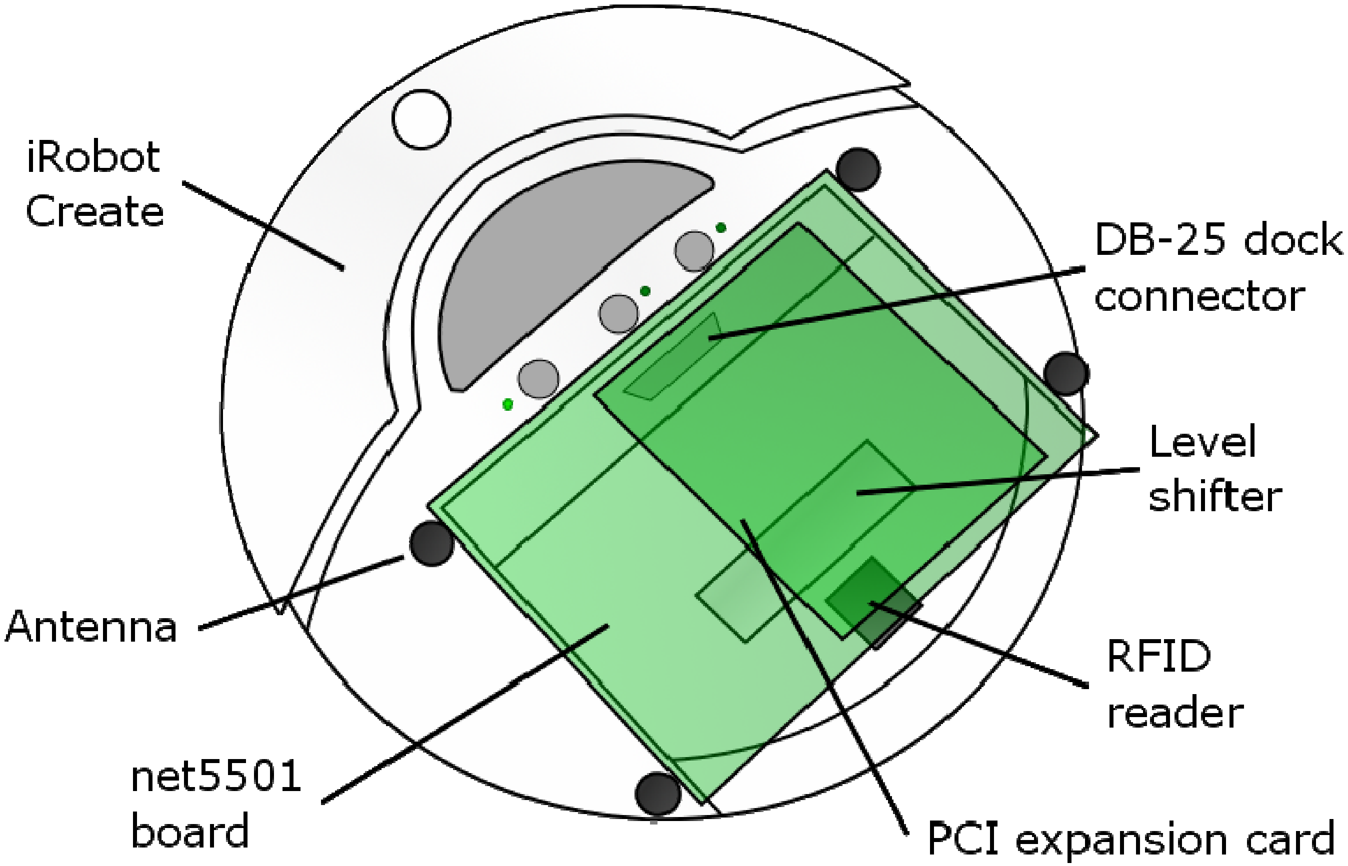
The MiNT-2 Node
(Architecture)

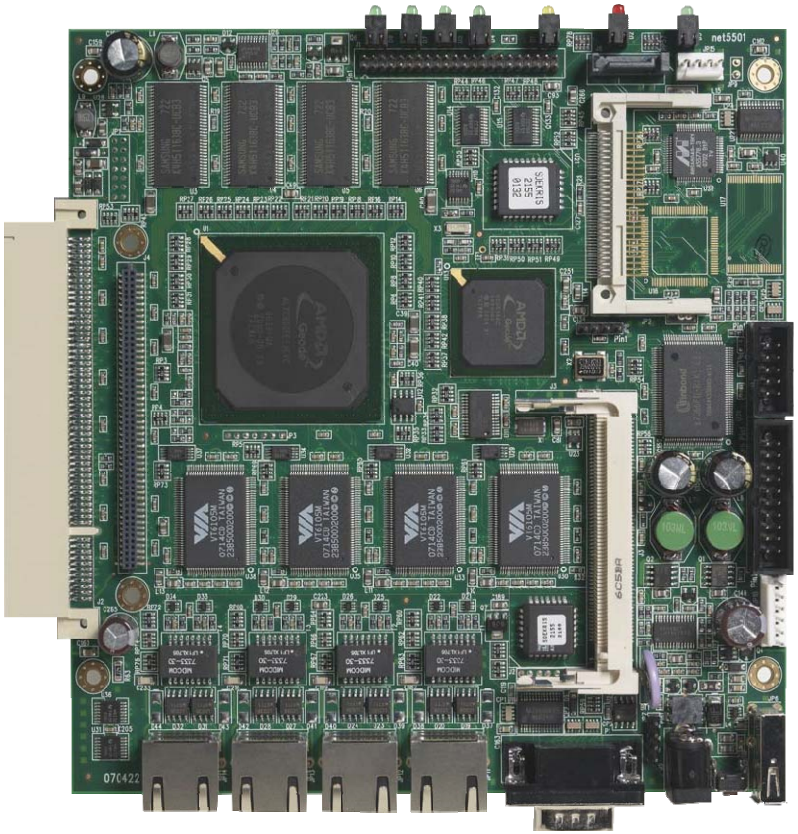


The MiNT Node
(Mobility & Miniaturization)

- **Mobility base:** Create robot
  - Wide range of 2D mobility:
    - Forward and reverse straight lines, Arcs of arbitrary radius, Rotation in place
  - Well-powered
    - Up to 4 hours of battery life
- **Miniaturization:**
  - 20dB fixed attenuator
  - Transmission power control

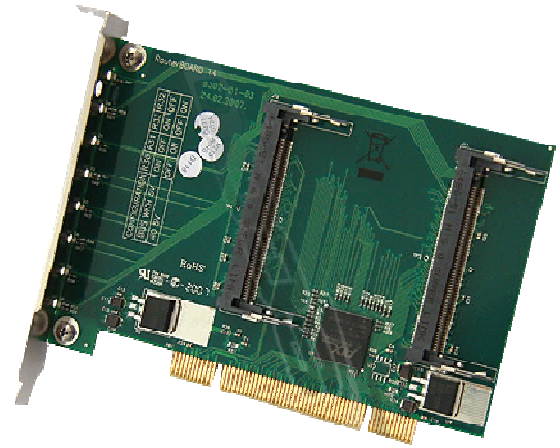
The MiNT Node
(Processing)

- Soekris net5501 x86 embedded board
- 433MHz processor
- 256MB RAM
- 2GB Flash card
- Support for external router board



The MiNT Node
(Wireless Communication)

- One 802.11g interface used for control
- Up to four simultaneous 802.11a interfaces for experiments



The MiNT Node
(Localization Hardware)

- RFID: Radio Frequency Identification
  - *Passive* RFID technology
  - Short-distance reading range
  - Inexpensive tags and readers
- RFID Reader
  - mounted on the base of each robot
  - Connected via serial interface to the Soekris board
- RFID Tag
  - Array of tags on floor
  - Each RFID tag is associated with *(x,y)* coordinate
- Error margin for position estimation: 2.25cm

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RFID-based Localization
(Motivation)

- Localization support from iRobot Create
  - Angle and distance sensors (readings w.r.t. last query)
  - Significant inaccuracies due to:
    - rounding error,
    - wheel slippage,
    - encoder error

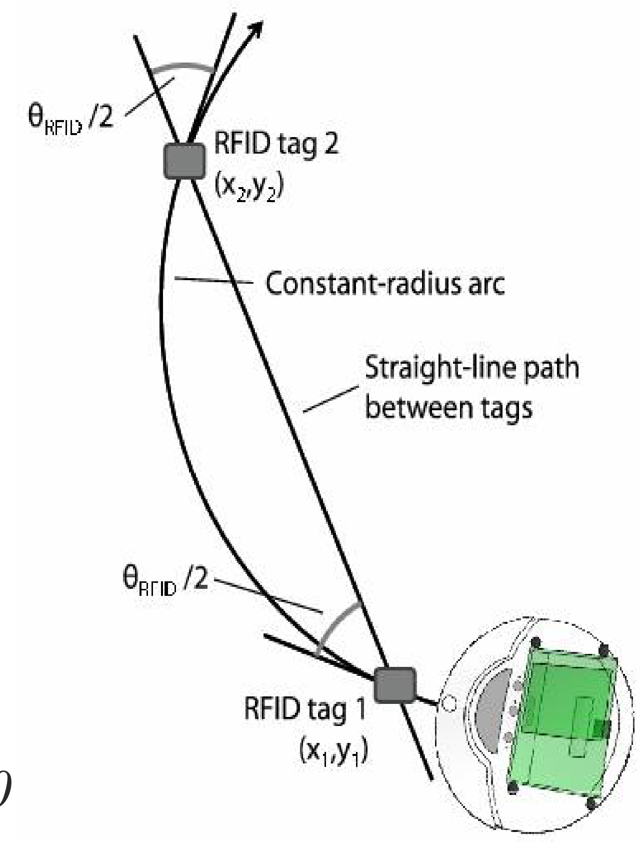
Thus, a need for additional localization mechanism.

RFID-based Localization
(Advantages)

- Position error is bounded by the reading range of the tag
- Each node can independently determine its own position – thus, easily scalable
- Inexpensive in terms of processing and overall cost
- No line-of-sight requirement

RFID-based Localization
(Approach)

- Position calibration: upon tag detection
- Frequency of reading position sensors: *50 milliseconds*
- Orientation calibration:
  - Necessary to estimate position between two tags



$$\theta = (\tan^{-1}[(y_2 - y_1)/(x_2 - x_1)] + \theta_{RFID}/2)\ \%\ 360$$

RFID-based Localization

- **Initial calibration:**
  - To support dropping off of the robot at any place in the testbed
  - Cross two tags in a straight line to determine orientation

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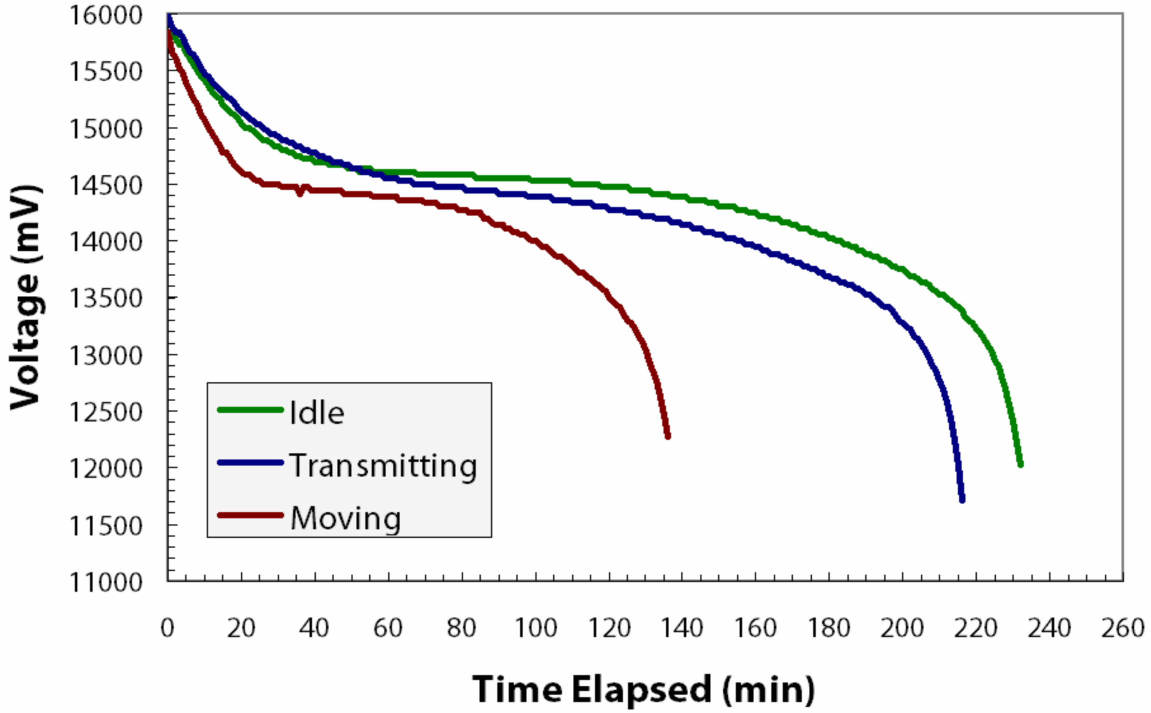
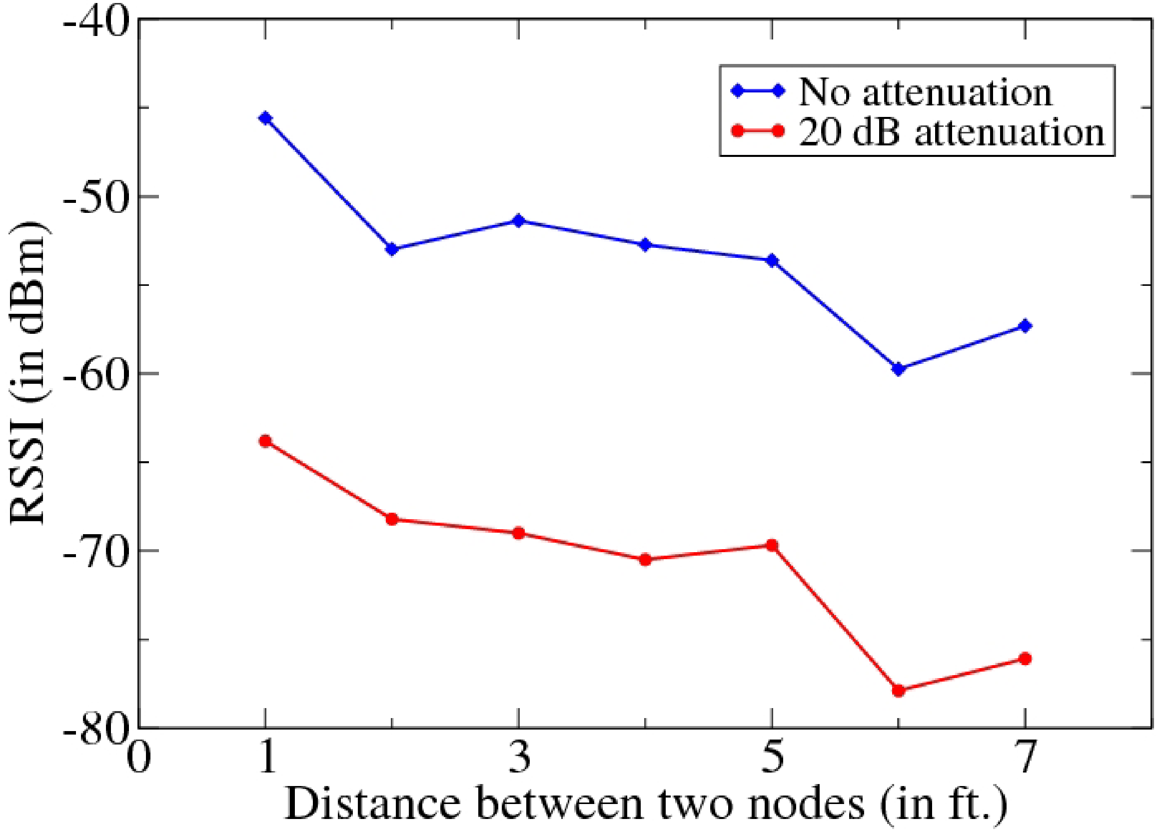
The MiNT Node
(Energy dissipation)



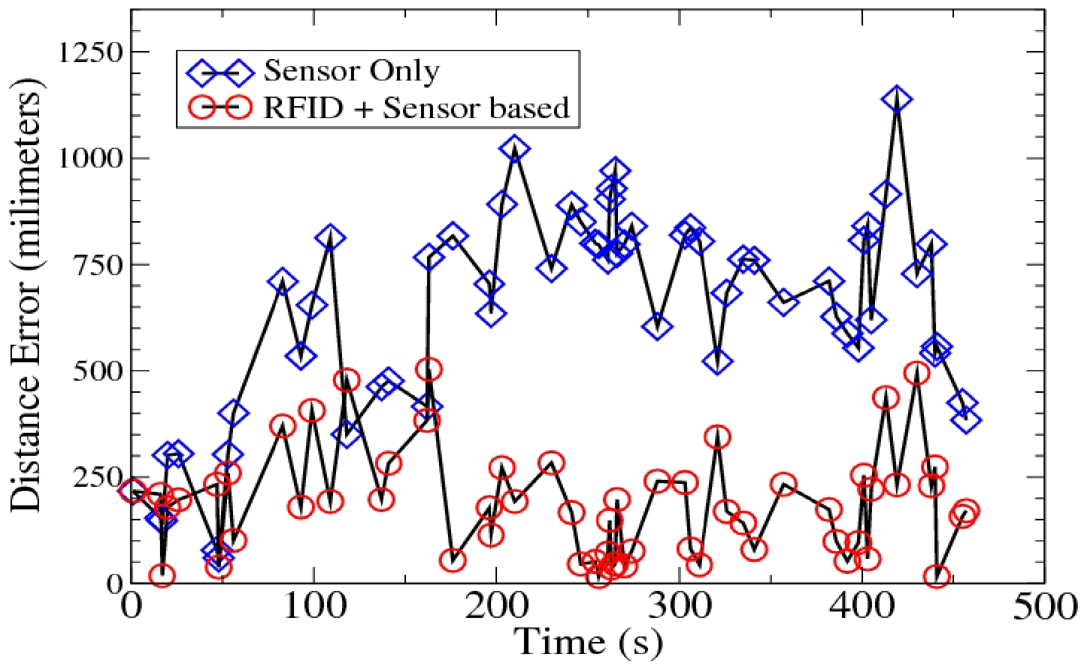
Idle: 3 hours 55 minutes
Constant WiFi Transmission: 3 hours 36 minutes
Constant Movement: 2 hours 15 minutes

Experimental Evaluation
(RF Attenuation)



Experimental Evaluation
(Localization)

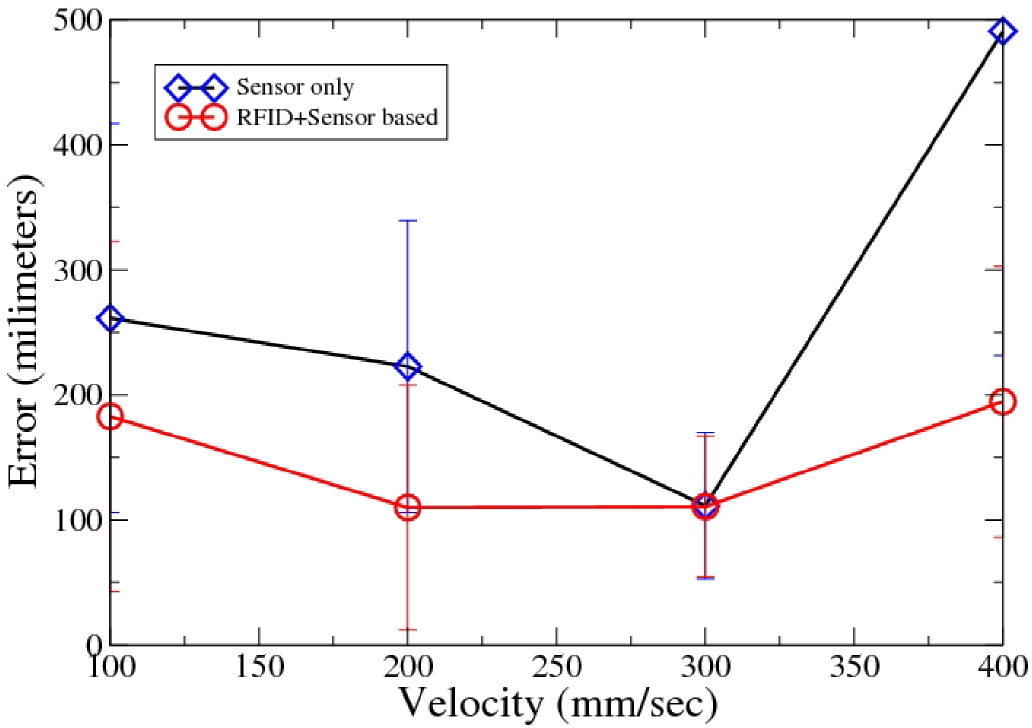
- Sensors-based vs RFIDs-based localization



Position error has been reduced to avg. 6cm with more recent improvements

Experimental Evaluation
(Localization)

- Effect of parameters: Robot velocity



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Conclusion & Future Work

- In this work, we proposed
  - Design and construction of MiNT-2 nodes
  - Design and development of RFID-based localization mechanism
- In future, we plan to
  - Improve the accuracy of the localization technique
  - Automatic topology formation
  - Fault injection support

Thank you!

Questions?

The MiNT Node
(Processing)

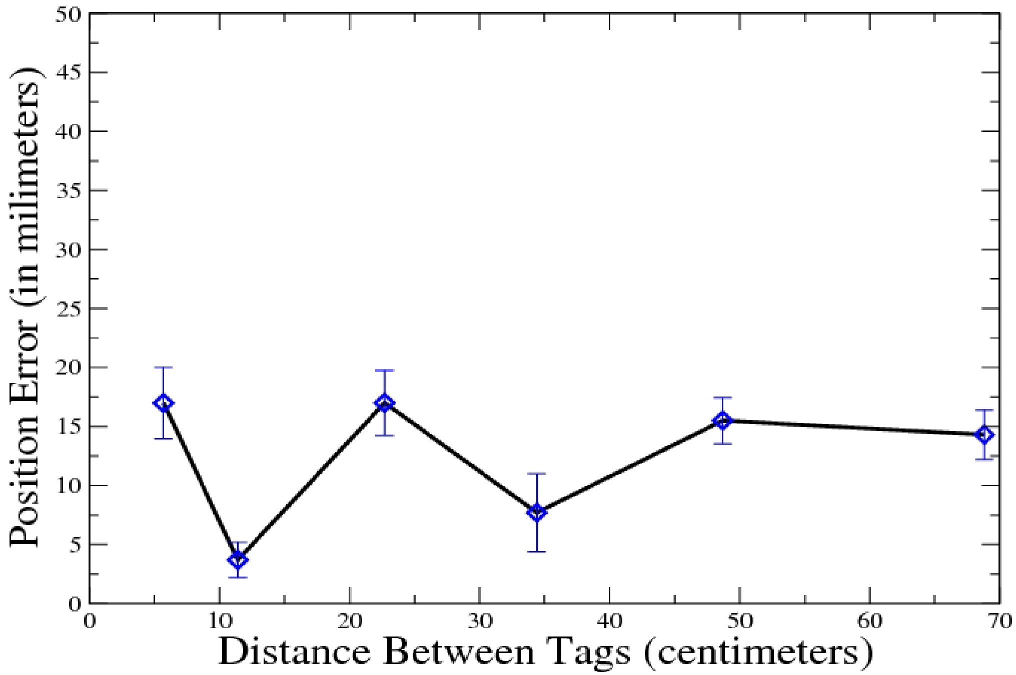
- Operating System: Voyage Linux
  - Debian-based, light Linux distribution
  - Preconfigured for Soekris net5501
  - Designed to run off a Compact Flash card
    - Optimized to minimize writes
- Distributed, hybrid NS2
  - Pass packets over physical network interfaces
  - Maintain ability to run NS2 scripts

The MiNT-2 Node
(Cost)

iRobot Create with battery and charger	$250
Soekris net5501 x86 embedded board	$260
PCI to 4x miniPCI adapter card	$65
4x R52 802.11a/b/g cards	$200
4x antennae	$60
3x attenuators	$100
ID-12 RFID reader	$30
Small miscellaneous components	$35
Total	**$1000**

Experimental Evaluation
(Sensors Accuracy)

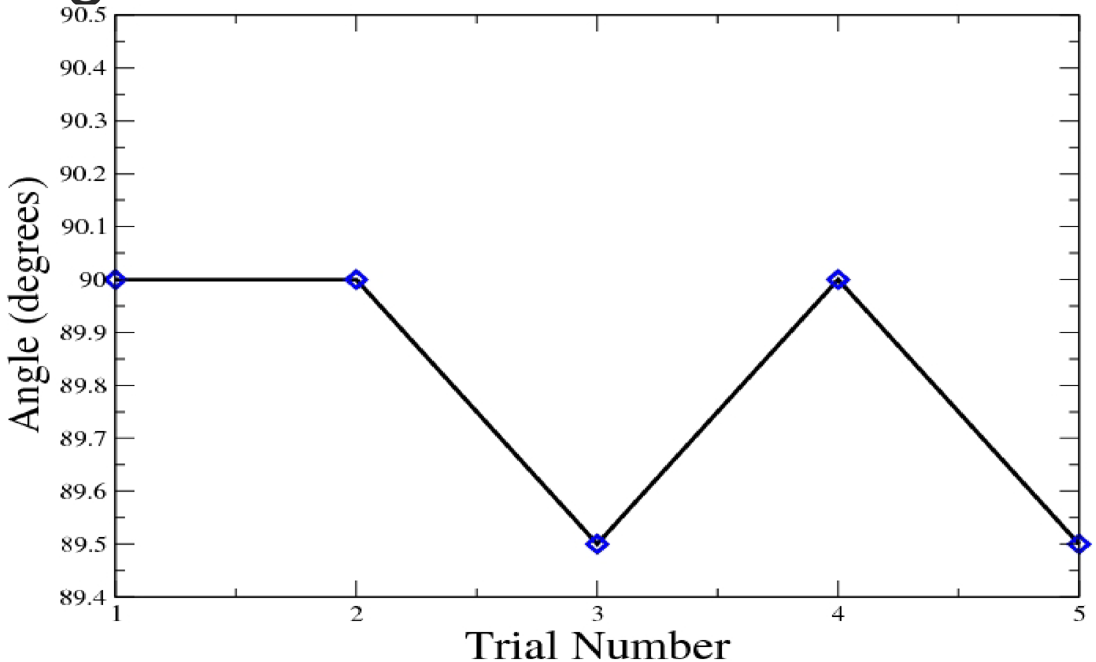
- Distance Sensor



- RFID tags deployment: Uniform
- Straight line movement

Experimental Evaluation
(Sensors Accuracy)

- Angle Sensor



- RFID tags deployment: Pyramid-like structure
- Straight line movement from the tip to the base

Experimental Evaluation
(Localization)

- Effect of parameters: frequency of updates