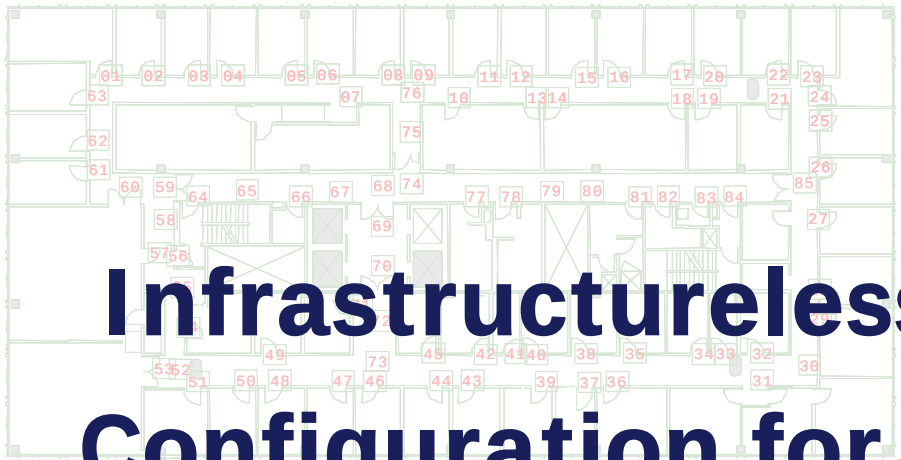
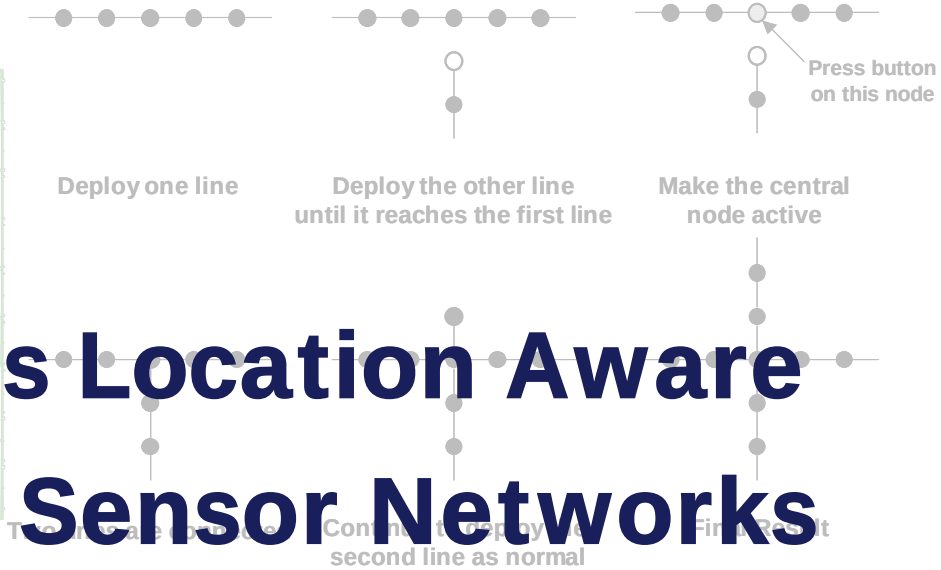


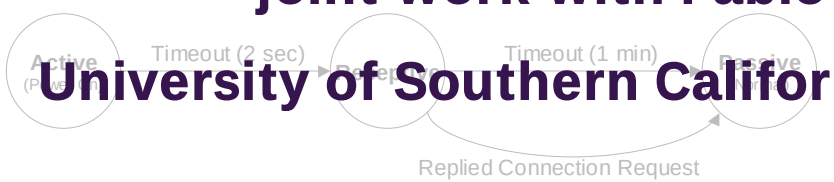


Infrastructureless Location Aware Configuration for Sensor Networks

Xi Wang

joint work with Fabio Silva and John Heidemann

University of Southern California, Information Sciences Institute



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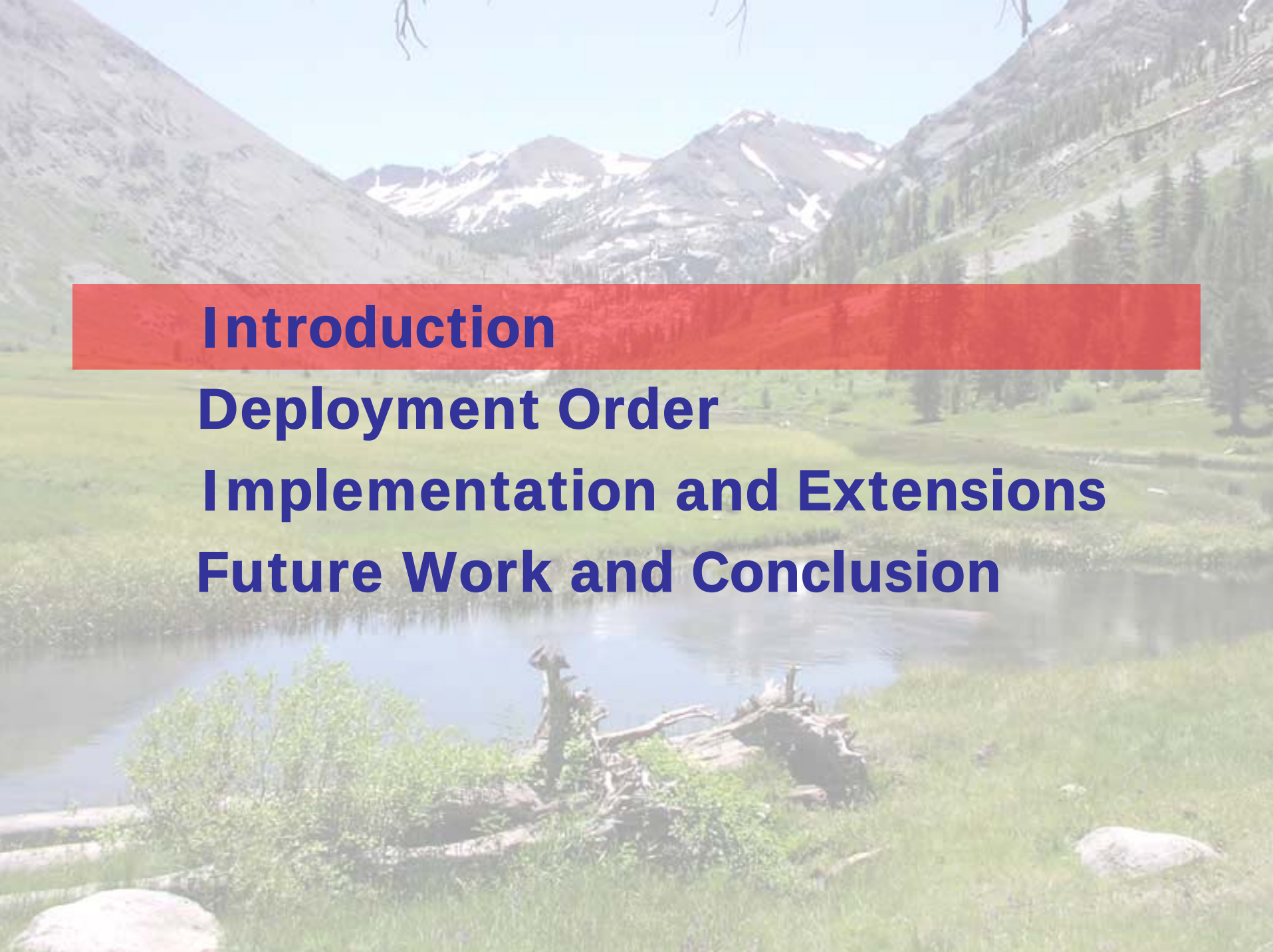
12/20/2004

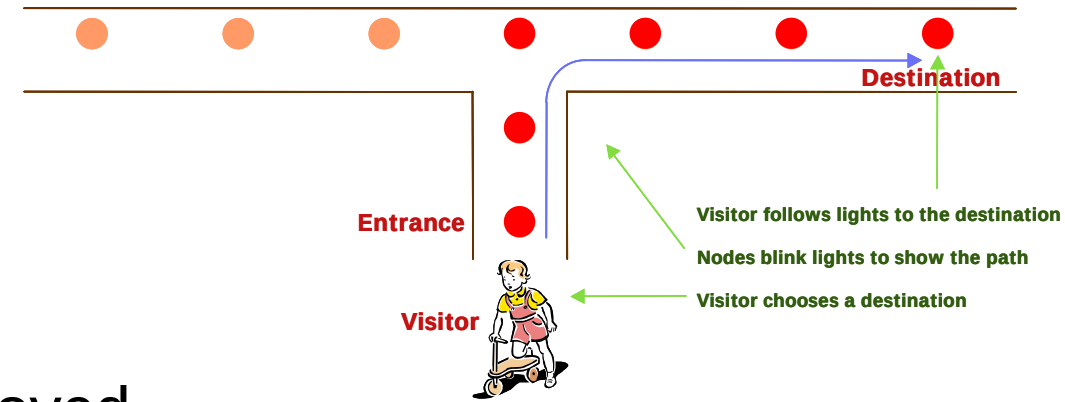

Introduction
Deployment Order
Implementation and Extensions
Future Work and Conclusion

Background

- Sensor networks
  - Configuration is important
    - Network: Ad hoc deployment
    - Nodes: Numerous, small and inexpensive
  - Location information is important
    - Essential environmental parameter
- This paper
  - Deployment order – configuration of (logical) location
  - Follow-me – a working application

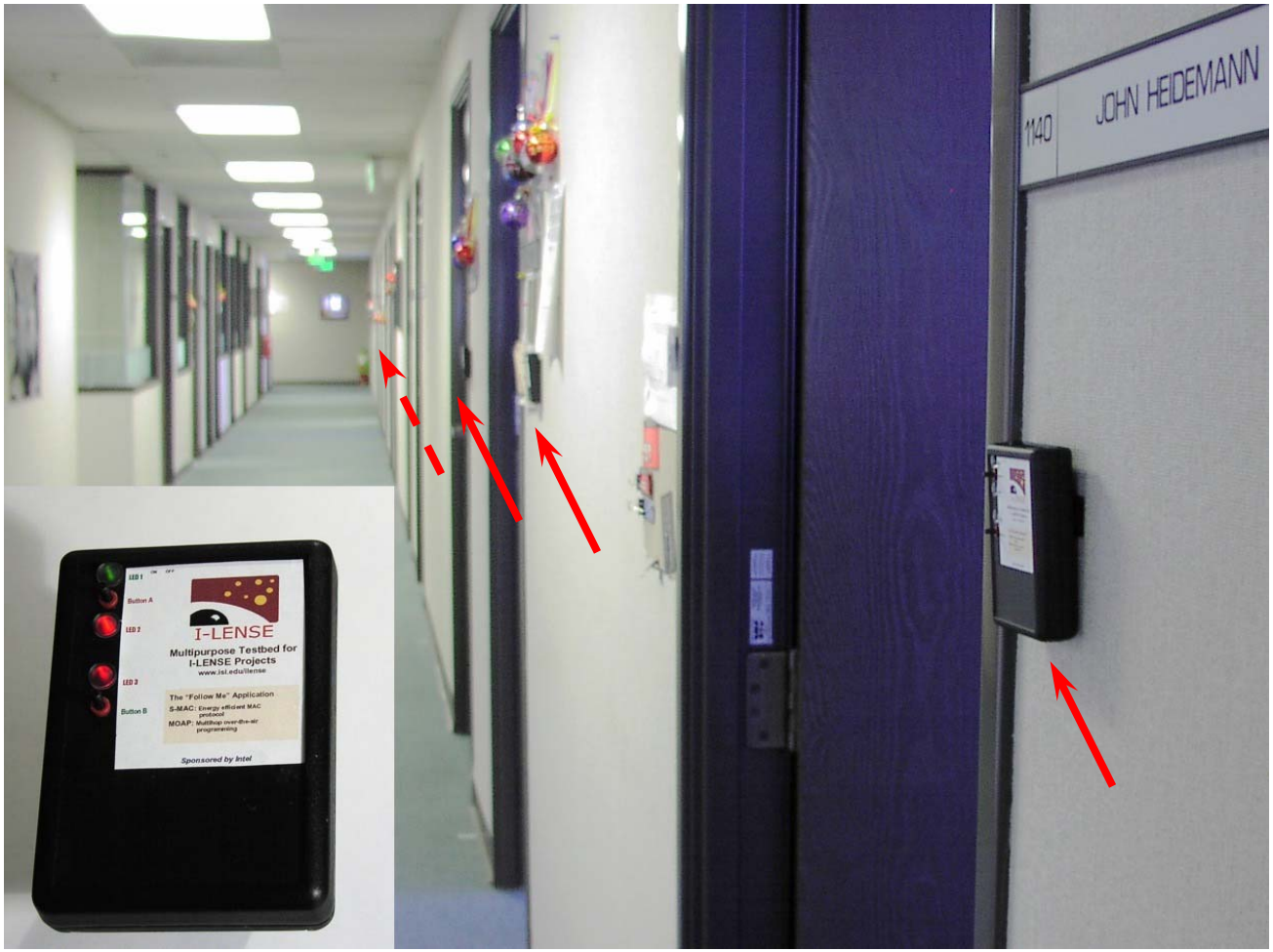
Follow-Me Application

- Motivation - Let's start from an application
- Follow-me: Guide a visitor from point A to point B



- Our approach
  - Sensor nodes are deployed around a building on walls, one at each office doorway
  - A visitor selects a destination (e.g. using a touch screen)
  - Nodes blink their lights to indicate a path, guiding a visitor with a "breadcrumb trail" to the destination

Follow-Me @ ISI



Node Hardware

Mica2Dot +
"Button Box"
(Sponsored by Intel)

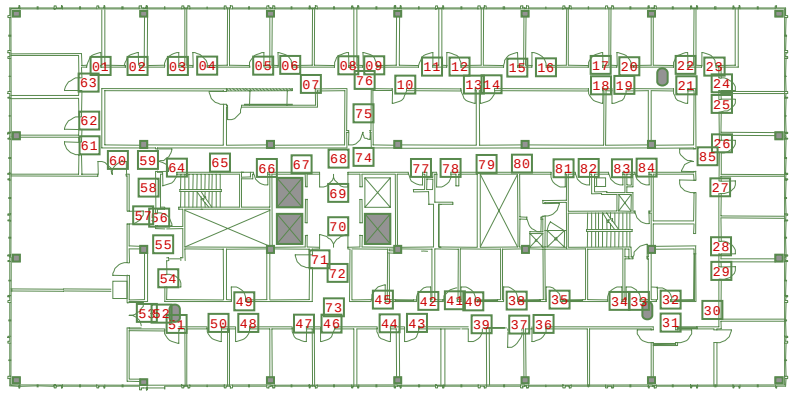
Follow-Me In Context

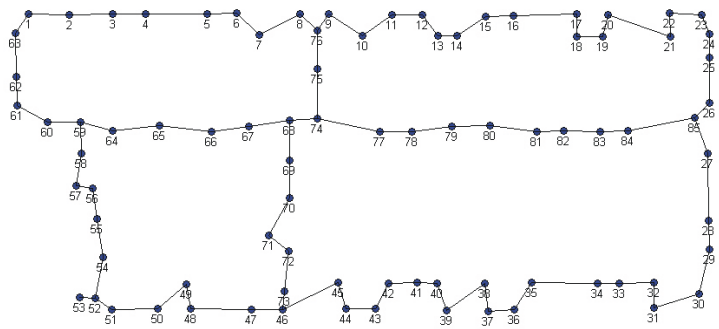
- Compared with signs or computer kiosks
  - Follow-me guides visitors as they move through a building (active assistance)
- Applications
  - Demonstrate basic technologies in office environments
  - Other applications about sensor node assisted navigation can be derived, including:
    - Emergency evacuation
    - Underground exploration

Logical Location & Logical Topology

- Logical Location
  - The relationship of nodes with each other and their environment
  - E.g. at room 1234, at the intersection of x and y
- Logical Topology consists of Logical Locations
- Logical Topology in this work
  - Connects nodes as a human would walk, as opposed to the radio or physical topologies, or we can call it “walkable connectivity”

Map of ISI 11th Floor
(physical topology)



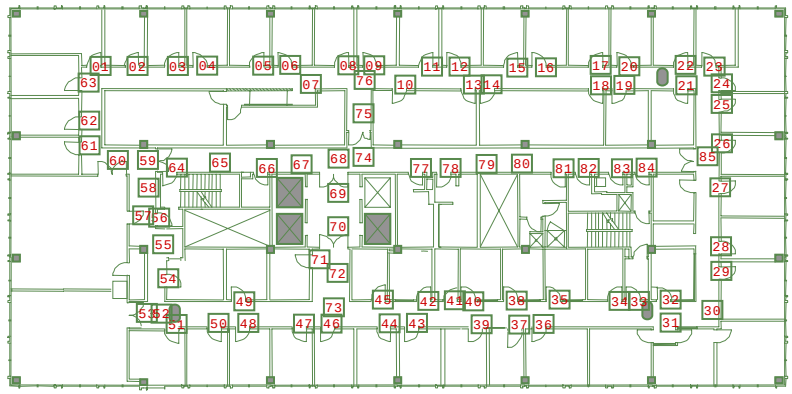


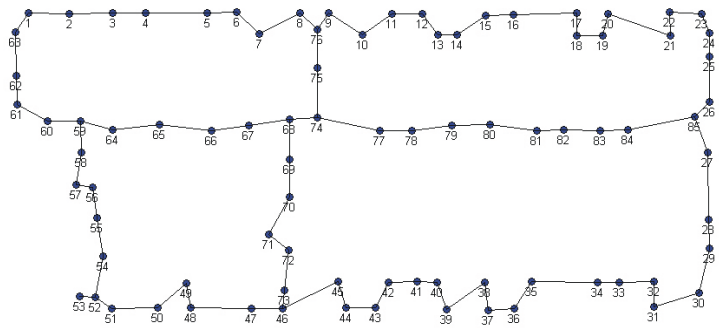
Logical Topology

Logical Location & Follow Me

- Specific definition of logical location in this work
  - In logical topology, which sensor nodes are adjacent to which other sensor nodes
  - Expressed as a set of neighbors for each node
- Deriving logical location information for path finding is the main technical challenge of follow-me
- We developed the *deployment order* method for *logical location* configuration

Map of ISI 11th Floor
(physical topology)



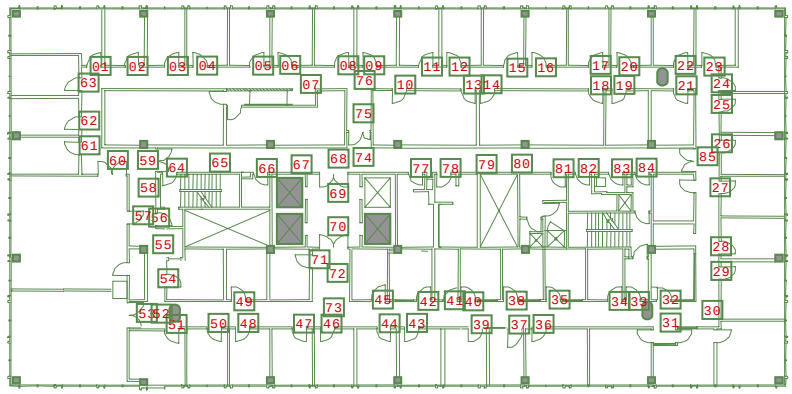


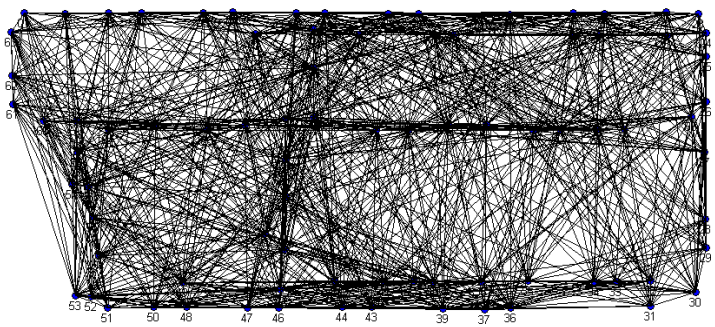
Logical Topology

Logical Location vs. Routing

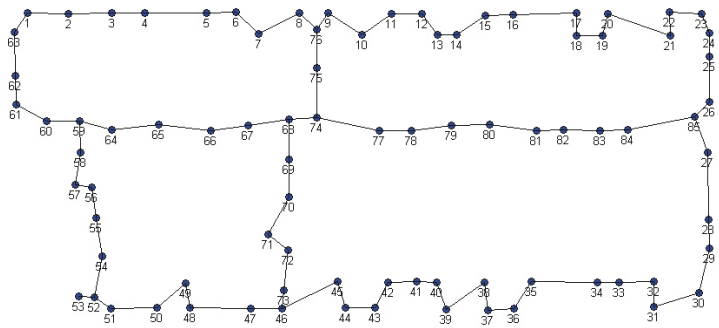
- Network connectivity cannot directly infer logical location
  - Unlike radio waves, humans are constrained by physical walls

Map of ISI 11th Floor
(physical topology)





Radio Connectivity



Logical Topology

Introduction

Deployment Order

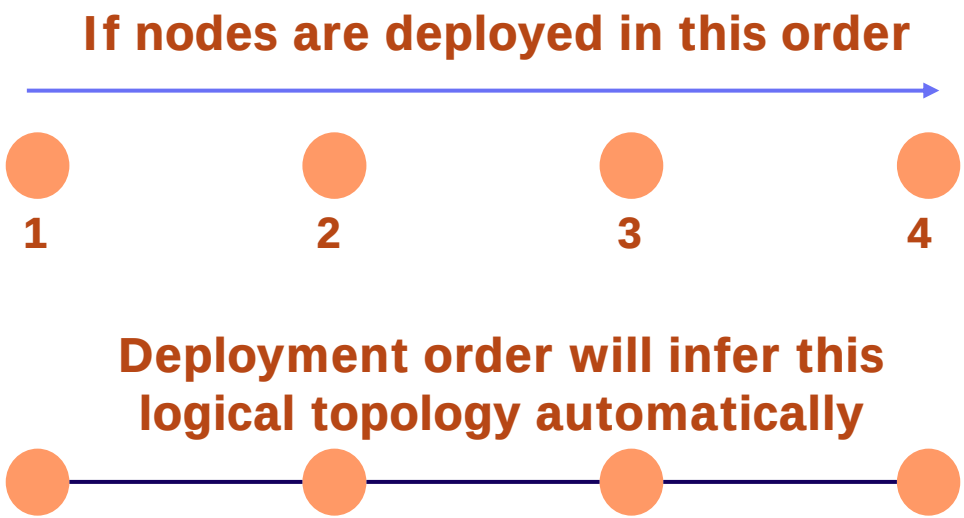
Implementation and Extensions

Future Work and Conclusion

Deployment Order – The Idea

- Sensor nodes are often deployed (switched on) sequentially
  - E.g. Dropped one by one by a person or vehicle
- Deployment order takes advantage of this information to infer logical topology
- An “easy” description
  - When two nodes are deployed (switched on) one after the other within a short time, we assume that they are neighbors in logical topology

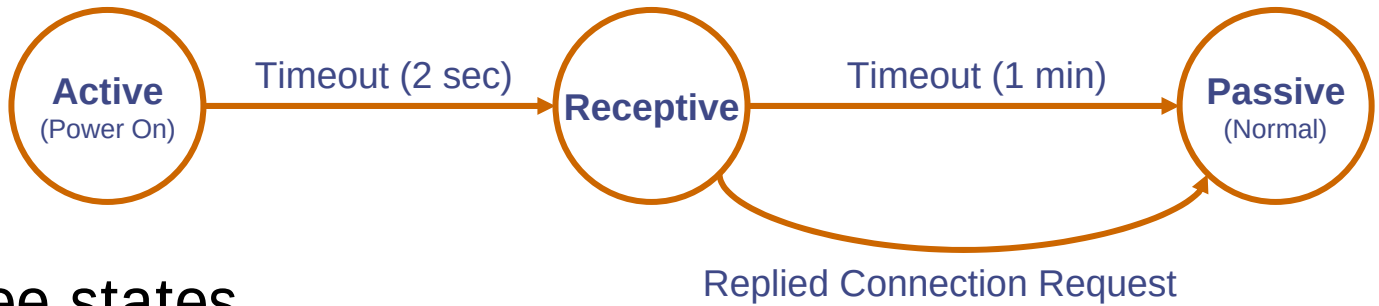
Deployment Order Overview



- The basic mechanism
  - A newly deployed node communicates with existing nodes to find out deployment order information
- "Intersections" (non-linear topologies) are handled by interactive configuration

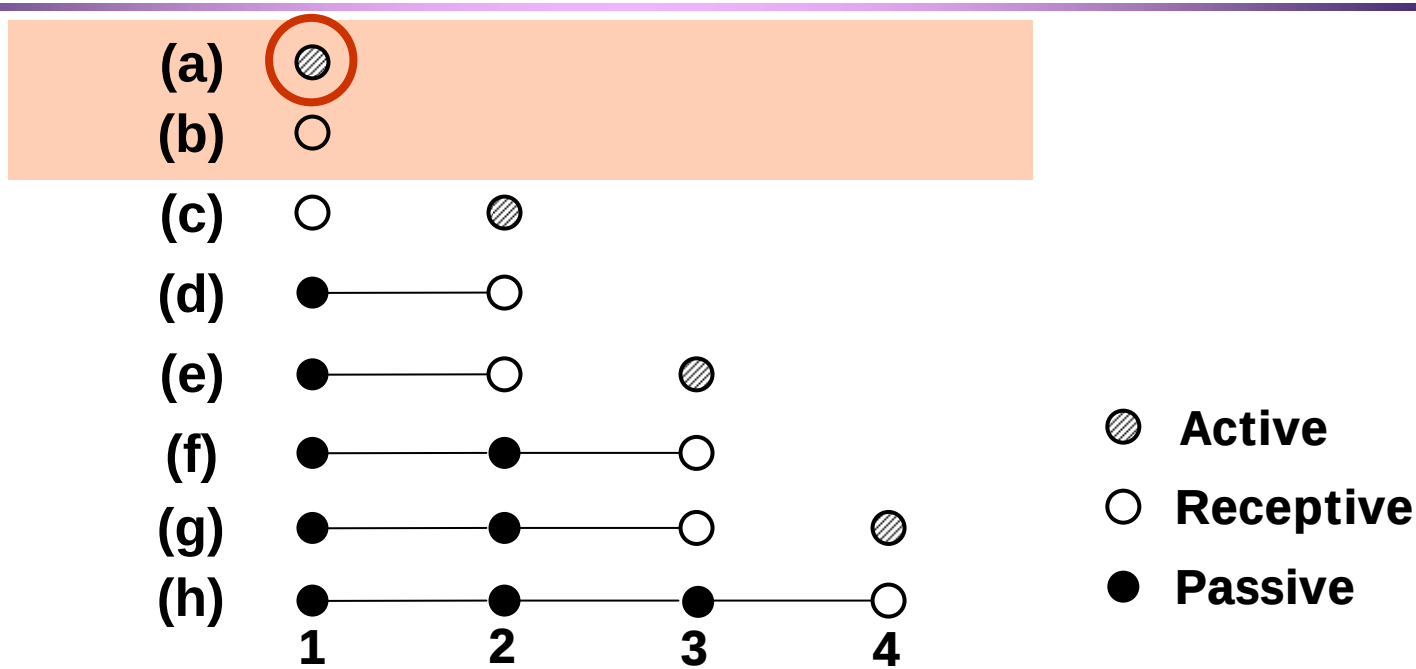
Deployment Order Defined

- Deployment order is defined with a simple state machine



- Three states
  - *Active:* Looking for existing nodes
    - The state after a node is switched on
    - Send out connection request packets
  - *Receptive:* Want to link to a new node
    - Will reply to connection request packets and create a link
  - *Passive:* Done
    - Will not be involved in link operations – state for normal operation

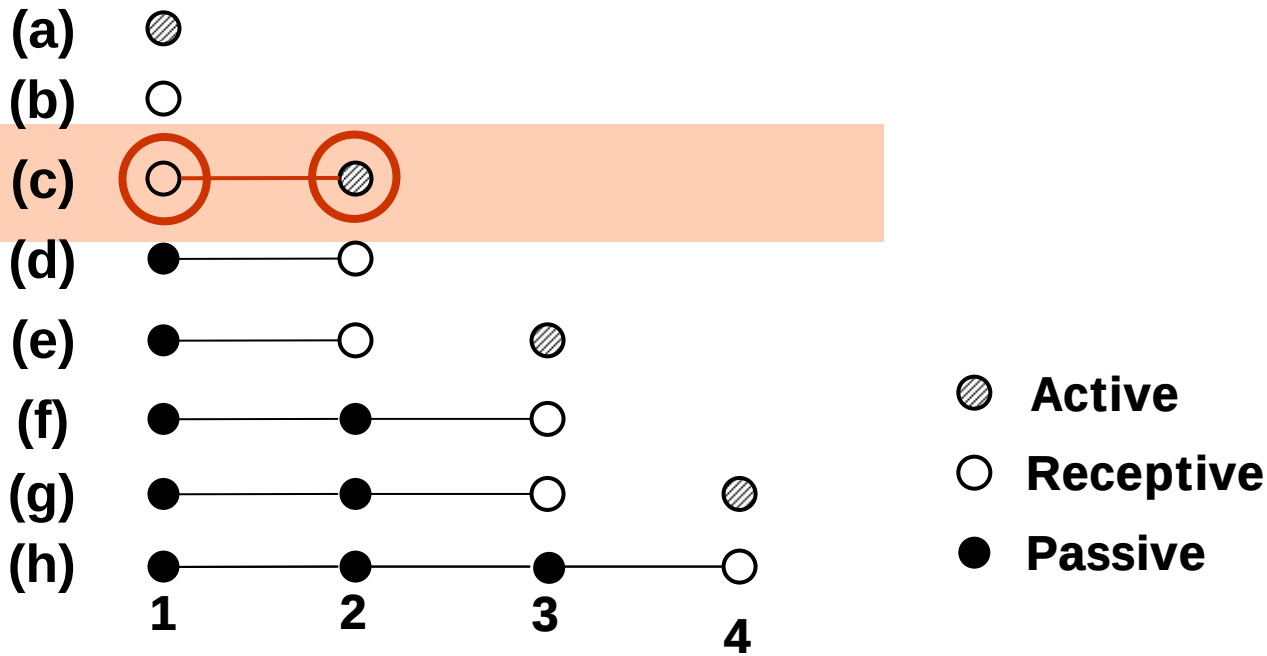
Linear Topology Example – First Node



(a) The first node is switched on

(b) It won't find any neighbor and will go to receptive state

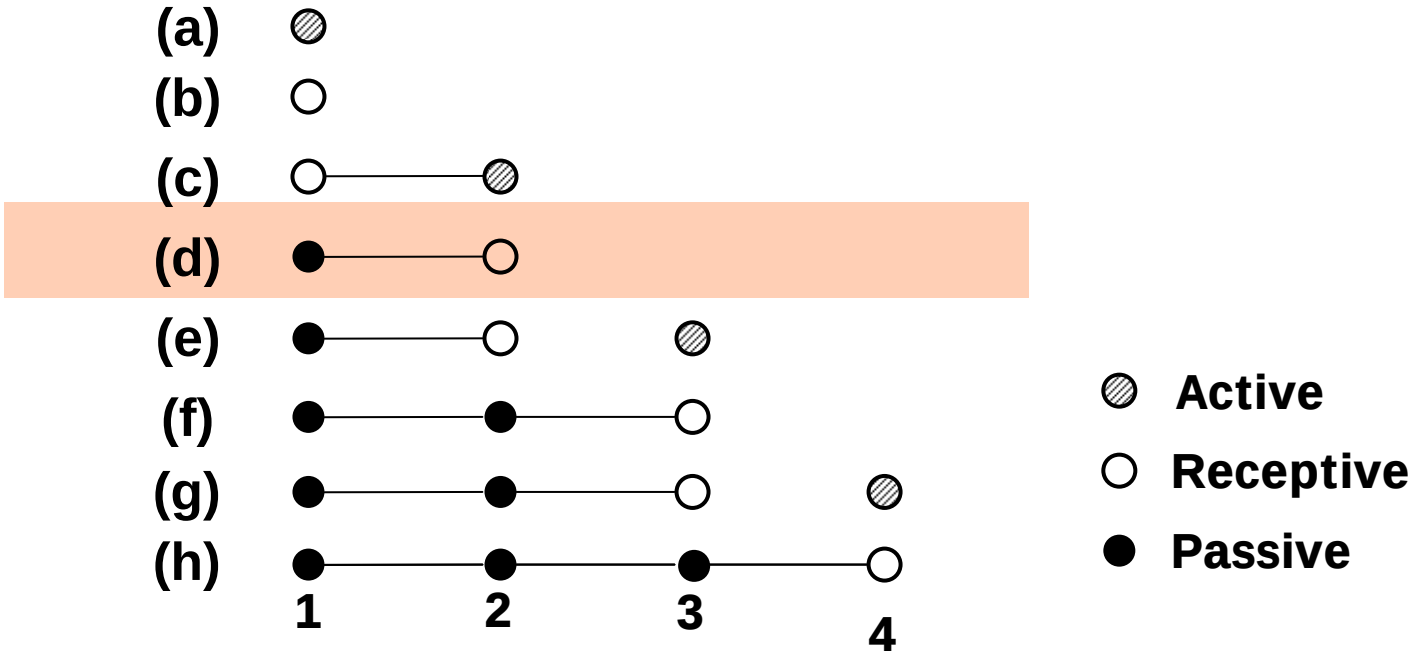
Linear Topology Example – First Link



(c) When the second node is switched on it begins in active state and will search for neighbors

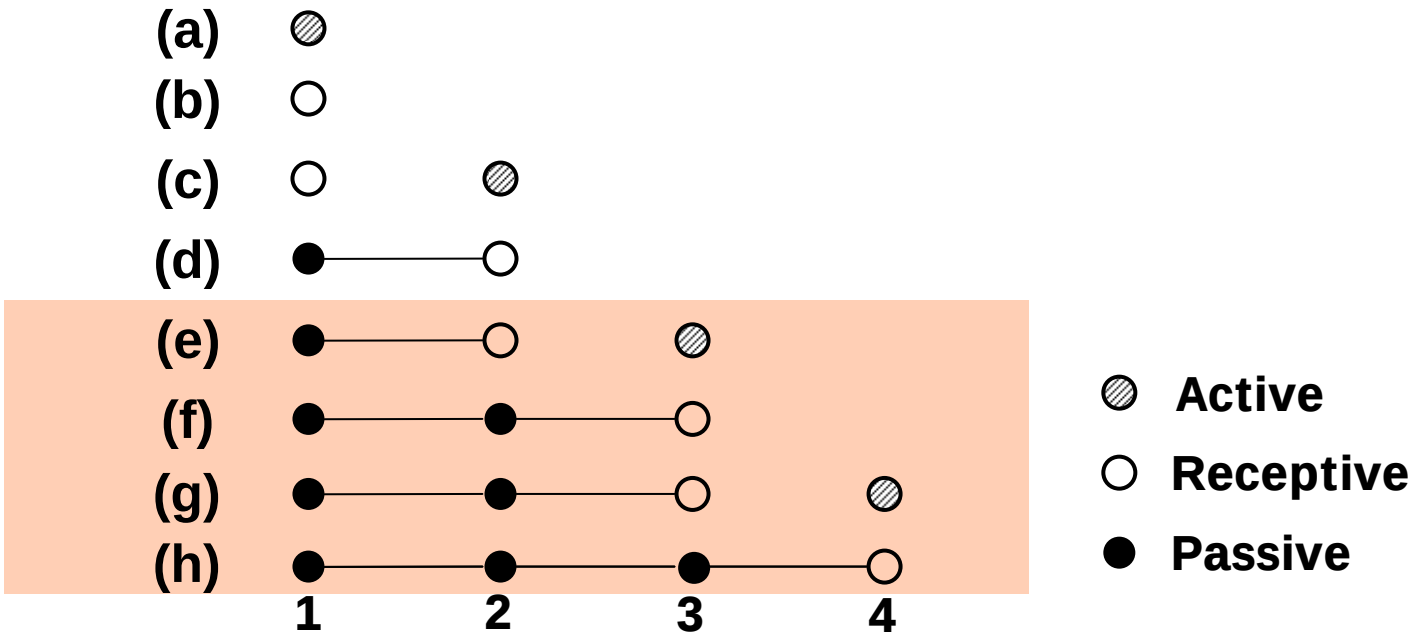
The first node (currently receptive) will reply, establishing a link between these two nodes

Linear Topology Example – Ready For Another Node



(d) The first node will move to passive state after creating the link, and the second will go to receptive state

Linear Topology Example – More Nodes

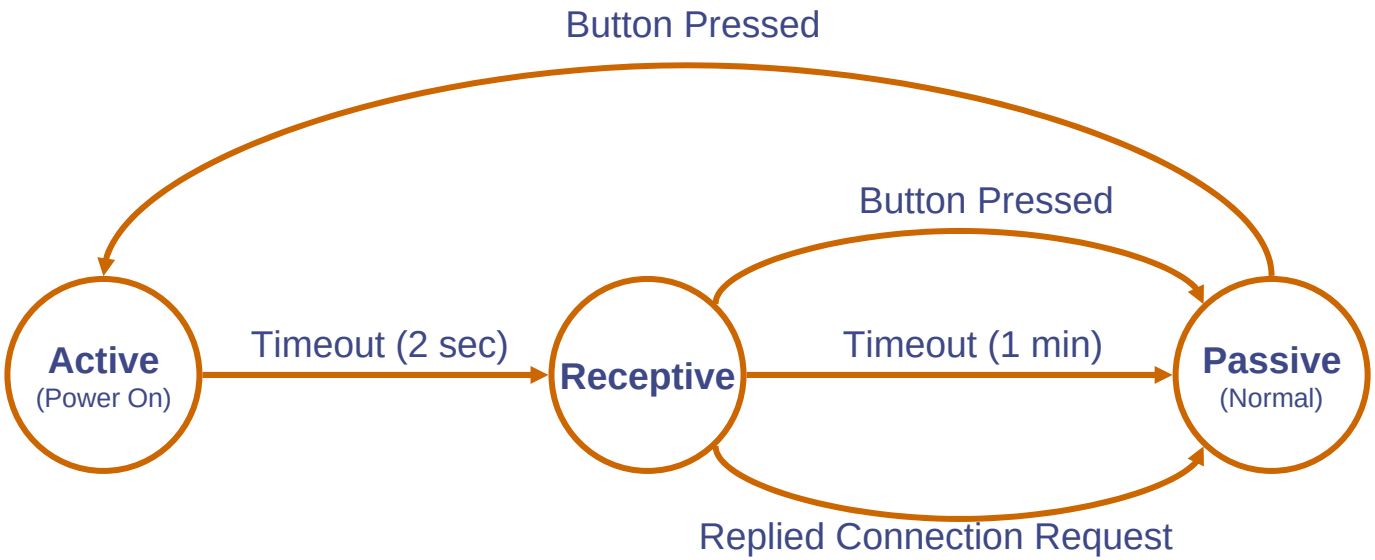


(e) – (h) Similarly, the third node will link to the second node, and so on

Intersections and Arbitrary Topologies

- Intersections mean nodes with more than 2 neighbors
- Approach
  - If we give users a little bit of control over the state machine, they can then connect nodes to make arbitrary topologies
  - We use a button on sensor node to toggle node states

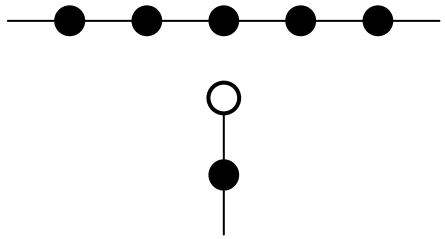
Updated State Machine



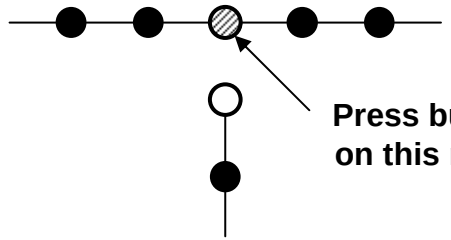
- When a node is in passive state, pressing the button will bring the node to active state.
- When a node is in receptive state, pressing the button will bring the node to passive state.

Intersection Example

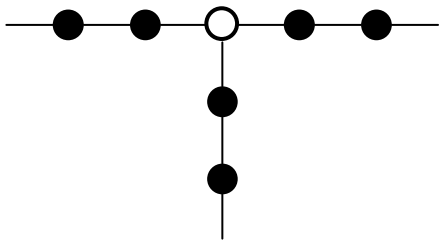
Deploy one line



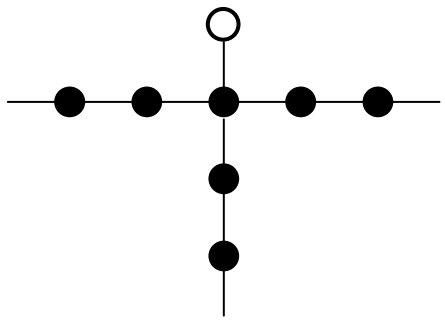
Deploy the other line
until it reaches the first line



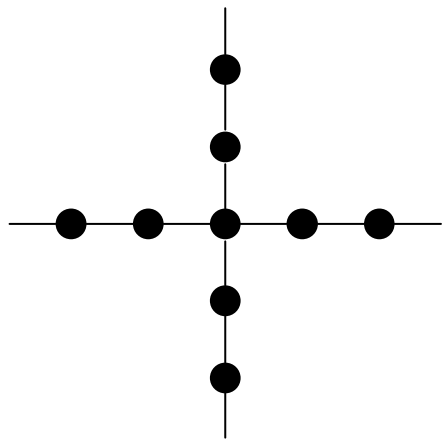
Make the central
node active



Two lines are connected



Continue to deploy the
second line as normal



Final Result

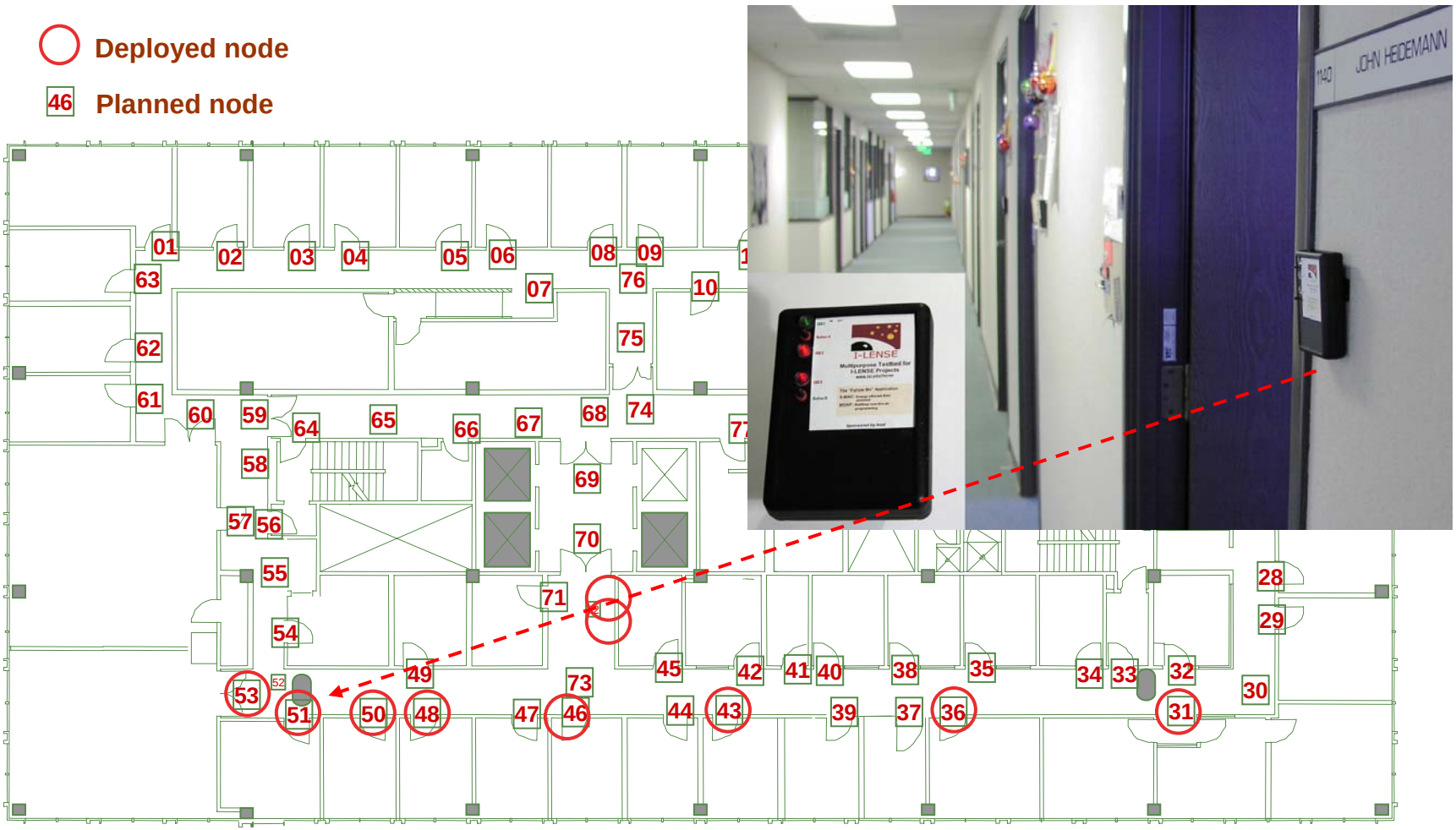
Introduction

Deployment order

Implementation and Extensions

Work and Conclusion

Follow-me Deployment at ISI

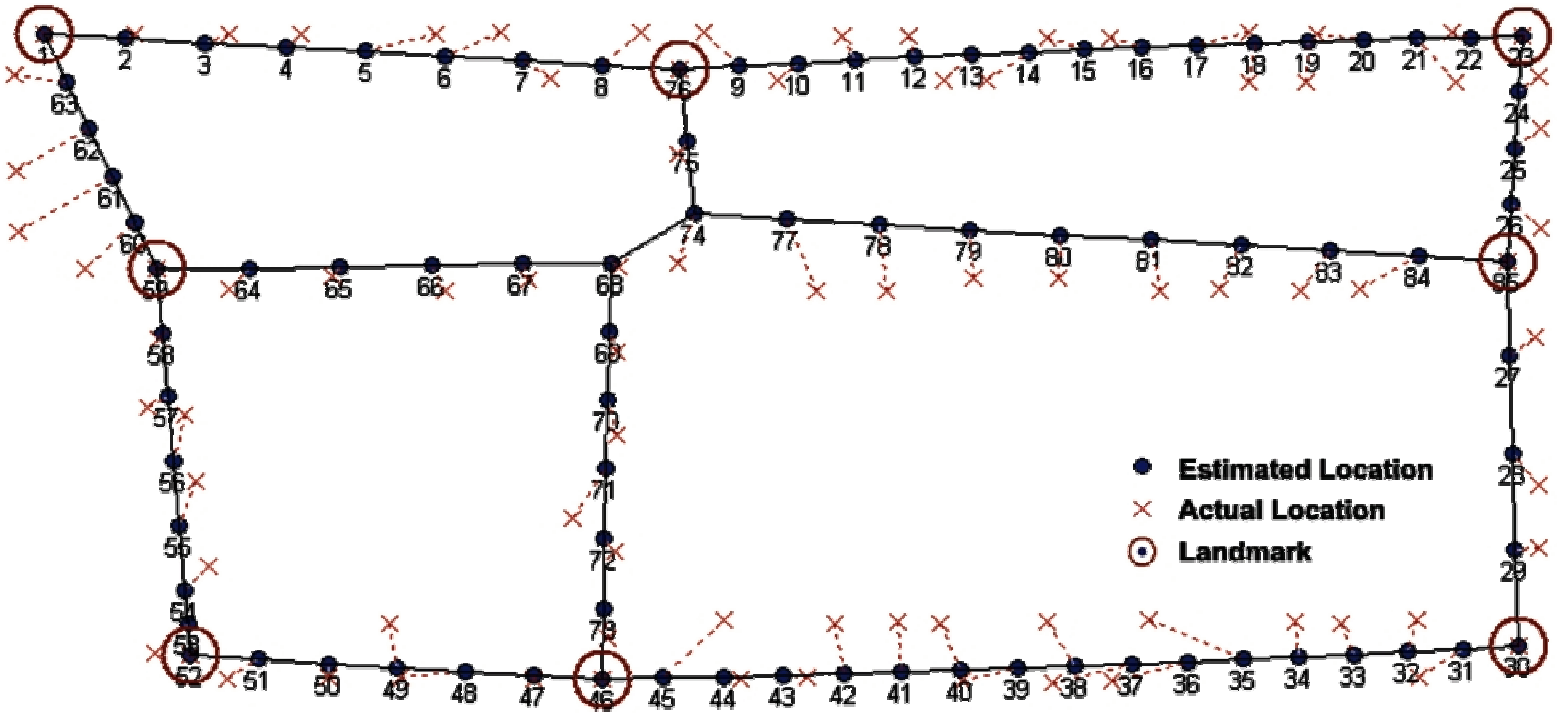


Map of ISI 11th floor – follow-me deployment example

Follow-Me Implementation

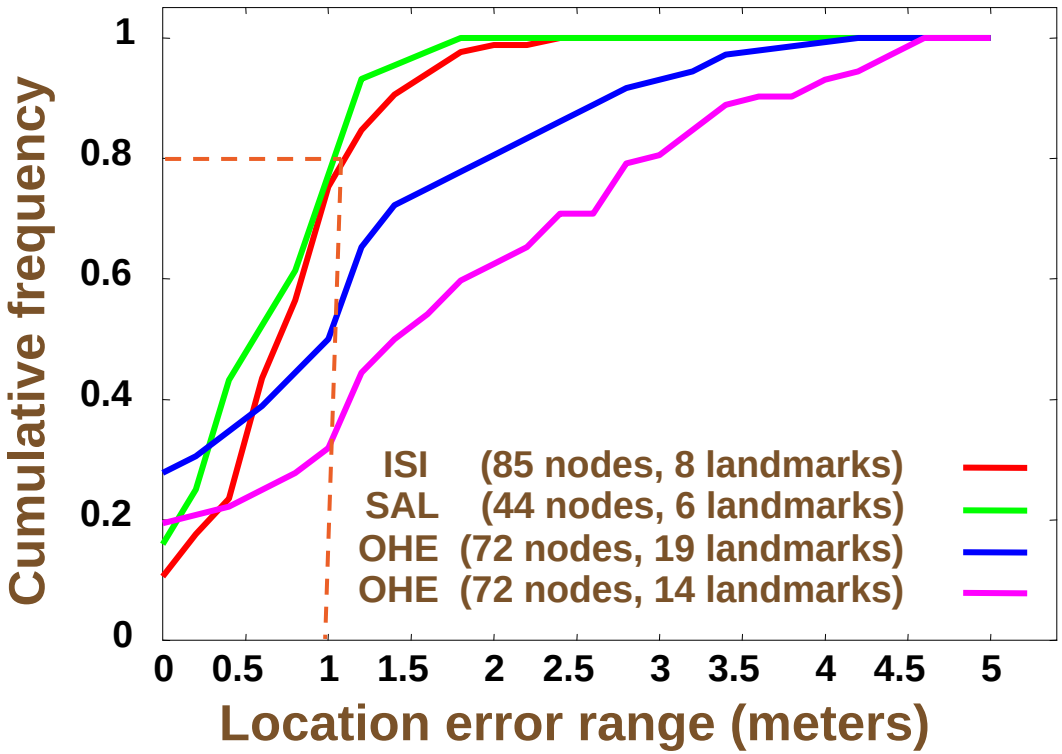
- Deployment order
  - Uses LEDs and beepers to give feedback to user
- Path finding
  - As simple as possible
    - Forward path: Broadcast forwarding (flooding)
    - Reverse path: Unicast backtrack
  - A subset of directed diffusion
- MAC layer
  - S-MAC for energy saving

Physical Location Estimation



- Landmark + Logical Location ⇨ Physical Location
  - If node density is nearly homogenous, we can use landmark and logical location to estimate physical location
- Algorithm derived from a spring-embedder system
  - Differences: all tension force, fixed landmark nodes

Physical Location Estimation - Results



- Results
  - Reasonable accuracy
    - For ISI and SAL, 80% of nodes within 1m
    - For OHE 80% of nodes within 3m, or 2m with additional landmarks
  - Accuracy depends on topology and number of landmarks

- A lightweight alternative to dedicated node hardware or infrastructure when required conditions can be satisfied

Other Topics

- Several other topics are covered in the paper
  - Link repairs and fault handling for deployment order
    - One hop failure can be automatically repaired
    - Manually patching nodes for other conditions or deployment errors
      - A “link remove” button for link removal
  - Time synchronization
    - For synchronized blinking
  - Route catching
    - Speed up path finding
  - Node locking
    - Prevent unwanted topology changes

Introduction

Deployment Order

Implementation and Extensions

Future Work and Conclusion

Future Work

- Concurrent visitor guidance
  - Possible ways
    - Use different colors and blinking patterns
    - Sense locations of visitors and only blink within visual range
    - Each visitor hold a node and get directions from the node
  - No perfect solution at this time. But in some applications multiple people go to the same destination
- Concurrent deployment (multiple deployment points)
  - We can create multiple segments of logical topology and connect them later
    - Nodes need to distinguish different deployment “trails”. For example, use signal strength or preprogrammed group ID

Conclusion

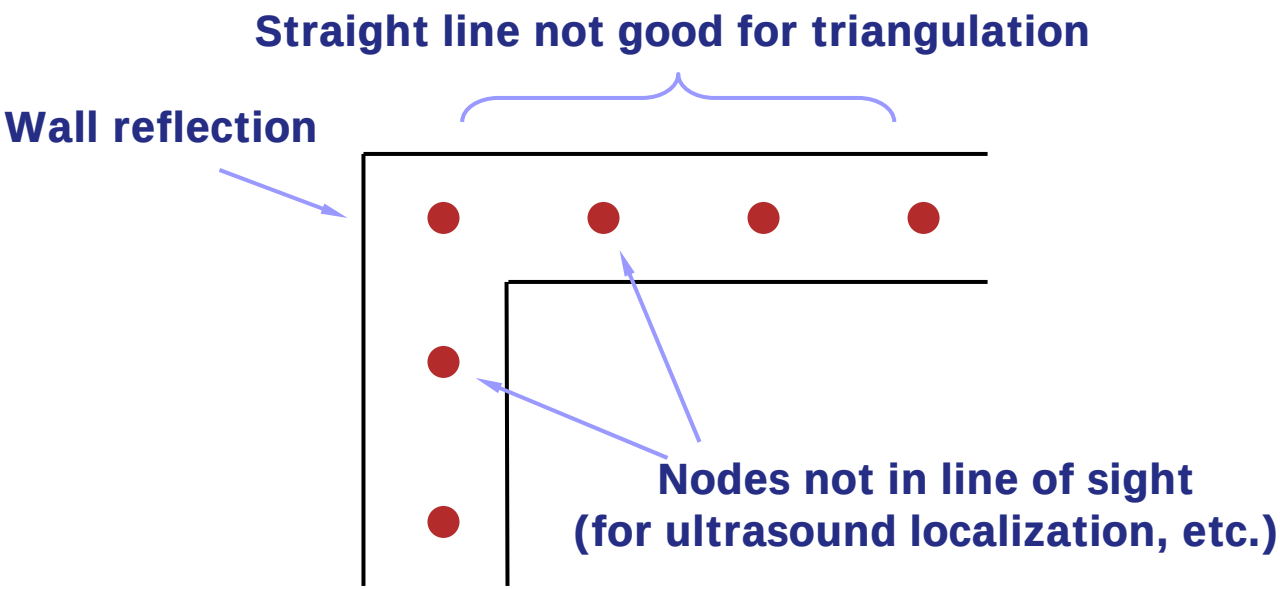
- Developed deployment order
  - Deployment order fills two roles:
    - A very small, light-weight approach for approximate location
    - Easy configuration of “walkable connectivity”
- Implemented and deployed follow-me
  - Follow-me demonstrates sensor network assisted navigation

Thank you !

- For this talk & source code
  - http://www.isi.edu/~xiw/followme

Why Deployment Order

- Why deployment order - indoor, low density and linear topology is hard for traditional localization techniques



Compared with Traditional Localization

- If we have to use traditional localization ...
  - More nodes than necessary
  - Wall reflection still an issue