Towards Design Tools for Wireless Networked Control Systems

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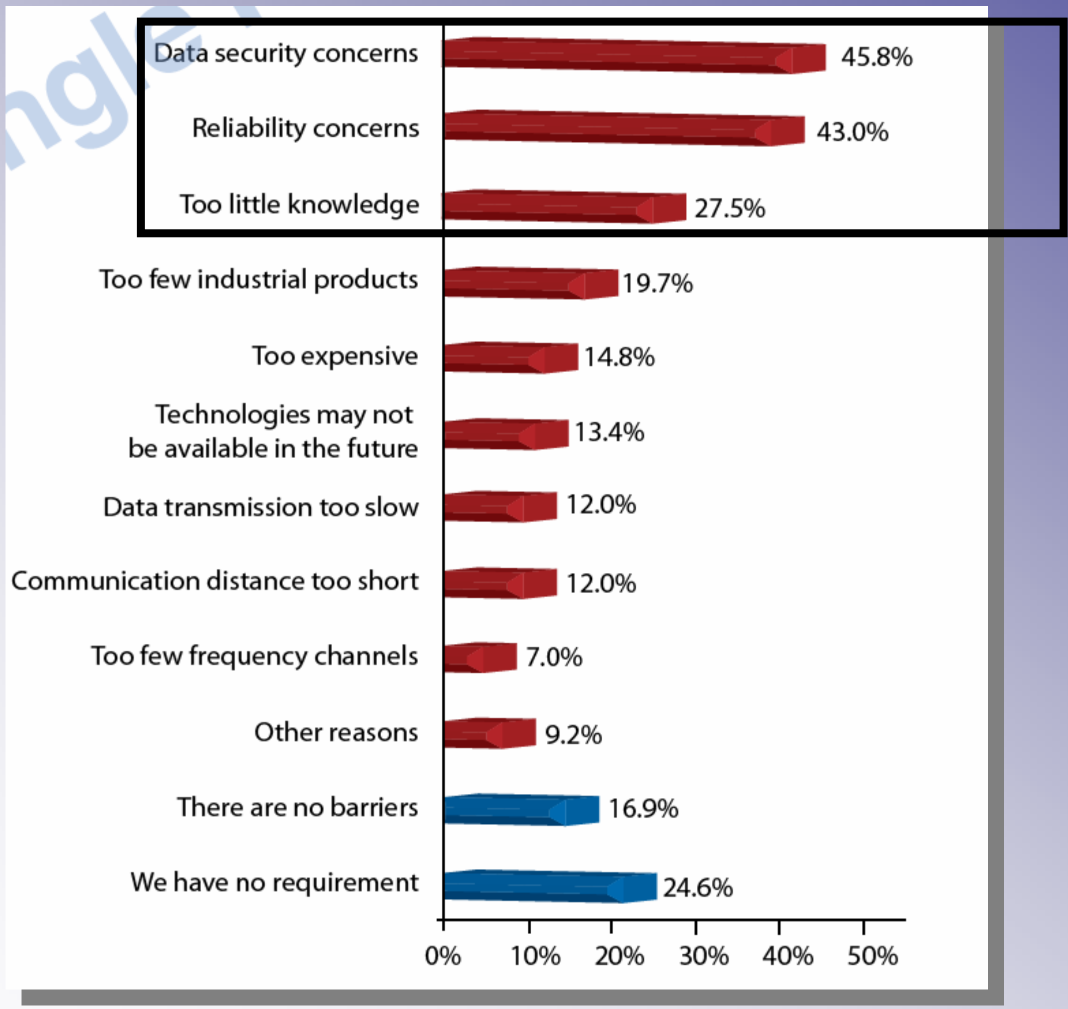
Outline

- **W**ireless **N**etworked **C**ontrol **S**ystems (WiNCS)
- Motivation
- Design tools
- PiccSIM-platform
- Case studies
- Demo

Wireless automation today: A journey towards reliable wireless automation

- **Wireless Networked Control Systems** are real-time computing and control systems over wireless networks.
- That is, **embedded systems** where the different devices (sensors, controllers and actuators) *communicate seamlessly* using *wireless technology*
- Connection of field devices through a field bus requires a lot of network planning, wiring and troubleshooting as a result, for many automation systems the cost is in "*all in the wires*"
- Wireless vision: autonomic communications and computing gets rid of the human-in-the-loop by making the systems self-configuring, self-healing, self-optimizing and self-protecting

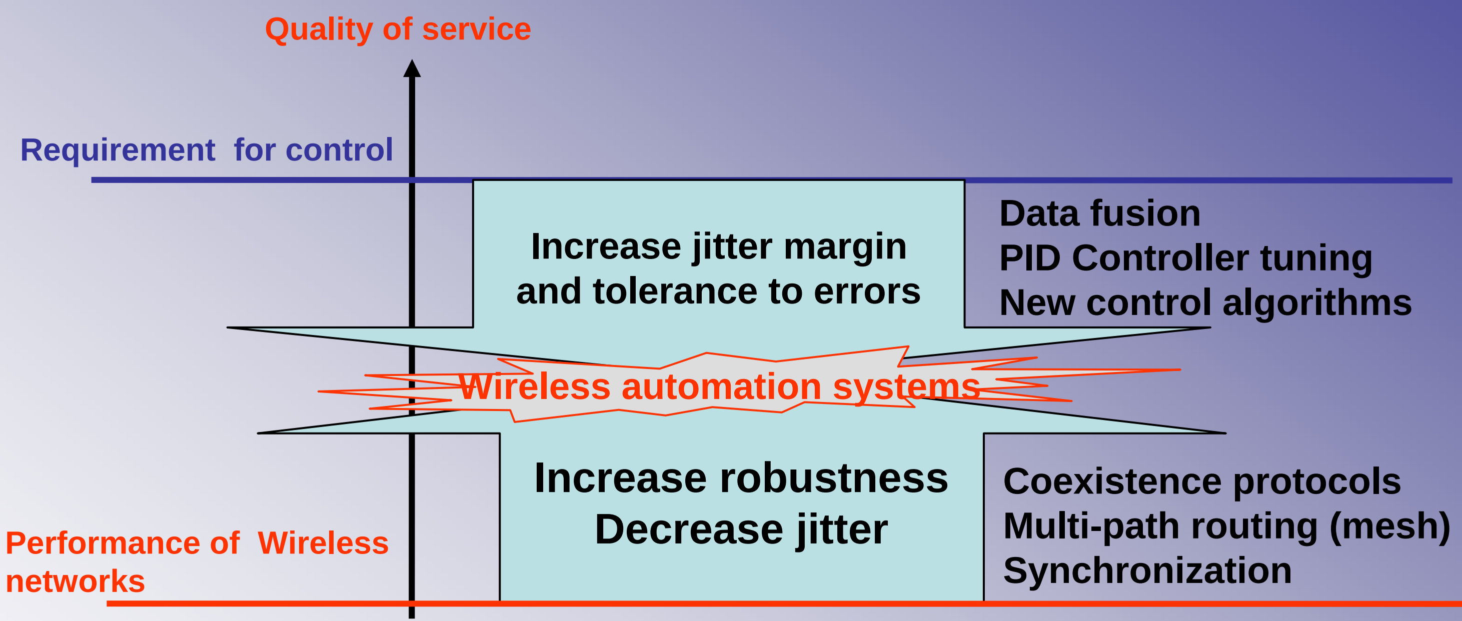
Challenges: the user perspective



Our focus

”Market pulse: Wireless in industrial systems: cautious enthusiasm”, Industrial Embedded Systems, Winter 2006.

Wireless automation today: A journey towards Reliable Wireless automation

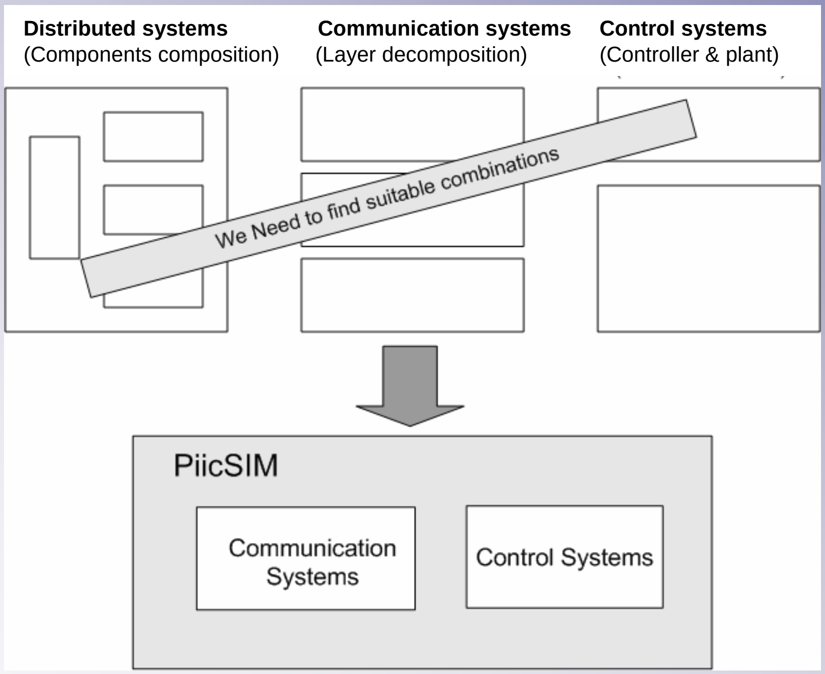


Performance Evaluation: **A need for having a common testing platform for integrated Communication and Control Design**

Tools for design?

- There is a lack of design tools that are able to deal with *integrated communication and control systems*
- TrueTime (Lund University): Network simulation with MATLAB/Simulink
  - Accuracy of network simulation?
  - Few network protocols available
  - Good for control performance analysis

Platform for integrated communication and control design Simulation, Implementation and Modelling (PiccSIM)



Option 1: Develop a New Simulator (example: Java or MATLAB based simulators)

Option 2: Integrate existing available simulators

Control Design:

- MATLAB/Simulink/xPC Target (automatic code generation), MoCoNet-platform

Communications Systems Design:

- Ns2, OPNET, QUALNET, SENSE, etc.

PiccSIM = MoCoNet + Ns2

PiccSIM- Key Features

Communications System Design (Ns2):

- System Level communication protocols testing from Control perspective
- Emulation testing platform for building automation design engineers for various wireless topologies/scenarios testing
- Wireless Network Simulations using Real processors
- Laboratory Resource Management
- Easy-to-use network configuration tool and accessible over Internet

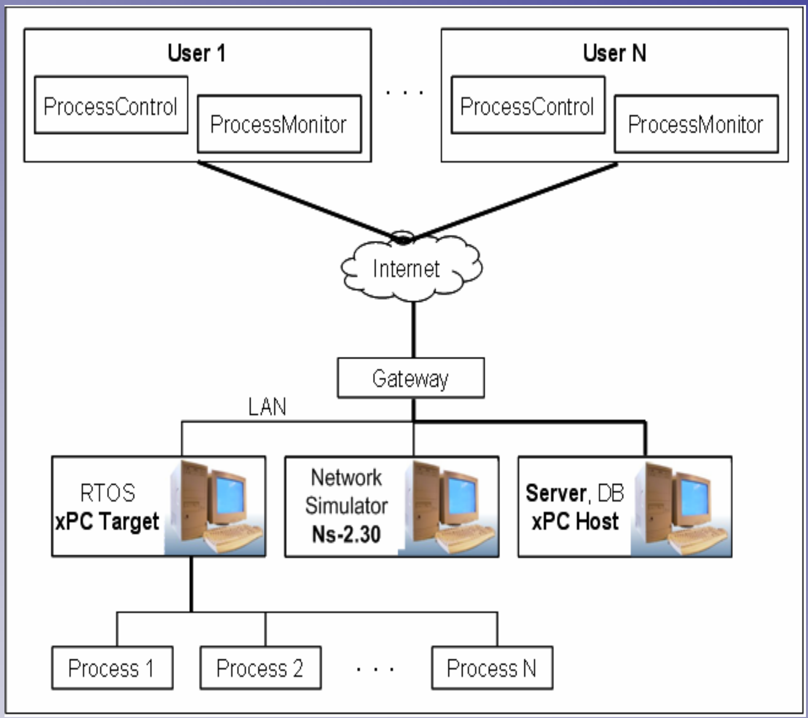
Control Design (MoCoNet system):

- The impact of network parameters on the control system performance can be studied.
- New challenges for control design can be pointed out and the platform offers a possibility of verifying new stability proofs, and control and data fusion algorithms.
- Support for powerful control design and implementation tools provided by MATLAB
- Enabling automatic code generation from Simulink models for real-time execution real-time control of a true or simulated process over a user-specified network

Platform for **i**ntegrated **c**ommunication and **c**ontrol design **S**imulation, **I**mplementation and **M**odelling (**PiccSIM**)

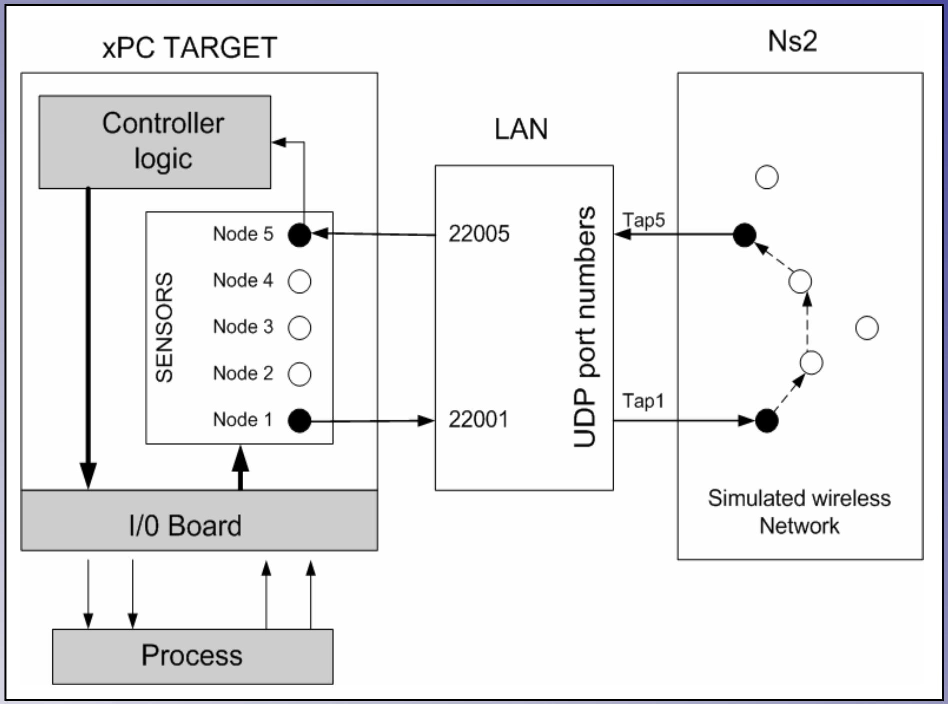
The system consists of **Three** computers:

- **Webserver, Database, xPC Host:** The server computer is responsible for maintaining connections between users and processes, running a reservation system for controlling Processes.
- **RTOS xPC Target:** the computer controls the real process or simulates a process in real-time. Equipped with an I/O controller board.
- **Network simulator (Ns2):** this computer runs simulated networks
- **Router:** All computers are connected through a network router



An example

- Two Models (xPC Target and Ns2)
- UDP packets are generated from the signal measured from the process.
- Packet are sent on to the network
- Ns2 computer using TAP agent captures packets and then node mapping is done using UDP port numbers



- On successful reception the packet is sent back to xPC TARGET

Simulation case studies

- Building Automation
- Target tracking and control

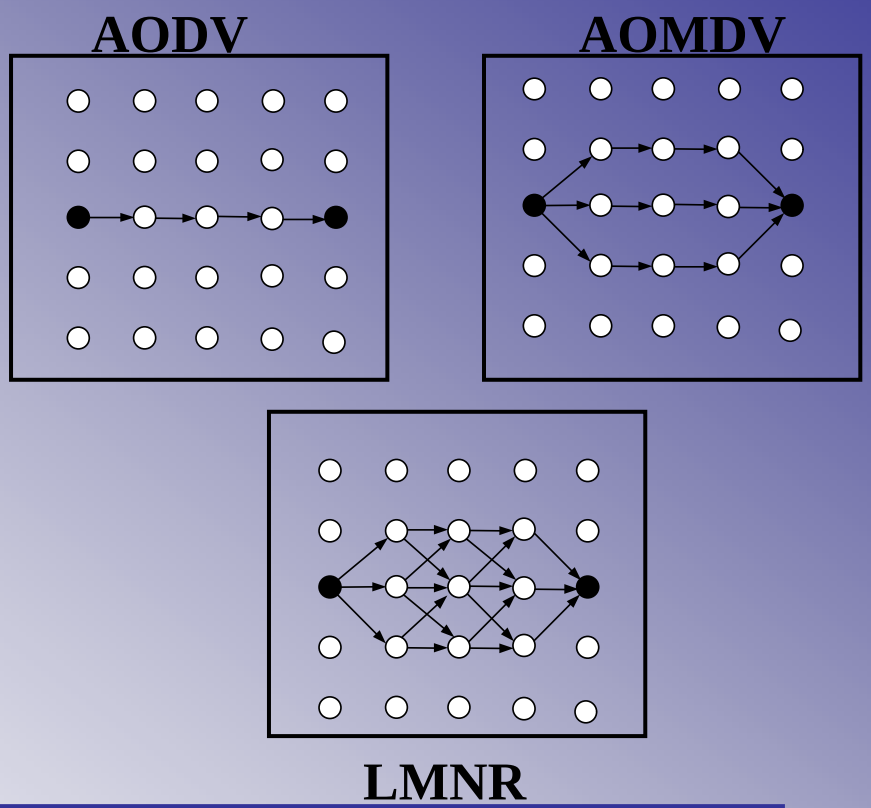
Performance comparison of AODV (Single path) and LMNR (Multipath Routing protocol) in different scenarios of industrial wireless systems

S. Nethi, M. Pohjola, L. Eriksson, R. Jäntti. Simulation case studies of wireless networked control systems, submitted to the *10th ACM/IEEE International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MsWIM'2007),* Crete Islands, Greece, October 22-26, 2007

Multi-path routing

- **LMNR (Localized Multiple next hop routing)**
  - Set up multiple routes
  - Next hop is locally decided based on load, interference, and link availability

  => Increase robustness against link faults (decrease the need for rerouting in case of failures)



S. Nethi, C. Gao and R Jäntti, "Localized Multiple Next-hop Routing Protocol", to appear in *Proc. 7th international conference on ITS telecommunication (ITST 2007),* Paris, France, June 5-8, 2007

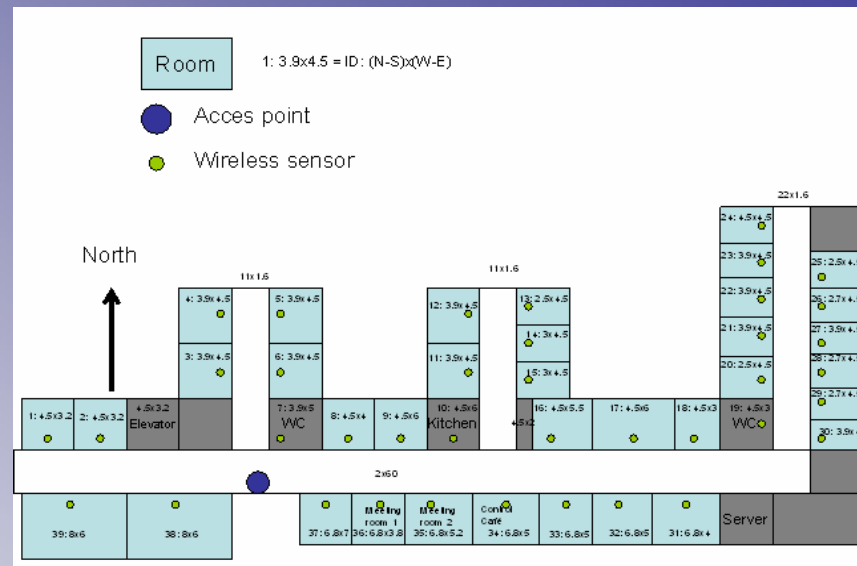
Building Automation

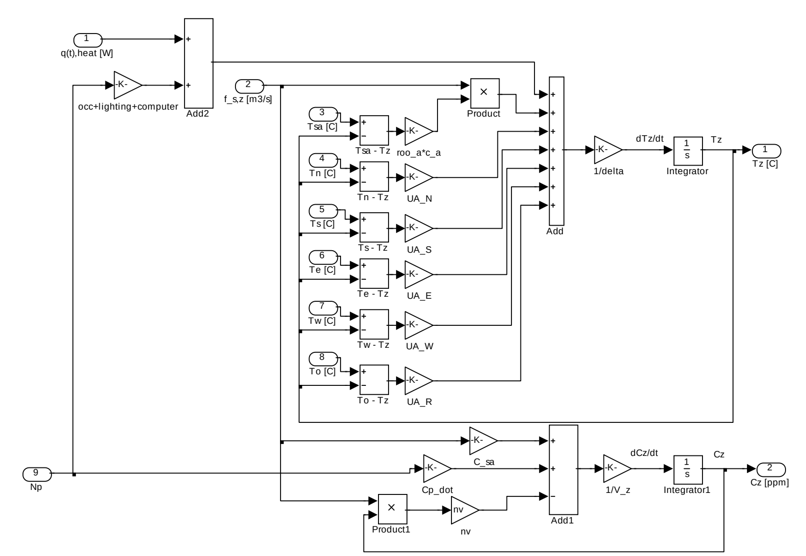
Physical Models:

- Heat balance in rooms (PID control)
- CO_2 concentration in rooms (relay control)
- Event driven signals, lighting (on/off)

Communication Model:

- Zigbee motes (15m range)
- Ricean propagation channel





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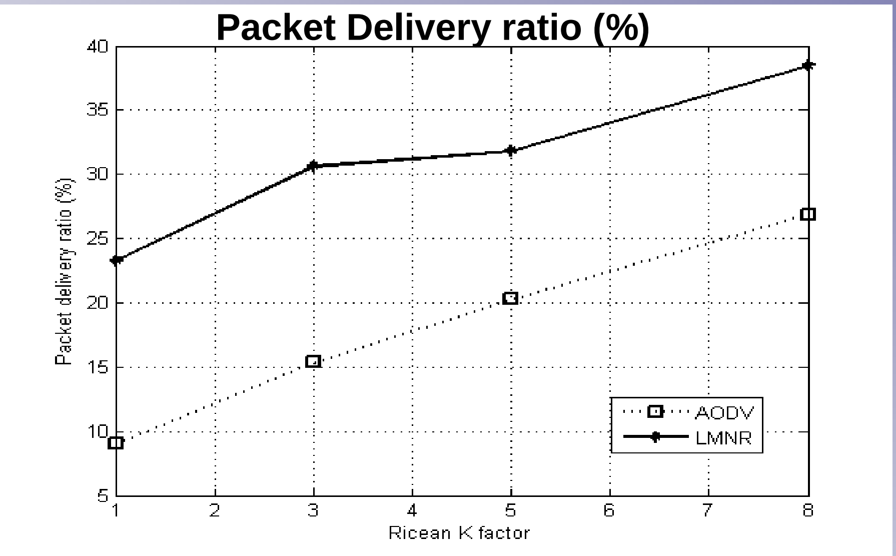
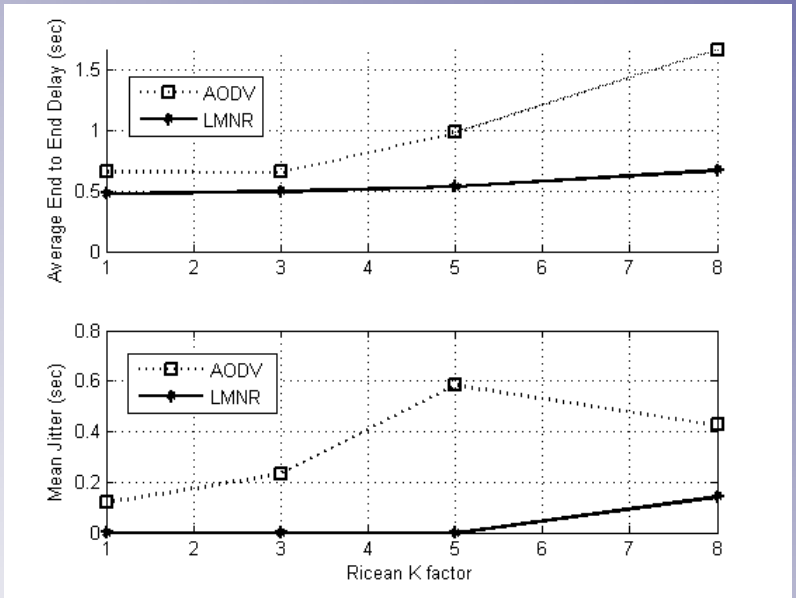
Results (LMNR vs. AODV)



Results clearly indicate that multipath routing has contributed to increased packet delivery ratio and decreased jitter (delay variance)

Avg. end-to-end delay and jitter (sec)

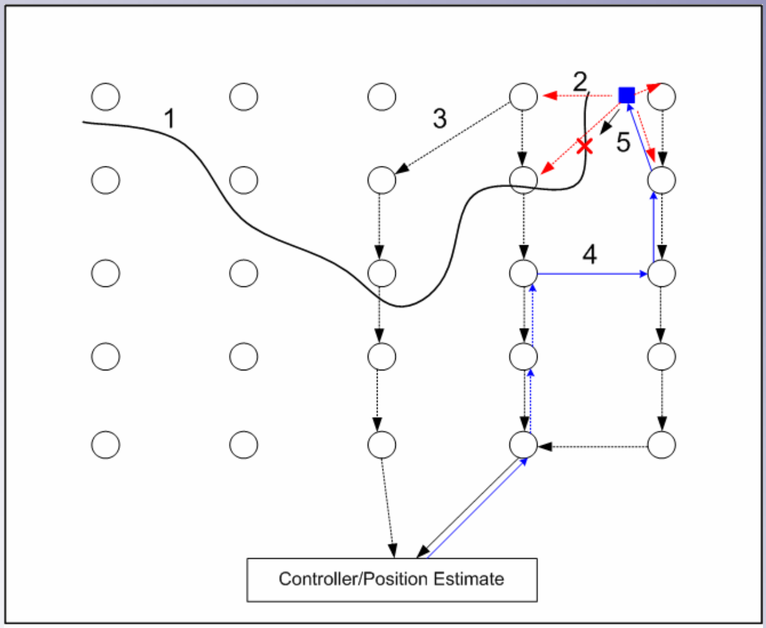


To improve system performance:

-Utilize group coordination and data aggregation to localize computation and decrease network traffic

- Redesign of network, i.e. adding more access points

Target tracking and Control



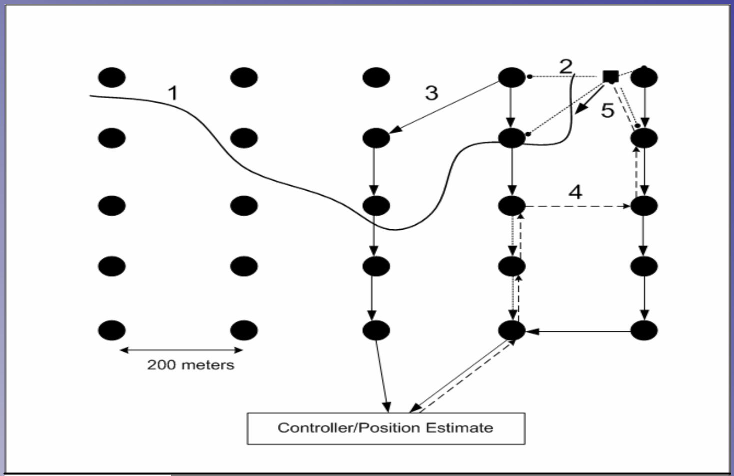
Sensors->Controller
Controller->Mobile Node

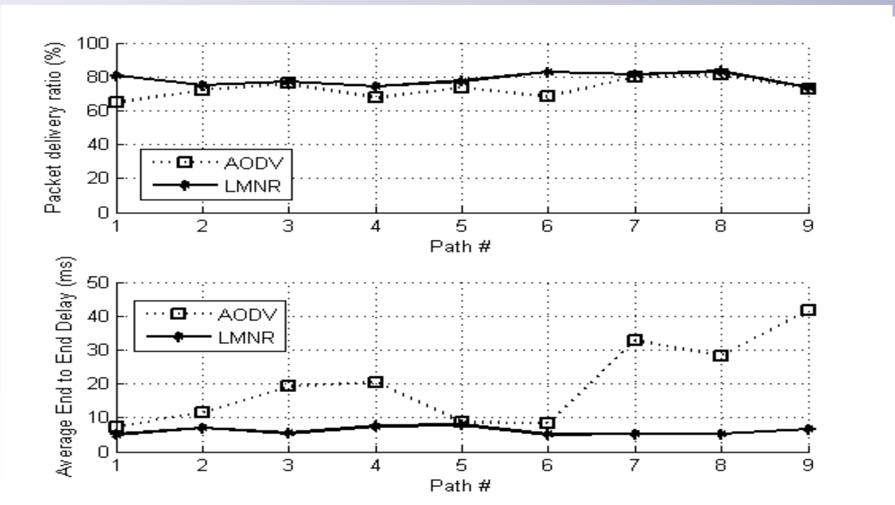
Model:

1. Sensor Motes equipped with Ultra sound receivers and a radio module forms a Grid network
2. A **mobile** Node (Trolley/Robot) emits Periodic Ultrasound pulse
3. Sensor Motes estimate the distance to the Mobile using
4. Distance information is forwarded to the Controller, where Position estimation is done
5. Controller estimates the position using 3-D Position Sensing scheme, where the Differences in the Time-of-Flights from a Wave Source to Various Receivers [Ajay].
6. Finally controller sends Control (Action) Message to the Mobile nodes.

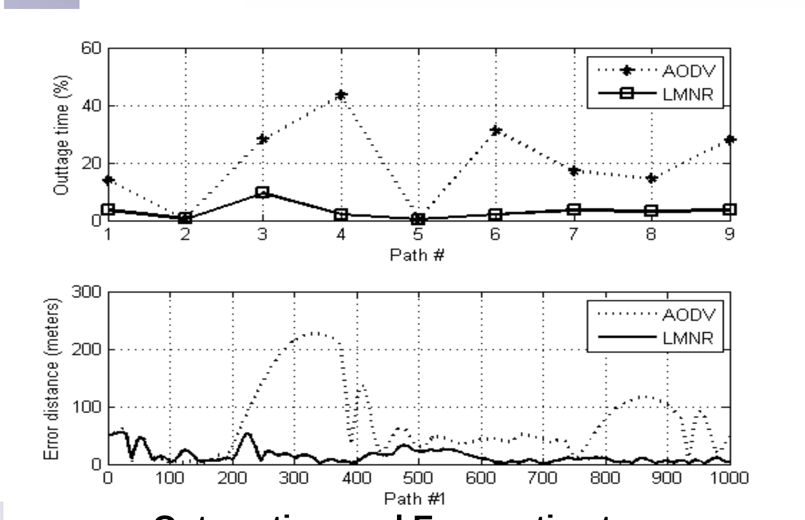
Target Tracking and Path Management

- **Two Communication pairs:**
  - Sensors-Controller
  - Controller-Mobile Node
- Propagation model:
  - Two ray ground model
- Results produced for 9 different reference paths





Packet delivery fraction and Avg. end-to-end delay



Outage time and Error estimate

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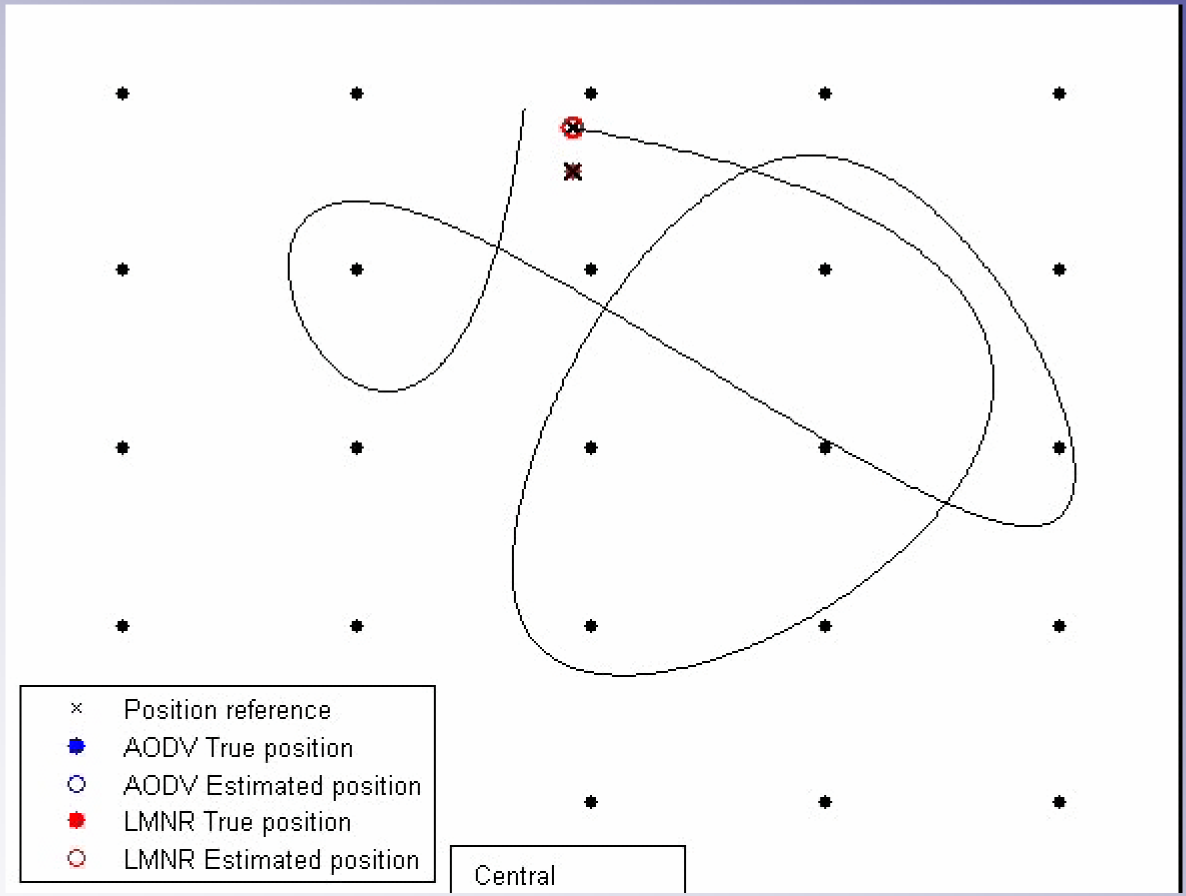
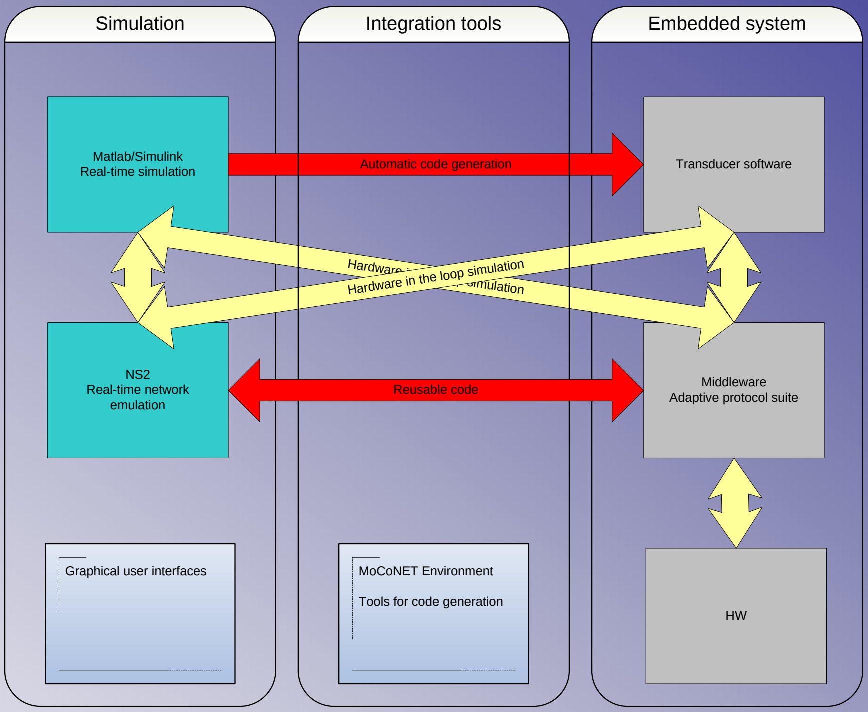
Recorded simulation for Target tracking



Way forward

- Graphical user interfaces
  - setting the network parameters jointly for Ns2 and Matlab
- Automatic code generation
  - Control design
- Code reusability
  - The same networking protocols can be run both in real sensor network hardware and Ns2 emulator
- Hardware in the loop simulation
  - Laboratory scale processes
  - Real sensor network



Conclusions

- The traditional control theory assumes constant sample times and it is not well suited for asynchronic systems such as Wireless Networked Control Systems.
  - Need to develop new theory to deal with integrated wireless communications and control
  - Need to develop simulation platforms for testing and verifying the theories before implementing them on real industrial systems.
- Based on widely used simulation software tools such as MATLAB/Simulink (control design) and ns-2 (communications), we are currently developing a platform for evaluating and demonstrating interactions of wireless communications and embedded control systems.

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