How to Deal With MAC Shortcomings for Sensor Networks
or:
Sensor Network Self Organization
Rendezvous Clustering Algorithm

March 16, 2004

Kathy Sohrabi

Sensoria Corporation

Internetworking the Physical World

About Sensoria

- Founded in 1999
  - Founder: Bill Kaiser, UCLA Faculty/Chairman EE Department
- HQ in San Diego, Design Center in Los Angeles
- Consequence of work on Sensor Nets at UCLA
- Builds and markets networked embedded systems
  - Sensor networking platforms and solutions
  - Ad-hoc Mobile communication systems
- Hardware, software, system design expertise

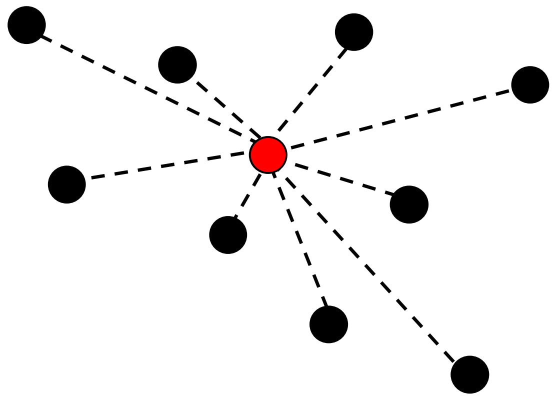
Outline

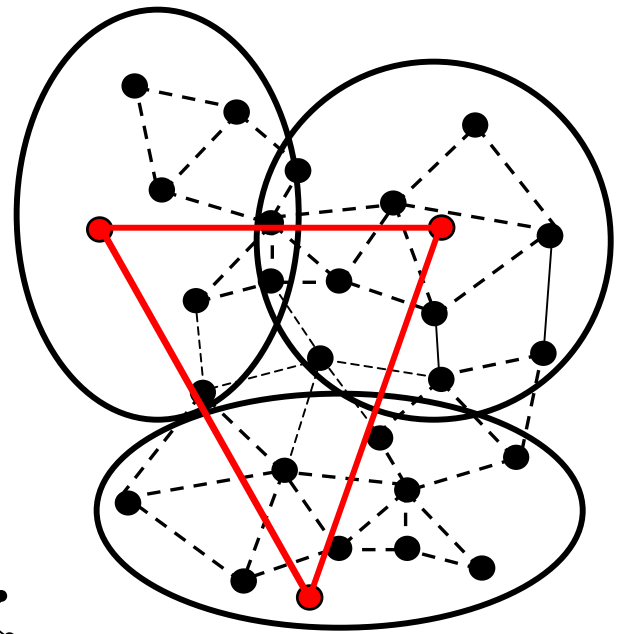
- Introduction
- Problem of self organization
- Observations about MAC
- Why we need to actively manage links (self-organize)
- Rendezvous Clustering Algorithm (RCA)

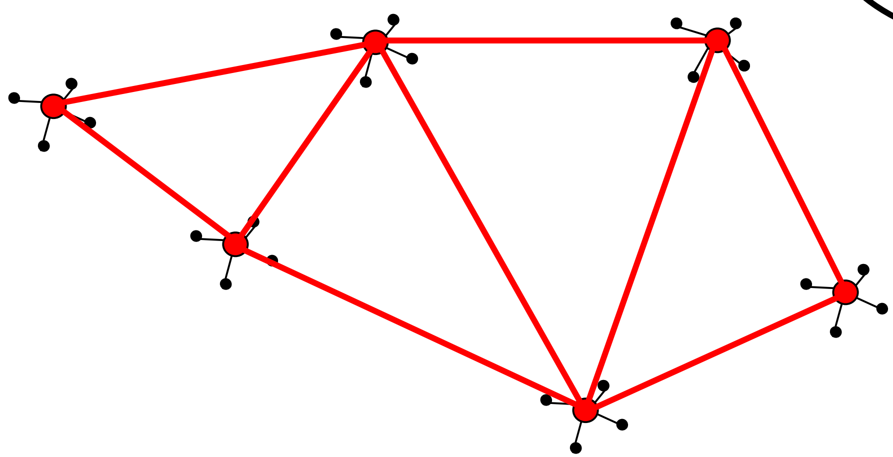
What does Self Organization Mean?

- Self formation at various layers
  - At the highest level, self organizing is expected to provide a distributed computing environment
  - Self forming routes in the face of fast changing and/or ad-hoc topologies. In fact a lot of work has been concentrated on the self organization at layer 3.
  - The clustering mechanism discussed here is concerned with self –organization at layer 2.

Sensor Network Scenarios







Different Classes of Sensor Networking Applications Exist

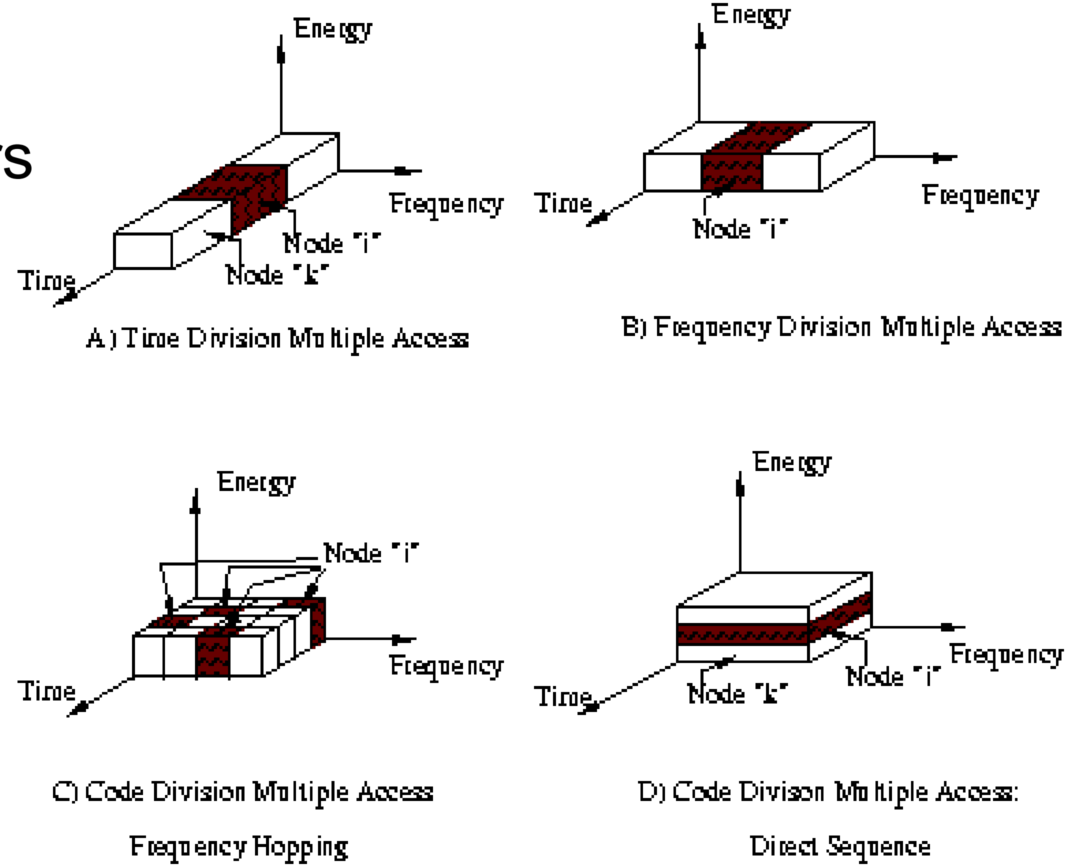
Wireless MAC

- Medium Access Control
  - Share a common channel with others

    •No Coordination: ALOHA

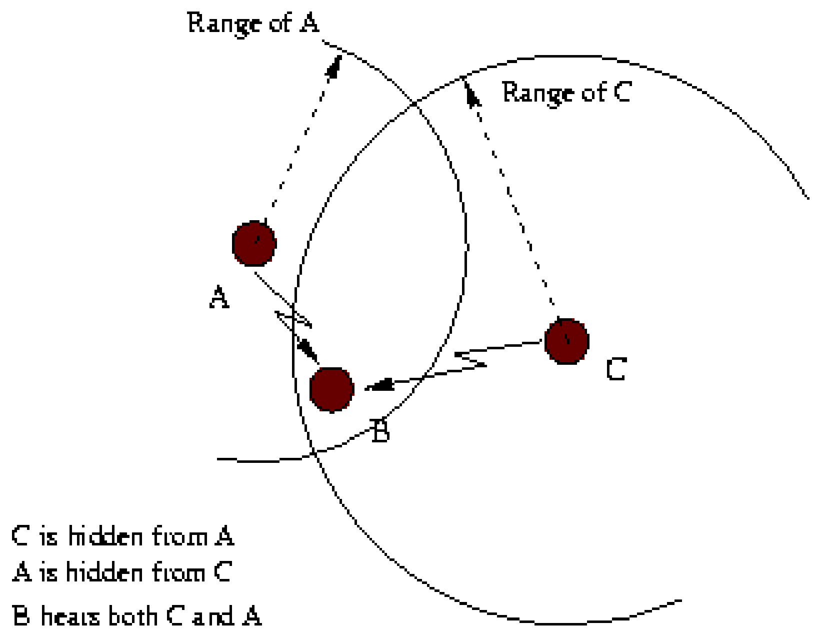
    •Total Coordination: fixed access such as TDMA

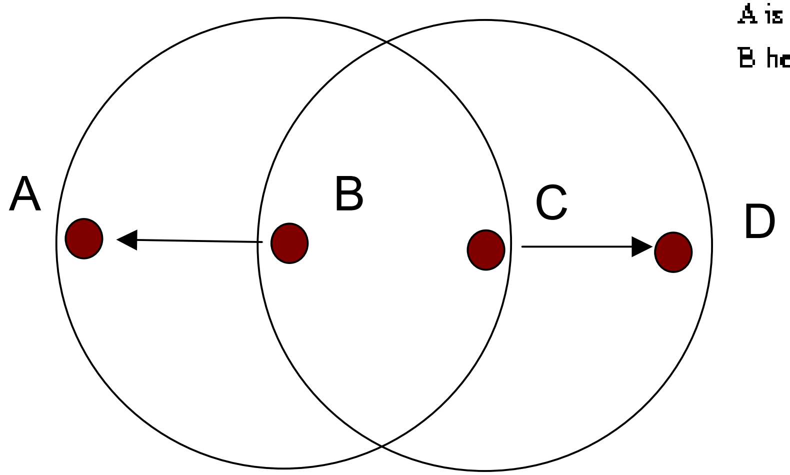
    •Others in between: coordinate only when sending (variations of CSMA, reservation schemes)



MAC for Multihop – Random Schemes

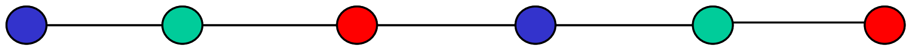
- Hidden Terminal Problem
- Exposed Terminal Problem
- Requires the receiver be turned or all the time
- Channel sensing is not always accurate
- Example: ad-hoc mode of 802.11



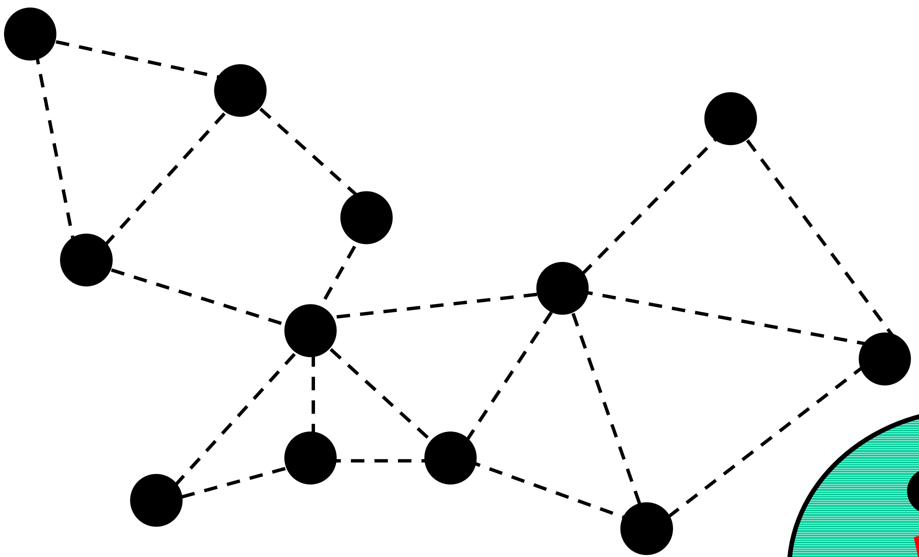


MAC for Multihop – Fixed Access

- Need network link connectivity and interference information (local or global)
- Assignment of optimal transmission schedules is NP-complete
- Approximate schemes that are good exist
- They still need global synchronization
- Mechanism beyond the ability of simple fixed access radios

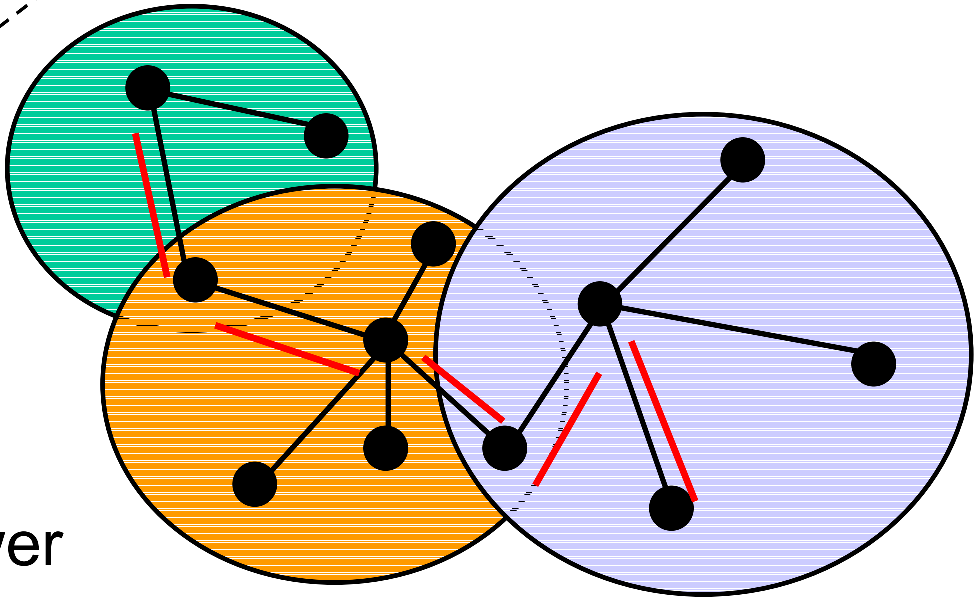


Network Self Assembly Process



Clustering:
Neighbor Discovery & Link Formation

Adaptive Routing:
Formation of Network Layer Routes



Fixed Radio Transmit Power

Rendezvous Clustering Algorithm

Kathy Sohrabi, William Merrill, Jeremy Elson, Lew Girod

About RCA

- Rendezvous Clustering Algorithm (RCA) is really a mechanism for distributed collaboration
  - We use it to form clusters in a distributed fashion
  - Does not necessarily need to be used for managing links
  - Can be used to set up coordinated agreement amongst nodes in a distributed fashion
  - Built on top of the radio' s native MAC
  - Native MAC must be able to
    - Form local wireless networks (typically with one or two hop diameter)
    - Operate on different channels
    - Switch between these channels

Channel Switching

- The ability of the radio to take on various states and switch between them rapidly and efficiently affects the operation
  - Multihop, ad-hoc wireless networks, that need low energy
  - States transitions
    - off->idle
    - idle->on
    - one channel to another channel
  - Order of seconds to switch from channel to channel (RCA native radios)
  - Other radios such as Bluetooth also require on the order of seconds to switch (needed for scatternet formation)
  - Zigbee very good, on the order of milliseconds to switch

sensoria

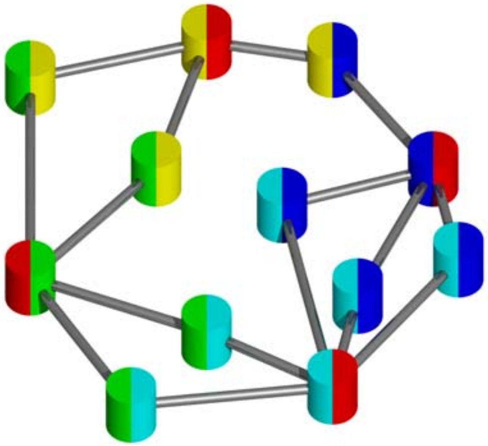
Factors Contributing to Switching Overhead

- HW
  - Phase lock loops : carrier phase and frequency acquisition
  - Power regulators

- PHY
  - Code Acquisition
  - Symbol Acquisition
  - Frame acquisition
- MAC
  - Protocol

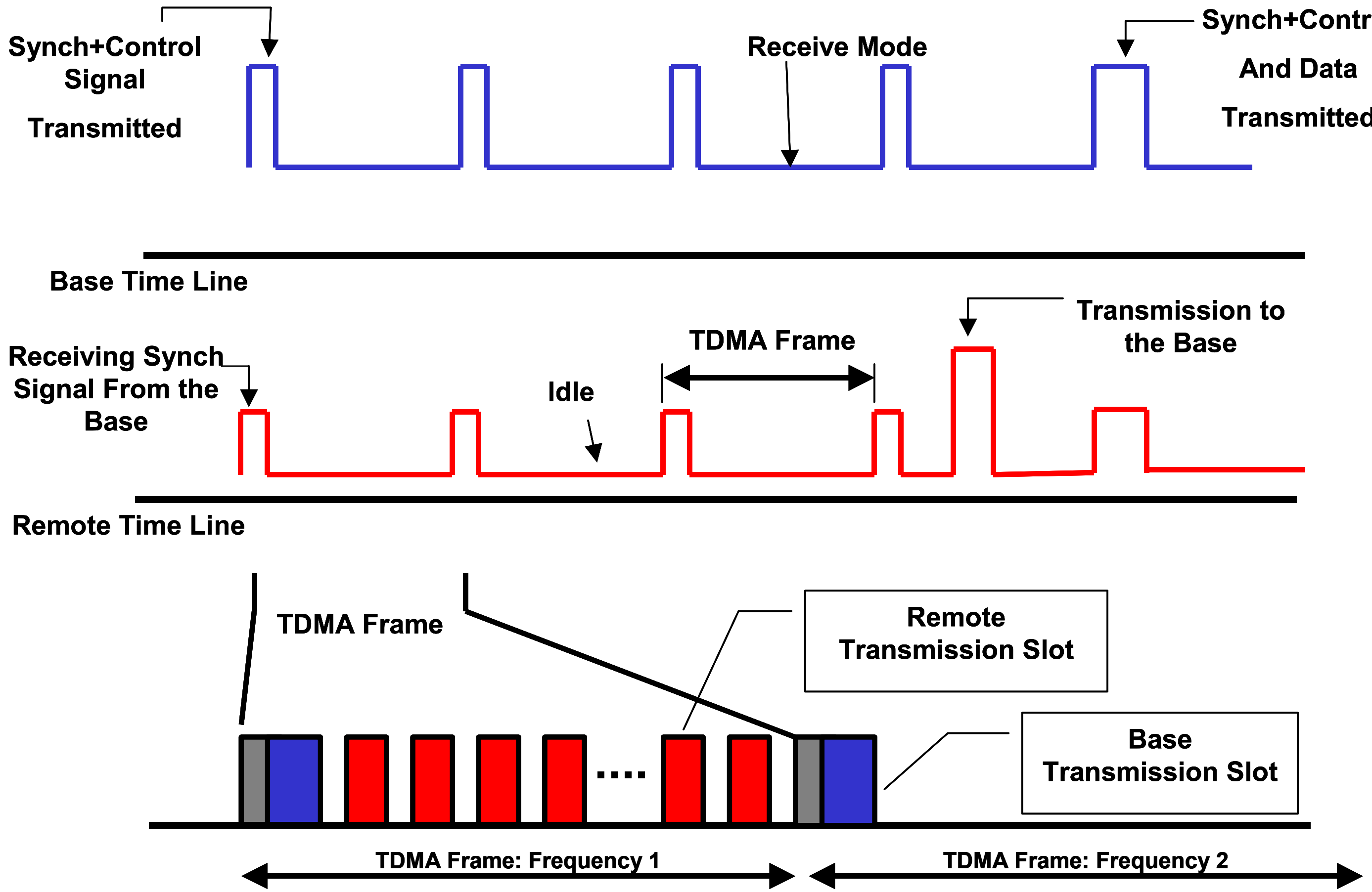
Issues Related to Radios

- To mitigate switching delays chose a dual radio option
  - Each node is equipped with two radios, each operating independently of each other
  - Each radio is a TDMA radio that participates in a start topology network.
  - Each TDMA local network slowly frequency hops (controlled by the star controller)



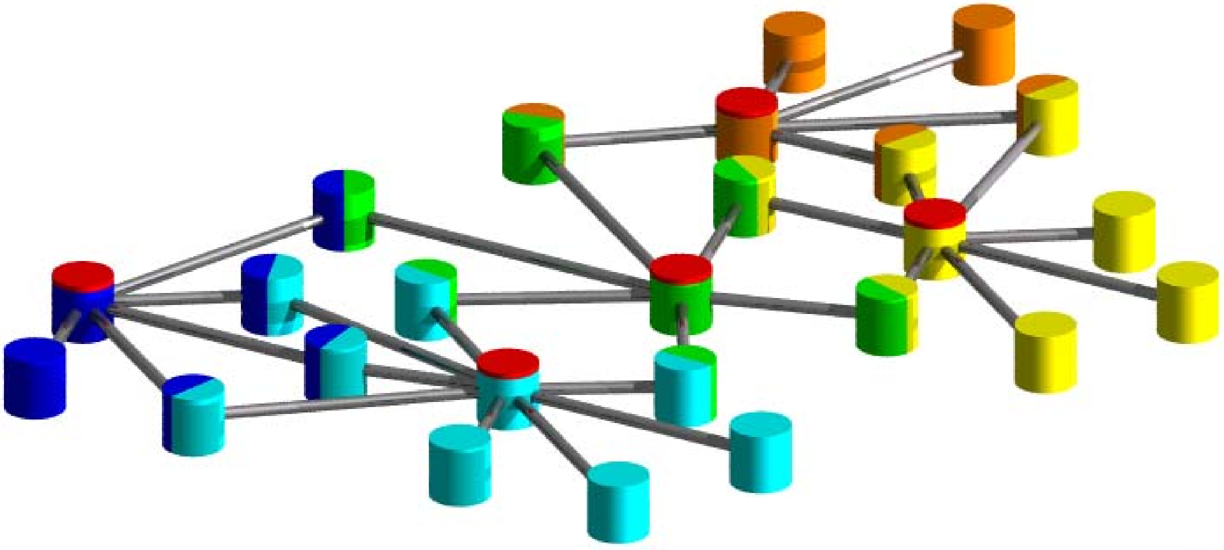
sensoria

Details of the Frame Structure for TDMA/FH Radios



Details of RCA

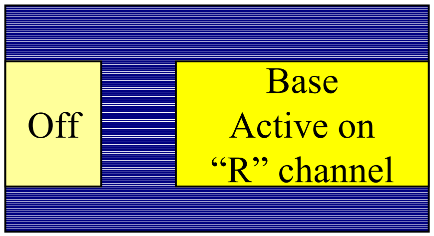
- Three phases of a node in RCA
  - Search mode
  - Cluster head
  - Cluster member



sensoria

Possible RCA Radio State Combinations

Search Mode

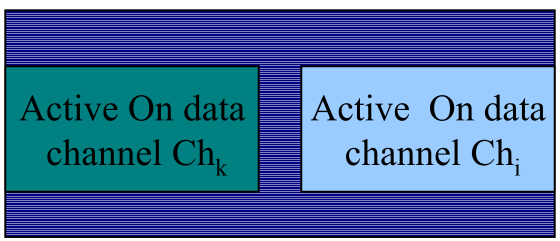


For a dual radio architecture, each radio is tuned to a different channel.

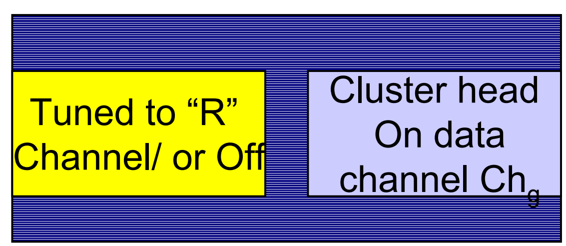
For single radio architecture, the single radio interface will switch between various channels.

Our current radios form a star network with a Base and a number of remote members.

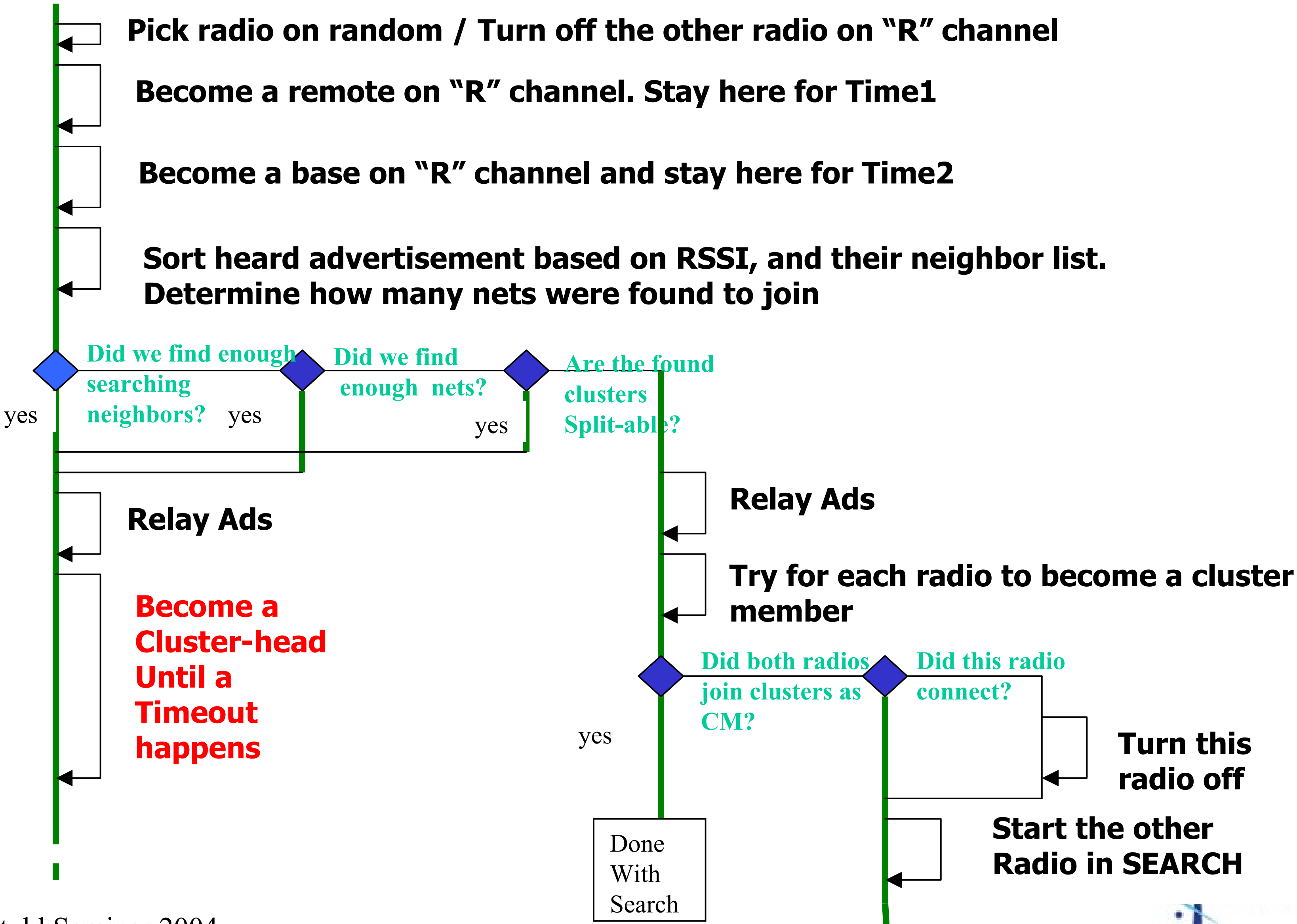
Cluster Member



Cluster Head



Search Mode: When it all begins



Cluster-Head Time Out

Become a Cluster-head until a Timeout happens. Involves inviting other searching nodes to join this radio

Does the CH have less than the minimum number of neighbors?

yes

Kick any existing attached neighbors off this network

Make the CH's data radio inactive, then turn it off.

Put the other radio into SEARCH mode

Continue as a cluster head, until a timeout occurs

How to Become a Cluster Member

Precondition: Have received over the "R" channel an invitation from a CH to join its cluster

Choose the appropriate radio to join the suggested network as a cluster member(SEARCHing radio first, then inactive radios)

Tune the chosen radio to the proper network, connect to the base on that network. Stay in this condition until a timeout occurs.

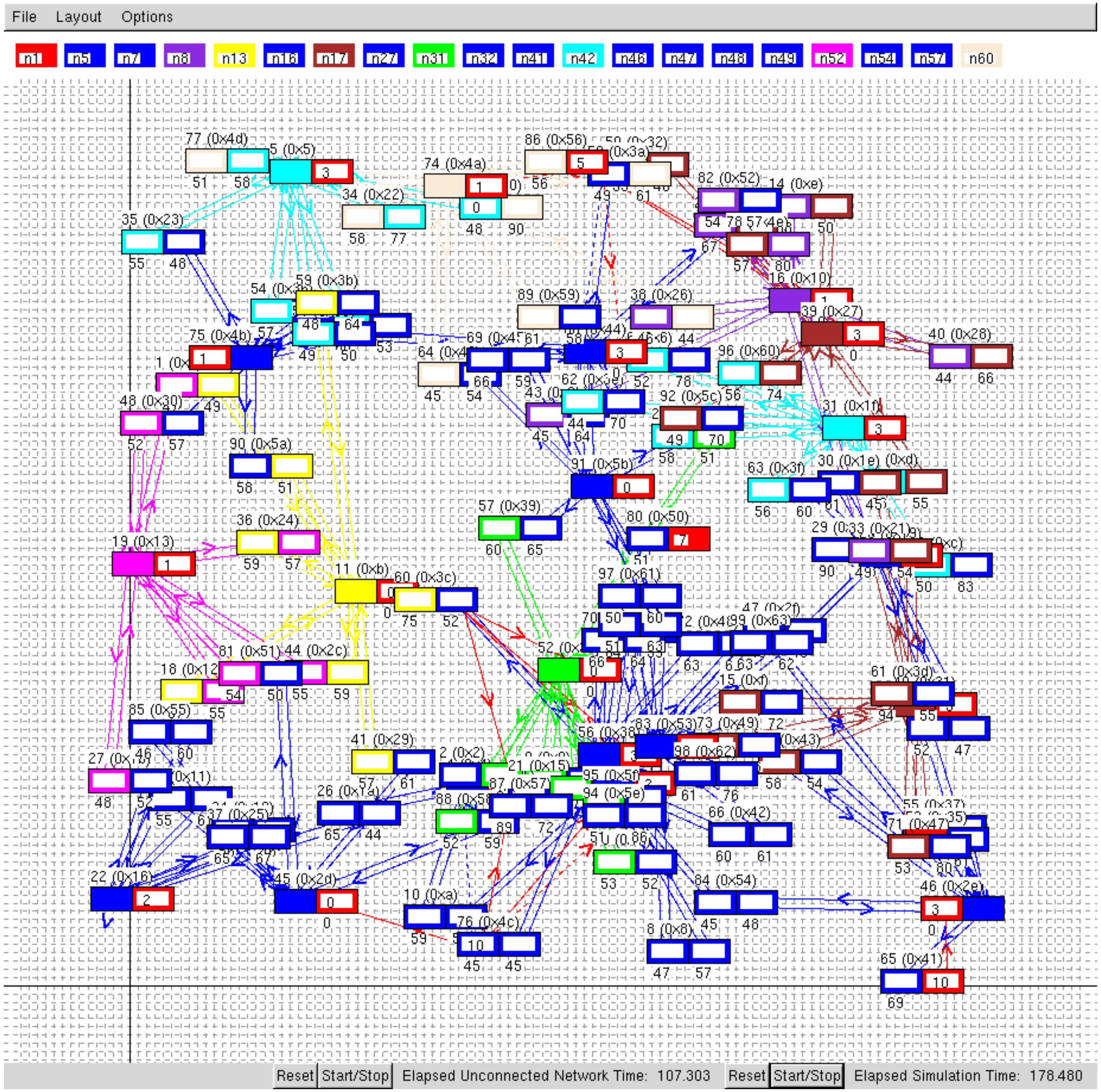
Are we attached to the base?

Stay attached to the base, and set the timeout again

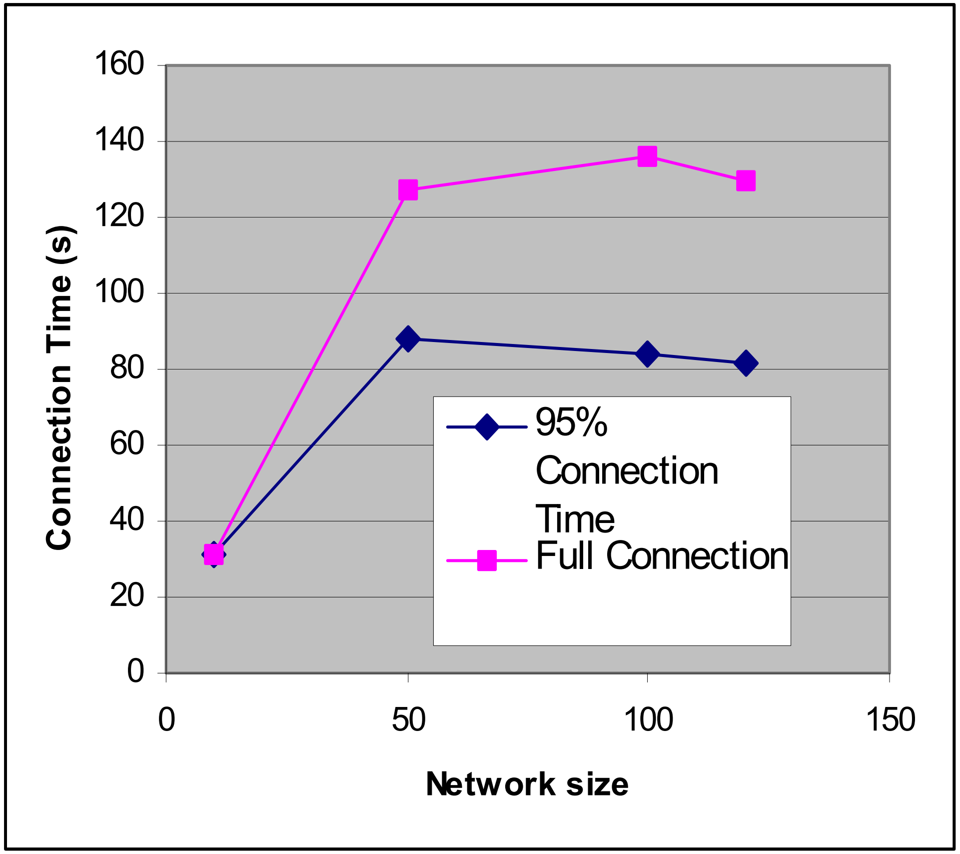
Start SEARCHing again,
Or make the other radio start SEARCHing if not connected

Results

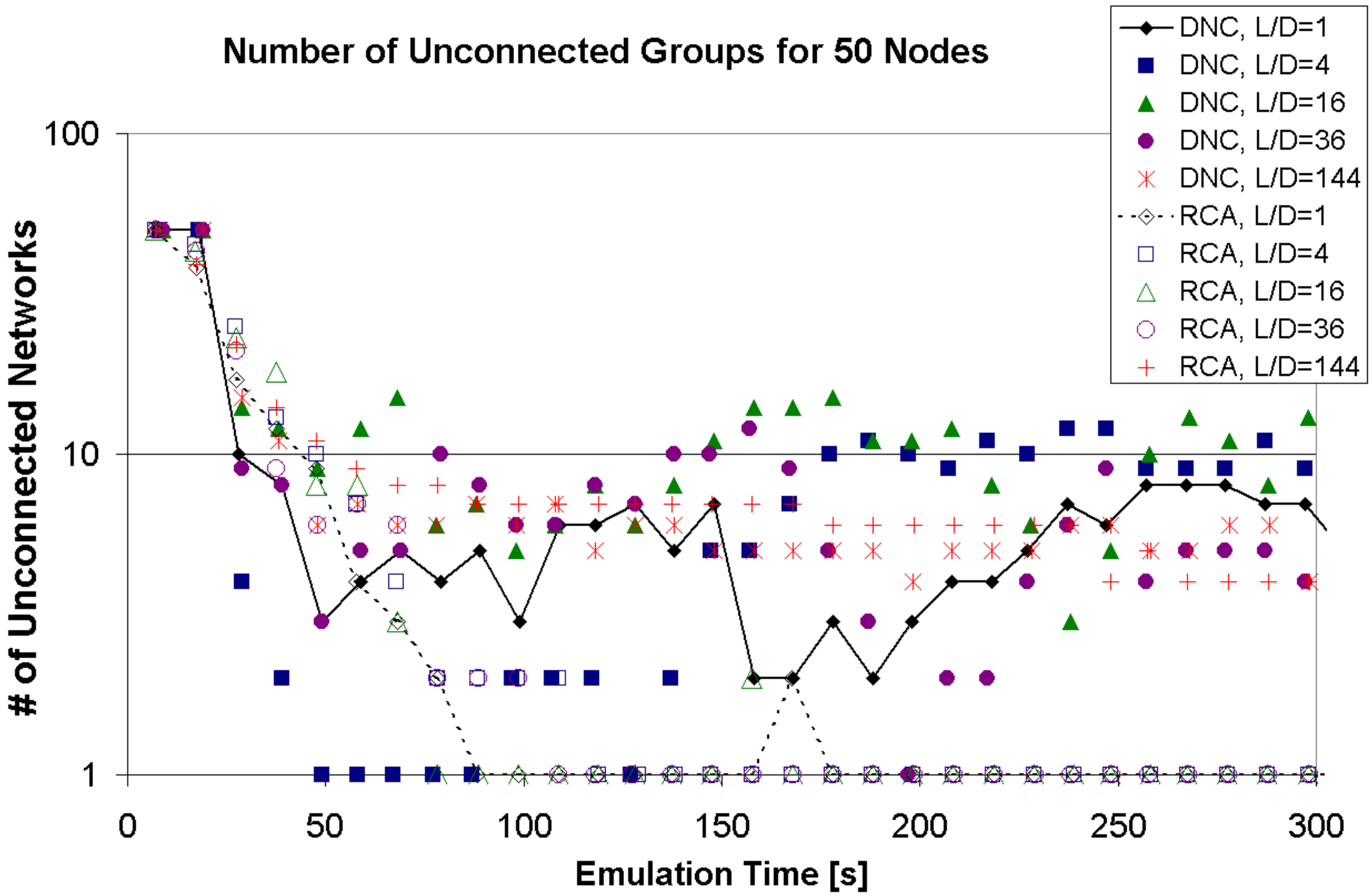
RCA Connected Network



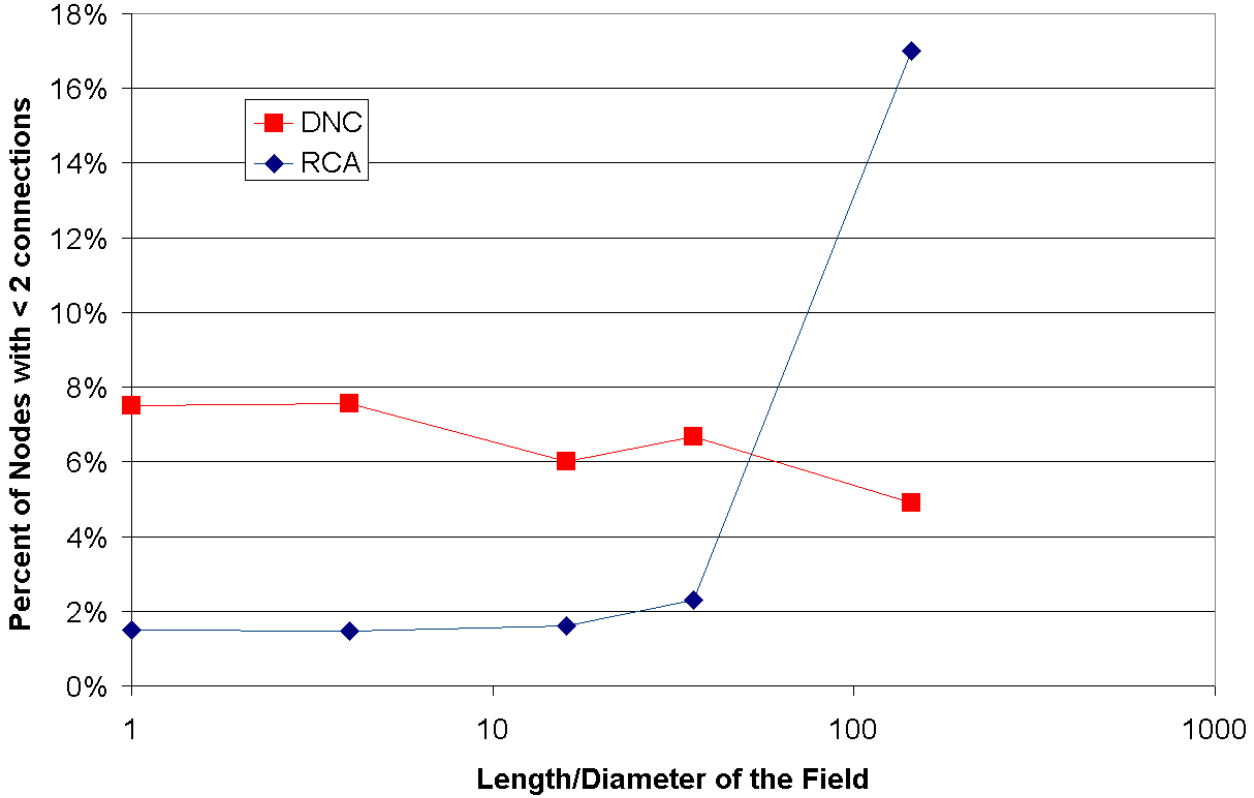
Scalability



Connectedness Over Time



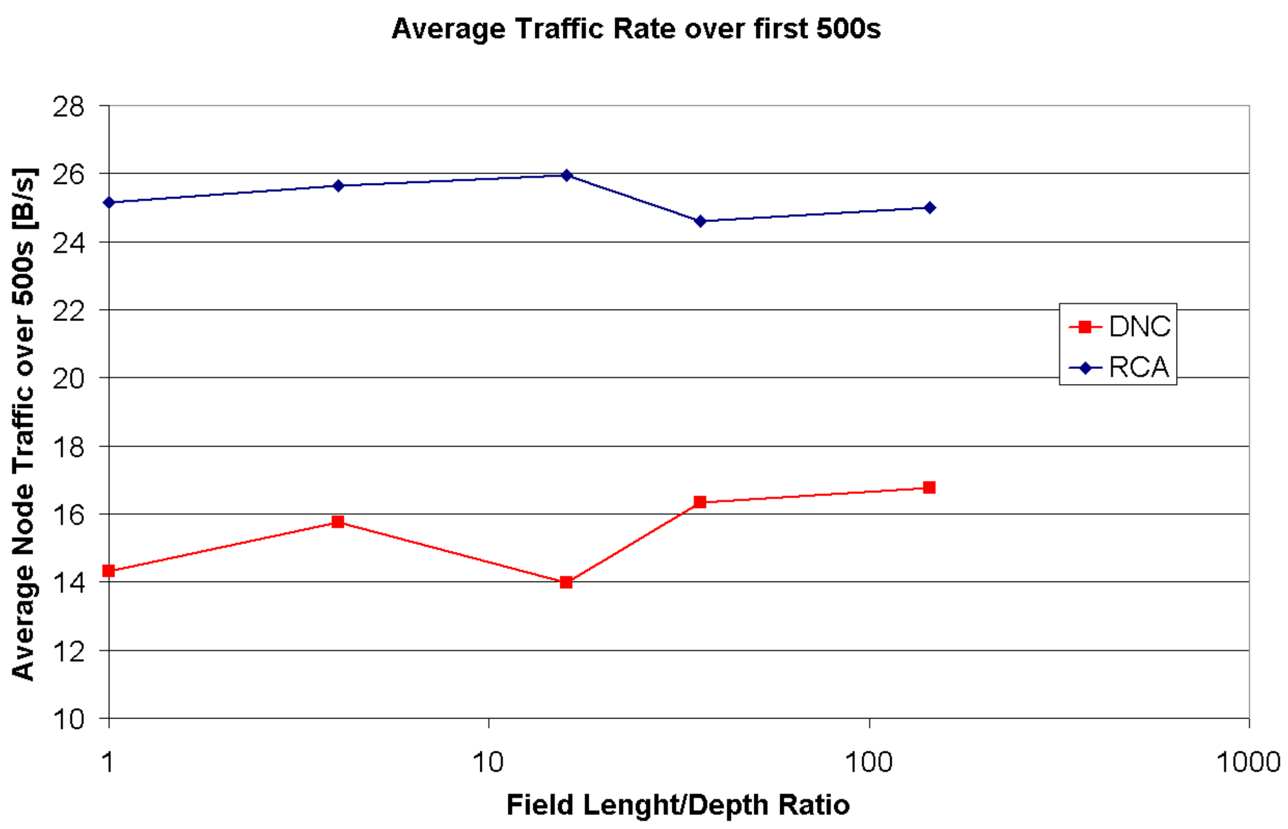
Percent Nodes Not Connected



Dagstuhl Seminar 2004

sensoria

Traffic Overhead



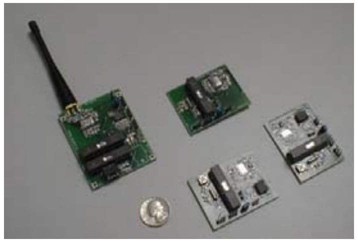
Hardware Platform History

Sensoria Platform History

WINS 1.0 - 1999

- 4-channel 12-bit analog interface
- Windows CE processing platform
- Integrated 2.4 GHz radio
- COTS processor boards

Pico WINS - 1999



- Wireless sensor tags
- Low power
- Miniaturization
- Small Antenna/Flexible PCB

WINS 2.0 - 2001

- Custom 32-bit processor system using Linux OS
- DSP co-processor controlling analog interface
- 4-channel 16-bit analog interface
- Dual 2.4 GHz radios
- External interfaces: Ethernet, PCMCIA/CardBus

WINS 3.0 - 2003

- 32-bit processor module with up to 128 MB SDRAM using Linux OS
- Low-power DSP co-processor
- 16-channel 24-bit analog interfaces
- External interfaces: RS-232, PCMCIA/CardBus, USB, Ethernet
- Embedded dual 802.11 cards
- Fully modular design with system bus

Further Questions