Wireless Sensor and Control Networks

Reliable Low Power, Ad Hoc Wireless Networks

February 16, 2006

DUST™ NETWORKS

The Vision

"Just as the personal computer was a symbol of the '80s, and the symbol of the '90s is the World Wide Web, the next nonlinear shift, is going to be the advent of cheap sensors."

-Paul Saffo

Institute for the Future

The Engineering Challenge

The scale and operational requirements lead engineers down new paths in design

- Faster is not better
- Low power rules
- Make wireless simple
- Kept the technology simple and small - **conserve bits and gates**
  - Compact code and data storage is more important then time-to-market
  - Complex modulation and transmission schemes cost too much time and power

Agenda

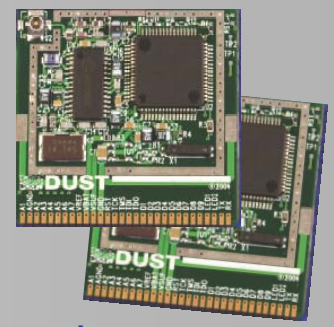
- Dust Overview
- Markets
- Technologies – the landscape
- Standards/Groups
- Q&A

Dust Overview

- Background
  - VC funded
  - Products in the field

  - Founded 2002, Berkeley roots
  - Located in Hayward
- What Dust Networks does:
  - Develops and sells wireless network modules and software for sensor and control networks
- Key technologies:
  - TDMA – access
  - Mesh – network topology

  - Frequency hopping - radio



- What we emphasize:
  - Reliability – radio data delivery is as good as wired, works in harsh RF environments
  - Deterministic – bounded latency, dedicated resources
  - Low power – deterministic, long battery life
  - Easy to install & operate – ad hoc network, no RF planning

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  - Background
  - Requirements
  - Why not existing technologies?
- Technologies – the landscape
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Market Segmentation

Enterprise Applications

security
HVAC
AMR
lighting control
access control

BUILDING AUTOMATION

asset mgt
process control
environmental
energy mgt

INDUSTRIAL CONTROL

Border protection
Perimeter Security
Battlefield Information Awareness

DEFENSE

Consumer Applications

CONSUMER ELECTRONICS

TV
VCR
DVD/CD
remote

PC & PERIPHERALS

mouse
keyboard
joystick

RESIDENTIAL/ LIGHT COMMERCIAL CONTROL

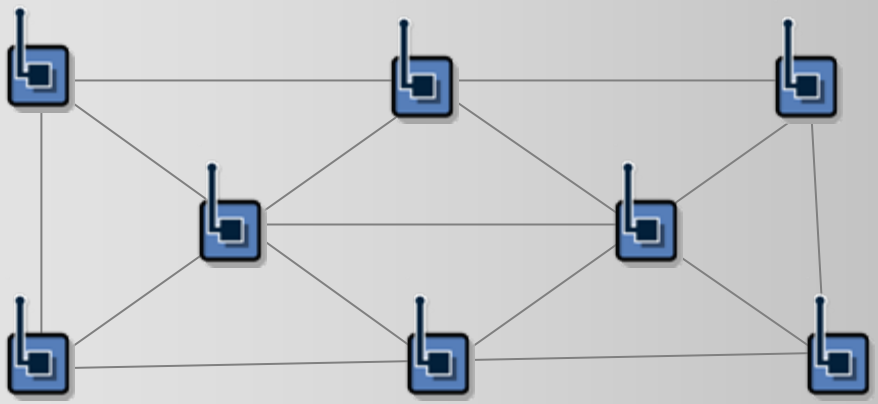
Home security
Home HVAC
Home lighting control
lawn & garden irrigation

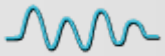
Enterprise Sensor & Control Networking

Monitoring Systems

Control Systems

Enterprise Applications

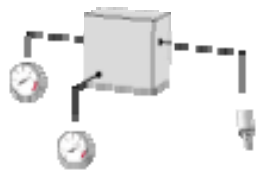




Analog Sensors

Digital Sensors and Actuators

Serial Devices



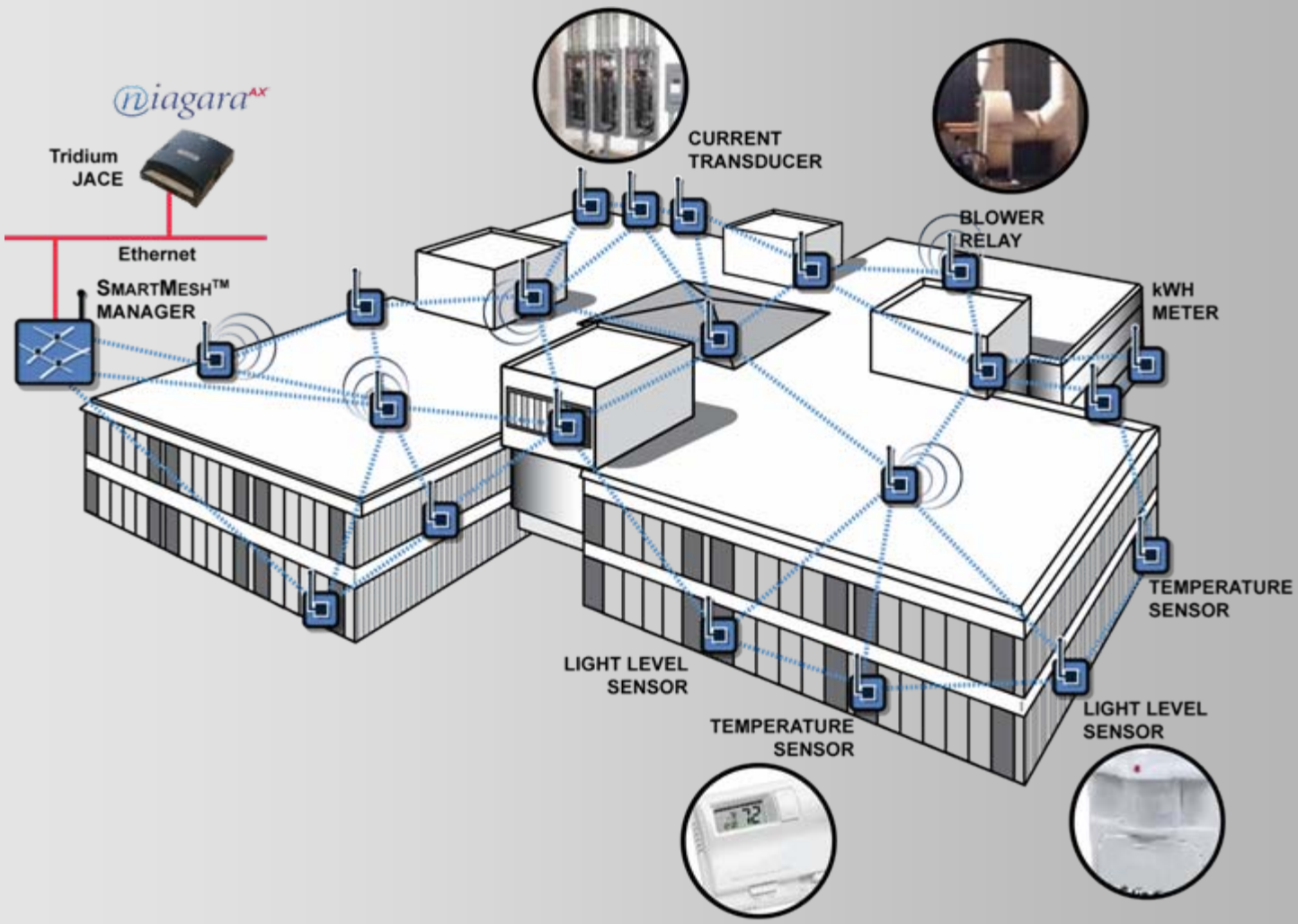
Example Systems: Database, Embedded Control System, Logging, Alarming

Example Sensors: Temperature, Pressure, Flow, Level, Magnetometers, Cameras, Motion, Light level, and many others.

Example Actuators: relays, switches, lighting ballasts, door locks, air dampers, valves, fans, and many others

Easy to install **Reliable** **Low Power**

Energy Management



Energy Monitoring

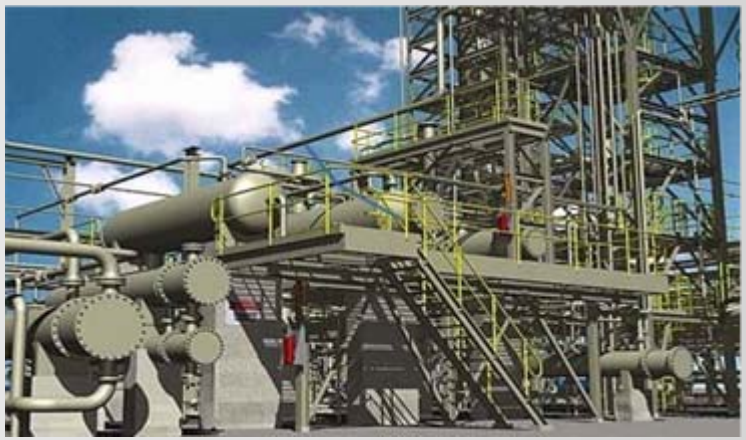
- Energy is the #1 cost of supermarkets after shelf stock
- Analyze and reduce power consumption
- The Challenge:

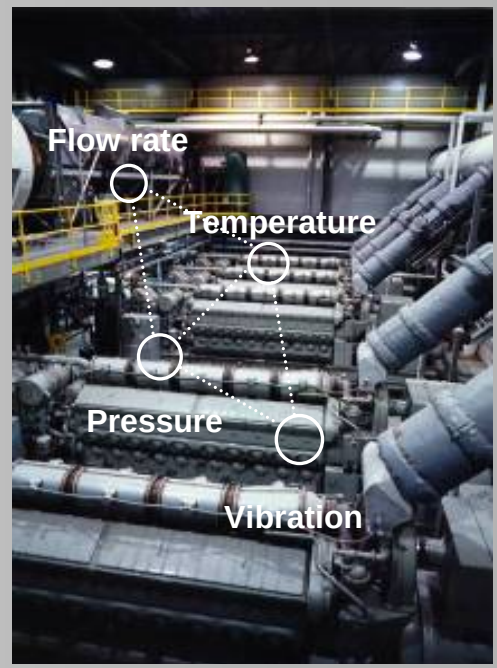
  How can energy consumption points be monitored without running costly and intrusive wires ?
- Data brought back to expert analysts who make recommendations to **save 10-25% of total energy costs**

Industrial Monitoring & Control

Cost-effectively extend monitoring to more points

- Refineries
- Oil & gas fields
- Continuous process control
- Discrete manufacturing





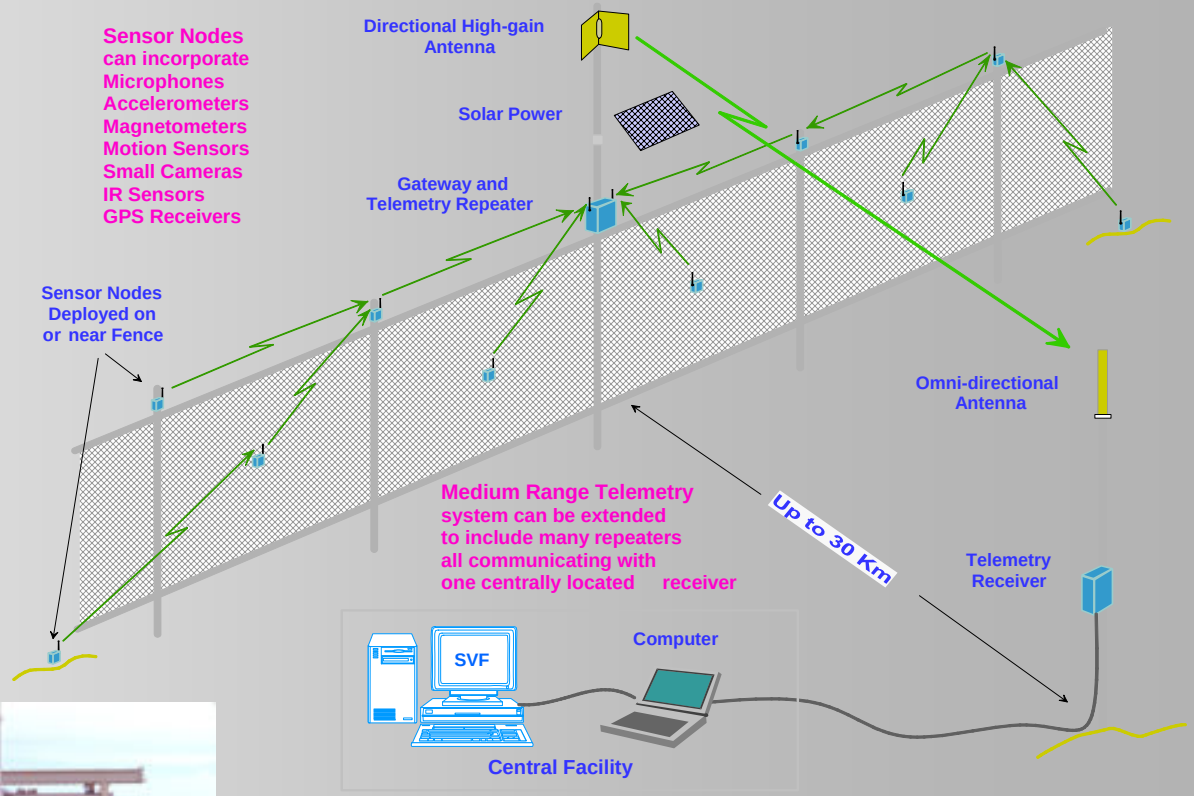
Extra sensing & control points:

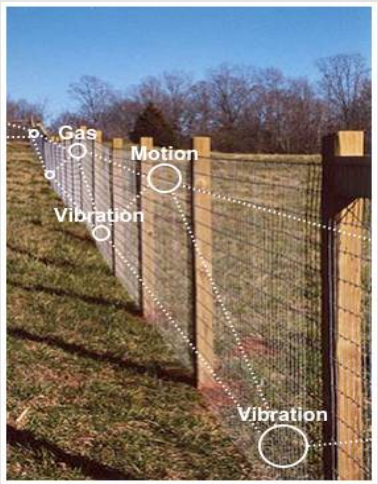
- Increases process efficiency
- Increases reliability (built-in redundancy)
- Often replaces manual labor “sneaker net”

Perimeter Security

Enforce 24/7 perimeter security around fixed installations including key assets – reduced need for guards

- 30-40% less expensive than vibration wires
- Easily augmented with new sensors (on or off the fence)
- Cameras for visual confirmation
- Easy to deploy
- More precise location of intruder

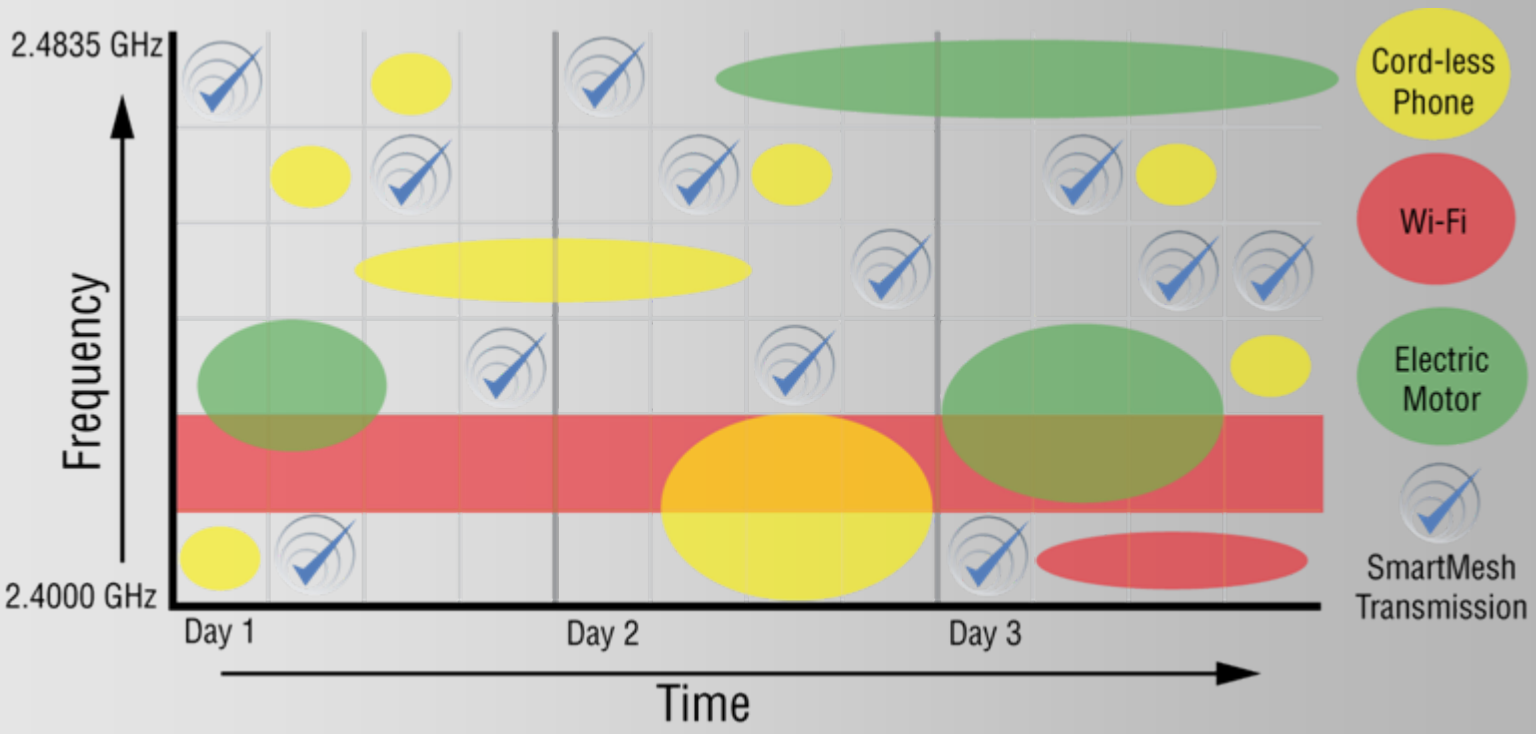




Key Enterprise Requirements

- Reliable: > 99.9%
- Scalable: up to 10s of thousands of points per facility
- Flexible and Tunable
  - Applications vary in service needs
  - Growth
- Easy to Install –
  - No to site surveys, RF planning and network planning
  - YES to coexistence
- Low Power (<40 uW average for 1 minute/message)
- Security – similar issues as with other wireless networks

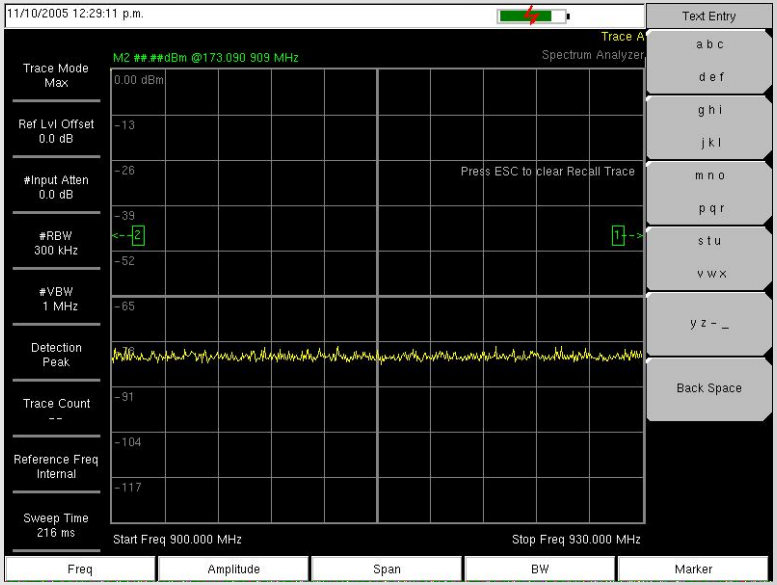
Reliability

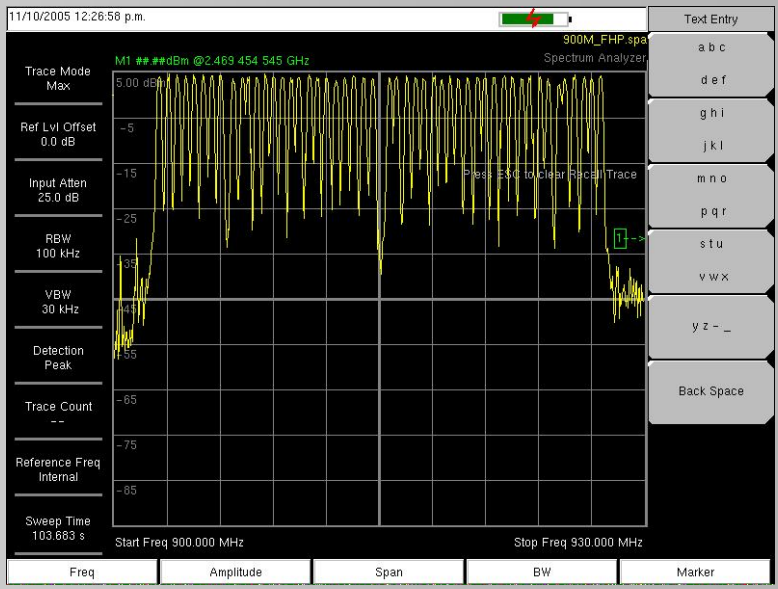


- Key to reliability: Full diversity to avoid interferers
  - Frequency, path, and time
  - Frequency hopping, to

RF Impairment

Noise Measurements Made At An ISA Expo showroom floor

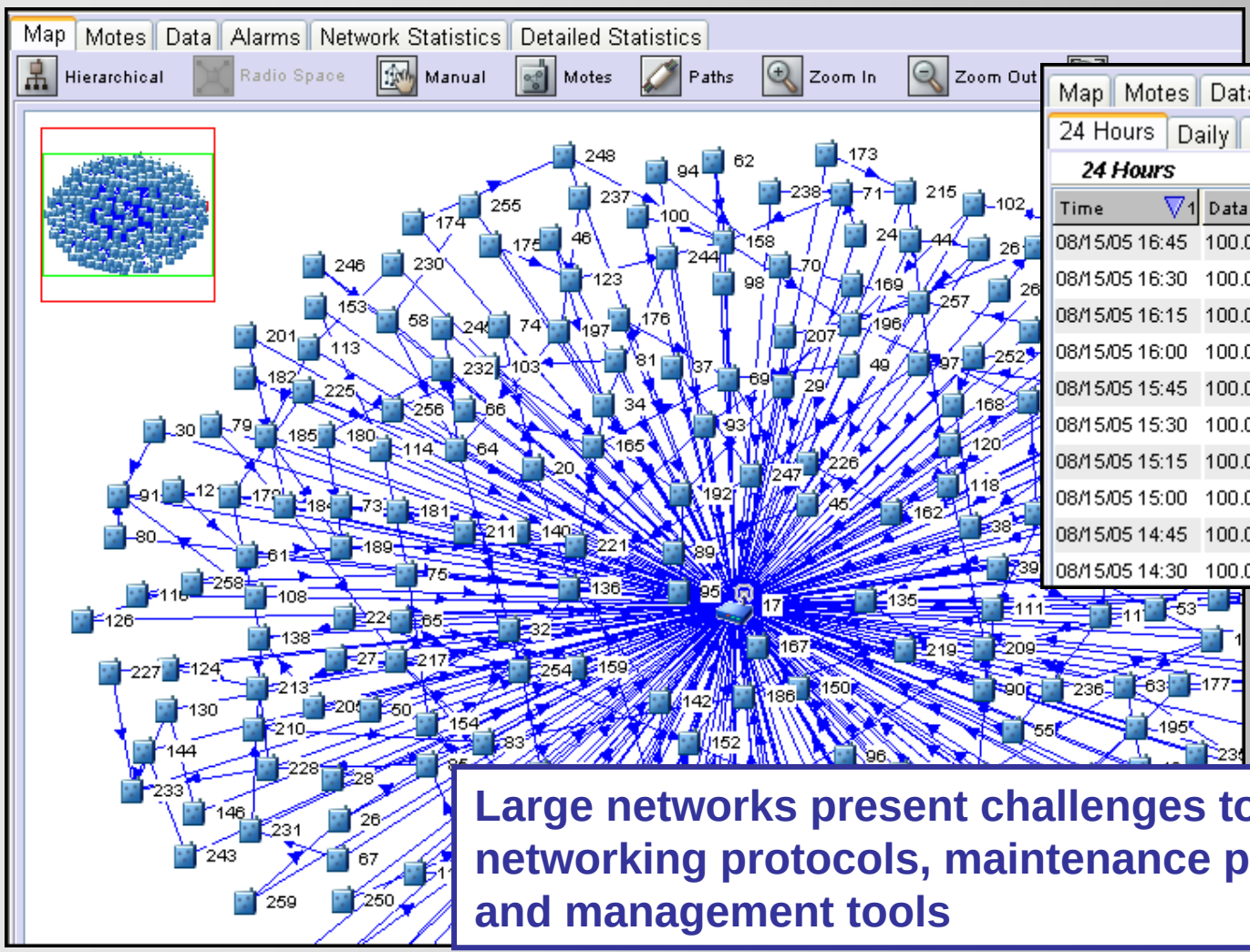




- **The very quiet noise floor at 900 MHz (early in the morning before the show opens).**
- **At 12:30PM, the 900 MHz band has reached saturation, or rather that the “background” floor has risen by over 60 dB (x1000000).**

Scaling

A 250 node network



Map | Motes | Data | Alarms | Network Statistics | Det

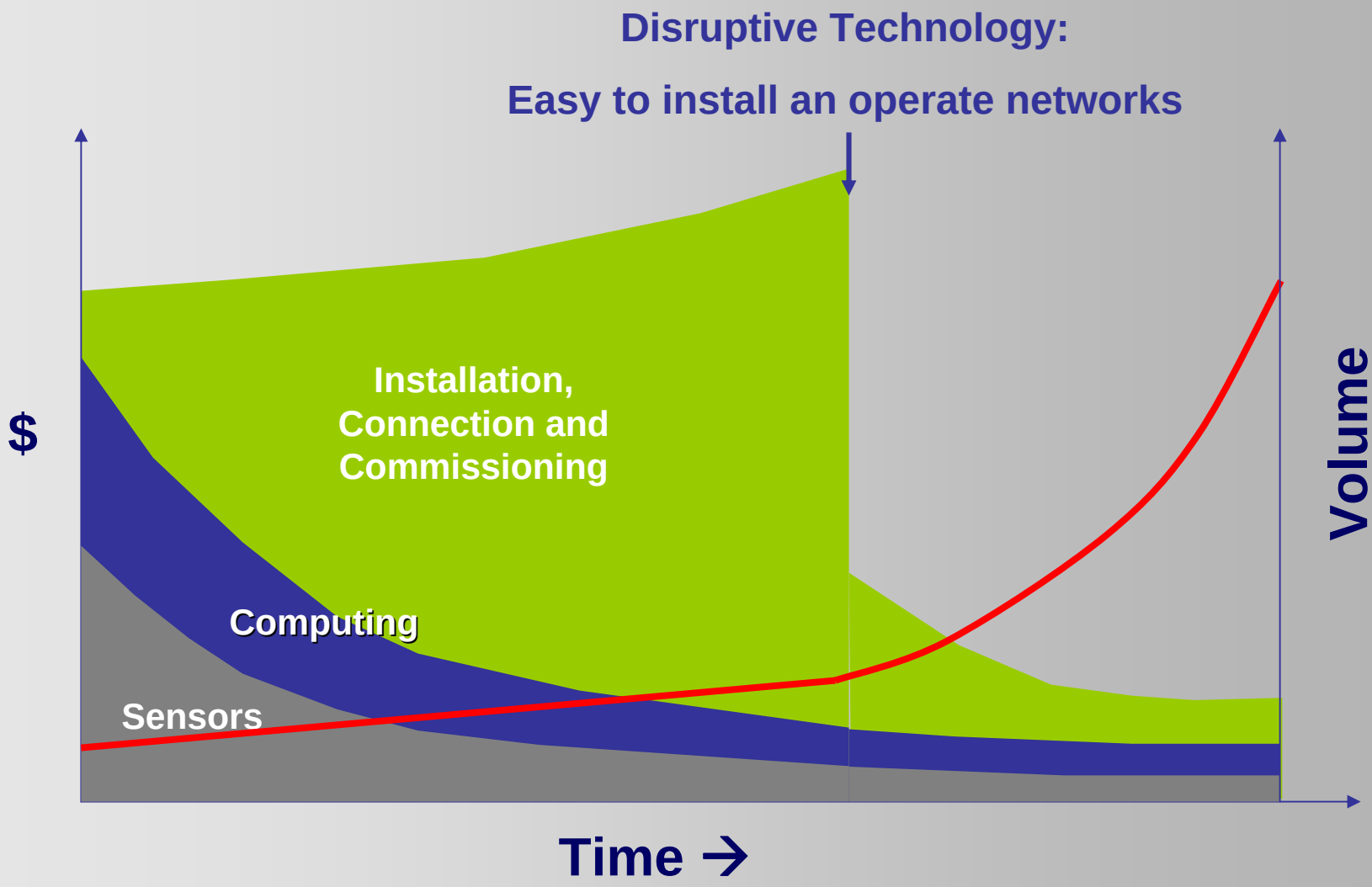
24 Hours | Daily | Lifetime

24 Hours

Time	Data Reliability (%)	Path Stability (%)
08/15/05 16:45	100.000	90.930
08/15/05 16:30	100.000	90.740
08/15/05 16:15	100.000	90.080
08/15/05 16:00	100.000	90.090
08/15/05 15:45	100.000	90.490
08/15/05 15:30	100.000	89.500
08/15/05 15:15	100.000	88.940
08/15/05 15:00	100.000	88.890
08/15/05 14:45	100.000	88.120
08/15/05 14:30	100.000	86.580

Large networks present challenges to networking protocols, maintenance practices and management tools

Wireless Sensor Network Market Growth



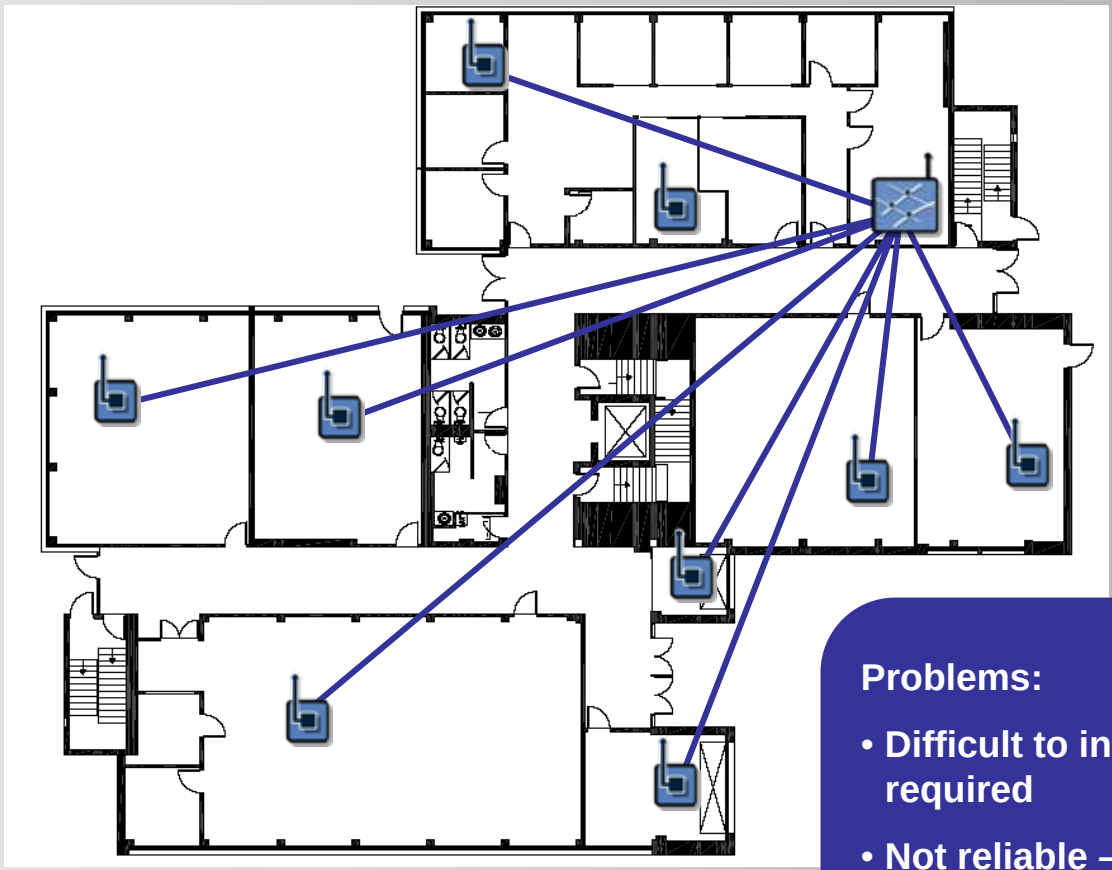
New Technologies Are Needed

- Existing technologies don’t meet all the requirements
- 802.11 and WiMAX
  - Scale in dense deployments, power, RF environment, installation and management
- Wireless Blue Tooth
  - Limited Networking
- Cell Phones
  - Scale in dense deployments, power, RF environment, and management
- Even 802.15.4 & ZigBee
  - Scale in dense deployments, power, RF environment

Agenda

- Dust Overview
- Markets
- Technologies – the landscape
  - Mesh and Star
  - Frequency hopping and single channel
  - TDMA and CSMA-CA
- Standards/Groups
- Q&A

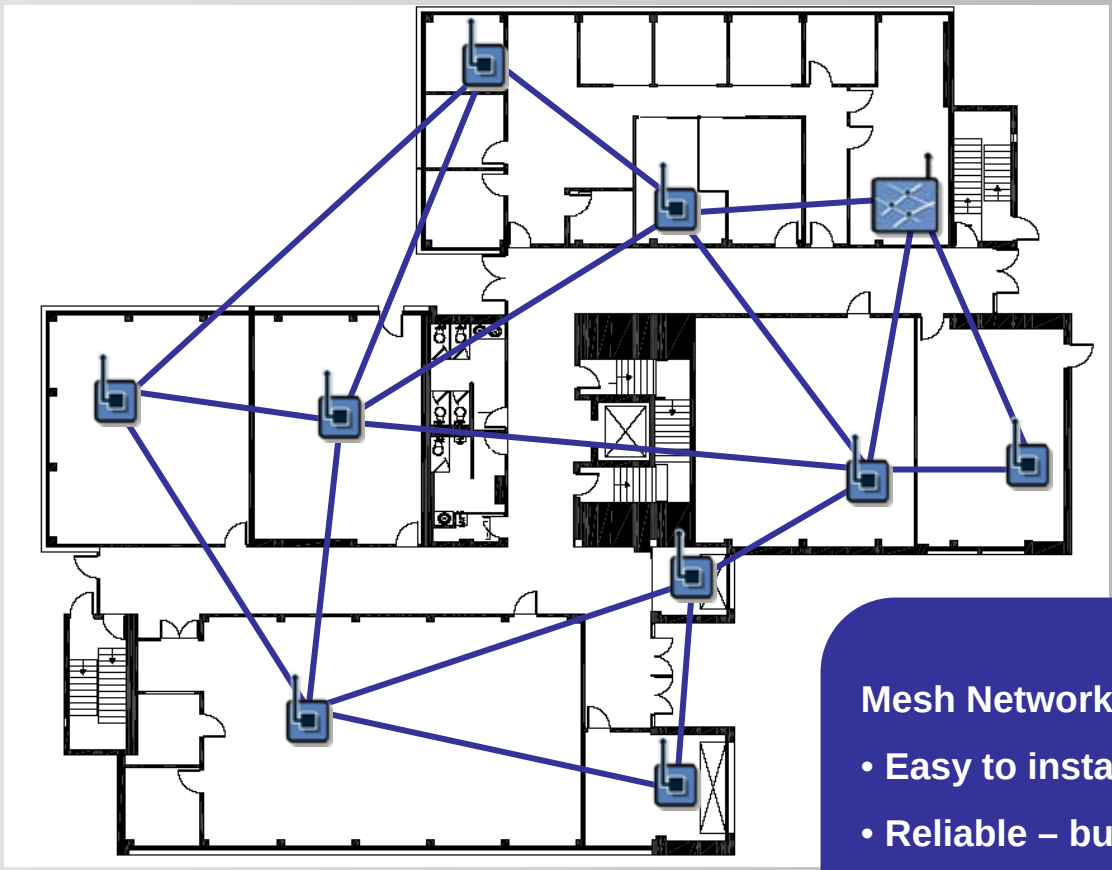
Star Network Wireless



Problems:

- **Difficult to install – RF site survey required**
- **Not reliable – many single points of failure**
- **High Power – many long links**

Mesh Network Wireless



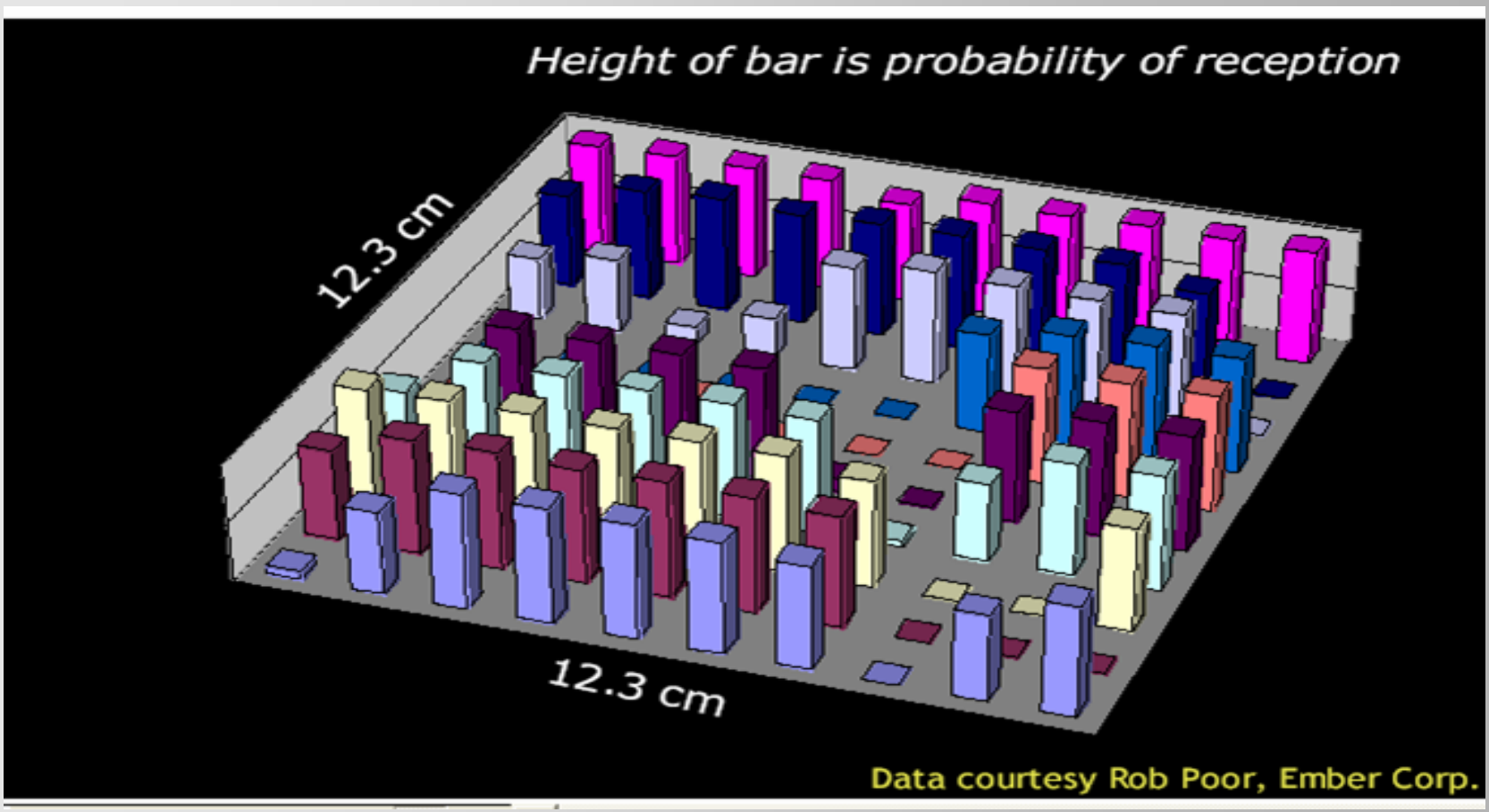
Mesh Networks:

- **Easy to install – self configuring**
- **Reliable – built in redundancy**
- **Low power – multi-hopping reduces consumption**

Key Elements of Mesh Technology

1. Strong radio links:
   - Direct Sequence Spread Spectrum (DSSS), Frequency Hopping Spread Spectrum (FHSS)
2. Robust installation processes:
   - Automatic configuration & joining
3. Reliable networking:
   - Built-in redundancy & self healing

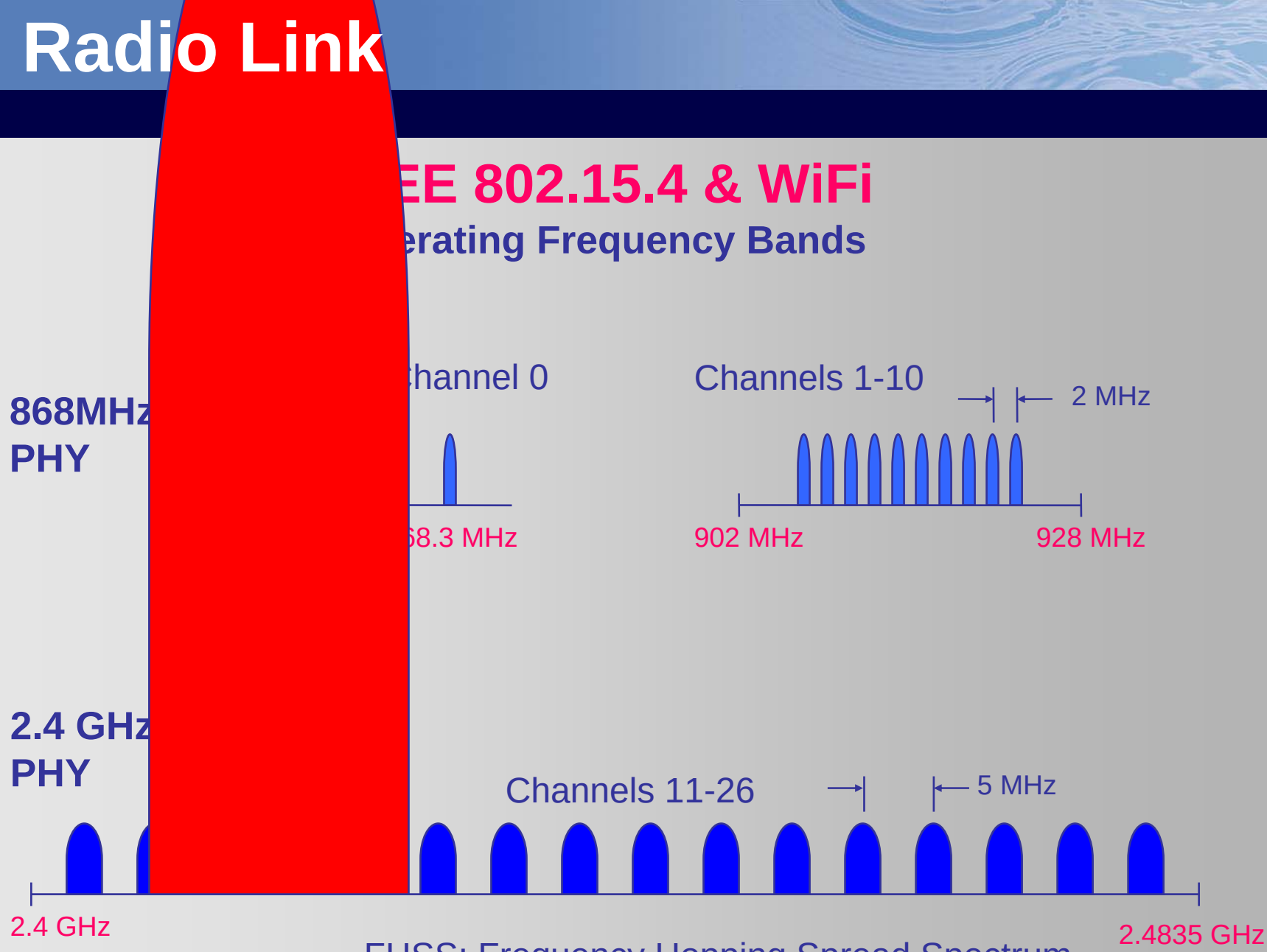
Spatial effect of multipath



Radio Link

EE 802.15.4 & WiFi

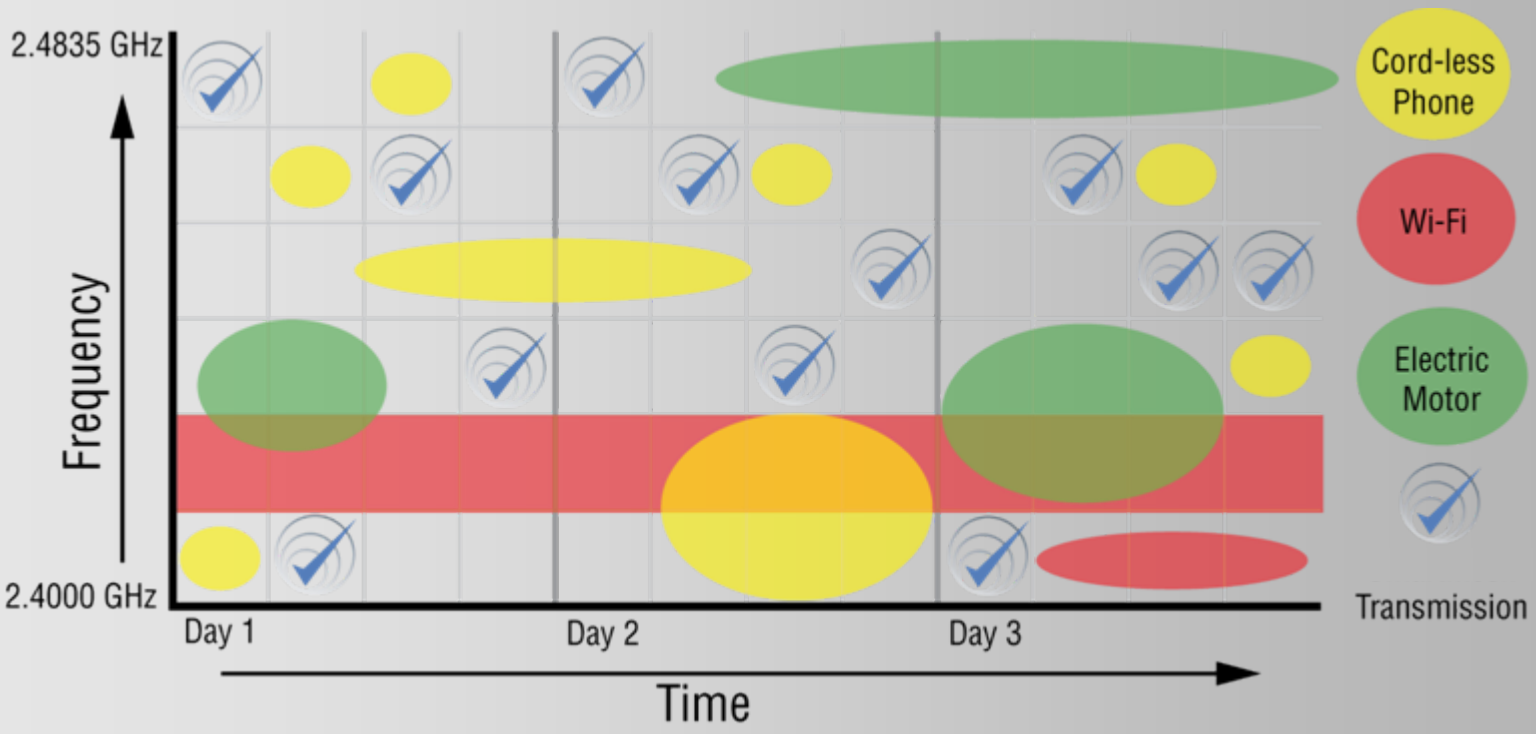
erating Frequency Bands



FHSS: Frequency Hopping Spread Spectrum

DSSS: Direct Sequence Spread Spectrum

Reliability: Frequency Hopping & Mesh



- keys to reliability:
  - Full path diversity (mesh)
  - Frequency hopping, to avoid time varying interferers

Network Reliability

Results:

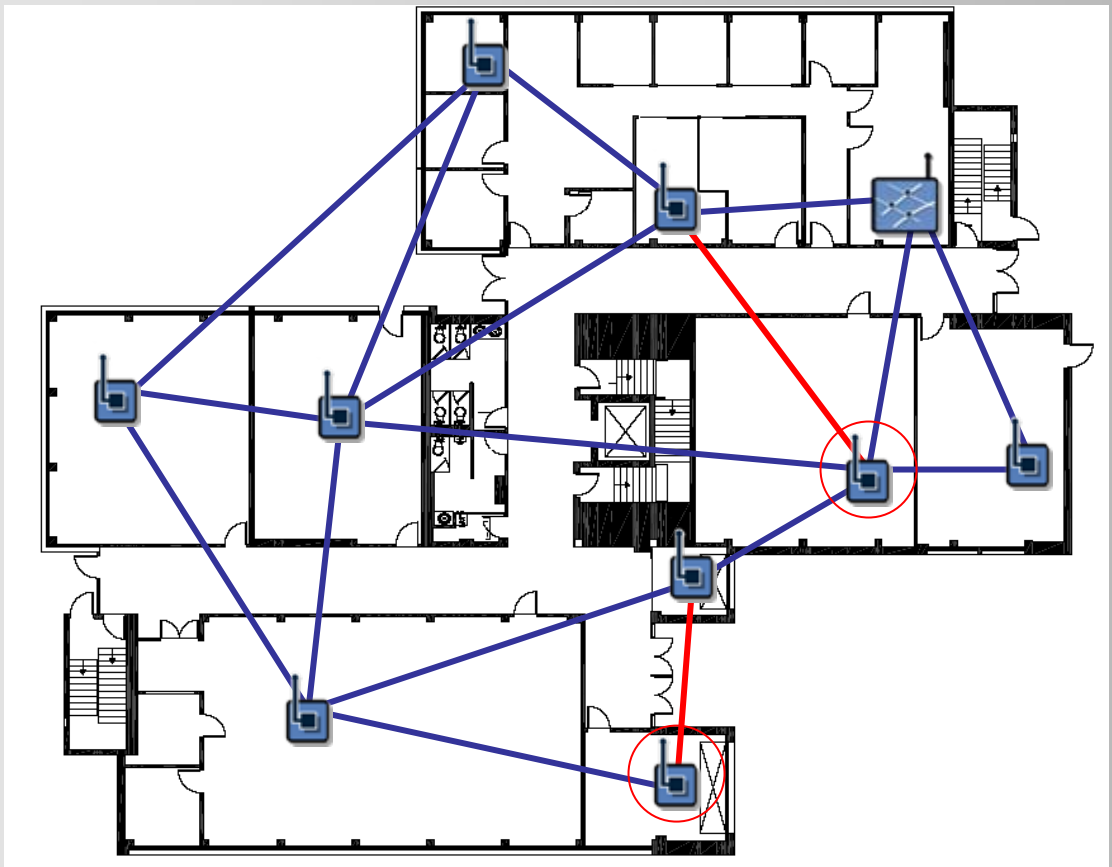
> 99.99% reliability in typical deployment

Networking Protocols- TDMA & CSMA-CA

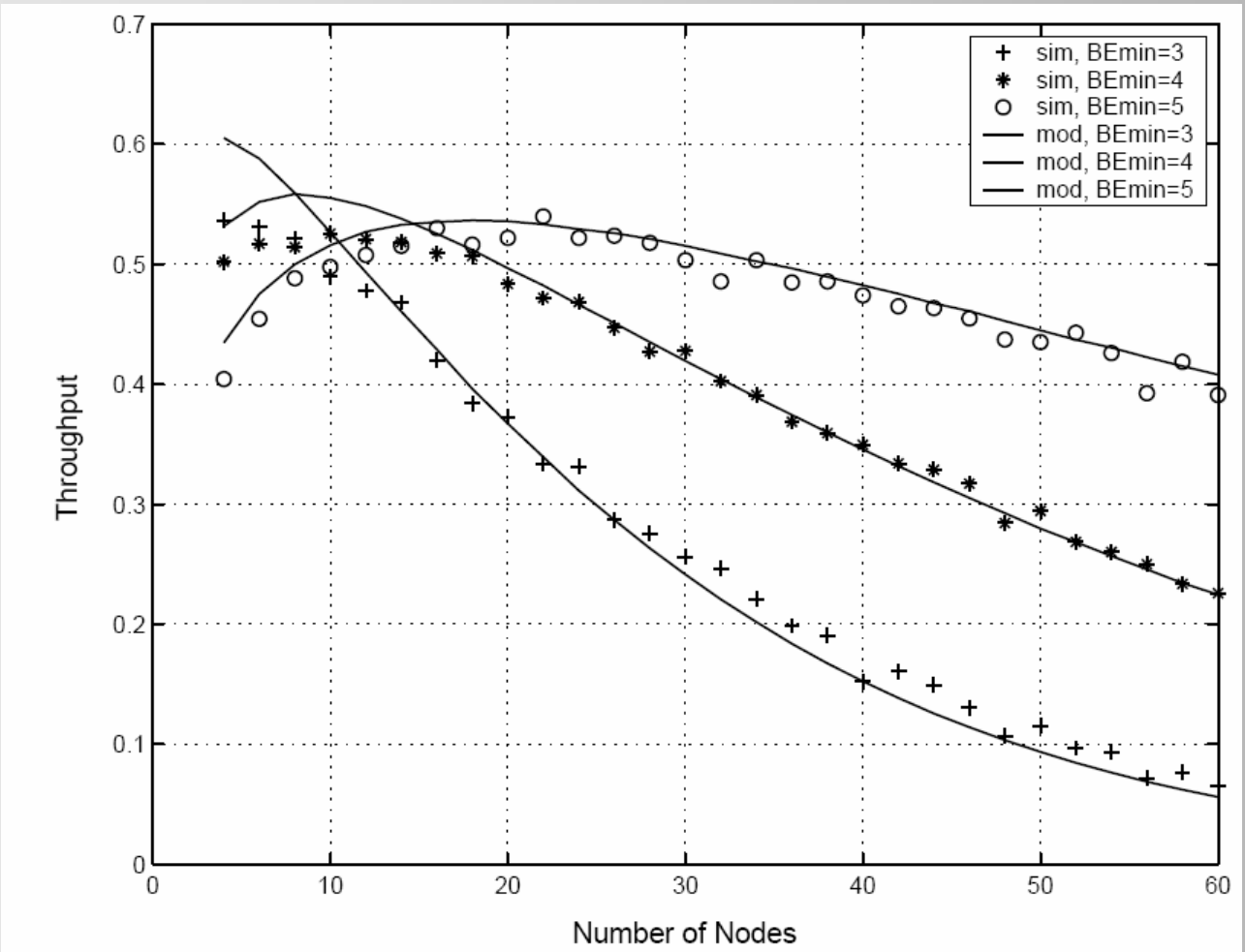
- CSMA-CA: Carrier Sense Multiple Access-Collision Avoidance
  - Always-on nodes give lower latency
  - Quick discovery simplifies installation
- TDMA: Time Division Multiple Access
  - Coordinated network for predictable performance
  - Efficiently use the entire allocated frequency spectrum
  - Reliable use of frequency hopping
  - All nodes can be battery operated

CSMA Networks

Non-deterministic collisions



CSMA-CA Scaling

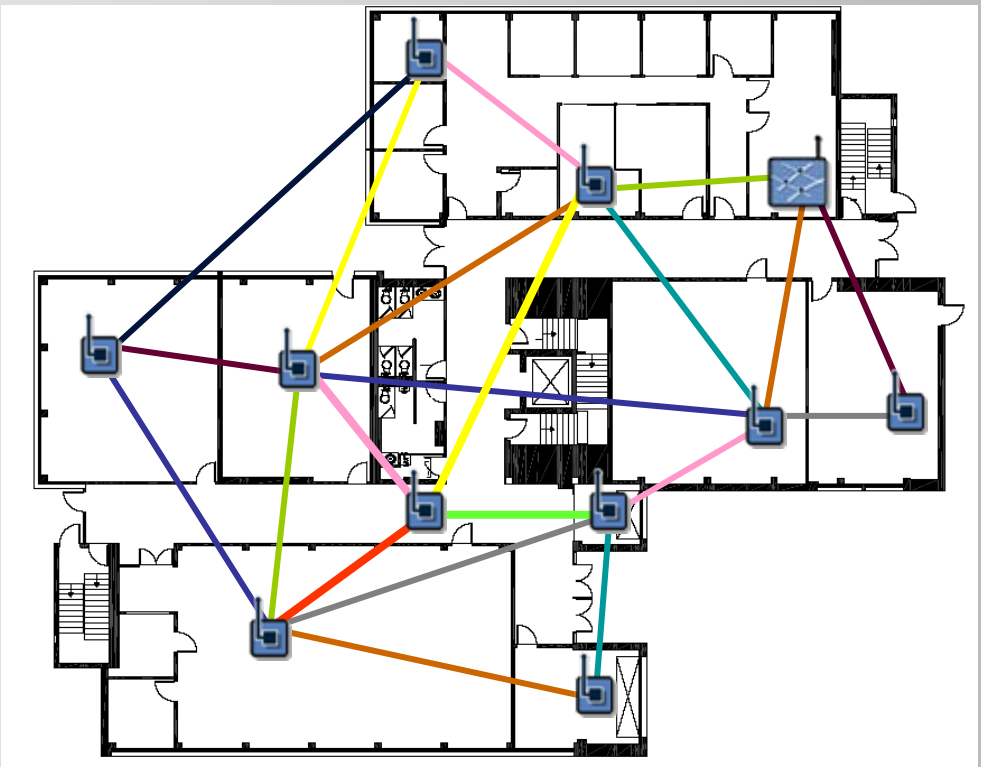


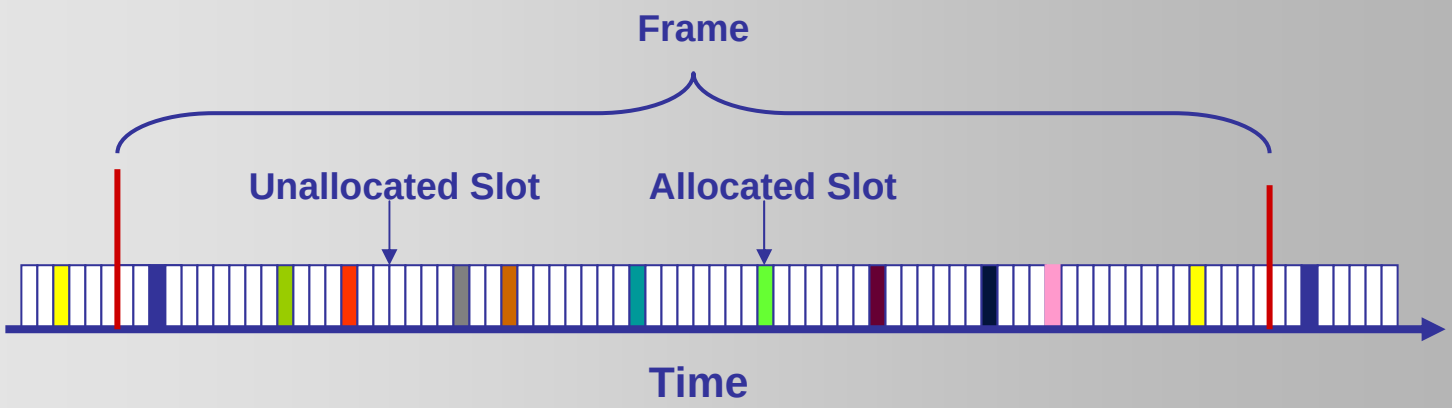
Extrapolate to hundreds of nodes

- CSMA-CA does not scale well with large number of nodes

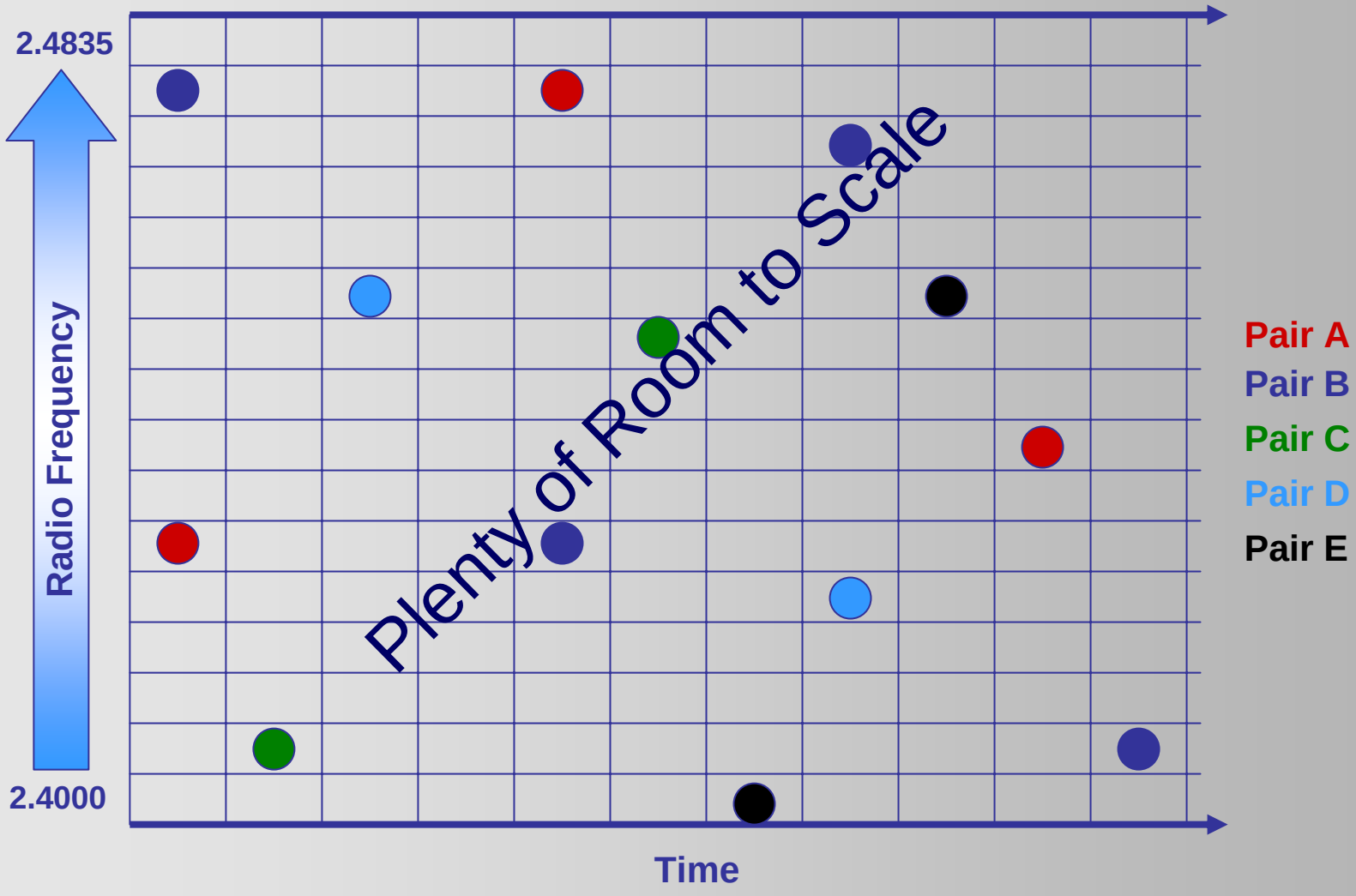
"Performance Analysis of Slotted IEEE 802.15.4 Media Access Layer", Pollin, Sofie et al

TDMA Networks





Time and Frequency Matrix at 2.4 GHz



Technology Trends

- Continued exponential reduction in size, power, & cost
  - More opportunities for wire-replacement
  - More wireless-enabled applications
- Tighter integration
  - “Mesh on a chip”
- Lower power
  - Reductions from better hardware & better software
- More flexibility
  - Dynamic bandwidth allocation & duty cycling based on application need

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Standards

- Wireless HART (Highway Addressable Remote Transducer
  - In the technology selection phase
  - Selected frequency hopping and studying mesh and TDMA
- Instrumentation, Systems, and Automation Society (ISA) SP100
  - In the requirements development and organization phase
- 802.15.4
  - Published standard
  - Working groups looking at mesh and tighter transmission timing
- ZigBee
  - Based on 802.15.4 phy and MAC
  - Working groups looking at mesh and low power routers and devices
- WINA (Wireless Industrial Networking Alliance)
  - A marketing and wireless sensor/control network promotion consortium

Questions?

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