

The Internet of Things: The Challenge of the Last Meter

WINLAB 

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Winlab IAB, May 2011

The Internet of Things

(A Peek into the Basement)

■ The Vision

A better life through seamless behind-the-scenes networking of the important “things” in the world.

■ System, Social, and Economic Challenges

- Turning a flood of data into information and then into valuable actions
 - (Without distracting the customer)
- Privacy, security, managing bandwidth, validation, reliability, economic models, human interface,

■ Invisible Challenges

- Making the actual wireless connection to the world of objects.
(Physics gets in the way of marketing)
 - Energy, propagation, antenna size, interference, etc.

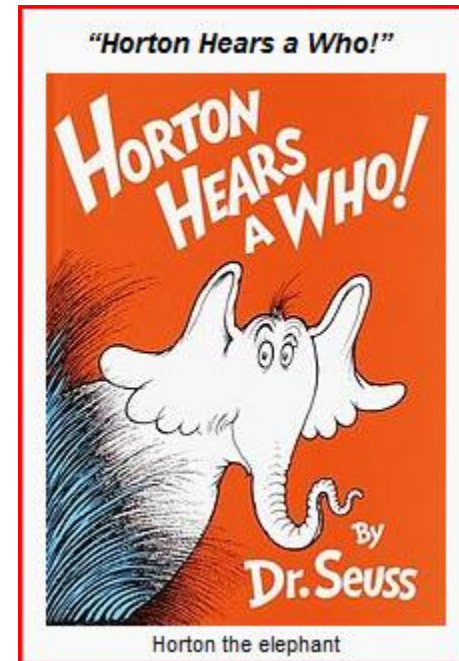
The Future

"Eventually, even particles as small as dust might be tagged and networked,"

International Telecommunication Union study reported in NY Times 11/20/2005

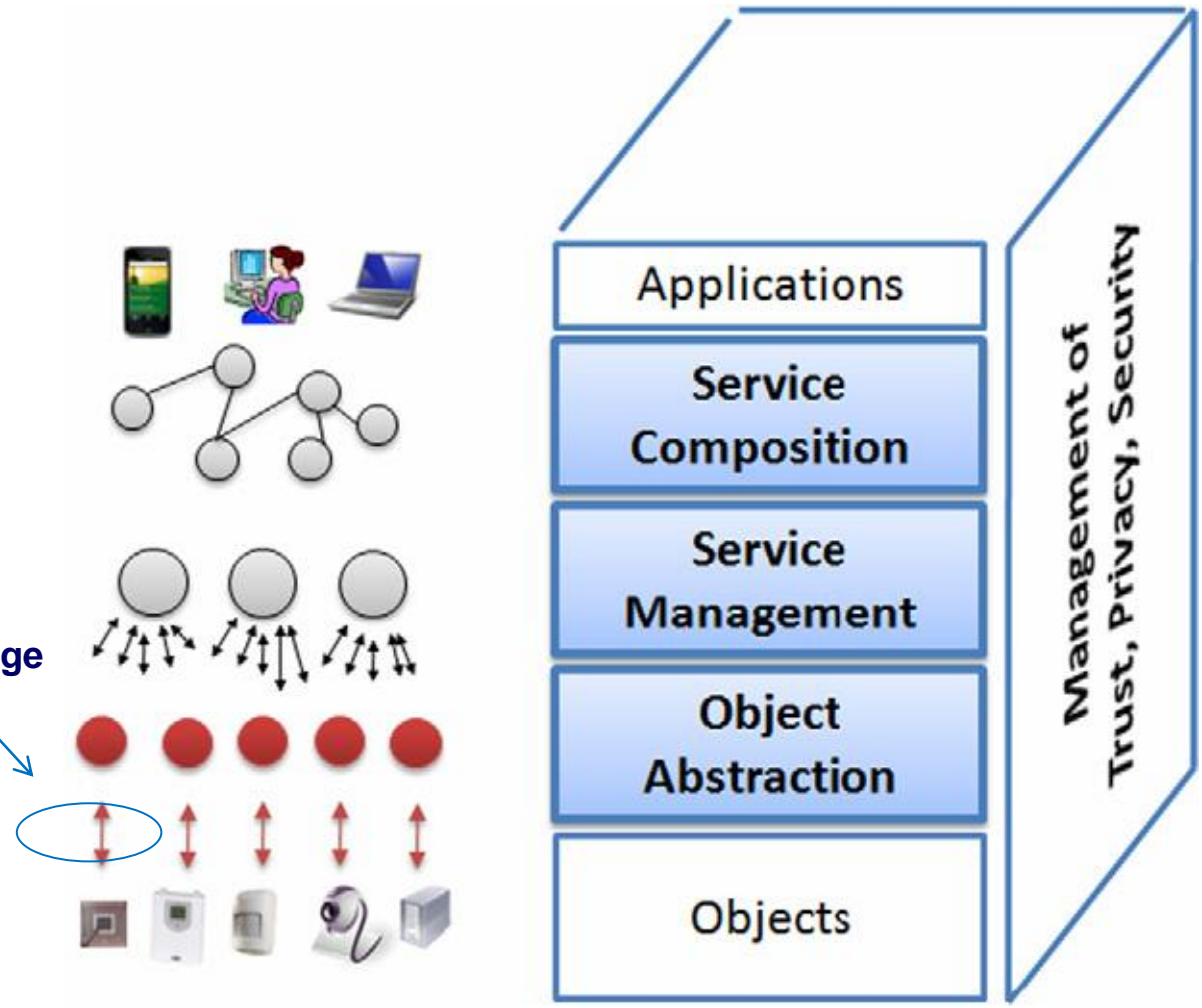
"I say!" murmured Horton. "I've never heard tell Of a small speck of dust that is able to yell."

Horton Hears a Who, Dr. Seuss.



The Internet of Things

The Last Meter
The Radio Challenge



Wishin' Don't Make It So

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Despite Wal-Mart's Edict, Radio Tags Will Take Time

By BARNABY J. FEDER
Published: December 27, 2004

A year and a half ago, Wal-Mart served notice that it expected its top 100 suppliers to be shipping goods to it with new radio tagging technology by Jan. 1, 2005.

While it may still be true, as the saying goes, that the best way to predict the future is to create it, Wal-Mart's experience so far has served as a reminder that creating the future is not all that easy.

With Jan. 1 just days away, the technology is not yet ready to meet the needs of either Wal-Mart or its suppliers. The tags, which are typically about the size of a credit card and contain an antenna and microchip encased in plastic, receive query signals from scanning devices called readers. Using the energy captured from those signals, they broadcast a snippet of code identifying the goods to which they are attached.



Zebra Technologies

A warehouse worker uses a radio frequency identification reader to check inventory. The technology has a spotty track record.

ARTICLE TOOLS

**Announced
Mid 2003**

**Backpedal
End 2004**



Wal-Mart Takes a New Approach to RFID

Topics/Verticals: [Supply Chain](#), [Inventory/Warehouse Management](#), [More...](#)

Here are five reasons the retailer's efforts will be more successful this time.

July 26, 2010—Last week, [Wal-Mart Stores](#) announced that it planned to refocus its efforts to track goods with radio frequency identification technology based on [EPCglobal's](#) second-generation ultrahigh-frequency (UHF) standard (see [Wal-Mart Relaunches EPC RFID Effort, Starting With Men's Jeans and Basics](#) and [Privacy Nonsense Sweeps the Internet](#)). Some skeptics, no doubt, will say, "Here we go again." Wal-Mart (including its [Sam's Club](#) division) has twice before announced initiatives that did not pan out. Here is why this time should be different.

Mid 2011
Still not happening

Micro-radios—The Connection Issue

What works

- No Wires!!

What does not work

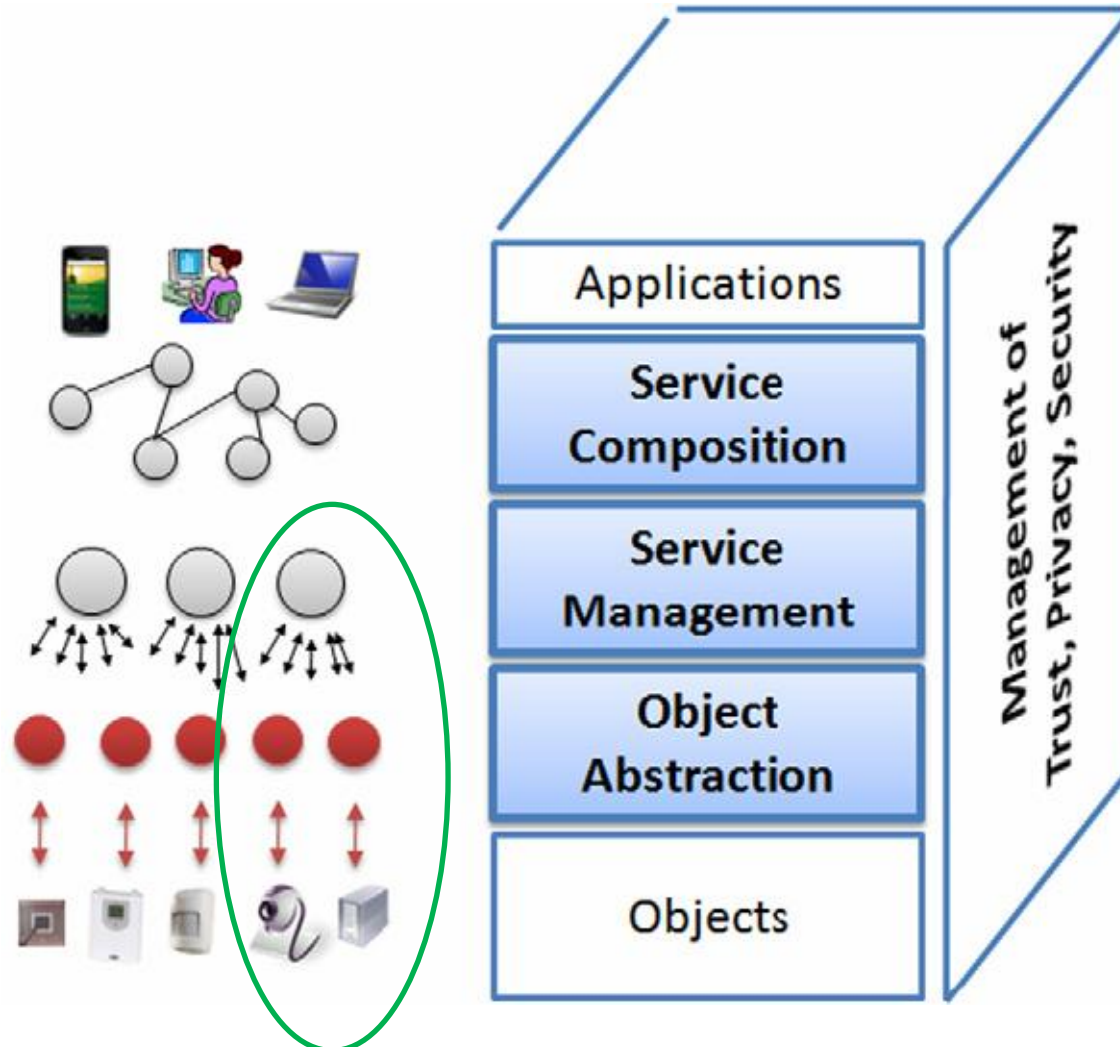
- Energy
 - Wireless and portable means no connection to energy grid
- Unreliable propagation
- Size (1 GHz antenna ~ 7 cm long)
- Interference (the “elevator” syndrome)
- Errors
 - Fiber Networks and Disk Drives
 - 1 error every 10^{14} bits.
 - Radio...
 - “In a typical radio system a packet error rate of at least 1 % should be tolerated in order to ensure robustness.” Texas Instruments, CC1100 errata.

Energy

Aggregation

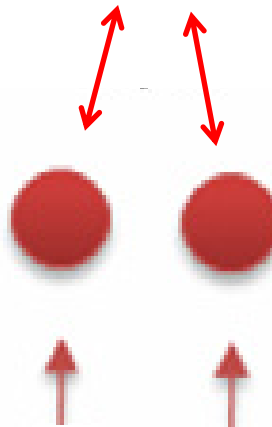
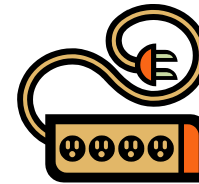
Forwarding

Sensing



The Internet of Things

The Power Challenge



???

Batteries—There's No Magic

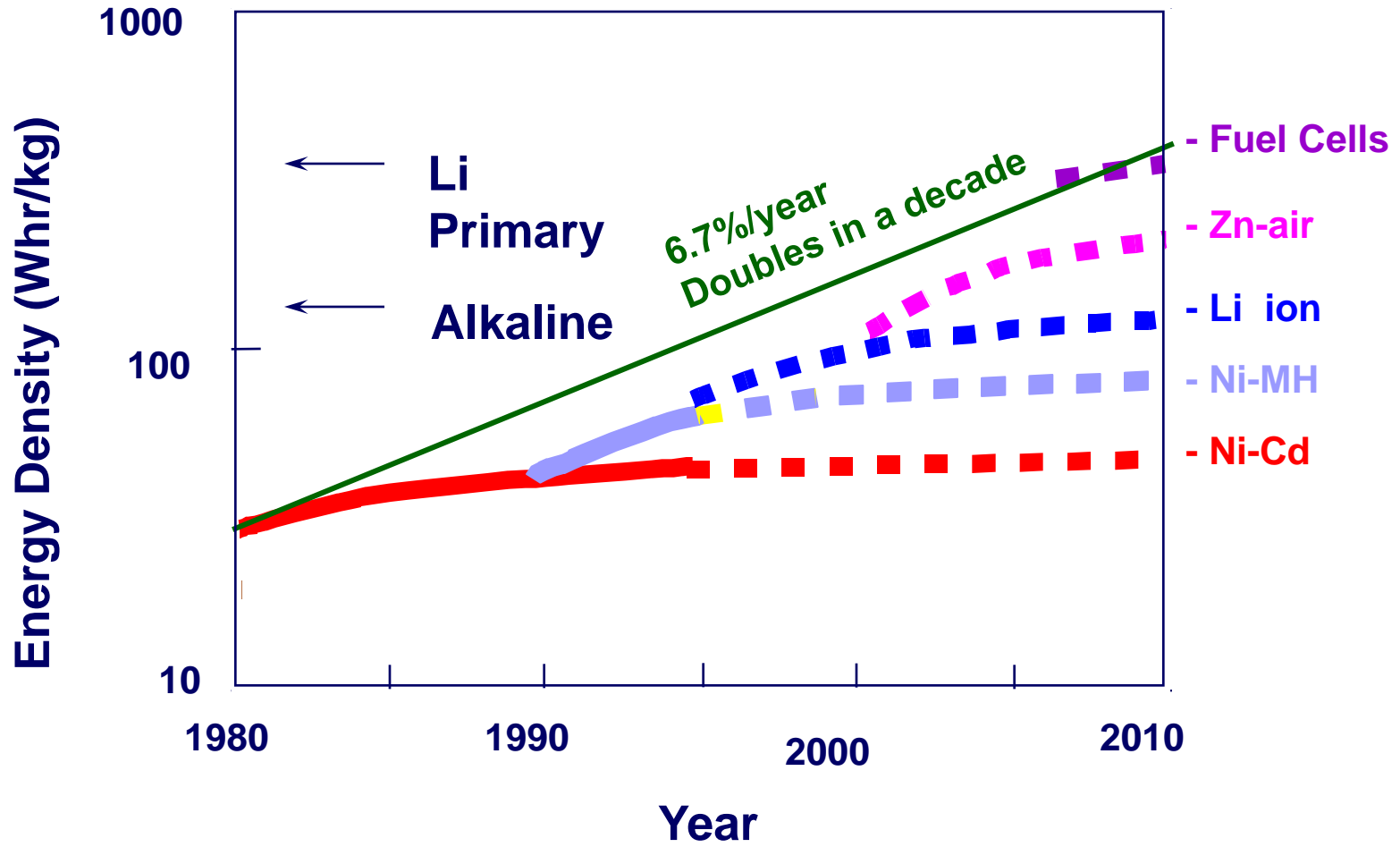


Figure Courtesy Brij Vyas

Energy Sources--The Hard Limits

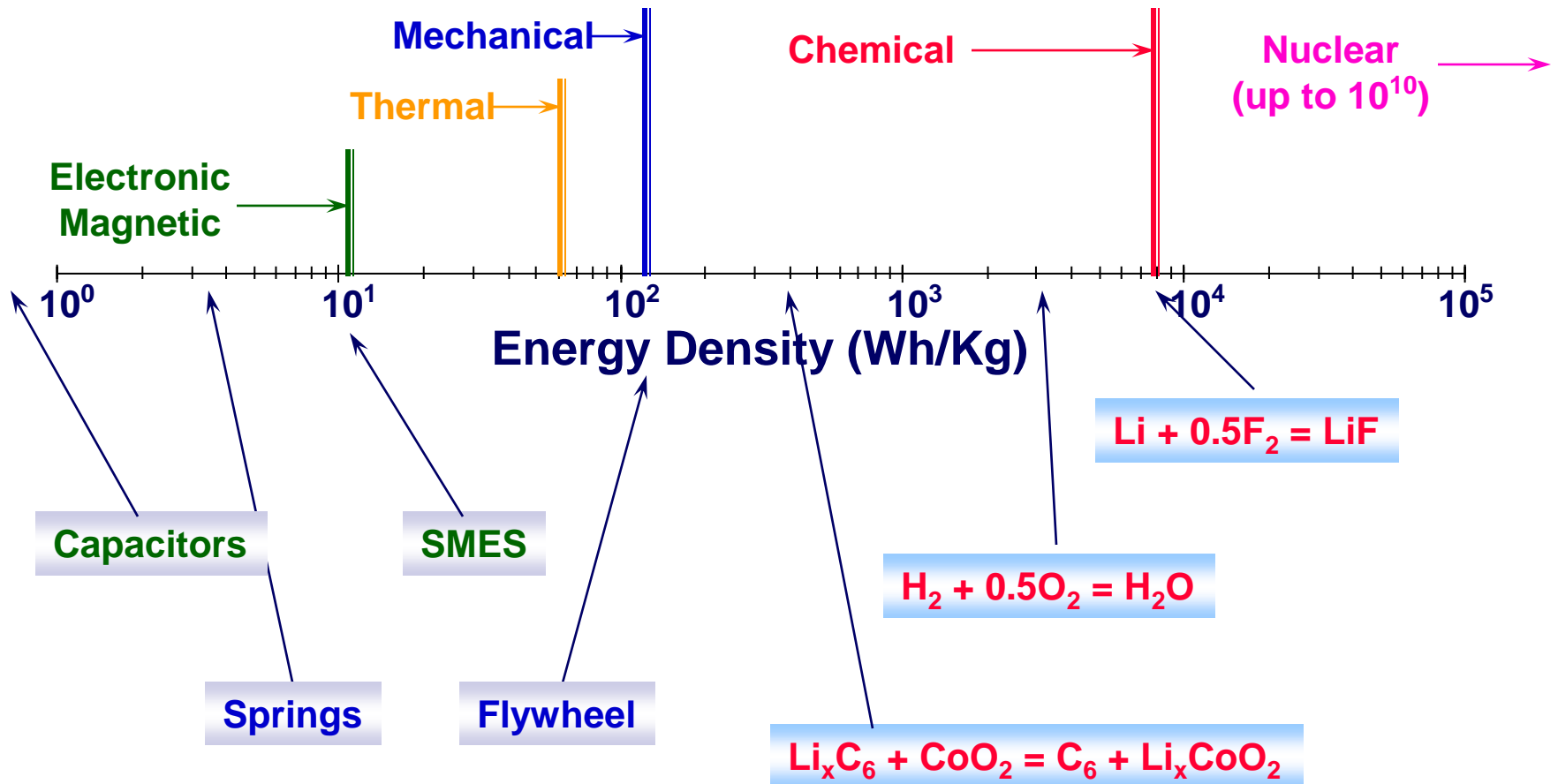


Figure Courtesy Brij Vyas

Micro-radios—The Energy Issue

- Near 1 GHz--1 mW transmitter has a range of about 100 meters (in an empty field).
 - Most sensing is in areas that contain “stuff” to sense.
 - Range about 20-30 meters in cluttered environments (e.g. indoors)
- Receivers use a comparable amount of power (!)
 - Even more for weak signals
- TI CC1101 class transceiver (250 kbps, 1 mW)
 - Transmit 50 mW @ 3V
 - Receive 49 mW @ 3V

Micro-radios—The Energy Issue

- 1 year operation

- Xmit (25 bps) 44 mW Hours
- Rcv (listening) 429,240 mW Hours

- XMIT ~15 years on a CR2032 battery

- RCV ~1.5 year on a car battery

- More efficient XMIT--easy

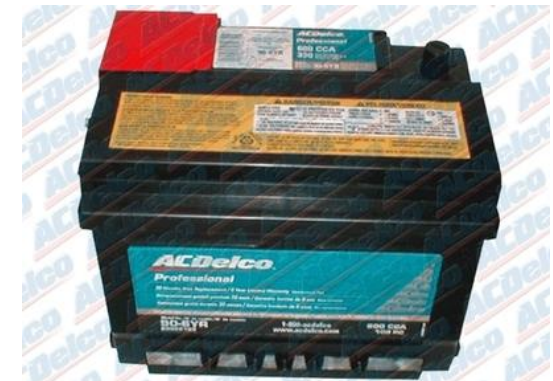
- More efficient RCV--??

Duty Cycle? Have to know when to turn it on to listen.

Have to pay (power) for high resolution system clocking

Tricky at best!

25 mm



Micro-radios—The Energy Issue

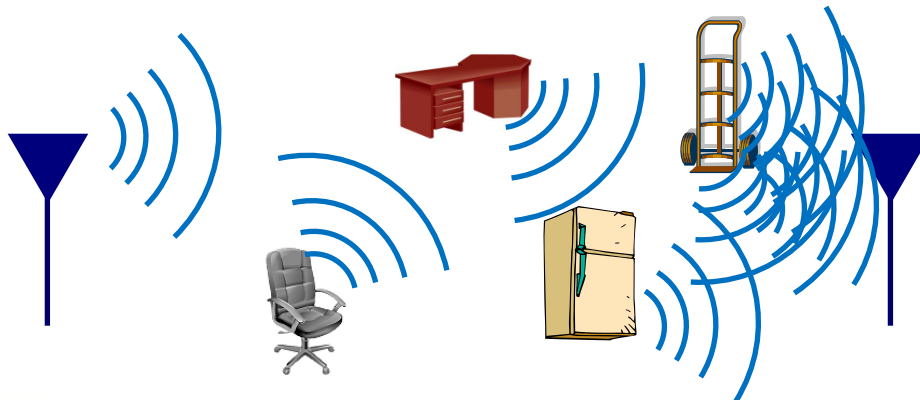
- Transmit-only (or mostly) is essential
- Extreme care in managing all other aspects of energy usage
 - There will be no “magic” batteries to bail us out
 - Sensors use energy, too.
- Extreme miniaturization is a problem
 - Antenna efficiency drops dramatically with decreasing size relative to λ
 - Battery volume drops as the cube of the size.
 - Energy needed to transmit a bit stays the same.
- Energy harvesting might help
 - Only for very low data rate or long times
 - Rapidly more difficult for small sensors.
 - Office lighting $\sim 0.25 \text{ w/m}^2 \Rightarrow 50 \text{ mW/m}^2$ electric $\Rightarrow 50 \text{ nW/mm}^2$
Buildings going “green” means even less energy to harvest!

Murphy's Laws of Radio Propagation

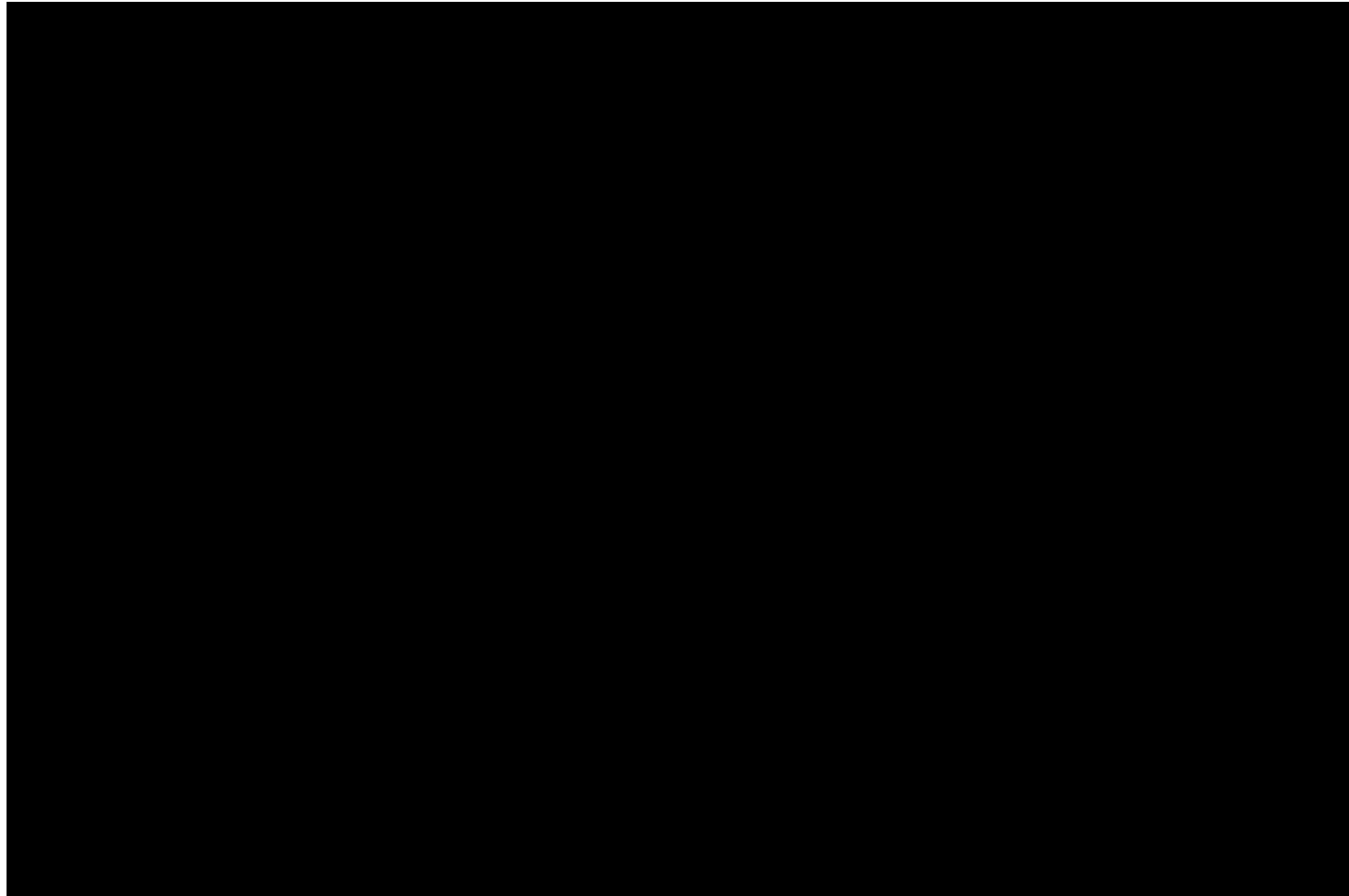
Radio is completely reliable in empty space.



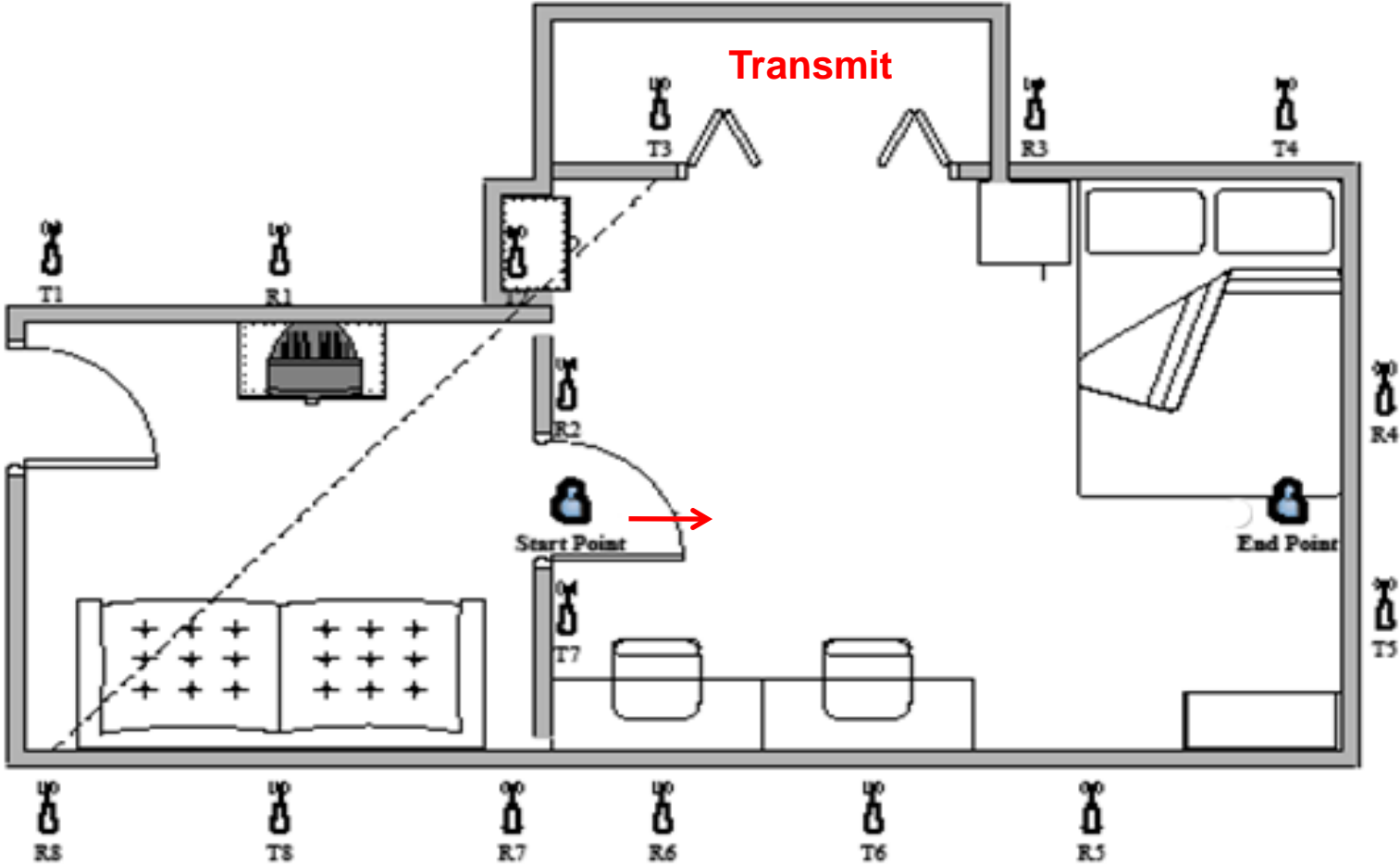
Where there is enough stuff worth tracking or measuring, radio propagation is bad.



Indoor Propagation



Indoor Propagation

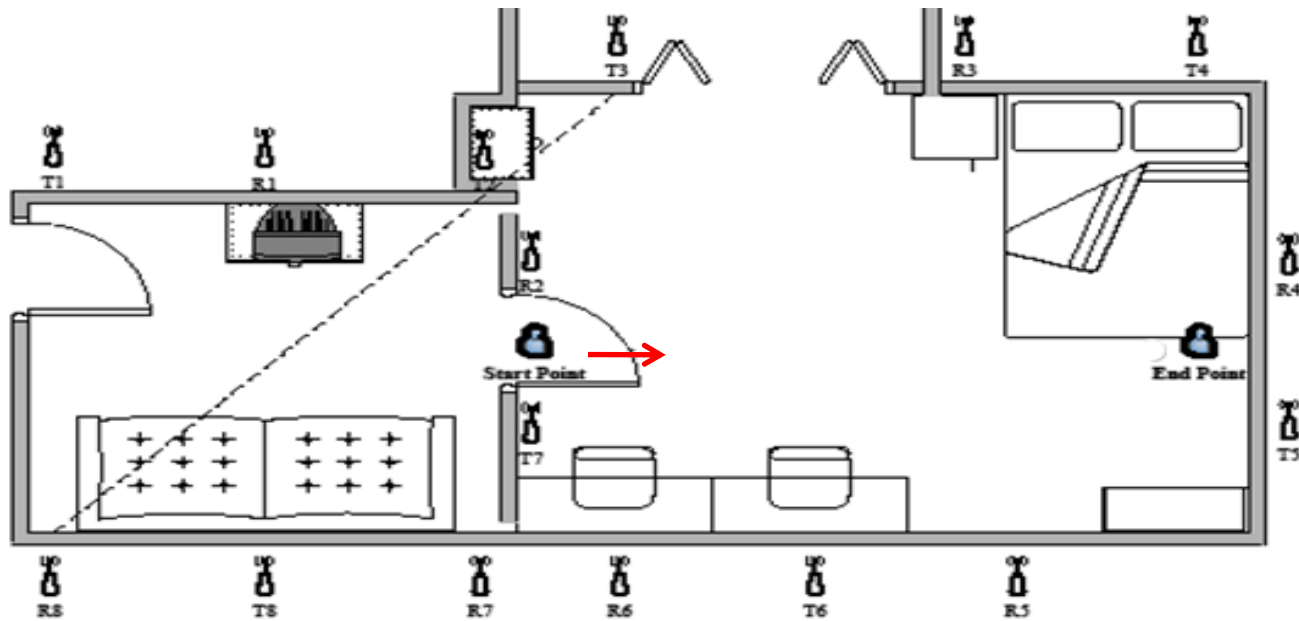
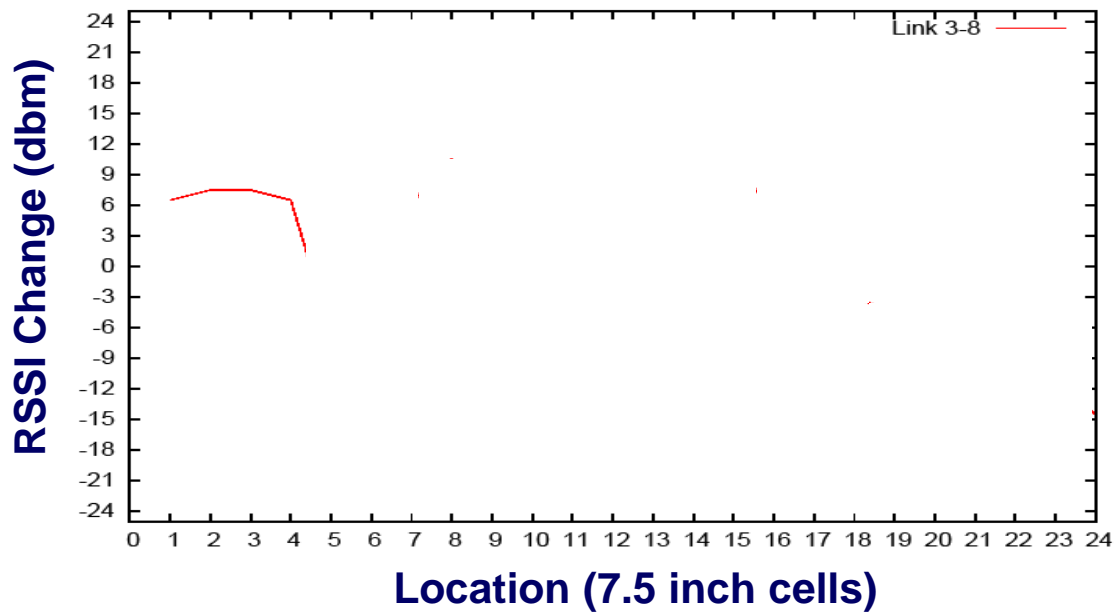


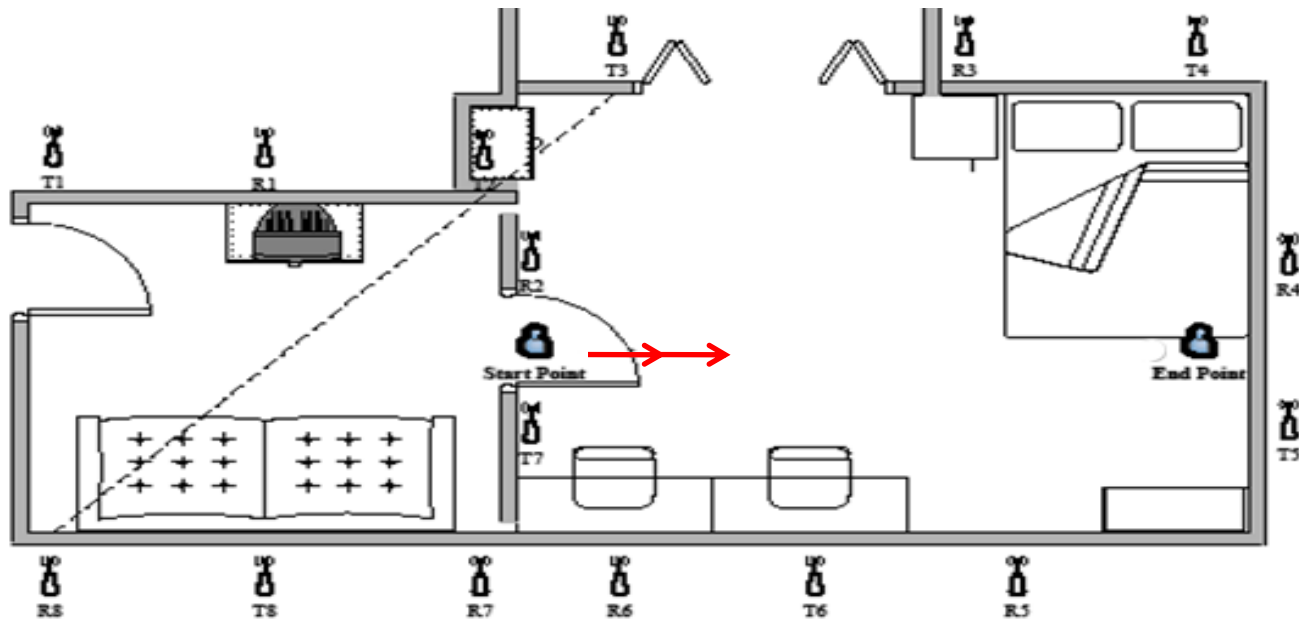
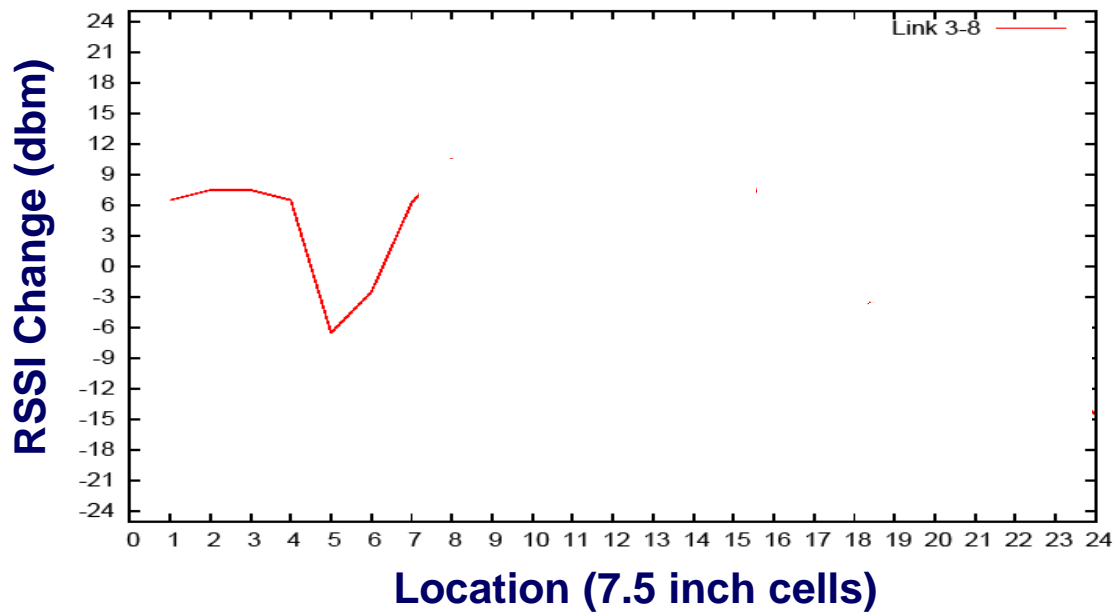
Transmit

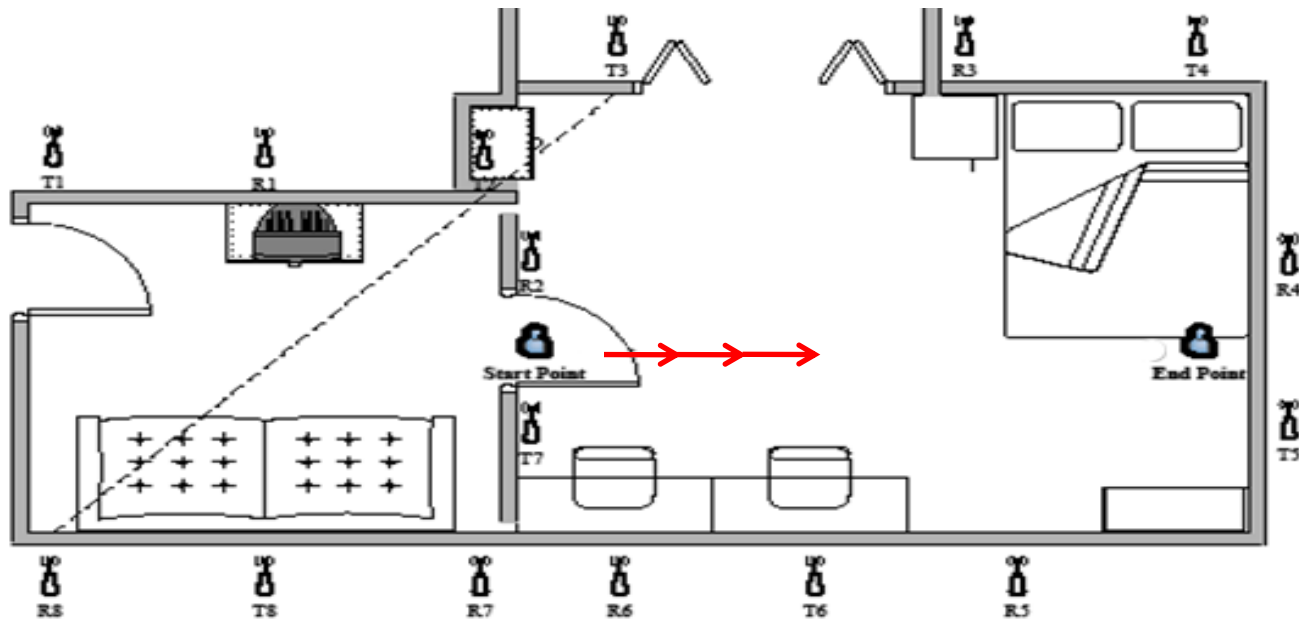
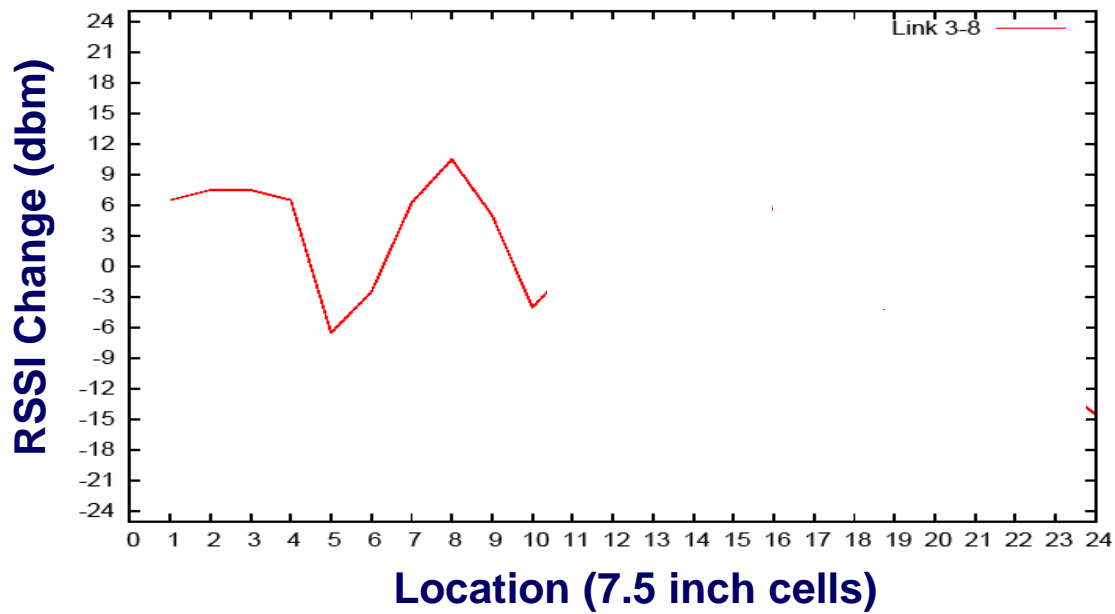
Start Point

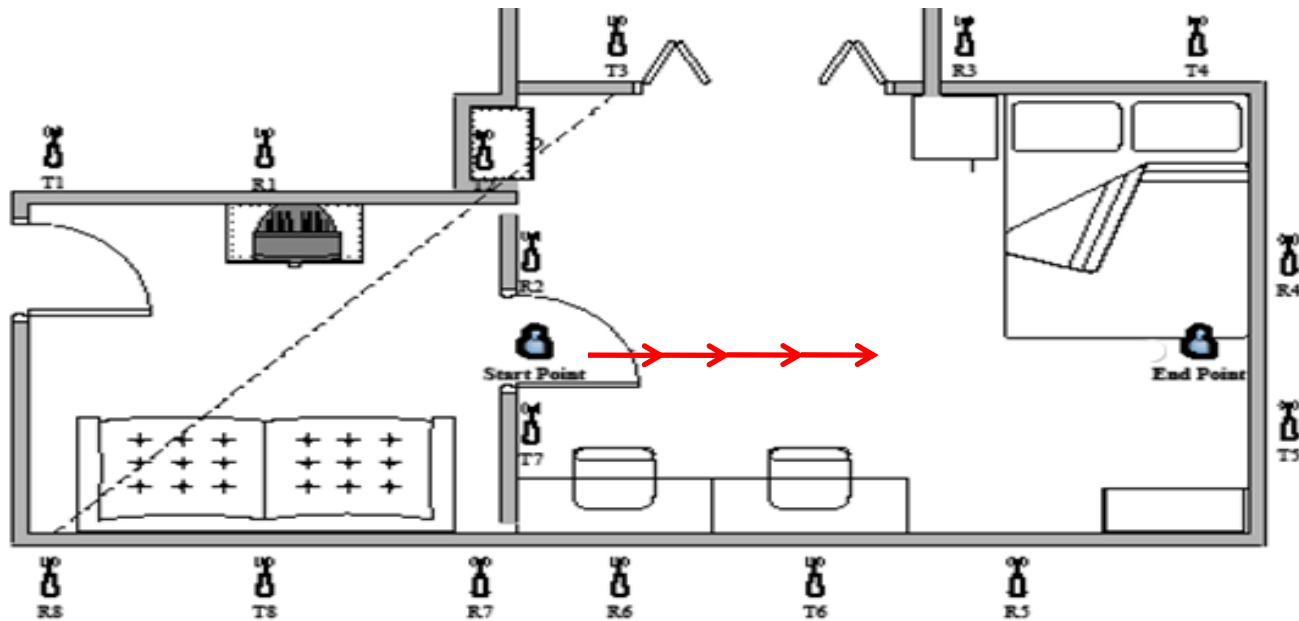
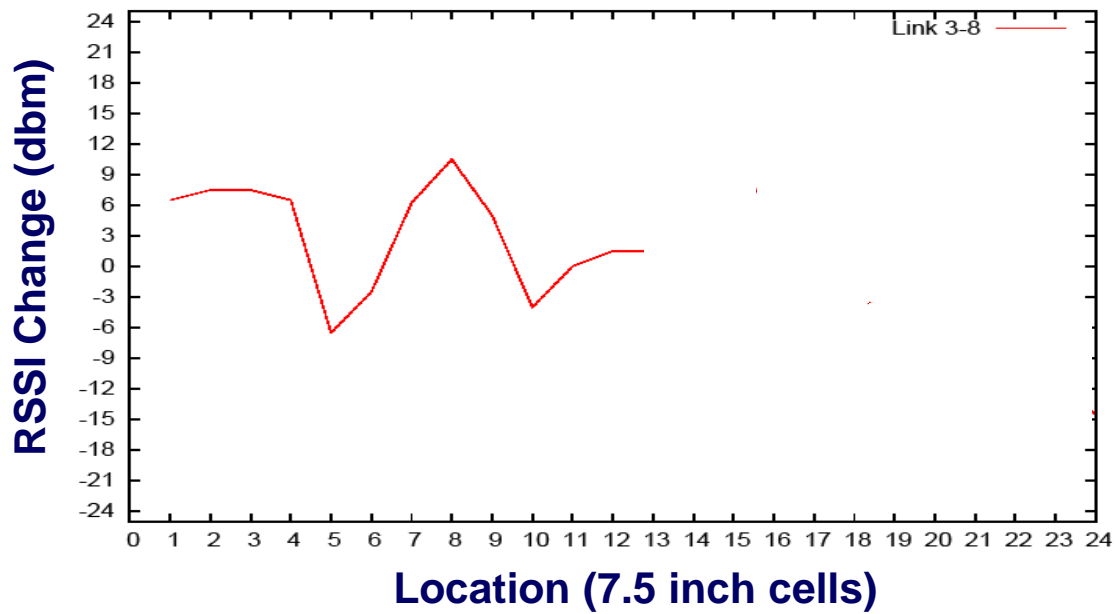
End Point

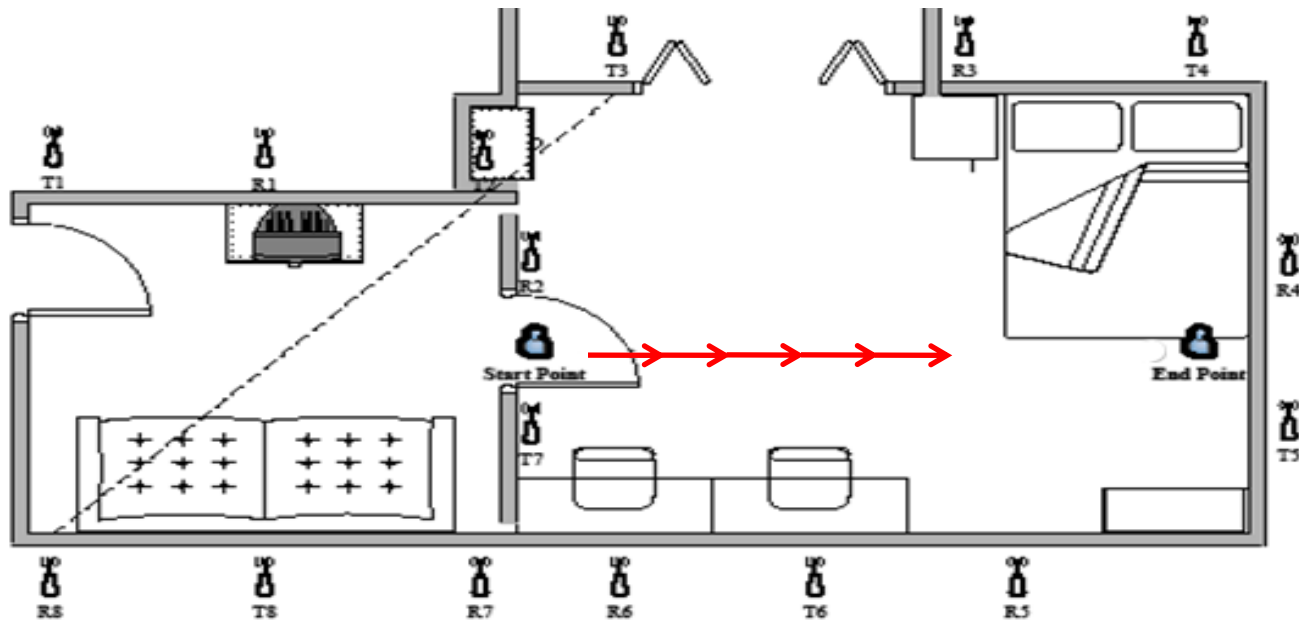
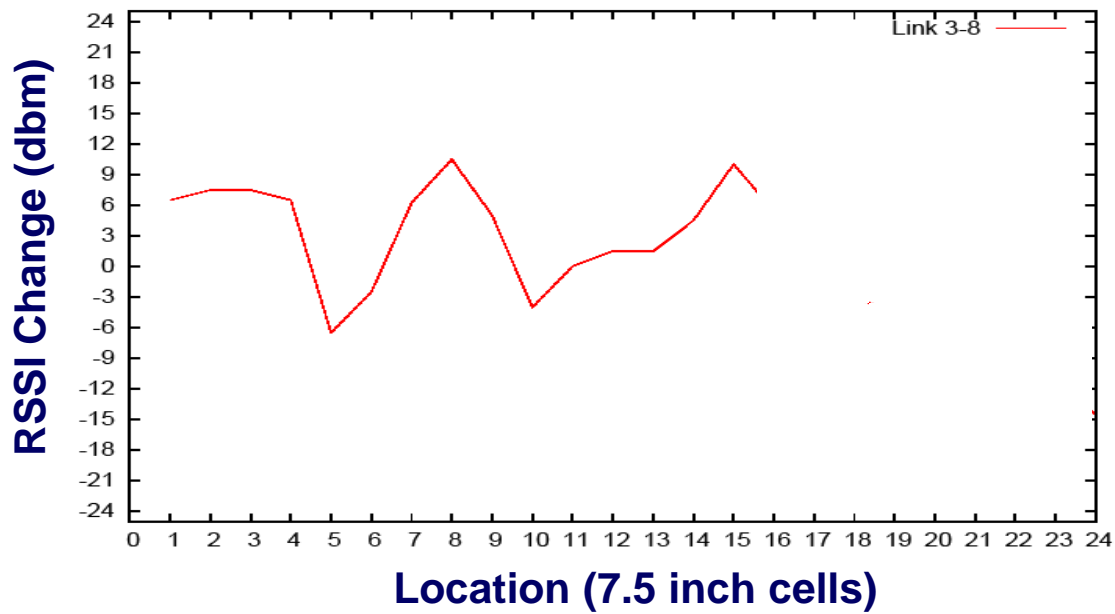
Receive

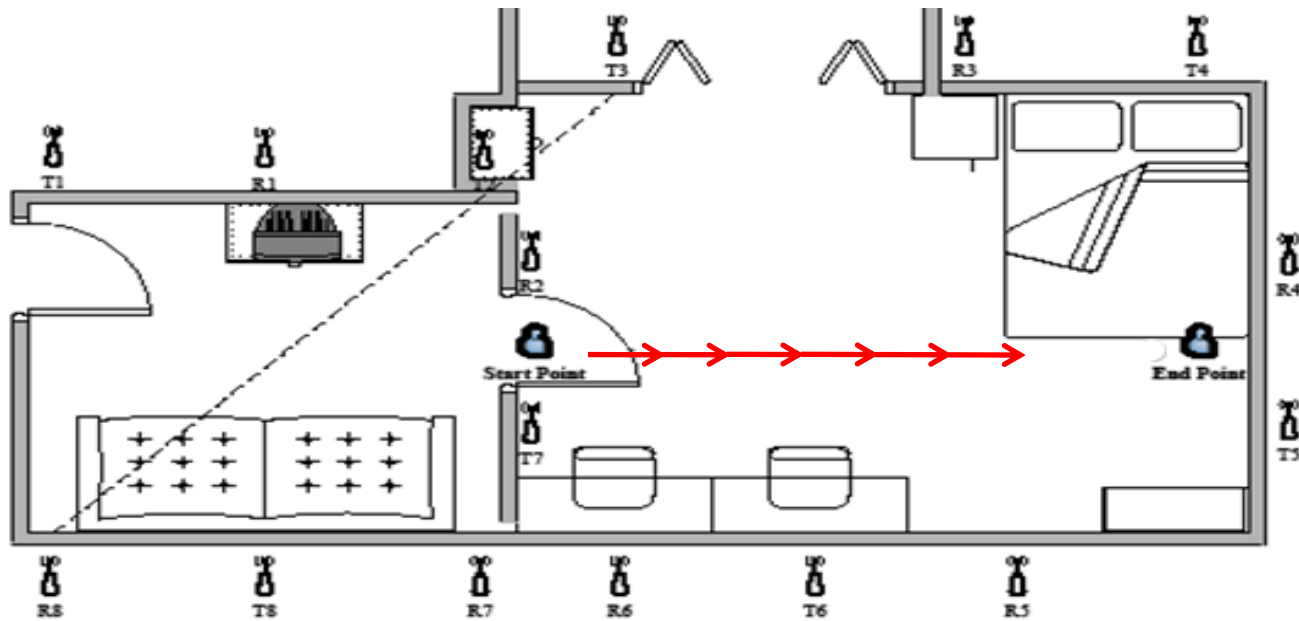
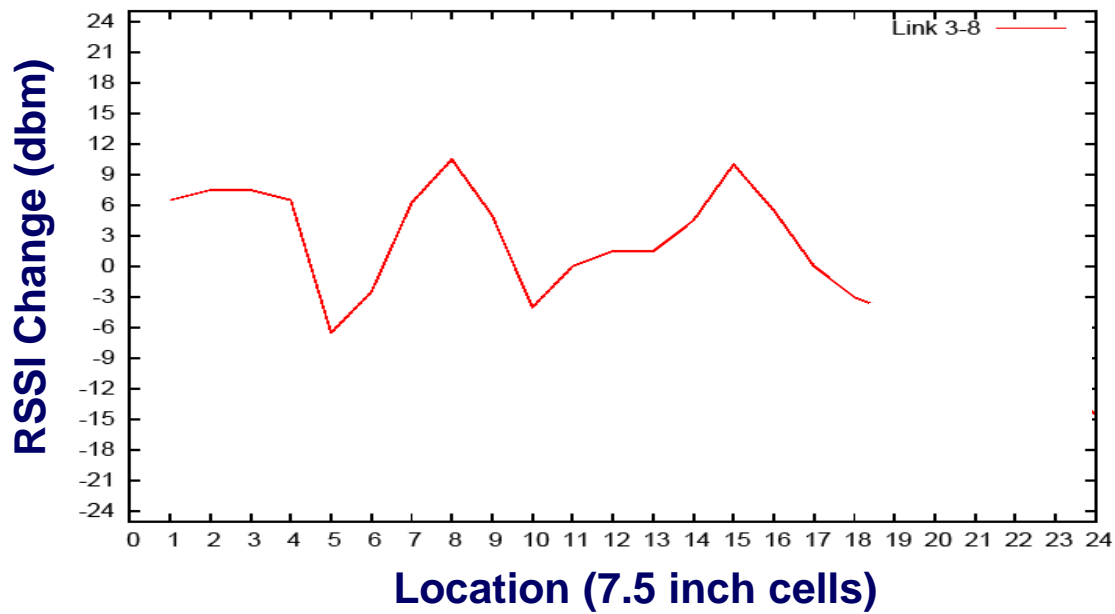


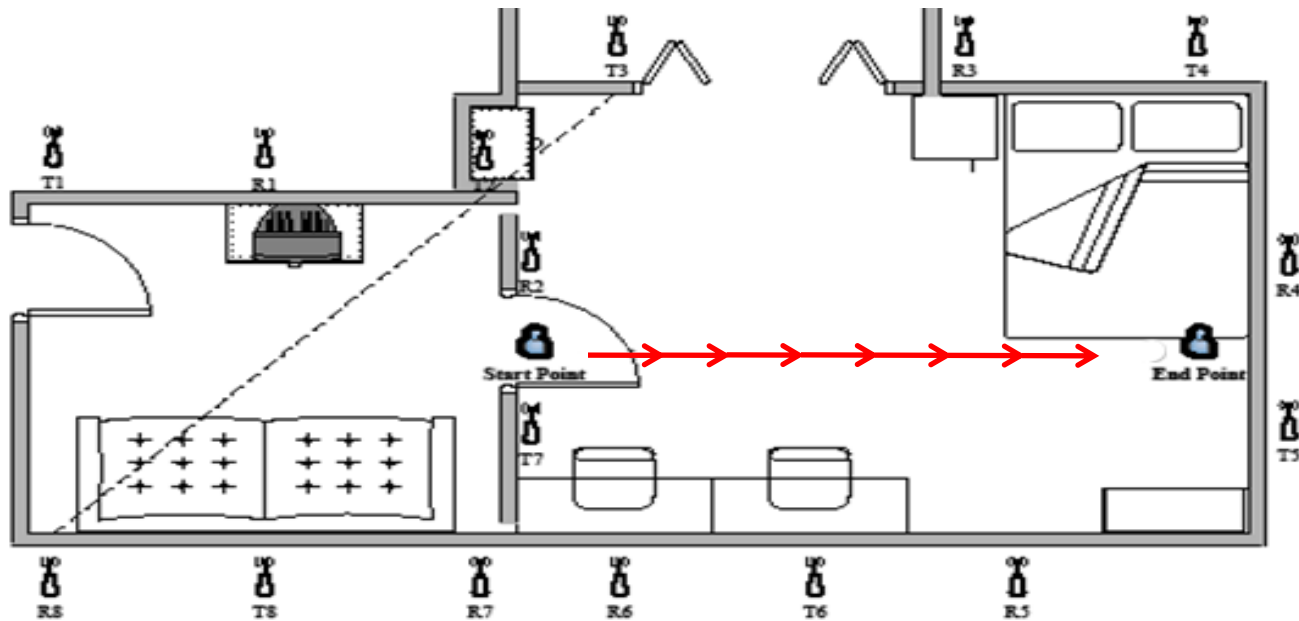
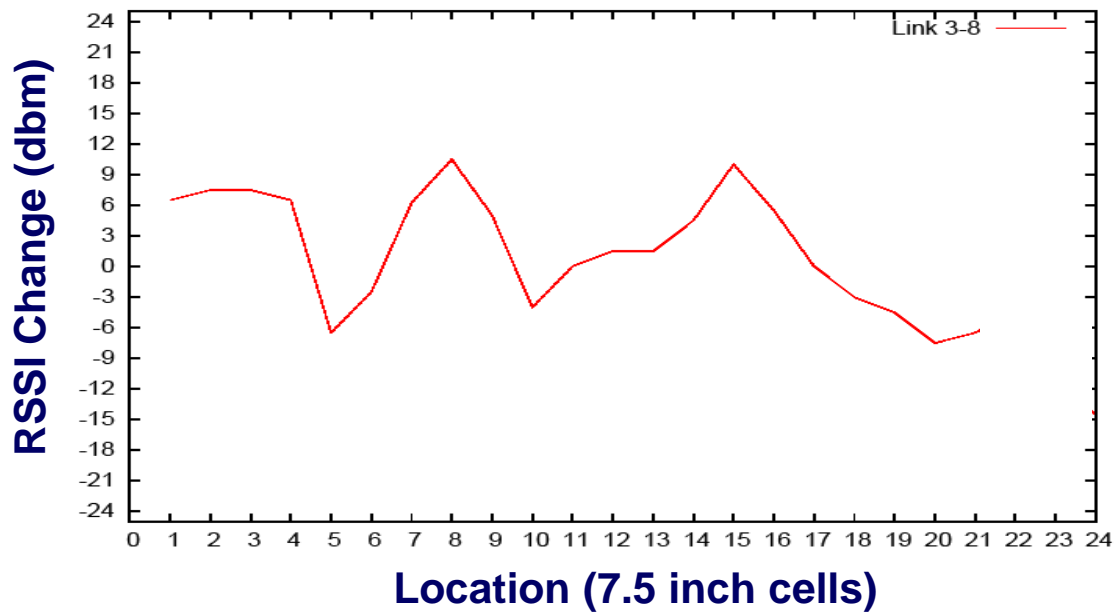


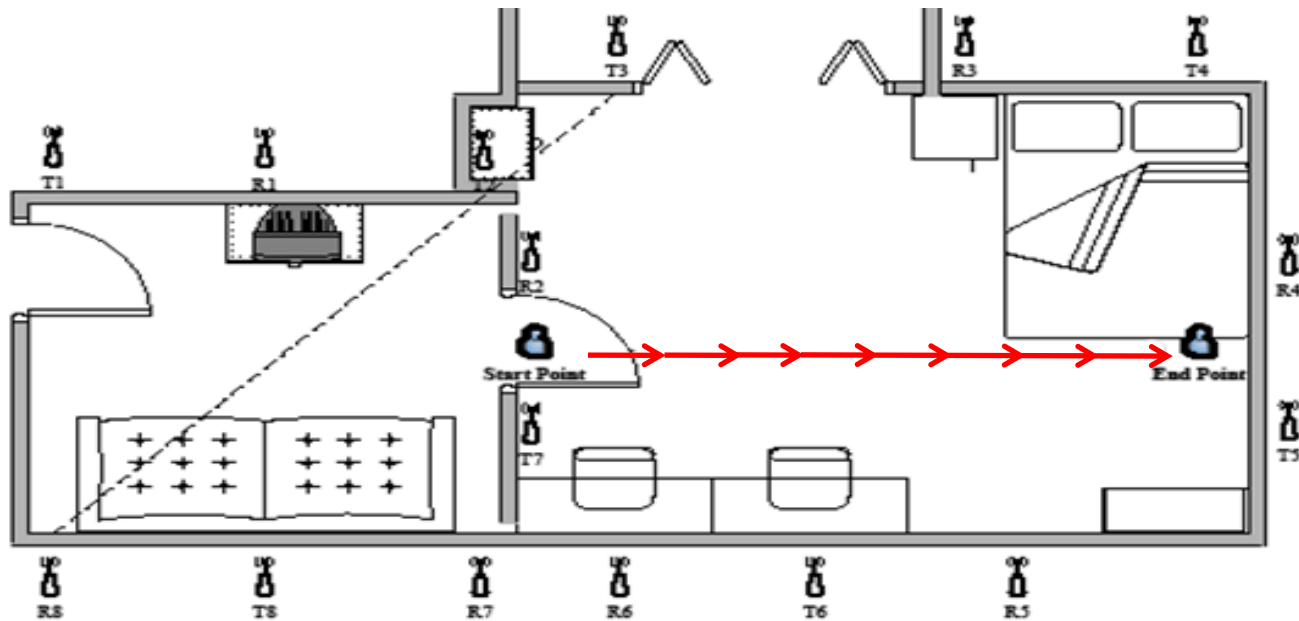
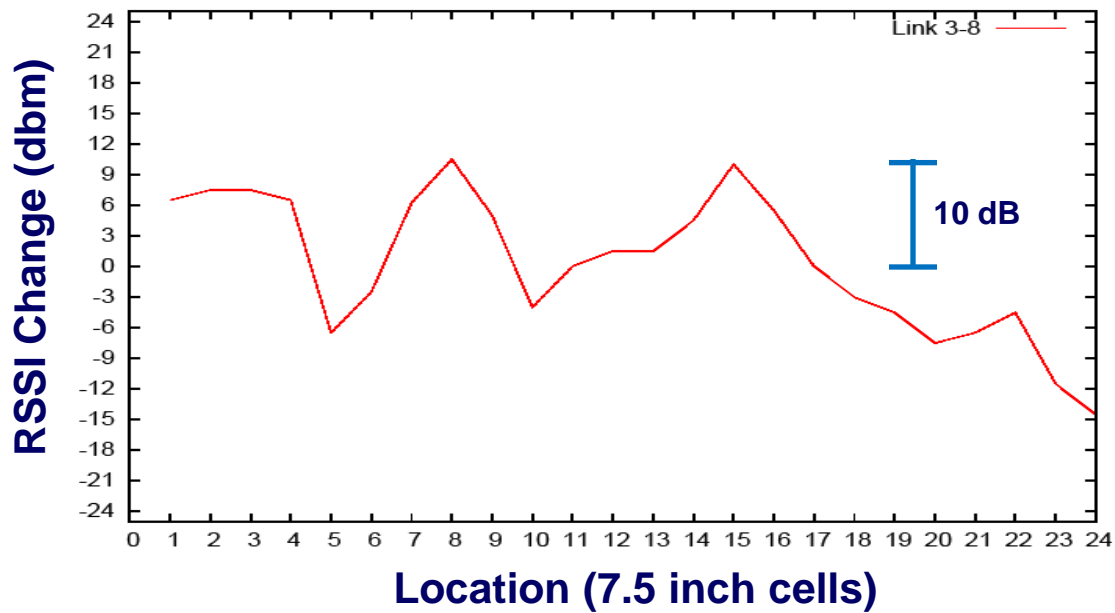












Micro-radios—Propagation

Real environments are too complex (and unstable) to predict theoretically.

Use multiple, networked receivers to provide a diversity of “views” of the environment.

Old ideas, but low cost radios and networking offers interesting new opportunities.

The Internet of Things

Ignoring real issues of energy and RF leads to the “Wal-Mart Effect”—

Press releases just aren't enough.

Like the “last mile” problem in broadband internet, the “last meter” issues will be the key to making a true IOT.

End