# An Empirical Study of Antenna Characteristics Toward RF-based Localization for IEEE 802.15.4 Sensor Nodes

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# Difficulties in RF-based Localization

- **Node connectivity**
  - Connectivity to anchor nodes
  - Connectivity between nodes

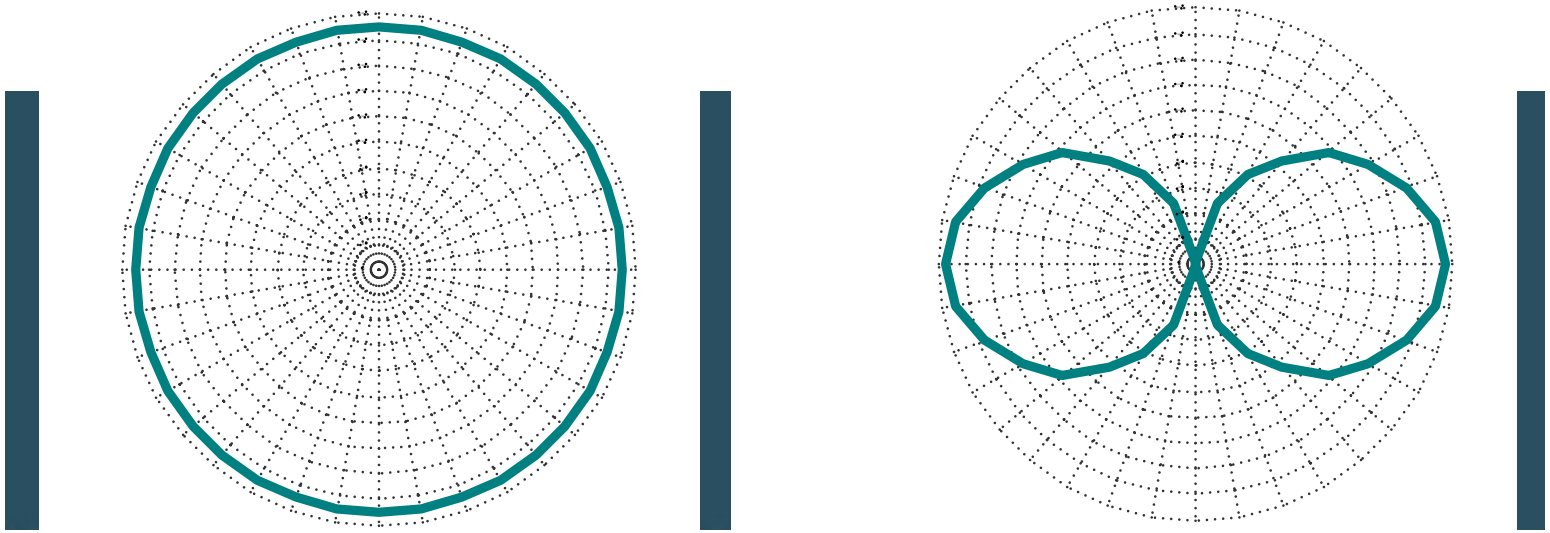
  Antenna Orientation Problem

- **RSS (Received Signal Strength)**
  - Convert RSS to actual distance
  - Compare RSSs to determine relative distance

  RSS Fluctuation Problem

# The First Motivation (1)

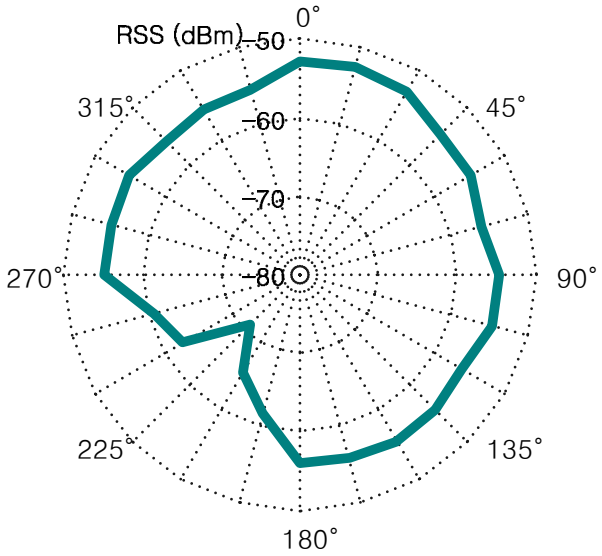
- **Antenna orientation problem**
  - In theory, RF is radiated regularly at a monopole antenna…



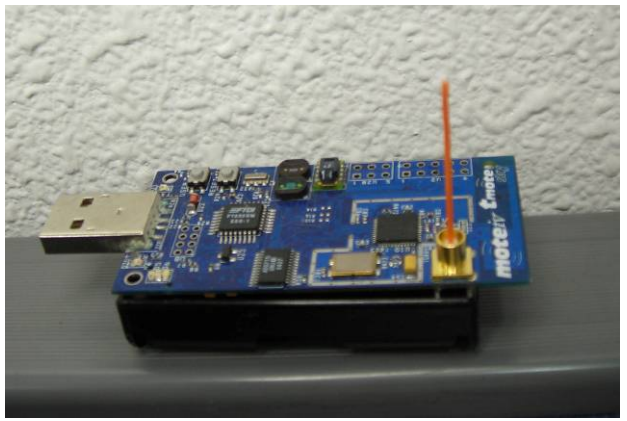
Horizontal Radiation Pattern | on Pattern at Monopol | Vertical Radiation Pattern

# The First Motivation (2)

- **Antenna orientation problem**
  - But, in real world, the radiation pattern is irregular




Horizontal Radiation Pattern

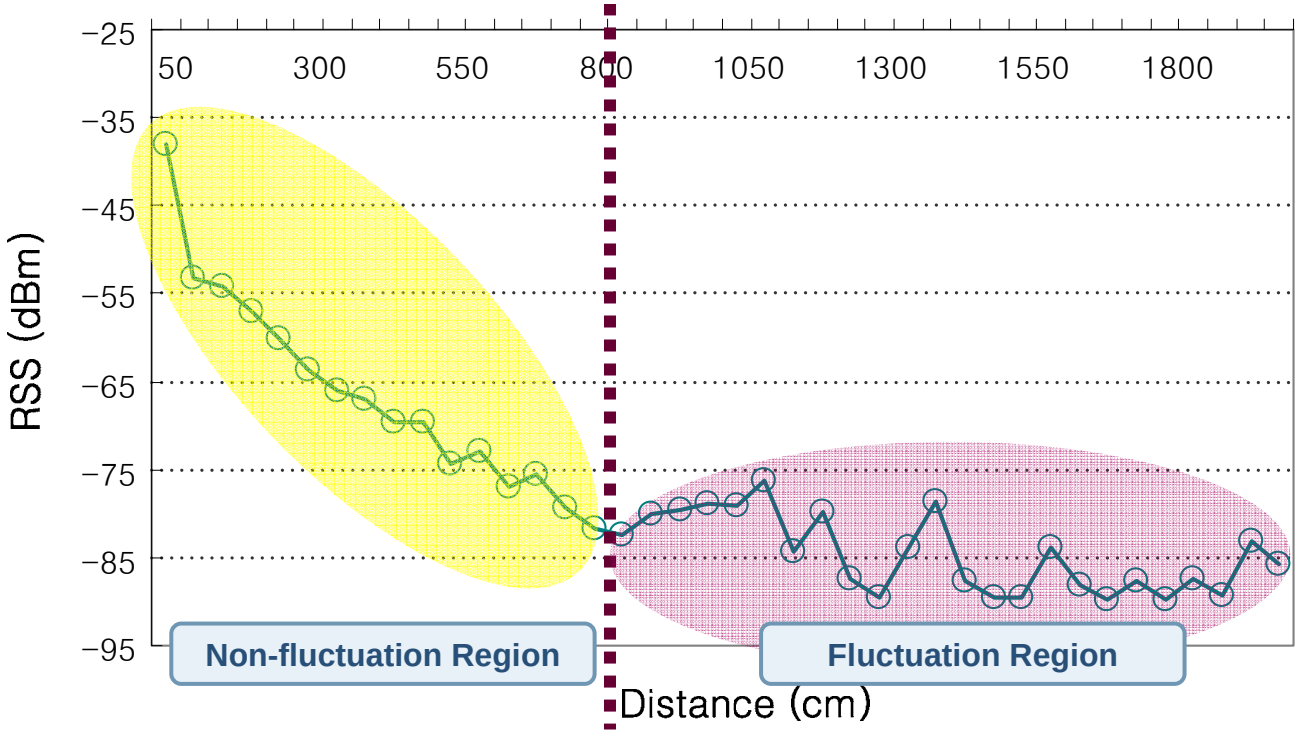


Tmote Sky with an external antenna

**Why irregular radiation pattern? How solve it?**

# The Second Motivation

- **RSS fluctuation problem**
  - –But, in real world, RSS fluctuates out of certain region



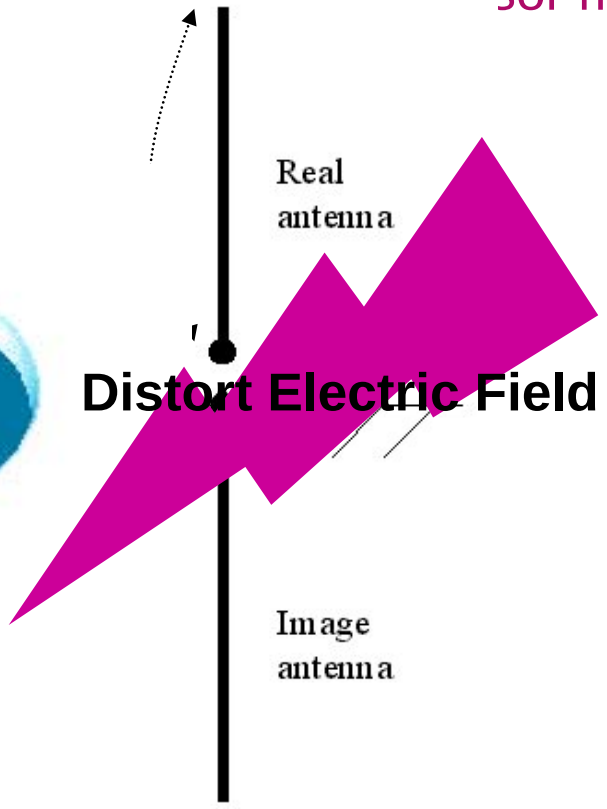

**Why RSS fluctuates? How solve it?**

# Related Work

- **Link asymmetry and irregular radio range**
  - Phenomena mentioned only
  - Caused by radio quality and hardware calibration
  - Ref : D. Ganesan et al. (2002), A. Cerpa et al. (2003), Y. Zhao et al. (2003)
- **Classifying radio irregularity**
  - Heterogeneous properties of devices
  - Non-isotropic properties of propagation media
  - Ref : G. Zhou et al. (2004)
- **Radio properties of 2.4GHz**
  - CC2420 with a monopole antenna
  - Experiments in obstacle-free/indoor environments
  - Antenna orientation and irregular RSS attenuation
  - Ref : D. Lymberopoulos et al. (2006)

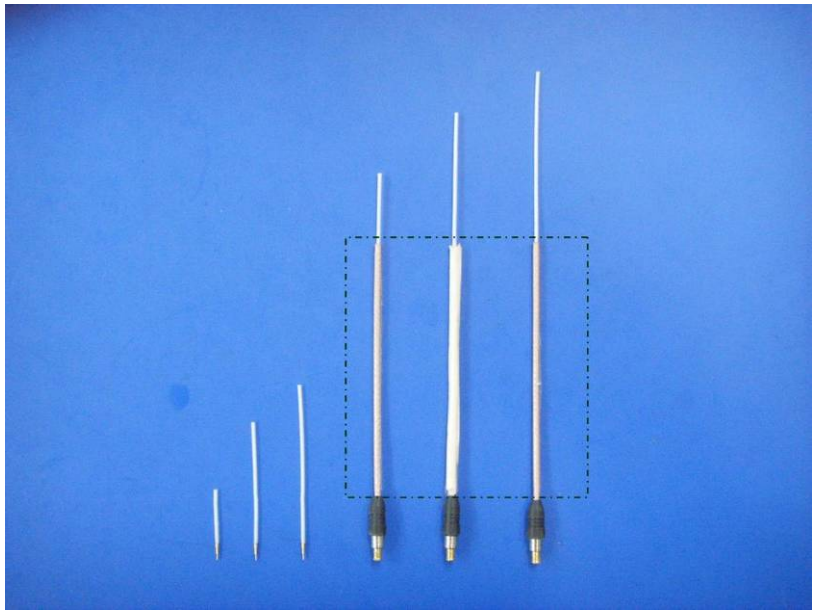
# Cause of Antenna Orientation

- **Sensor mote influences the radiation pattern**
  - Unstable ground plane
  - Hypothesis : Elec sor mote

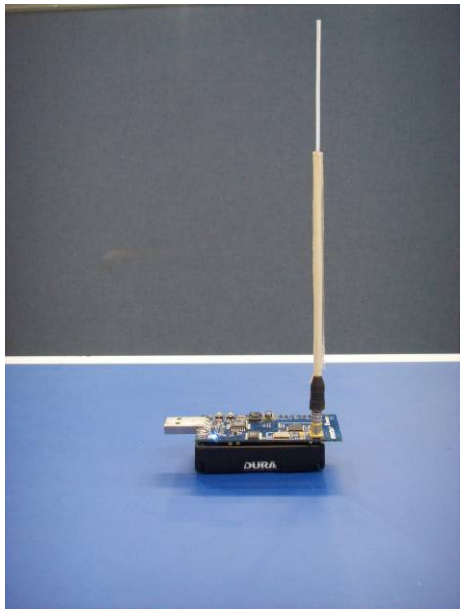



# Validation - Antenna Adjustment (1)

- **Reduce electric interference**
  - Keep distance from sensor mote using coaxial cable
  - Change antenna length (¼ default → ½ and ⅝ wavelength)



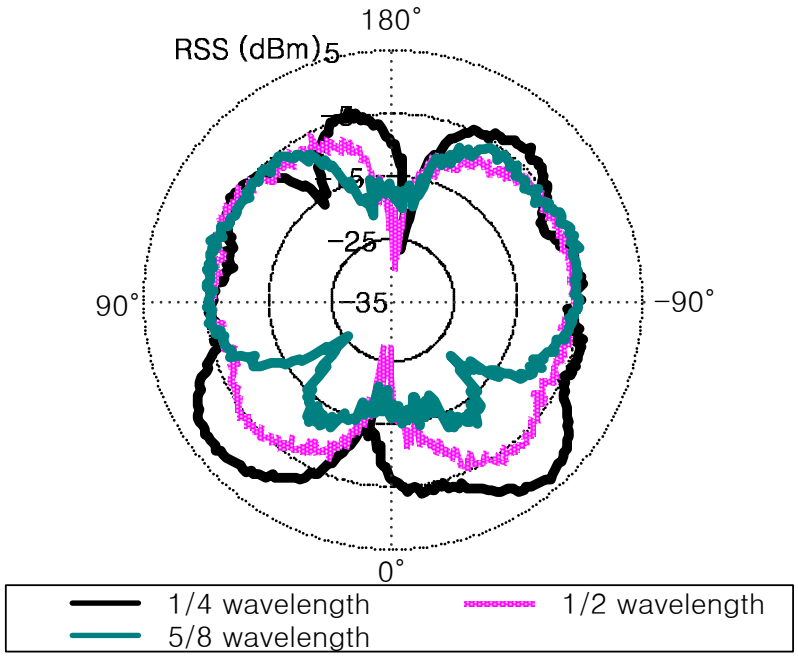
½, ¼, and ⅝ wavelength antennas



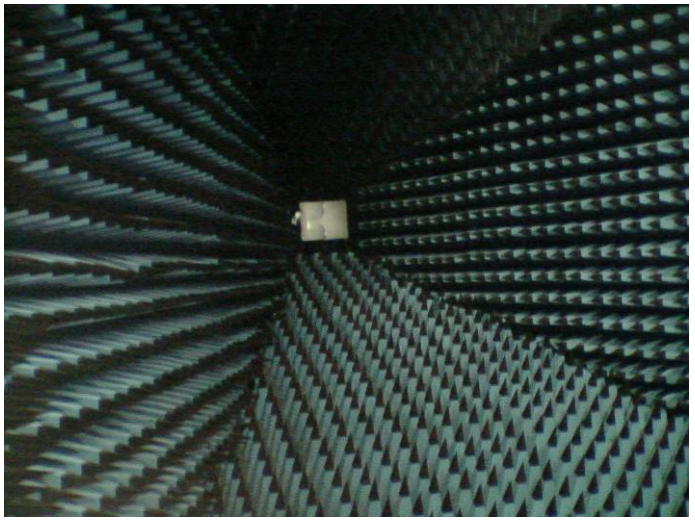
Antenna with a coaxial cable

# Validation - Antenna Adjustment (2)

- **Why change the antenna length**
  - Vertically narrow electric field is less distorted by sensor mote
  - Vertical radiation strength changes by the length of antenna



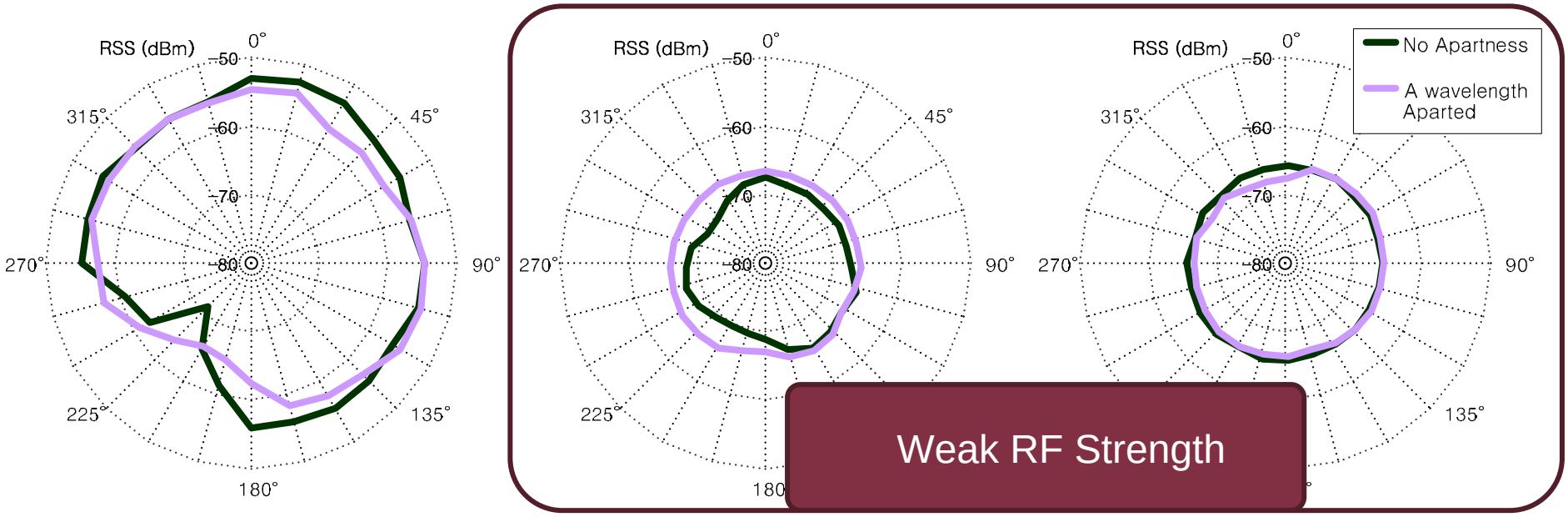

Vertical Radiation Patterns



Anechoic Chamber

# Validation - Antenna Adjustment (3)

- **Improved radiation patterns**
  - Keep 10cm distance using coaxial cable
  - Change antenna length (¼ default → ½ and ⅝ wavelength)



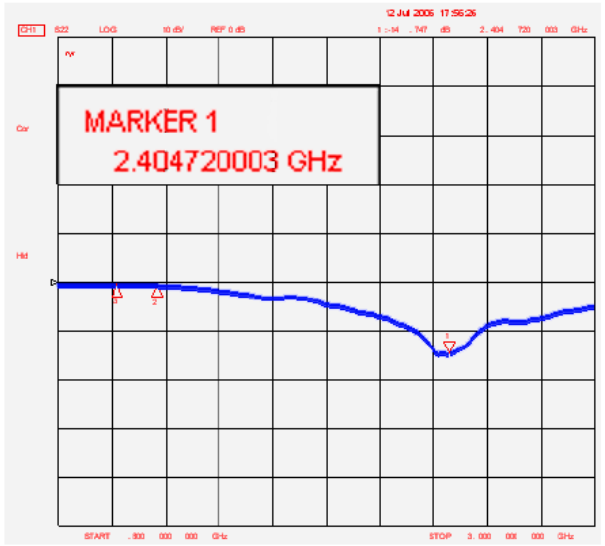

¼ wavelength antenna

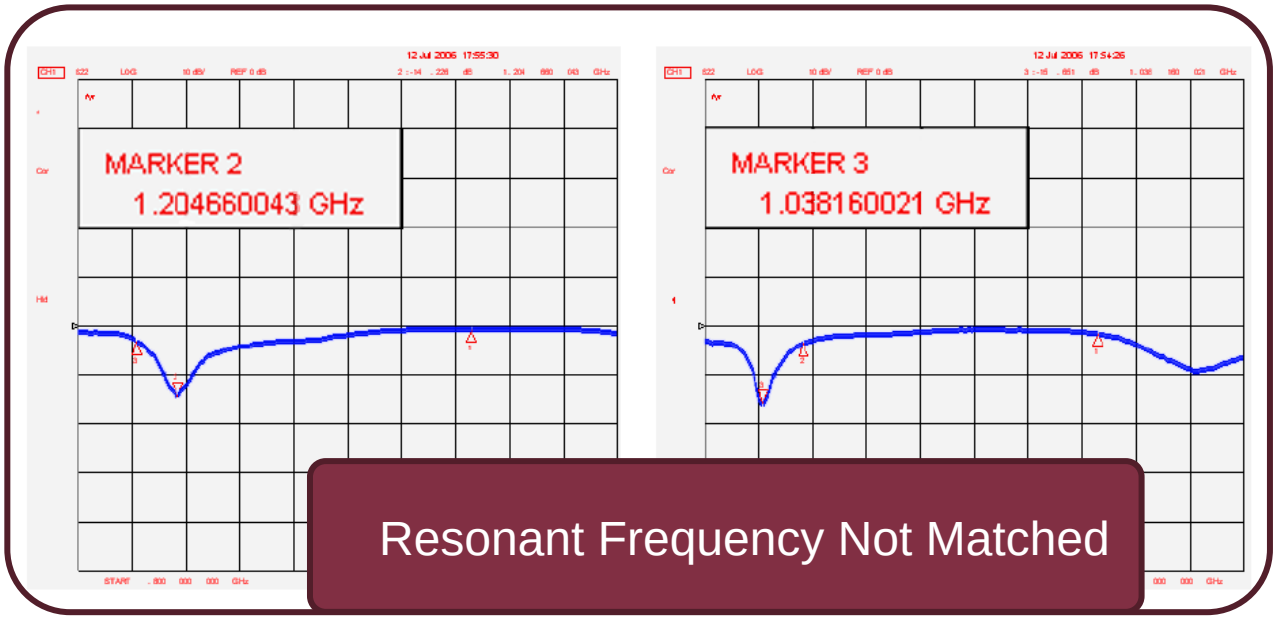
½ wavelength antenna

⅝ wavelength antenna

# Validation - Antenna Adjustment (4)

- **Reason of weakened signal strength**
  - Proper antenna length for given frequency
  - Unmatched antenna length does not resonate well



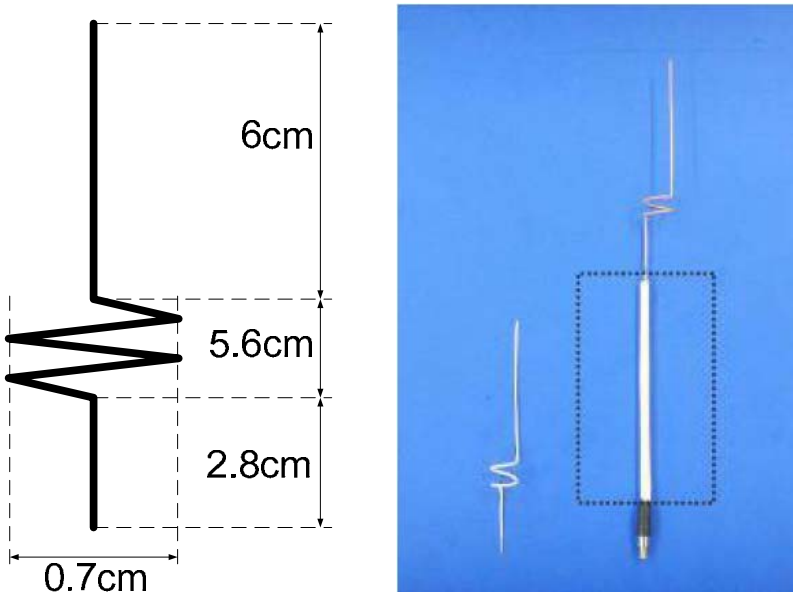

¼ wavelength antenna

½ wavelength antenna

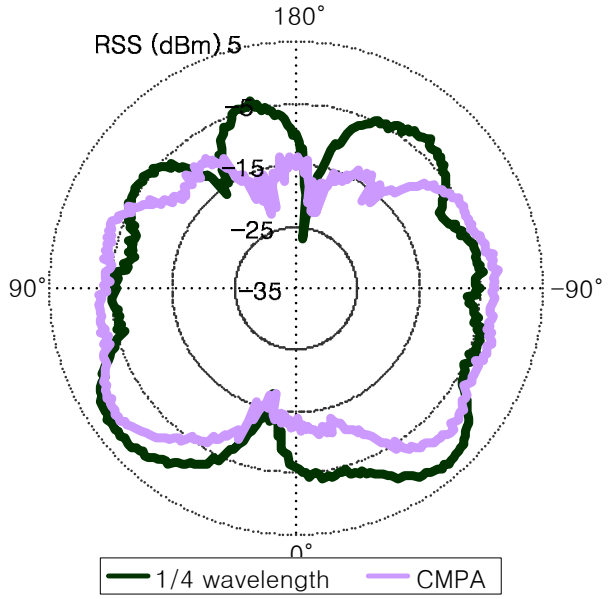
$\frac{5}{8}$ wavelength antenna

# Our Suggestion – New Antenna Type (1)

- **Reduce electric interference**
  - Change antenna type
  - CMPA (Collinear Monopole Antenna) can be one example
  - Our CMPA has lower vertical radiation than default antenna



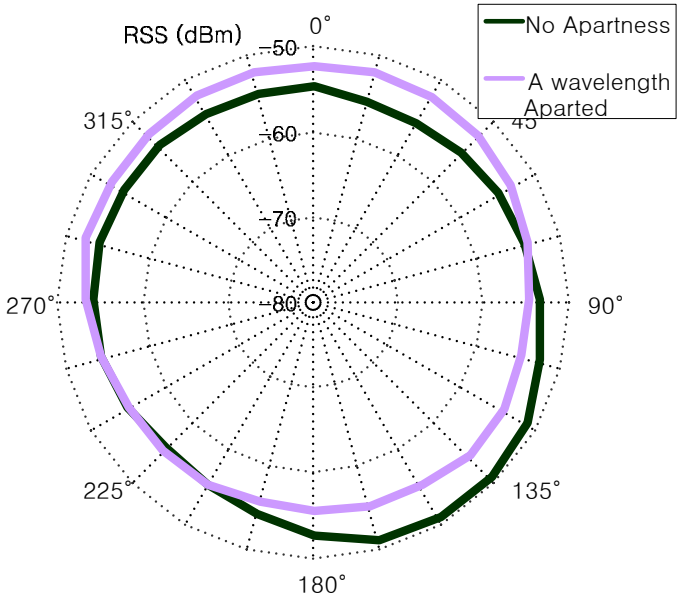

Designed Collinear Monopole Antenna



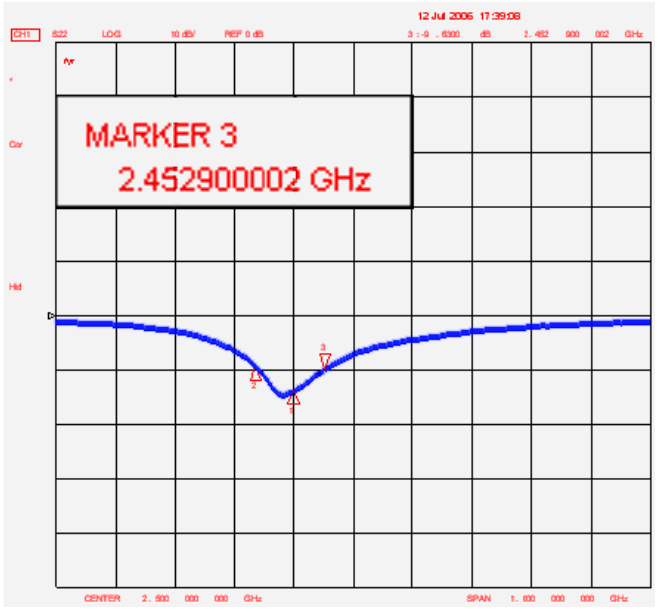

Vertical Radiation Patterns

# Our Suggestion – New Antenna Type (2)

- **Performance of CMPA**
  - Our CMPA presents almost omni-directional pattern
  - Our CMPA resonates well at given frequency of 2.4GHz



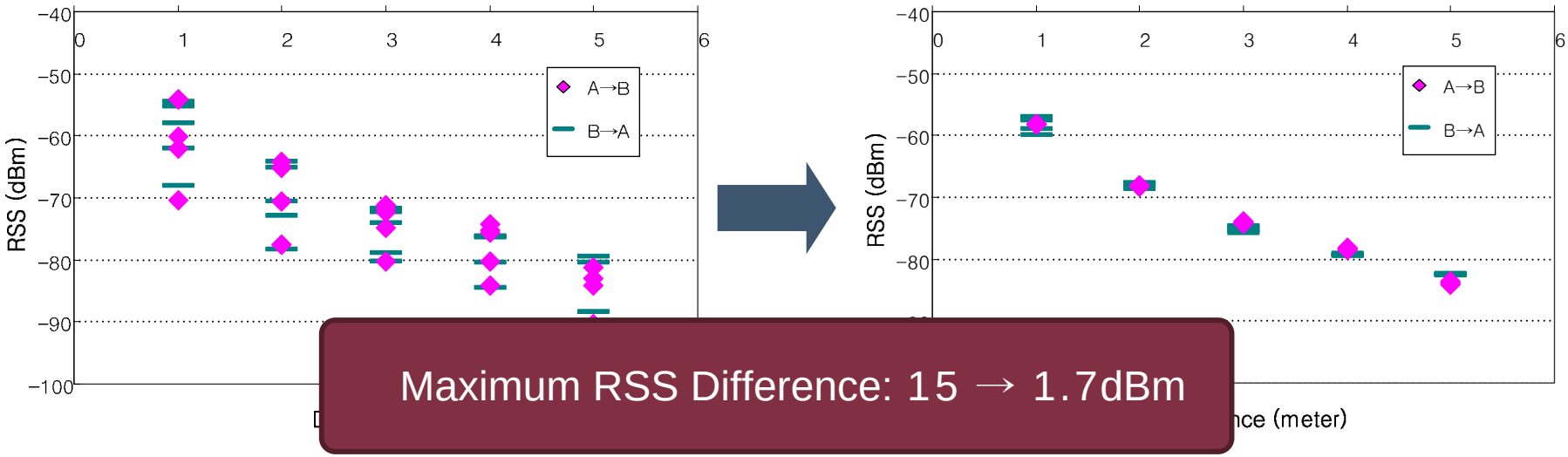

Horizontal Radiation Patterns




Return Loss of CMPA

# Net Effect 1: Symmetric Connectivity

- **Comparison test for link symmetry**
  - ¼ wavelength default Vs. ⅝ wavelength omni-directional
  - Symmetric connectivity guaranteed with omni-directional antenna

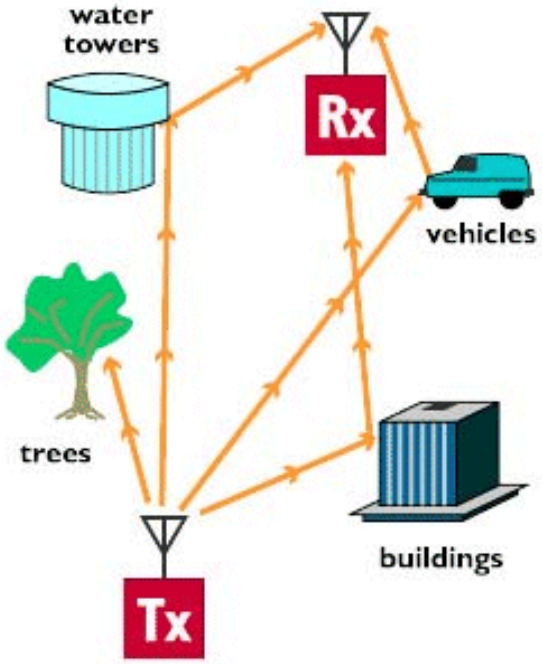


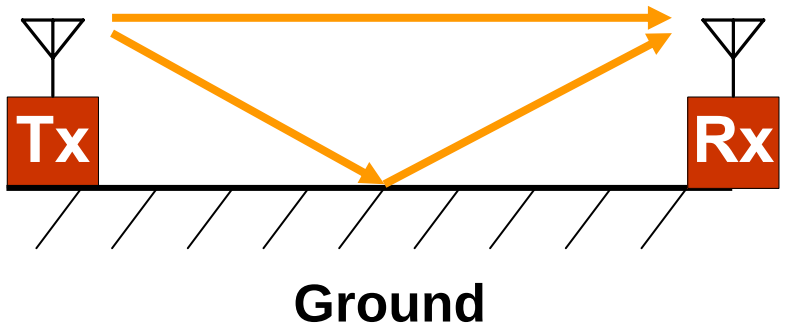

¼ Wavelength Default Antenna

⅝ Wavelength Omni-directional Antenna

# Cause of RSS Fluctuation

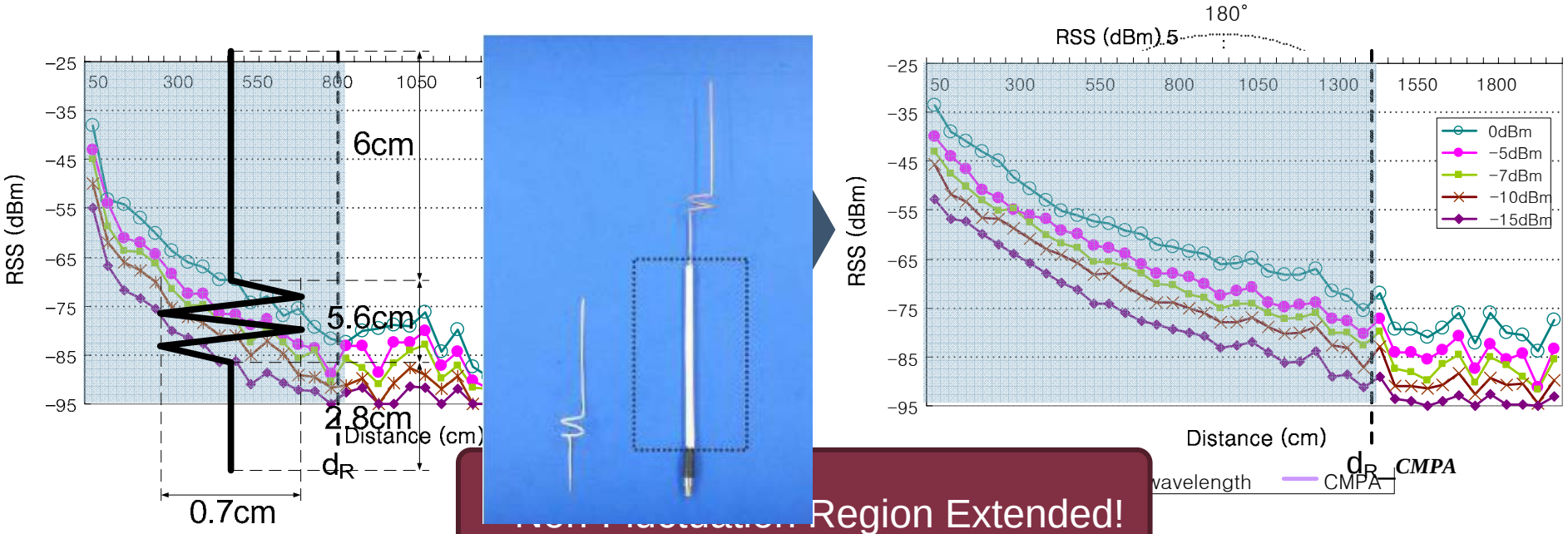
- **General environment**
  - Multi-path fading
- **Obstacle-free environment**
  - Hypothesis : Ground reflection



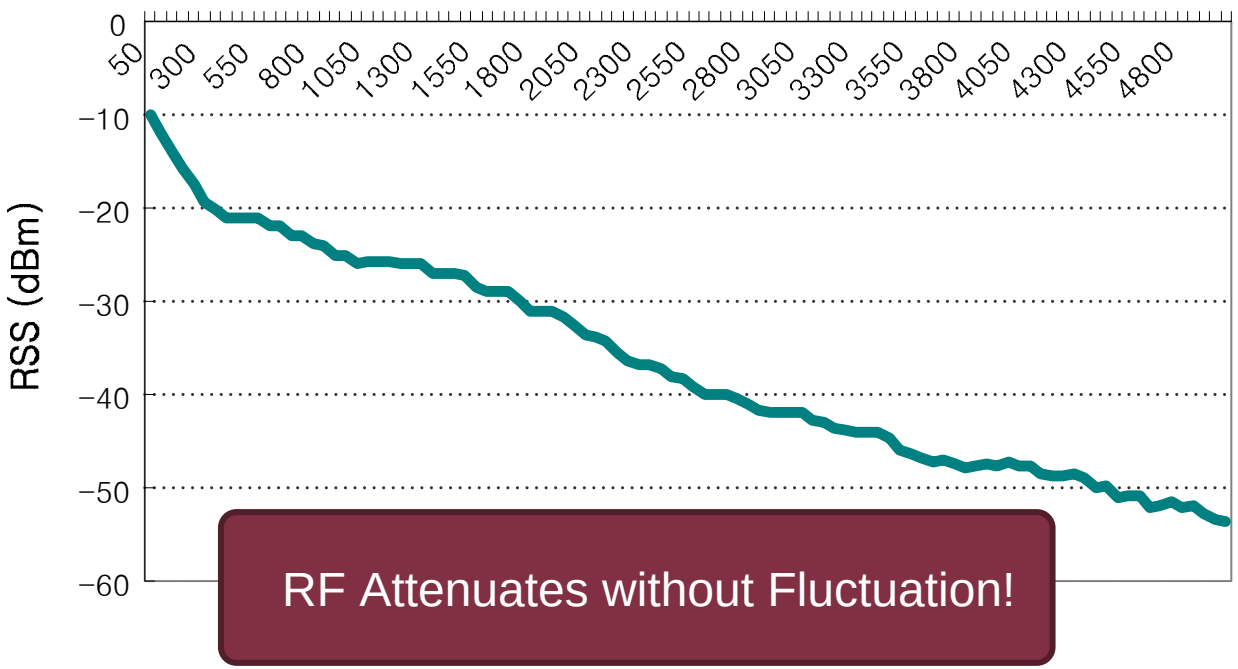
# Validation

- **Reduce ground reflection**
  - Less downward RF radiation
  - Experiment with CMPA



# Net Effect 2: RSSI-Distance Correlation

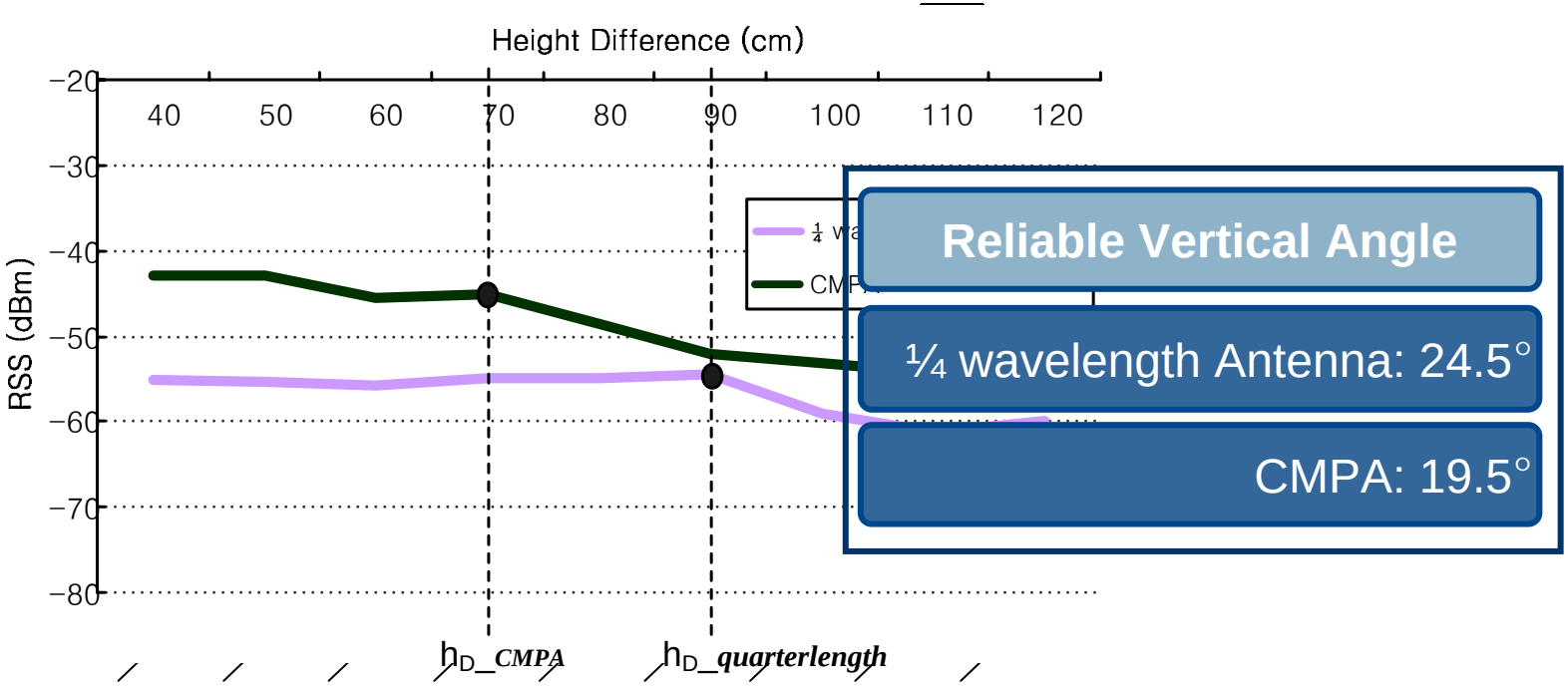
- **No ground-reflection environment**
  - Experiment with Parabolic Antennas




Tmote Sky Sensor Mote with 15dBi Gain Parabolic Antenna

# Practical Limits

- **Antenna with vertically narrow radiation**
  - Horizontally omni-directional radiation pattern
  - Symmetric link
  - Less RSS fluctuation problem
  - Worse performance in non-flat environment



# Conclusions

- **Difficulties in RF-based localization**
  - Antenna orientation problem
  - RSS fluctuation problem
  - → ***Our solution : "Antenna with less vertical radiation!"***
    1. ***Antenna length adjustment***
    2. ***Aggressive antenna type (e.g. CMPA, dual-reflector, ceramic…)***

- **Contributions**
  - Understand the radio properties of real sensor motes.
  - Understand the source of RF-based localization problem.
  - Guideline for antenna design in wireless sensor networks.

# Questions