Computing with Directional Antennae in WSNs

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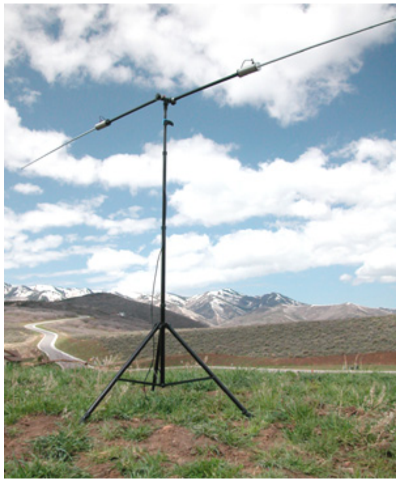
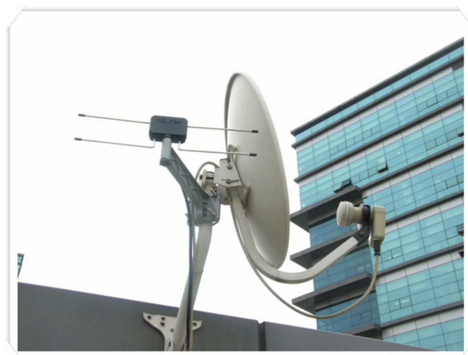
Outline of Tutorial

- Motivation
- Antennae Basics
- Network Connectivity
  - One Antenna
  - Multiple Antennae
- Neighbor Discovery
- Wormhole Attacks
- Coverage and Routing

Motivation

Antennae Everywhere...





...Beginning

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- Two antennae meet on a roof, fall in love, and get married. The service wasn't all that great, but the reception was wonderful!
- They were on the same wavelength but what did they gain? Instead of rice, Marconi was thrown, right? And in nine months or so there will be a little half wave dipole as long as the impedance was near perfect...

Comparison of Omnidirectional & Directional Antennae

	Omnidirectional	Directional
Energy	More	Less
Throughput	More	Less
Collisions	More	Less
Interference	More	Less
Connectivity	Stable	Intermittent
Discovery	Easy	Difficult
Coverage	Stable	Intermittent
Routing $SF^{(*)}$	Less	More
Security	Less	More

(*) SF = Stretch Factor

Why Directional Antennae

- Transmitting in particular directions results in a higher degree of spatial reuse of the shared medium.
- Directional transmission uses energy more efficiently.
- The transmission range of directional antennas is usually larger than that of omnidirectional antennas, which can reduce hops for routing and make originally unconnected devices connected.
- Directional antennas can increase spatial reuse and reduce packet collisions and negative effects such as deafness.
- Routing protocols using directional antennas can outperform omnidirectional routing protocols.

Simple Estimate: Energy Consumption of an Antenna

- An ominidirectional antenna with range r consumes energy proportional to $\pi \cdot r^2$.
- A directional antennae with angular spread α and range R consumes energy proportional to $\frac{\alpha}{2} \cdot R^2$.
- Given energy E
  - an ominidirectional antenna can reach distance $\sqrt{E/\pi}$, and
  - a directional antenna can reach distance $\sqrt{2E/\alpha}$
- Hence the smaller the angular spread the further you can reach.

Energy Consumption of a System of Antennae

- For a network of n omnidirectional sensors having range r_i, for $i = 1, 2, \ldots, n$ respectively, the total energy consumed will be

$$\sum_{i=1}^{n} \pi \cdot r_i^2.$$

- For a network of n directional sensors having angular spread α_i and range R_i, for $i = 1, 2, \ldots, n$ respectively, the total energy consumed will be

$$\sum_{i=1}^{n} \frac{\alpha_i}{2} \cdot R_i^2.$$

- Given that by shortening the angular spread you can increase the range of a directional sensor the savings can be significant.

A Deeper Question

- There is a deeper question here that is worth studying:

  Give orientation algorithms that attain optimal energy/interference tradeoffs for a given set of sensors.

- Observe that in the resulting sensor network, the coverage areas of (directional) antennae overlap.

  To what extent can we analyze objectively the network performance?