Low-Power Wireless Links

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Berkeley Motes Timeline

1999 2000 2001 2002 2003 2004

Adapted from Joe Polastre, Designing Low-Power Wireless Systems
Inherent challenges

- Low-power radios are exposed to all sorts of RF phenomena
- Wireless links...an oxymoron?
- Single-hop or multi-hop?
- Even non-RF physical phenomena may impact communication
Disk Model?

• No such thing for WSNs!


• D. Ganesan et al., Complex Behavior at Scale: An Experimental Study of Low-Power Wireless Sensor Networks, UCLA Tech Rep 2002
Dealing with RF

- Low-power transceivers are even more vulnerable to the vagaries of RF propagation
- Path loss: power loss due to distance between rx and tx
- Shadowing: power loss due to the presence of an obstacle
- Reflections: wave hits a surface and part of the energy bounces back, part goes through
- Fading: several reflected paths make it to the rx
Flavors of Fading

Dynamic Fading
- Nodes in motion relative to one another
- Fading patterns naturally change
- Comes with changes in the path loss as well

Static Fading
- Fading patterns change only if the area layout changes

Induced Fading
- Fading patterns are temporarily modified by the motion of people or objects
RF propagation

Different static fading levels

Fading (!)

Fading

Shadowing

Received Signal Strength [dBm]
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Multipath fading

Indoors, fading can dominate over the path loss

Impact of fading: 40dB!!!

Revolution period
Induced Fading

E1
Chair moved close to node 1

E2
Person through (2, 0)

E3
Chair moved close to node 2
Impact of Induced Fading

A
Induced Fading

B
Dynamic Fading + Path Loss
Impact on Higher-End Radios

- Fading is still there but
- May use higher power
- Better Sensitivity

CISCO Aironet 350

11Mbps => -85 dBm
5.5 Mbps => -89 dBm
2 Mbps => -91 dBm
1 Mbps => -94 dBm
Sensorless Motion Detection

A
Erratic motion detected by accelerometer

B
Accelerometer can’t make it, RSS can!
Low-power wireless links

Links are NOT Boolean:
If B can hear A once, it doesn’t mean they’re connected

Links are NOT bidirectional:
if A can hear B, B doesn’t necessarily hear A

Links are probabilistic: B can hear A with a given probability

In practice, a link can be characterized in terms of
• Received Power (RSS)
• Packet Delivery Rate (PDR)
• Required Number of Packets (RNP)
Transitional links

- **Solid links (PDR > 0.8)**
- **Transitional links**
  - RSS range between -95 and -80 dBm
  - Where PDR has a huge variance
  - Asymmetric links all lie within this region
- **Disconnected links**
  - Below -95 dBm, PDR is virtually 0
Transitional Can Become Disconnected

Shadowing!
PDR vs. RSS

![Graph showing PDR vs. RSS with data points注明: All links and Asymmetric links.](image)
RNP: the cost of using a link

Node A sends, B does not receive, no ACK: $\text{RNP} \geq 2$

Node A resends, B does not receive, no ACK: $\text{RNP} \geq 3$

Node A resends, B receives, ACK is lost: $\text{RNP} \geq 4$

Node A resends, B receives, ACK is received: $\text{RNP} = 4$
Connectivity

- Definitely not circular
- Blobs of connectivity
- Being close doesn’t necessarily mean being connected (fading!)

connected to A

connected to B
Single-hop or multihop?

Do we use (A, C)?
Or do we use (A, B) and (B, C)?
Nodes need to relay on behalf of others...
...but relaying is not free:
- energy cost
- risk of packet loss

- B works for free on behalf of A
- Extra energy cost for B
- Packet may get lost on (A, B) and on (B, C)

Hey, B, this is for C
Do I really have to???
Benefits of a few long hops

• Less radio activity: less interference
• Tx power reduction does not yield proportional energy savings
• Not relaying means you can sleep!
• Less overhead
• Energy balancing

When multihopping:
• if any of the links breaks, the end-to-end route breaks
• if any of the relays moves, the route is endangered
Impact of non-RF phenomena

Temperature has a huge impact on received signal strength

Wireless Sensor Networking for “Hot” Applications: Effects of Temperature on Signal Strength, Data Collection and Localization
K. Bannister, G. Giorgetti and S.K.S. Gupta, HotEmNets’08