Wireless Sensor Networks

5th Lecture

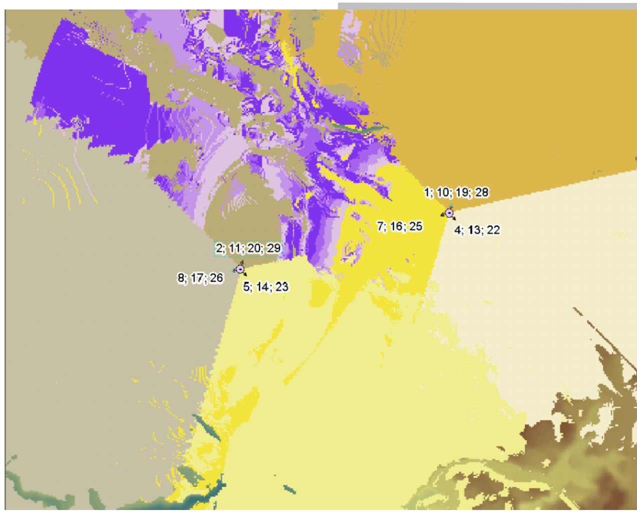
08.11.2006

CoNe Freiburg

University of Freiburg
Computer Networks and Telematics
Prof. Christian Schindelhauer

Christian Schindelhauer
schindel@informatik.uni-freiburg.de

Sharing the Medium



- **Space-Multiplexing**
  - Spatial distance
  - Directed antennae
- **Frequency-Multiplexing**
  - Assign different frequencies to the senders
- **Time-Multiplexing**
  - Use time slots for each sender
- **Spread-spectrum communication**
  - Direct Sequence Spread Spectrum (DSSS)
  - Frequency Hopping Spread Spectrum (FHSS)
- **Code Division Multiplex**

Frequency Hopping Spread Spectrum

- **Change the frequency while transfering the signal**
  - Invented by Hedy Lamarr, George Antheil
- **Slow hopping**
  - Change the frequency slower than the signals come
- **Fast hopping**
  - Change the frequency faster

University of Freiburg
Institute of Computer Science
Computer Networks and Telematics
Prof. Christian Schindelhauer

Direct Sequence Spread Spectrum

- **A Chip is a sequence of bits (given by {-1, +1}) encoding a smaller set of symbols**
- **E.g. Transform signal: 0 = (+1,+1,-1), 1=(-1,-1,+1)**

  0 1 0 1

  +1 +1 -1, -1 -1 +1, +1 +1 -1, -1 -1 +1
- **Decode by taking the inner product for bits c_i of the received signals si and the chips $c_0 = - c_1$:**

$$\sum_{i=1}^{m} c_{0,i} s_i \qquad \sum_{i=1}^{m} c_{1,i} s_i$$

- **Now if an overlay arrives then the signal can be deconstructed by applying dedicated filters**
- **DSSS is used by GPS, WLAN, UMTS, ZigBee, Wireless USB based on an**
  – Barker Code (11Bit): +1 +1 +1 –1 –1 –1 +1 –1 –1 +1 –1
  – For all v<m

$$\left| \sum_{i=1}^{m} a_j a_{j+v} \right| \leq 1$$

Code Division Multiple Access (CDMA)

- **Use chip sequence such that each sender has a different chip C with**
  - $C_i \in \{-1,+1\}^m$
  - $-C_i = (-C_{i,1},-C_{i,2}, \ldots, -C_{i,m})$
- **For all i≠j the normalized inner product is 0:**

$$C_i \bullet C_j = \frac{1}{m} C_i \cdot (C_j)^T = \frac{1}{m} \sum_{k=1}^{m} C_{i,k} C_{j,k} = 0 \; .$$

- **If synchronized the receiver sees linear combination of A and B**
- **By multiplying with proper chip he can decode the message.**

CDMA (Example)

- **Example:**
  - Code C_A = (+1,+1,+1,+1)
  - Code C_B = (+1,+1,-1,-1)
  - Code C_C = (+1,-1,+1,-1)
- **A sends Bit 0, B sendet Bit 1, C sendet nicht:**
  - $V = C_1 + (-C_2) = (0,0,2,2)$
- **Decoded according to A: $V \bullet C_1 = (0,0,2,2) \bullet (+1,+1,+1,+1) = 4/4 = 1$**
  - equals Bit 0
- **Decoded according to B: $V \bullet C_2 = (0,0,2,2) \bullet (+1,+1,-1,-1) = -4/4 = -1$**
  - equals Bit 1
- **Decoded according to B: $V \bullet C_3 = (0,0,2,2) \bullet (+1,-1,+1,-1) = 0$**
  - means: no signal.

University of Freiburg
Institute of Computer Science
Computer Networks and Telematics
Prof. Christian Schindelhauer

Overview

- **Frequency bands**
- **Modulation**
- **Signal distortion – wireless channels**
- **From waves to bits**
- **Channel models**
- *Transceiver design*

Some transceiver design considerations

- **Strive for good power efficiency at low transmission power**
  - Some amplifiers are optimized for efficiency at high output power
  - To radiate 1 mW, typical designs need 30-100 mW to operate the transmitter
    - WSN nodes: 20 mW (mica motes)
  - Receiver can use as much or more power as transmitter at these power levels

    ! Sleep state is important
- **Startup energy/time penalty can be high**
  - Examples take 0.5 ms and ¼ 60 mW to wake up
- **Exploit communication/computation tradeoffs**
  - Might payoff to invest in rather complicated coding/compression schemes

Choice of modulation

- **One exemplary design point: which modulation to use?**
  - Consider: required data rate, available symbol rate, implementation complexity, required BER, channel characteristics, …
  - Tradeoffs: the faster one sends, the longer one can sleep
    - Power consumption can depend on modulation scheme
  - Tradeoffs: symbol rate (high?) versus data rate (low)
    - Use m-ary transmission to get a transmission over with ASAP
    - But: startup costs can easily void any time saving effects
    - For details: see example in exercise!

- **Adapt modulation choice to operation conditions**
  - Akin to dynamic voltage scaling, introduce ***Dynamic Modulation Scaling***

Summary

- **Wireless radio communication introduces many uncertainties and vagaries into a communication system**

- **Handling the unavoidable errors will be a major challenge for the communication protocols**

- **Dealing with limited bandwidth in an energy-efficient manner is the main challenge**

- **MANET and WSN are similar here**
  - Main differences are in required data rates and resulting transceiver complexities (higher bandwidth, spread spectrum techniques)

Transceiver characteristics

University of Freiburg
Institute of Computer Science
Computer Networks and Telematics
Prof. Christian Schindelhauer

- **Capabilities**
  - Interface: bit, byte, packet level?
  - Supported frequency range?
    - Typically, somewhere in 433 MHz – 2.4 GHz, ISM band
  - Multiple channels?
  - Data rates?
  - Range?
- **Energy characteristics**
  - Power consumption to send/receive data?
  - Time and energy consumption to change between different states?
  - Transmission power control?
  - Power efficiency (which percentage of consumed power is radiated?)
- **Radio performance**
  - Modulation? (ASK, FSK, …?)
  - Noise figure? NF = SNR_I/SNR_O
    - output noise added
  - Gain? (signal amplification)
  - Receiver sensitivity? (minimum S to achieve a given E_b/N_0)
  - Blocking performance (achieved BER in presence of frequency-offset interferer)
  - Out of band emissions
  - Carrier sensing & RSSI characteristics
    - Received Signal Strength Indication
  - Frequency stability (e.g., towards temperature changes)
  - Voltage range

Thank you

(and thanks go also to Holger Karl for providing some slides)

CoNe Freiburg

University of Freiburg
Computer Networks and Telematics
Prof. Christian Schindelhauer

Wireless Sensor Networks
Christian Schindelhauer
schindel@informatik.uni-freiburg.de

5th Lecture
08.11.2006