Communication Theory as Applied to Wireless Sensor Networks

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Objectives

- Understand the constraints of WSN and how communication theory choices are influenced by them
- Understand the choice of digital over analog schemes
- Understand the choice of digital phase modulation methods over frequency or amplitude schemes

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Objectives (cont.)

- Understand the cost/benefits of implementing source and channel coding for sensor networks
- Understand fundamental MAC concepts
- Grasp the importance of node synchronization
- Synthesize through examples these concepts to understand impact on energy and bandwidth requirements

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Outline

- Sensor network constraints
- Digital modulation
- Source coding and Channel coding
- MAC
- Synchronization
- Synthesis: Energy and bandwidth requirements

WSN Communication Constraints

- Energy!

Data Collection Costs

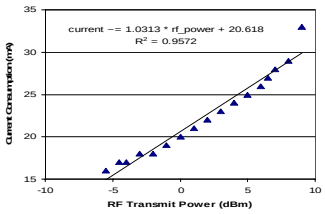
- Sensors
- Activation
- Conditioning
- A/D

Computation Costs

- Node life support
- Simple data processing
- Censoring and Aggregation
- Source/Channel coding

Communication constraints

Communication Costs



Communication constraints

Putting it all together

Communication constraints

Outline

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Modulation

- Review

- Motivation for Digital

The Carrier

Amplitude Modulation (AM)

DSB-SC (double sideband – suppressed carrier)

Frequency representation for DSB-SC (the math)

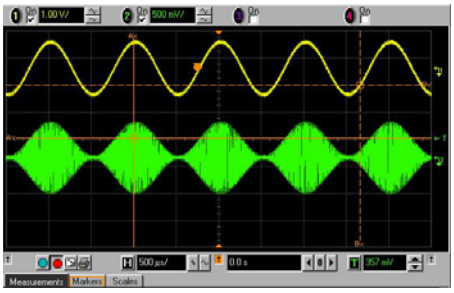
Frequency representation for DSB-SC (the cartoon)

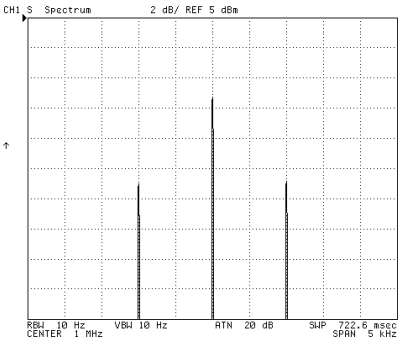
Demodulation – coherent receiver

DSB-LC (or AM as we know it)

Frequency representation of DSB-LC

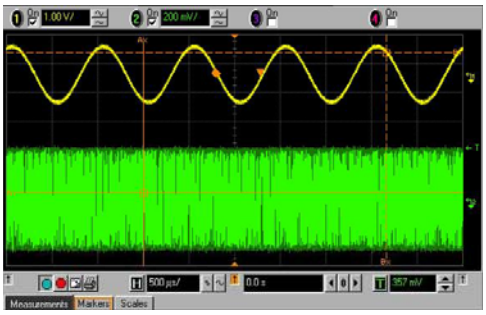
Amplitude Modulation

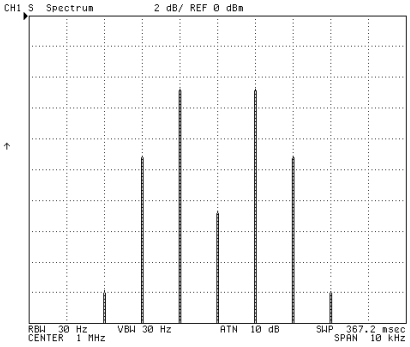




Frequency Modulation (FM)

Frequency Modulation





Phase Modulation

SNR Performance

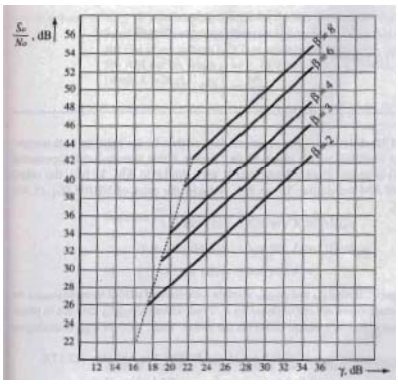
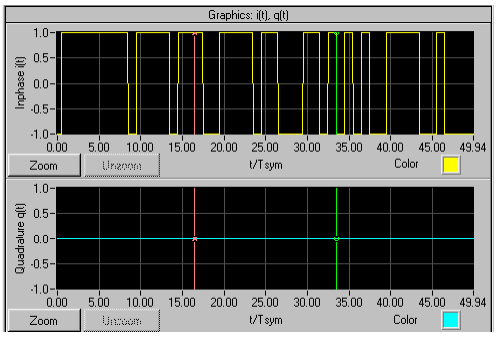


Fig. Lathi

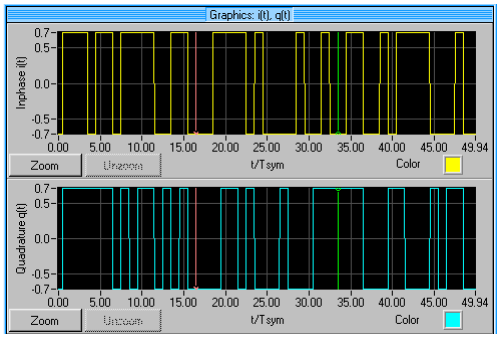
Digital Methods

Quadrature Modulation

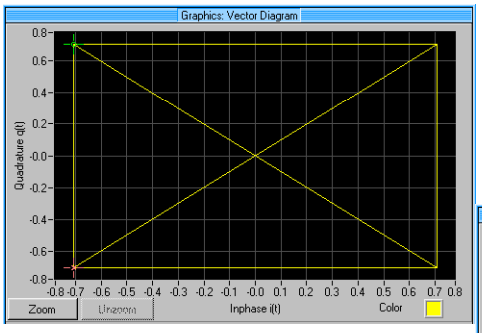
BPSK

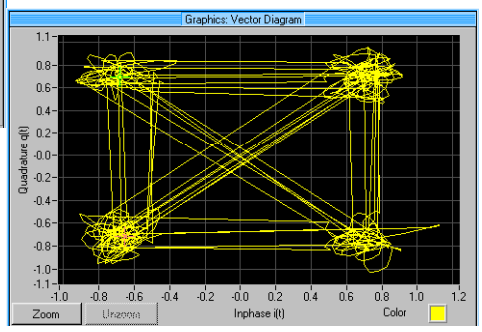


QPSK



Constellation Plots





BER Performance vs. Modulation Method

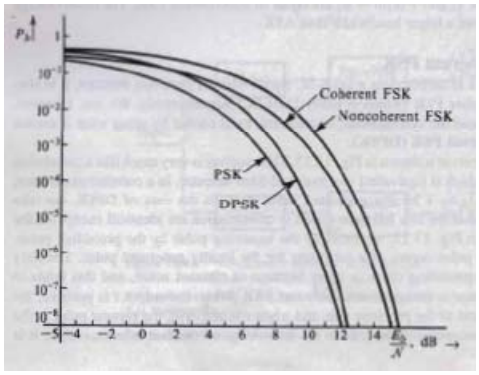


Fig. Lathi

Digital Modulation

BER Performance vs. Number of Symbols

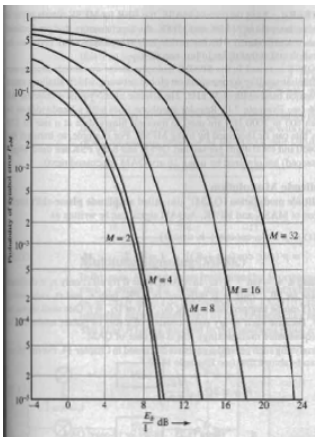


Fig. Lathi

Digital Modulation

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Source Coding

- Motivation
- Lossless
- Lossy

Lossless Compression

- Zip files
- Entropy coding (e.g., Huffman code)

Lossless Compression Approaches for Sensor Networks

- Constraints
- Run length coding
- Sending only changes in data

Lossy Compression

- Rate distortion theory (general principles)
- JPEG

Example of Lossy Compression - JPEG

Another comparison

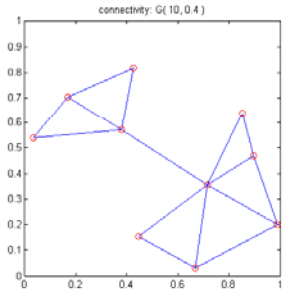
Lossy Compression Approaches for Sensor Networks

- Constraints
- Transformations / Mathematical Operations
- Predictive coding / Modeling

Source Coding

Example Actions by Nodes

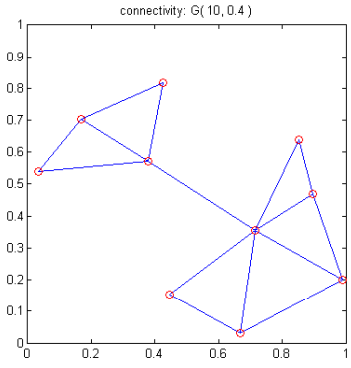
- Adaptive Sampling
- Censoring



Source Coding

In-Network Processing

- Data Aggregation



Source Coding

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Channel Coding (FEC)

- Motivation
- Block codes
- Convolution codes

Channel Coding Approaches for Sensor Networks

- Coding constraints
- Block coding

Example: Systematic Block Code

Alternative: Error Detection

- Motivation
- CRC

Performance

- Benefits
- Costs

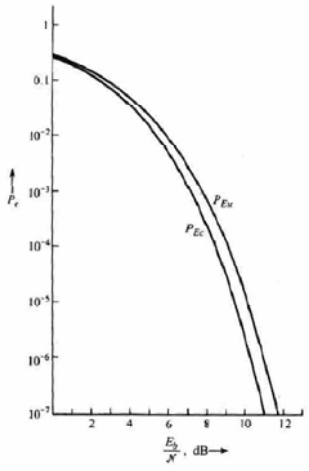

Fig. Lathi

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Sharing Spectrum

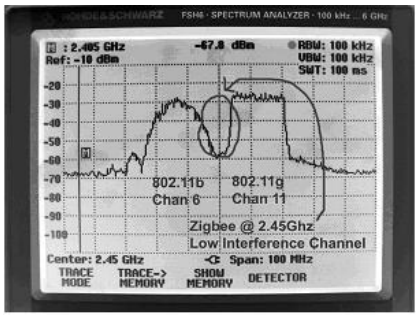
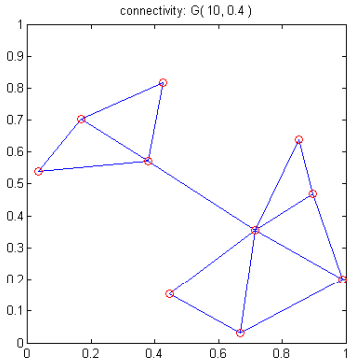


Fig. Frolik (2007)

MAC

- Motivation
- Contention-based
- Contention-free



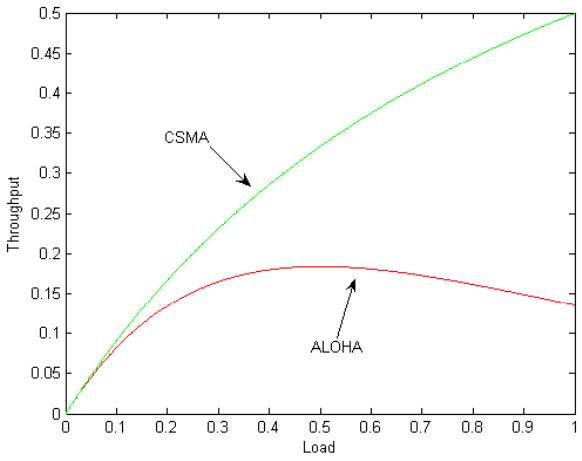
ALOHA (ultimate in contention)

- Method
- Advantages
- Disadvantages

CSMA (contentious but polite)

- Method
- Advantages
- Disadvantages

Throughput comparison



Contention Free Approaches

- RTS/CTS
- Reservations

MAC for Sensor Networks: 802.15.4

- Beacon enabled mode for star networks

Bandwidth details: 802.15.4

- 2.4 GHz band (2.40-2.48 GHz)
- Sixteen channels spaced at 5 MHz (CH 11 – 26)
- Data rate – 250 kbps
- Direct sequence spread spectrum (DSSS)
- 4 bits → symbol → 32 chip sequence
- Chip rate of 2 Mcps
- Modulation – O-QPSK
- Total bandwidth requirement: ~3 MHz

DSSS

- Motivation
- Operation

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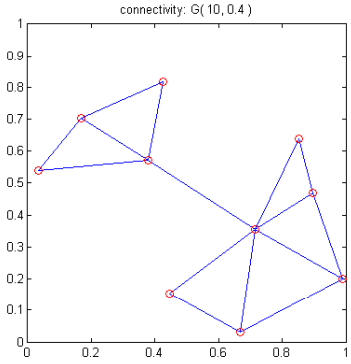
Synchronization

- Motivation
- Categories

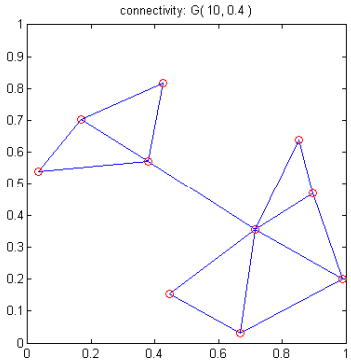
Node Scheduling

- Sleep
- Listening
- Transmitting



Synchronization

Sleep Scheduling for Sensor Networks: S-MAC



Synchronization

Synchronizing for Effective Communications

- Carrier
- Bit/Symbol
- Frame

Synchronization

Outline

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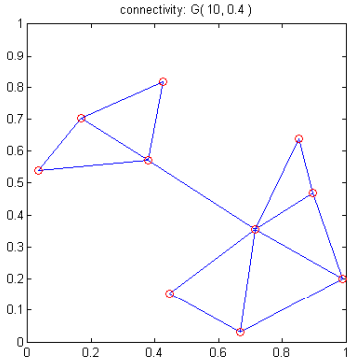
Putting the Pieces Together

Synthesis: Energy and Bandwidth

- M-ary Signaling
- Channel Coding

Sensor Network Example 1: Single vs. Multihop

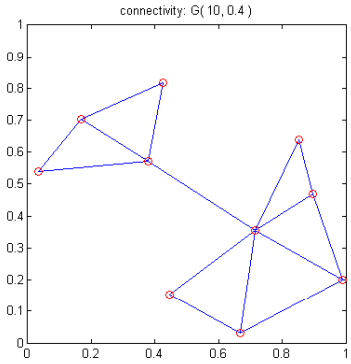
- Multihop
- Single hop



Energy & Bandwidth

Sensor Network Example 2: Polling vs. Pushing

- Polling
- Pushing



Energy & Bandwidth

Conclusions

- A digital communications approach to WSN has advantages in robustness, energy, and bandwidth performance
- Source coding reduces overall system level energy requirements
- Simple channel coding schemes improve data reliability minimizing the need for retransmissions

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Conclusions - 2

- MAC and routing strategies should be chosen with an eye towards network architecture – cross-layer design
- Node synchronization must occur regularly due to clock drift between nodes
- Simple digital communication techniques enable low-energy, low-bandwidth WSN system requirements

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What to know more?

- B. Lathi, *Modern Analog and Digital Communication Systems*, 3rd ed., Oxford, 1998.
- B. Krishnamachari, *Networking Wireless Sensors*, Cambridge Press, 2005.
- J. Frolik, "Implementation Handheld, RF Test Equipment in the Classroom and the Field," *IEEE Trans. Education*, Vol. 50, No. 3, August 2007.