Quick Fundamentals of Wireless Networks

IMA Summer Program on Wireless Communications

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Quick Fundamentals of Wireless Networks

• Overview
• Wireless Network Architectures
  – infrastructure-free networks
  – infrastructure-based networks
    • legacy
    • all IP
• The digital wireless link
  – channel models
    • propagation
    • fading and shadowing
  – modulation
  – coding
  – adaptive coding and modulation
  – ARQ and Fast ARQ
• Traffic
  – conversational
  – streaming
  – interactive
  – bet effort
• Capacity & Performance measures
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Interface to the Public Network

Base Site Controller

Access Node

Internet

Packet Core

Packet Core

Base Site (Access Point)

Client

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An Infrastructure-free “Ad-Hoc” Network

1st hop  2nd hop  3rd hop
The Wireless Link: Channel Models

- Environmental conditions effect the qualities of a wireless link depending on:
  - frequency and bandwidth
  - terrain or urban “clutter”
    - shadowing
    - fading (multipath interference)
    - ambient noise
  - distance and transmit power
  - relative speed of transmitter and receiver
  - antenna type and properties
    - gain
    - diversity and array
    - directionality
The Wireless Link: Propagation

• Models of received signal strength:
  \[ e^{Xr^{-\mu}} \]
  - \( r \) is the distance between transmitter and receiver
  - \( \mu \) is typically between 3 and 4
  - \( X \) is a Normal random process with spatial correlation

• Less shadowing and fading at lower frequencies
  - lower frequencies are better able to penetrate buildings and other urban “clutter”
The Wireless Link: Modulation

- Changes in the electromagnetic waveform convey information in the form of a “symbol.”
- Common Examples
  - Phase-Shift Keying (PSK)
    - symbol corresponds to phase
    - amplitude is constant
    - Binary: 0 and 1 are the symbols and the phases are 0 and $\pi$
    - Quadrature: (0,0), (0,1), (1,0) and (1,1) are the symbols corresponding to phases $\pi/4$, $3\pi/4$, $5\pi/4$ and $7\pi/4$.
  - Quadrature [Phase and] Amplitude Modulation (QAM)
    - symbol corresponds to phase and amplitude pair
    - 16-QAM: symbols are four bit sequences corresponding to values of $Ae^{j\theta}$
The Wireless Link: Channel Coding for Bit Error Correction

- Efficient error-correcting codes convert strings of \( k \) information bits into codewords of length \( n \)
  - \( k/n \) is the rate of the code
  - received “words” are decoded by finding the codeword that is “closest” to the received word
- Convolutional Codes
  - information bit sequence is passed through a finite state shift register
  - maximum likelihood decoding
- Turbo Codes
  - close to realizing the Shannon capacity bound
  - maximum a posteriori decoding (MAP)
- Channel coding is typically used in conjunction with interleaving
The Wireless Link: ARQ and Fast ARQ for Frame Error Correction

- (ARQ) Automatic Repeat Request
- Session Layer: e.g. TCP
  - IP packets are re-transmitted across multiple network links.
  - round trip time: approx 0.5 to 1 sec.
- Link layer: e.g. Radio Link Control (RLC) or RLP
  - Radio link frames are re-transmitted across backhaul and radio link.
  - round trip time: approx 50 to 200 msec.
- Physical Layer: e.g. Fast ARQ or Hybrid ARQ
  - radio link sub-frames are re-transmitted over the radio link
  - re-tx bits combined (IR or CC) with previous bits before final decode
  - short round trip time: approx 5 to 20 msec
Traffic

- Conversational (http://www.webtutorials.com/sndsmpl/)
  - phone call
  - gaming
- Streaming
  - IP radio and video
  - push-to-talk
- Interactive
  - web browsing
  - instant messaging
  - gaming
- Best effort
  - file transfer
  - push data (e.g. stock quotes, weather, sport’s scores)
System Capacity

- Interactive Sessions: conversational, streaming, interactive
  - Average number of sessions per sector per carrier
    - erlangs: average number of simultaneous calls supportable at some quality criterion
  - Average number of sessions per sq mile
  - Average number of sessions per Hz

- Packet Data
  - bits per sec per Hz
  - bits per second per sector per carrier
Performance: User experience

• Phone call and push-to-talk
  – Call setup time
  – Voice path delay
  – Voice quality
  – Audio holes
  – Coverage: call initiation, call drop

• Streaming
  – session intiation
  – image quality
  – stop/start frequency

• Interactive
  – session intiation time
  – response time

• Best effort
  – file download time
Mathematical disciplines related to wireless communications

• Information theory
• Queueing theory and stochastic modeling
• Control and Stochastic Control
• Decision theory
• Game theory