T-79.7001 Postgraduate Course in Theoretical Computer Science
T-79.5401 Special Course in Mobility Management: Ad hoc networks
(2 - 10 cr) P V

professor Hannu H. Kari
Laboratory for Theoretical Computer Science
Department of Computer Science and Engineering
Helsinki University of Technology (HUT), Espoo, Finland
email: Kari [at] tcs [dot] hut [dot] fi
Practical issues

- **How many credits:**
  - 2 cr (ECTS) for one presentation (30 minutes) + slides + summary paper.
  - 1 cr (ECTS) for reviewing two summary papers and opponenting two other participants' presentations.
  - Either of them can be taken several times.
  - Additional credits can be achieved based on the number of presentations:
    - A presentation includes archivable slides and short summary. Credits are given with the following rules:
      - 3 ECTS per topic (for dissertation)
      - 2 ECTS per topic for master’s thesis and
      - 1 ECTS for journal/proceeding.
Practical issues

• Dates:
  • Seminar schedule: Wednesdays 14-16
  • Topic selection deadline: 31.1.2007
Credits

• Material based on
  • C. Siva Ram Murthy and B. S. Manoj: "Ad Hoc Wireless Networks: Architectures and Protocols"
  • Stefano Marinoni:” Performance of wireless ad hoc routing protocols — a simulation study in realistic environments”, Master's thesis http://www.tcs.hut.fi/Publications/bibdb/MarinoniMsc.pdf
Figure 1.1. The electromagnetic spectrum.
### Table 1.1. Frequency bands and their common uses

<table>
<thead>
<tr>
<th>Band Name</th>
<th>Frequency</th>
<th>Wavelength</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely Low Frequency (ELF)</td>
<td>30 to 300 Hz</td>
<td>10,000 to 1,000 Km</td>
<td>Powerline frequencies</td>
</tr>
<tr>
<td>Voice Frequency (VF)</td>
<td>300 to 3,000 Hz</td>
<td>1,000 to 100 Km</td>
<td>Telephone communications</td>
</tr>
<tr>
<td>Very Low Frequency (VLF)</td>
<td>3 to 30 KHz</td>
<td>100 to 10 Km</td>
<td>Marine communications</td>
</tr>
<tr>
<td>Low Frequency (LF)</td>
<td>30 to 300 KHz</td>
<td>10 to 1 Km</td>
<td>Marine communications</td>
</tr>
<tr>
<td>Medium Frequency (MF)</td>
<td>300 to 3,000 KHz</td>
<td>1,000 to 100 m*</td>
<td>AM broadcasting</td>
</tr>
<tr>
<td>High Frequency (HF)</td>
<td>3 to 30 MHz</td>
<td>100 to 10 m</td>
<td>Long-distance aircraft/ship communications</td>
</tr>
<tr>
<td>Very High Frequency (VHF)</td>
<td>30 to 300 MHz</td>
<td>10 to 1 m</td>
<td>FM broadcasting</td>
</tr>
<tr>
<td>Ultra High Frequency (UHF)</td>
<td>300 to 3,000 MHz</td>
<td>100 to 10 cm</td>
<td>Cellular telephone</td>
</tr>
<tr>
<td>Super High Frequency (SHF)</td>
<td>3 to 30 GHz</td>
<td>10 to 1 cm</td>
<td>Satellite communications, microwave links</td>
</tr>
<tr>
<td>Extremely High Frequency (EHF)</td>
<td>30 to 300 GHz</td>
<td>10 to 1 mm</td>
<td>Wireless local loop</td>
</tr>
<tr>
<td>Infrared</td>
<td>300 GHz to 400 THz</td>
<td>1 mm to 770 nm</td>
<td>Consumer electronics</td>
</tr>
<tr>
<td>Visible Light</td>
<td>400 THz to 900 THz</td>
<td>770 nm to 330 nm</td>
<td>Optical communications</td>
</tr>
</tbody>
</table>

* Throughout this book, the unit m refers to meter(s).
Radio propagation mechanisms

- Direct signal
- Reflection
- Diffraction
- Scattering

Figure 1.2. Propagation mechanisms.
\[ P_r = P_t G_t G_r \left( \frac{\lambda}{4\pi d} \right)^2 \]

where

- \( P_r \) receive power
- \( P_t \) transmission power
- \( G_t \) transmission gain
- \( G_r \) receive gain
- \( \lambda \) wavelength
- \( d \) distance between transmitter/receiver
Path loss: Two ray ground model

\[ P_r = P_t G_t G_r \left( \frac{h_t h_r}{d} \right)^2 \]

where

- \( h_r \) receiver height from ground
- \( h_t \) transmitter height from ground

or

\[ P_r = P_t G_t G_r \left( \frac{\lambda}{4\pi d} \right)^2 \left( \frac{4\pi h_t h_r}{d} \right)^2 = P_t G_t G_r \left( \frac{\lambda}{4\pi d} \right)^2 \left( d_{\text{thresh}} \right)^2 \]

where

\[ d_{\text{thresh}} = \frac{4\pi h_t h_r}{\lambda} \]
Path loss:
Two ray ground model
Path loss: Strong attenuation

\[ P_r = P_t G_t G_r \left( \frac{\lambda}{4\pi} \right)^2 \frac{1}{d^\gamma} \]

where

\( \gamma \) propagation coefficient between 2 (open space) and 5 (strong fading)
Impact of antenna
Impact of obstacles
• **Fast fading (small-scale fading)**
  - Rapid fluctuation of signal (amplitude, phase, interference due to multi-path transmission)
  - If no line-of-sight signal: Rayleigh fading

• If line-of-sight signal available: Ricean distribution (indoor situation)

• **Slow fading (large-scale fading)**
  - Attenuation due to objects between transmitter and receiver
  - Fading lasts longer time (seconds or minutes)
Interference

- **Adjacent channel interference**
  - Signal disturbed by adjacent frequency transmission

- **Co-channel interference**
  - Interference caused by transmission at the same frequency
Doppler shift

- Caused by movement of transmitter and receiver (actually relative movement of them)

\[ f_d = \frac{v}{\lambda} \]

where

- \( f_d \) doppler effect on frequency
- \( v \) relative frequency
- \( \lambda \) wavelength
Transmission rate constraints

- **Nyquist’s theorem**

\[ C = 2B \log_2 L \]

*where*

- \( C \) maximum channel capacity
- \( B \) used bandwidth [Hz]
- \( L \) number of discrete signal levels

- **Shannon’s theorem**

\[ C = B \log_2 \left( 1 + \frac{S}{N} \right) \]

*where*

- \( C \) maximum data rate
- \( B \) bandwidth [Hz]
- \( S \) signal power
- \( N \) noise power
- \( SNR = 10 \log_{10} \left( \frac{S}{N} \right) \)

<table>
<thead>
<tr>
<th>S/N</th>
<th>bit/s/Hz</th>
<th>SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1.584963</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2.321928</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>3.459432</td>
<td>10</td>
</tr>
<tr>
<td>100</td>
<td>6.658211</td>
<td>20</td>
</tr>
</tbody>
</table>
Modulation techniques: Analog modulations
Modulation techniques:
Digital modulations

Figure 1.6. Constellation pattern in 8-QAM.
FDMA: Frequency Division Multiple Access
TDMA: Time Division Multiple Access

Figure 1.8. Illustration of TDMA.
CDMA: Code Division Multiple Access
Figure 1.11. Illustration of SDMA.
Error control

- Detection
  - Parity check
  - Cyclic Redundancy Check
  - Digital signatures
- Forward error correction (FEC)
  - Hamming coding
  - Convolutional coding
  - Turbo codes
- Automatic Retransmission reQuest (ARQ)
Questions

• Why X-rays or Gamma rays are not used in communication?
• Which modulation mechanism is best for ad hoc networks:
  • FDMA, TDMA, CDMA, or SDMA?
• Is there need to consider doppler shift in ad hoc networks
• Impact of Fast/Slow fading in ad hoc networks and simulating them?
• Impact of asymmetry of antenna?
• Impact of obstacles?