Mobile Data Networks

Lecturer: Victor O.K. Li
EEE Department
Room: CYC601D
Tel.: 2857 8425
Email: vli@eee.hku.hk
Course home page: http://www.eee.hku.hk/courses.msc/

Lecture 1: Introduction

- Mobile data network architecture
- Applications
- Generations of Wireless networks
- Syllabus
- References and assessment
Wireless comes of age

- Guglielmo Marconi invented the wireless telegraph in 1896
  - Communication by encoding alphanumeric characters in analog signal
  - Sent across the Atlantic Ocean
- Communication satellites launched in 1960s
- Advances in wireless technology
  - Radio, television, mobile telephone, communication satellites
- More recently
  - Satellite communications, wireless networking, cellular technology

Infrastructure-based mobile data networks
Infrastructure-less mobile data networks

Use of the Ad-Hoc Technology for Military Communications

Evolving wireless applications

- Asset positioning
- Tele-metering
- M-commerce
- Internet access
- Sensor networks
Generations of Wireless Networks

- **1G wireless standards: AMPS**
  - Analog
  - Frequency division duplexing
  - Non-compatible standards

- **2G: CDMA, GSM**
  - Voice dominant
  - Digital
  - TDMA/FDD, CDMA/FDD

- **3G: WCDMA, cdma2000, TDSCDMA**
  - CDMA
  - Voice, data
  - High speed

---

### Comparison of different networks

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Outdoor</th>
<th>Indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>Vehicle</td>
<td>Fixed</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>Pedestrian</td>
<td>Fixed</td>
</tr>
<tr>
<td>Fixed</td>
<td>Fixed</td>
<td></td>
</tr>
</tbody>
</table>

![Comparison of different networks diagram]

- **Bitrate (Mbps)**
  - 0.1
  - 1
  - 10
  - 100

WLAN

WPAN

2G

3G

WPAN
Limitations of wireless technologies

- Wireless is convenient and less expensive
- Political and technical difficulties may inhibit wireless technologies
- Lack of an industry-wide standard
- Device limitations
  - E.g., small LCD on a mobile telephone can only display a few lines of text
  - E.g., browsers of most mobile wireless devices use wireless markup language (WML) instead of HTML

Chapter 1: Basic Concepts of Wireless Data Networks

- Network architecture
- Applications
- Development of wireless networks
- Alternatives for physical transmission
- Medium access control design
- Basic operation of mobile data networks
Chapter 2: Data services in GSM
- Basic concepts of GSM system
- Short Message services (SMS) services in GSM
- High Speed Circuit Switched Data (HSCSD) services
- General Packet Radio Service (GPRS)

Chapter 3: Data services in 3G
- Basic concept of 3G system
- Enhanced Data Rates for Global Evolution (EDGE) service
- WCDMA system
- cdma2000
Chapter 4: Bluetooth technology

- Bluetooth air interface
- Protocol stack
- Bluetooth networking
- Development considerations

Chapter 5: Wireless LANs

- Evolution of WLAN industry
- Architecture and services
- PHY layer specification
- MAC layer
Chapter 6: Mobile IP

- Mobile IP overview
- Details of mobile IP
- Tunneling
- Security issues

References

- Data over wireless networks: Bluetooth, WAP and Wireless LANs, Gilbert Held, McGraw-Hill, 2000
- GPRS from A-Z, Artech House, 2000
Assessment

- HW: 10%
- Mid-term examination: 35%
- Final examination: 55%

Chapter 1 Basic concepts of wireless data networks

Part 1: Alternatives of physical transmission for mobile data networks
Considerations of wireless modem

- Bandwidth efficiency
- Power efficiency
- Out-of-band radiation
- Resistance to multipath
- Constant envelope modulation

Three categories of transmission schemes

- Baseband pulse transmission
  - Baseband pulse
  - Ultra wide band (UWB)
- Traditional modulated transmission
  - Gaussian Minimum Shift Keying (GMSK)
  - Quadrature Phase Shift Keying (QPSK)
- Spread spectrum transmission
  - Direct sequence spread spectrum (DSSS)
  - Frequency hopping spread spectrum (FHSS)
Short distance baseband transmission

- No modulation with a carrier
  - No frequency division multiplexing (FDM)
  - No attention to out-of-band radiation
- Two steps:
  - Line coding for synchronization and DC offset
  - Pulse modulation: amplitude, location or duration
- Applications: IR-based WLAN

An example of baseband transmission: IR-based WLAN

- Non-Return-to-Zero stream encoded by Manchester code
- Line-coded signal, then intensity modulated by emitted IR light.
- Receiver consists of photosensitive diode

<table>
<thead>
<tr>
<th>NRZ</th>
<th>Manchester</th>
<th>Light intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0 1 0 1 1 0 0 0 0 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Diagram illustrates the sequence of NRZ, Manchester encoding, and light intensity.
UWB pulse transmission

- A very narrow width and low power pulse for information transmission
  - Width: order of a few tenths of a nanosecond
  - High-duty cycle of several hundreds of nanoseconds
- Spectrum occupies a wide band: several GHz
- Spectral height is very low: comparable with background noise
  - May coexist with existing systems
- Minimal fading effect
- Applications: precision geo-location, high performance radar

An example of UWB system

- Developed by Time Domain Corporation (TDC)
- Width: 0.2ns – 1.5ns
- Pulse-to-pulse interval: 25 – 1000 ns

- Pulse shape:
  \[ v(t) = 6A \sqrt{\frac{e\pi}{3}} \frac{t}{\tau} e^{-6\pi\left(\frac{t}{\tau}\right)^2} \]

- Spectrum:
  \[ V(f) = -j \frac{2f}{3f_c^2} \sqrt{\frac{e\pi}{2}} e^{\frac{-\pi(f/f_c)^2}{6}} \]
Pulse and spectrum

- \( \tau = 0.5 \text{ns}, f_c = 2 \text{GHz} \)
- 3-dB bandwidth: 2GHz

Traditional modulated transmission

- Three types: amplitude-, frequency-, or phase-modulated
  - \( s(t) = A \sin(2\pi ft + \phi) \)
- As fading causes extensive amplitude fluctuations, AM not desirable.
- FM: GMSK in GSM
- PM: \( \pi/4 \)-QPSK in IS-136, US TDMA system
Digital frequency modulation

- bit 0: frequency $f_1$
- bit 1: frequency $f_2$
- Advantage: constant envelope
- Challenge: orthogonality for frequency spacing

FSK Demodulation (coherent)

- Received signal:
  \[ S(t) = \sin[2\pi f_1 a(t) + 2\pi f_2 (1-a(t))]t \]

\[ a(t) = 1 : \]
\[ O_1(T) = \int_0^T \sin(2\pi f_1 t) \times \sin(2\pi f_1 t) dt \]
\[ \approx \frac{T}{2} \]

\[ a(t) = 0 : \]
\[ O_0(T) = \int_0^T \sin(2\pi f_2 t) \times \sin(2\pi f_2 t) dt \]
\[ \approx \frac{1}{2} \frac{\sin 2\pi (f_1 - f_2) T}{2\pi (f_1 - f_2)} \]

- If orthogonal:
  \[ O_0(t) = 0 \Rightarrow 2\pi (f_1 - f_2) T = n\pi \]
  \[ \Rightarrow f_1 - f_2 = \frac{n}{2T} \]
**Gaussian minimum shift keying (GMSK)**

- Challenges for FSK: for optimal detection at receiver, orthogonality of transmitted symbols should be maintained, which can be achieved by proper frequency spacing.
- Non-coherent detection, $1/T$; coherent detection, $1/2T$: minimum shift keying
  - Smaller spacing, smaller occupied bandwidth
- Filters used for baseband signal to further reduce side lobes, which reduces interference to others
  - Gaussian filter used, GMSK

![Diagram of GMSK process](image)

**Digital phase modulation**

- Baseband information signal is encoded in the phase of the transmitted signal.
  - BPSK: 1, $0^\circ$; 0, $180^\circ$
- Multi-phase modulation possible

![Diagram of digital phase modulation](image)
**Quadrature PSK (QPSK)**

- 4 phases modulation, $0^\circ$, $90^\circ$, $180^\circ$, $270^\circ$:
  - 00, $270^\circ$; 10, $0^\circ$; 11, $90^\circ$; 01, $180^\circ$
- Bandwidth efficiency doubled

![Modulator and Demodulator Diagram]

**Spread spectrum transmissions**

- Transmitted signal occupies a much larger bandwidth than traditional modulation schemes
- Two basic methods: direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS)
- Applications: 3G, IEEE 802.11 WLAN
Advantages of spread spectrum

- SS signals overlaid onto bands used by other systems
- Better performance on fading channel
- Anti-interference
- Greater flexibility and capacity

Frequency hopping spread spectrum (FHSS)

- Information stream modulated in traditional scheme
- Central frequency shifted randomly

\[\text{Traditional modulation} \rightarrow \times \rightarrow \text{Random freq. hopper} \rightarrow \text{Traditional Demod.} \rightarrow \times \rightarrow \text{Random freq. hopper} \rightarrow \text{Data out}\]
An example of FHSS system

![Diagram of FHSS system]

Direct sequence spread spectrum

- **Two stage modulation:**
  - Stage 1: each transmitted bit is mapped into $N$ smaller pulses referred as chips.
  - Stage 2: chips are transmitted over a traditional digital modulator.

- **Demodulation:**
  - Received chips are demodulated first.
  - Then passed through a correlator to despread the signal.
An DSSS system: IEEE 802.11

- Barker code: \([1,1,1,-1,-1,-1,1,-1,-1,1,-1,-1]\)

\[ \begin{align*}
&\text{Data bit} \\
&\text{Spread bit} \\
\end{align*} \]

\[ \begin{align*}
\text{chip} \\
\end{align*} \]

\[
R_{aa}(l) = \sum_{j=-n}^{n} a_j a_{j-l}
\]

where the value of \(a_i\) is 0 when \(i<1\) and \(i>n\)

- For Barker code:

\[
R_{aa}(l) = \sum_{j=-11}^{11} a_j a_{j-l} \quad l = -11, -10, \ldots, 11
\]

\[
R_{aa}(1) = \sum_{j=-11}^{11} a_j a_{j-1} = 0
\]
Summary

- Baseband pulse transmission:
  - No carrier modulation
  - Short range

- Traditional transmission: GMSK and QPSK
  - Licensed spectrum
  - Reliable, relatively simpler
  - Suffers from multipath fading

- Spread spectrum
  - Wide bandwidth occupied
  - More complex
  - More efficient
  - Anti-interference

Summary (cont’d)

- Other new modulations:
  - OFDM orthogonal frequency division multiplexing
  - $\pi/4$-QPSK, OQPSK
  - QAM