Wireless Communication
for Traffic Signal Systems

For: Metropolitan Transportation Commission
Technology Transfer Program

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Presentation Outline

I. Transmission Media Considerations
II. Overview of Wireless System Technologies
III. Wireless System Considerations for Signal System Networks
Transmission Media Considerations

Wireline Systems
Wireless Systems
Wireline versus Wireless
Hybrid Systems
Wireline Systems

- Twisted pair
- Fiber
- Coaxial
- Leased Lines
  - Telephone
  - ISDN
  - DSL
  - T-1, T-3
Wireless Systems and Technologies

- Licensed frequencies (proprietary)
- Spread spectrum (proprietary)
- 802.11 (Wi-Fi)
- 802.16 (WiMAX)
- Cellular
  - AMPS
  - D-AMPS
  - CDPD
  - GSM/GPRS
  - CDMA
  - UMTS
- DSRC
# Wireline vs. Wireless

## Wireline considerations

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Many high bandwidth applications</td>
<td>- High installation $$$</td>
</tr>
<tr>
<td>- High reliability (up-time)</td>
<td>- Susceptible to damage from other construction</td>
</tr>
<tr>
<td>- Long transmission distance</td>
<td>- Network typically limited to road alignment</td>
</tr>
</tbody>
</table>

## Wireless considerations

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>- High reliability with line-of-sight (as the crow flies)</td>
<td>- Currently limited to low and medium bandwidth applications</td>
</tr>
<tr>
<td>- Low installation $$</td>
<td>- Susceptible to signal obstructions, e.g., new buildings</td>
</tr>
<tr>
<td>- Bridging a gap between wireline systems</td>
<td>- Service driven by line-of-sight</td>
</tr>
<tr>
<td>- Ability to broadcast radially with proper equipment</td>
<td>- Limited channel capability in urban areas</td>
</tr>
<tr>
<td>- Good for point-to-point trunking</td>
<td>- Limited vendors</td>
</tr>
<tr>
<td>- Rapid deployment, limited disruption to traffic</td>
<td></td>
</tr>
</tbody>
</table>
Hybrid Systems

• Combination of wireline and wireless technologies in a single system
  – Private wireline to leased wireless service, e.g., twisted pair to 802.11
  – Private wireless to leased wireline service, spread spectrum to T-1
The Radio Spectrum
Point-to-Multipoint Systems
Point-to-Point Systems
Cellular Systems
Radio Spectrum

- **30KHz to 3 GHz:**
  - AM Radio: 540 – 1800 KHz
  - FM Radio: 88MHz - 108 MHz
  - Cellular (AMPS): 824 – 849, 869 – 894 MHz
  - Cellular (GSM): 890 – 915, 935 – 960 MHz
  - PCS: 1800 – 2200 MHz

- **Microwaves:** 3 GHz – 300 GHz

- **Infrared Spectrum:** 300 GHz – 300 THz

- **Industrial, Scientific and Medical (ISM) Bands:** 900-928 MHz, 2.4-2.5 GHz, 5.725-5.875 GHz, 24-24.25 GHz
Spectrum for Public Safety

• Broadcast TV spectrum to be freed up for public safety uses (police and fire) and public transit

• Two spectrums:
  – Channels 63/64 (765-775 MHz)
  – Channels 68/69 (795-805 MHz)
Point-to-Multipoint Systems

Wireless Fidelity (Wi-Fi)
Worldwide Interoperability for Microwave Access (WIMAX)
Dedicated Short Range Communications (DSRC)
Wireless Fidelity (Wi-Fi)

• A local area wireless standard (IEEE 802.11) intended for indoor and short range applications
• Utilizes Ethernet for data transport (packet-switched)
• Network access is based on contention, i.e., first-come, first-served basis
• Half-duplex (send or receive, not both at the same time)
• 802.11a: 54 MBps theoretical maximum bandwidth on a 20 MHz channel
• Actual throughput is typically less than half of the theoretical maximum
• Point-to-point system requires line-of-sight
# Wireless Fidelity (Wi-Fi)

<table>
<thead>
<tr>
<th></th>
<th>802.11a</th>
<th>802.11b</th>
<th>802.11g</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Max. Data Rate</strong></td>
<td>54 MBps</td>
<td>11 MBps</td>
<td>54 MBps</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>5Ghz</td>
<td>2.4Ghz</td>
<td>2.4Ghz</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>OFDM</td>
<td>DSSS</td>
<td>DSSS</td>
</tr>
<tr>
<td><strong>Channels</strong></td>
<td>12</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td><strong>Bandwidth Available</strong></td>
<td>300 MHz</td>
<td>83.5 MHz (22MHz per channel)</td>
<td>83.5 MHz</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>40-800mW</td>
<td>100mW</td>
<td>100mW</td>
</tr>
</tbody>
</table>

OFDM=Orthogonal Frequency Division Multiplexing; DSSS=Direct Sequence Spread Spectrum.
Wi-Fi Elements
Wi-Fi Elements
Wi-Fi Applications

- As a trunkline for a group of traffic signals
- As a dedicated link for one or more CCTV cameras
- Requires all connected devices to be encoded and assigned an IP address
WIMAX

- Worldwide Interoperability for Microwave Access (WIMAX)
- Fixed wireless technology (IEEE 802.16)
- Will operate in the 3 to 66 GHz spectrums
- Range of up to 50Km
- Product rollout began Fall of 2003
- Network access is based on granting a request to connect and establishing a dedicated connection
- Up to a 100 MBps theoretical maximum on a 20 MHz channel
- Similarly to 802.11, actual throughput is typically less than half of the theoretical maximum
<table>
<thead>
<tr>
<th>Description</th>
<th>802.16</th>
<th>802.16a/802.16revD</th>
<th>802.16e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion Date</td>
<td>Dec. 2001</td>
<td>802.16a Jan. 2003, 802.16revD, June 2004</td>
<td>2nd Quarter 2006</td>
</tr>
<tr>
<td>Spectrum</td>
<td>10 to 66 GHz</td>
<td>&lt; 11 GHz</td>
<td>&lt; 6 GHz</td>
</tr>
<tr>
<td>Channel Conditions</td>
<td>Line of Sight only</td>
<td>Non-Line of Sight</td>
<td>Non-Line of Sight</td>
</tr>
<tr>
<td>Bit Rate</td>
<td>32 to 134 MBps (28 MHz channels)</td>
<td>75 MBps max (20 MHz channels)</td>
<td>15 MBps max. (5 MHz channels)</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK, 16QAM, 64QAM</td>
<td>OFDM, 256 subcarriers, QPSK, 16QAM, 64QAM</td>
<td>Same as 802.16a</td>
</tr>
<tr>
<td>Mobility</td>
<td>Fixed</td>
<td>Fixed</td>
<td>Pedestrian mobility, regional roaming</td>
</tr>
<tr>
<td>Channel Bandwidths</td>
<td>20, 25, and 28 MHz</td>
<td>Selectable between 1.25 and 20 MHz</td>
<td>Same as 802.16a with uplink subchannels</td>
</tr>
<tr>
<td>Typical Cell Radius</td>
<td>1 to 3 miles</td>
<td>3 to 5 miles (30 miles max based on tower height, antenna gain, and transmit power)</td>
<td>1 to 3 miles</td>
</tr>
</tbody>
</table>

Source: WiMAX Forum
QPSK=Quadrature Phase Shift Keying; QAM=Quadrature Amplitude Modulation; OFDM=Orthogonal Frequency Division Multiplexing
DSRC

- Dedicated Short Range Communications
- Communication in the 5.9 GHz spectrum
- Short to medium range communications service
- Supports both Public Safety and Private operations
- Roadside-to-vehicle and vehicle-to-vehicle communication environments
- Complements other communications links by providing very high data transfer rates with minimal latencies
- Primary communications for Vehicle Infrastructure Integration (VII)
- Future applications include toll tag systems and transit signal priority (TSP)
DSRC Radio Specifications

- Frequency Range: 5.855 – 5.925 MHz
- Data Rate: 6 Mbps - 27 Mbps
- Channel Bandwidth: 10 MHz
- Power output: 18 dBm
- Channel Switch Time: <= 2 us
- Internet Protocol Support: IPv6
- Operating Temperature: -10 to +70 deg C
DSRC Performance

Range (ft)

Data Rate (Mbps)

5850 - 5925 MHz Band Performance Envelope
(Approximate)

Emergency Vehicle Services

Data Transfer and Internet Access Services

Safety Message Services

Toll and Payment Services

902 - 928 MHz Band Performance Envelope

0.5 Mbps
DSRC and TSP

- OBU Antenna
- Human Machine Interface
- Traffic Management Center Server/Network Interface
- Two-way RF
- OBU Antenna
- RSU Antenna
- Equipment Cabinet
- Roadside Unit (RSU)
- Internet or Private Network
- ITS Application
- Traffic Management or Other Center
- In-Vehicle Network
- On-Vehicle Host Computer
- On-Board Unit (OBU)
Point-to-Point Systems

Spread spectrum techniques
Microwave systems
What is spread spectrum?

- A technology that “spreads” the transmission of data over a group of radio frequencies.
- Two techniques are used, frequency hopping and direct sequence.
- Frequency hopping radio uses one frequency at a time and at pre-determined intervals jumps to another frequency.
- Direct sequence spreads the transmission over several frequencies at the same time.
Why Spread Spectrum?

- Designed for unlicensed (ISM) radio bands (no need to deal with the FCC)
- Relatively immune to radio frequency interference
- Very secure
- Widespread use by wireless equipment manufacturers
- Cost effective
Spread Spectrum
Frequency Hopping

- Short duration “hops” between radio frequencies for data transmitted (each bit)
- Both sender and receiver know the sequence
Direct Sequence

- Original data is multiplied by a high bit rate "noise" signal then transmitted
- The noise is a pseudorandom sequence of 1 and -1 values
- The result is the outgoing signal’s energy is spread into a much wider band compared with the original data signal
- The resulting signal resembles white noise (like an audio recording of "static")
- The noise is filtered out at the receiving end to recover the original data
**Frequency Hopping vs. Direct Sequence**

- **Direct Sequence:**
  - Fixed wide channels
  - Prone to interference
  - Higher bandwidth
  - Typically deployed in the 2.4 GHz spectrum

- **Frequency Hopping:**
  - Narrow channel widths
  - Very immune to interference
  - Lower bandwidth
  - Typically deployed in the 900 MHz spectrum
  - Capable of multiple collocated antennas
Microwave Systems

- Requires direct line-of-sight
- Significantly impacted by weather (e.g., rain, fog) and obstructions (e.g., trees)
- Typically in the 5.8 and 24 GHz unlicensed spectrum
- Higher frequencies = higher bandwidth
- Can transmit over long distances with tall antenna heights
  - For example, a 100m high tower can transmit up to 80Km (line-of-sight)
  - Bandwidths as high 240 MBps
Microwave Systems
Cellular Systems

- **First Generation: Analog**
  - AMPS (USA)

- **Second Generation: Digital**
  - GSM/GPRS (1st Europe, then world-wide)
  - Digital AMPS (IS-54)

- **2.5: PCS**
  - DCS-1900 (USA)
  - CDMA (IS-95, USA)

- **Third Generation (3G): Personal Communication Systems**
  - CDMA2000
  - UMTS
## Cellular Systems

<table>
<thead>
<tr>
<th>Cellular Technology</th>
<th>Frequency</th>
<th>Carrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMPS</td>
<td>800 MHz</td>
<td>AT&amp;T, Verizon</td>
</tr>
<tr>
<td>CDMA</td>
<td>800, 1900 MHz</td>
<td>Verizon</td>
</tr>
<tr>
<td></td>
<td>1900 MHz</td>
<td>Sprint</td>
</tr>
<tr>
<td>GSM</td>
<td>850, 1900 MHz</td>
<td>Cingular (AT&amp;T), T-Mobile</td>
</tr>
<tr>
<td>iDEN</td>
<td>800 MHz</td>
<td>Nextel</td>
</tr>
<tr>
<td>TDMA</td>
<td>800, 1900 MHz</td>
<td>Cingular (AT&amp;T)</td>
</tr>
</tbody>
</table>
AMPS

- Advanced Mobile Phone System
- Uses 800 MHz spectrum
- Service providers phasing out their AMPS infrastructure (e.g., Cellular Digital Packet Data - CDPD)
- Few providers support this infrastructure
- Not recommended for signal systems
Global System for Mobile Communications

Utilizes time division multiple access (TDMA)

Circuit-switched, i.e., a dedicated circuit is established for each call

Has an effective data throughput of about 9.6 KBps, e.g., text messages

Cost depends on usage, but could be as high as $100/month
GPRS

- General Packet Radio System
- Uses same infrastructure as GSM
- Packet-switched
- Has an effective data throughput of up to 115 KBps (IP-based messages)
- Quick deployment with minimal installation requirements
- Cost = $40/month for service
- Works well for traffic signals if the system can tolerate long latencies
CDMA2000

- Code Division Multiple Access
- Multiple users on a channel each assigned a unique “code”
- Data rates between 153 to 307 KBps
- Cost depends on usage, but could be as high as $100/month
Lease vs. Own
Proprietary vs. Open Standards
Security and Reliability
Maintenance
Technological Obsolescence
Design Considerations
• Equipment and services
• Capital costs
• Recurring costs vs. maintenance costs
• Network reliability ("up time")
• Bandwidth
Proprietary vs. Open Standards

- Interoperability of different manufacturer’s equipment
- Integration with existing communication systems
Security and Reliability

- Utilize encryption for Wi-Fi systems
- More encryption = Less performance
- For example, frequency hopping is less susceptible to interference than direct sequence, but has a lower bandwidth
- Ensure that area is relatively void of frequency interference (conduct a site and path analysis)
- Leased services provide very secure links
Maintenance

• Staff training on technology and equipment
• How often to perform preventive maintenance
• Investment in required tools and equipment to perform maintenance functions, e.g., spectrum analyzer, GPS, bucket truck
• Use off-the-shelf equipment, e.g., yagi antennas
• Use standard interfaces, e.g. EIA-232, Ethernet
• If possible, select a wireless technology to accommodate increases in bandwidth, i.e., overprovision links
• For point-to-multipoint systems, design link capacity for expansion
  – For example, if a channel can handle up to six controllers based on bandwidth calculations, start with four controllers on that channel
Design Considerations

Line of sight
Antennas and radios
Radio spectrum
Interfaces
Testing
Design Considerations

- Line of Sight
Line of Sight

• Need “RF” line of sight which includes fresnel zone
• Use a combination of strobe lights, mirrors (which reflect the sun), binoculars and spotting scopes.
• Visual verification, however, does not guarantee a clean line-of-sight – site and path analysis
• Anticipate tree and shrub growth in Spring and Summer months
• Place antenna as high as possible
Design Considerations

- Antennas and Radios
  - Directional vs. Omnidirectional
Directional antennas

- Signal energy is concentrated in the direction of the antenna
- Better for longer distance transmissions, i.e., higher gain
- More susceptible to obstacles
Omnidirectional antennas

- Better for multiple devices communicating with a single source
- Signal energy is spread evenly over the 360 degree radiation pattern
- Limited transmission distances due to low gain potential
- Less susceptible to obstacles
Radios

• For unlicensed ISM frequencies:
  – Radios limited to a maximum of one watt of power output
  – Radio plus antenna power output (effective isotropic radiated power, EIRP) limited to four watts maximum

• Alternatives:
  – Use maximum power radios and lower gain antenna
  – Use lower power radios and higher gain antennas
Design Considerations

- **Radio Spectrum (unlicensed)**
  - **900 MHz**
    - Longer distance capability
    - Easier to “bend” around obstructions
    - Most reliable of the three
  - **2.4 GHz**
    - Most crowded spectrum due to Wi-Fi
    - Transmits easily through walls
    - Heavily impacted by leaves and moisture
  - **5.8 GHz**
    - Higher propagation loss, shorter reach
    - Higher bandwidth
  - **24 GHz**
    - Highest propagation loss
    - Highest bandwidth
    - Rarely used for traffic signal systems
    - Sometimes used for point-to-point backhaul (trunking)
Free Space Loss

Free Space Loss = 36.56 + 20\log_{10}(\text{Freq. in MHz}) + 20\log_{10}(\text{Dist. in miles})

A 2.4 GHz signal traveling 10 miles has a FSL of 124dB

Note: A measured value of -3dBm indicates a 50% loss in power, or signal strength.
Fresnel Zone

- Football shaped area between antennas
- Longer distances between antennas have larger fresnel zones
- Mounting antennas higher mitigates effects of fresnel zone
- Higher frequencies, smaller fresnel zones
## Free Space Loss and Fresnel Zone

<table>
<thead>
<tr>
<th>Distance between antennas</th>
<th>Fresnel Zone Diameter</th>
<th>Free Space loss (dB)</th>
<th>Fresnel zone diameter</th>
<th>Free Space loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 ft (300 m)</td>
<td>16 ft (7 m)</td>
<td>81</td>
<td>11 ft (5.4 m)</td>
<td>90</td>
</tr>
<tr>
<td>1 Mile (1.6 km)</td>
<td>32 ft (12 m)</td>
<td>96</td>
<td>21 ft (8.4 m)</td>
<td>104</td>
</tr>
<tr>
<td>5 miles (8 km)</td>
<td>68 ft (23 m)</td>
<td>110</td>
<td>43 ft (15.2 m)</td>
<td>118</td>
</tr>
<tr>
<td>10 miles (16 km)</td>
<td>95 ft (31 m)</td>
<td>116</td>
<td>59 ft (20 m)</td>
<td>124</td>
</tr>
<tr>
<td>20 miles (32 km)</td>
<td>138 ft (42 m)</td>
<td>122</td>
<td>87 ft (27 m)</td>
<td>130</td>
</tr>
<tr>
<td>40 miles (64 km)</td>
<td>192 ft (59 m)</td>
<td>128</td>
<td>118 ft (36 m)</td>
<td>136</td>
</tr>
</tbody>
</table>
Typical Transmission Ranges

- 2.4GHz, 1W radio power plus 6dB gain antenna = 5 - 15 miles

- 900MHz, 1W radio power plus 6dB gain antennas = 15 - 25 miles

- 2.4GHz, 100mW radio power plus 16dB antennas = 10 - 40 miles

- 900MHz, 100mW radio power plus 16dB antennas = 20 - 60 miles
• Serial links need converters for Wi-Fi or IP/Ethernet-based networks
• Up-down converters for hybrid wireless systems, e.g., between 2.4GHz and 900MHz
Testing

- Proper configuration and alignment
- Bandwidth analysis (throughput)
- Path loss
- Bit error rates
- Latency
BREAK