Bluetooth

Small Sensor Area Networks (SANs)

Thurston Brooks

with contributions by
Ericsson Mobile Communications AB
**Wireless Advantages**

- Augment wired LANS
- Minimize setup requirements by installing preconfigured WLANs without MIS support
- Factory floor can exchange data with central databases
- “Instant” reconfigurability
- Installation simplicity and flexibility
- Cost effective TOC
- Mobility-WLANs can provide access to real-time info on-the-go
- Scalability
Wireless Advantages (Cont.)

• Eliminates logging and paperwork
• Historical data is easily maintained
• Reduces data gathering errors
Wireless Condition Monitoring

• Will reduce monitoring installation cost
  – $20/ft typical, as much as $2000/ft some apps (e.g., Nuclear)
  – Cabling is 30-45% of TOC
• Real-time dynamic range is expensive (correlates to difficulty)
• Spread spectrum technology with data dumps is now feasible for low cost
• Portable
• Immediate alert of alarm conditions and follow-up data dumps are also feasible
Manufacturing Solutions

- Majority of wireless products in marketplace are proprietary spread spectrum and narrow band solutions in the ISM bands (400MHz, 900MHz, 2.4GHz)
  - Today 80% of customers → SS (*Garner Group)
- Typically constrain user to buy from a particular vendor
- Interoperability, low-cost, and broad user base (i.e., market demand) are stimulated by Standards
  - IEEE 802.11 (2.4GHz @1-2Mbps) LAN
  - Bluetooth (2.4GHz @ .75Mbps) PAN
- Potential Interference between 802.11 and Bluetooth
Narrowband Manufacturing Solutions

- Available since early 1980s
- Low throughput
  - term NB → RF BW typically 12.5-25.0 kHz
- Longest Range
- Low cost for large sites
- Little or no vendor interoperability
- Easily jammed
- Site license required for protected bands (450-470 MHz)
- Large form factor
900 MHz ISM Manufacturing Solutions

- Here Today – many 900 MHz LANs in use
- Data rates of 100-450 Kbps are sufficient for many manufacturing applications
- Typically better range than 2.4 GHz systems
- Very crowded band
  - US: cordless phones, vehicle locators, etc.
  - International: GSM cellular and military systems
- Little interoperability
- Lack international acceptance
2.4 GHz ISM Manufacturing Solutions

- Standards based systems
- Multi-vendor support
- High data rates available
  - IEEE 802.11 10 Mbps
  - Bluetooth 1 Mbps
- World-wide acceptance
- Limited range
  - Attenuation
  - Less power
  - Poor coverage – Increased infrastructure costs
IEEE 802.11b

- Defines wireless LAN interoperability
- Two forms:
  - Frequency Hopping Spread Spectrum (FHSS)
    - 2.4 GHz 79 Channels 1 MHz wide (US)
  - Direct Sequence Spread Spectrum (DSSS)
    - 2.4 GHz 3 non-overlapping Channels 22 MHz wide (US)
    - 2.4 GHz 1 Channel 22 MHz wide (Japan)
- Both techniques limited to 1W max radiated power US
802.11 and Bluetooth Interference Potential

- Both standards use frequency hopping
- Bluetooth is predicted to “jam” 802.11 FHSS operation
  - BT will most likely interrupt an 802.11 transmission many times before the 802.11 device hops to the next frequency (Jim Geier-Wireless Nets)
- FCC does not mediate frequency conflicts in the unlicensed bands
  - IEEE has created the 802.15 Coexistence Task Group 2
- Preliminary analysis by 802.15 Group indicates that 802.11 DSSS is very reliable in the presence of BT
- Solutions
  - BT falls off quickly, avoid close proximity with 802.11 devices
  - Reduce 802.11 radio distance
Advantages of Spread Spectrum

- SS can co-exist with other systems that are already using the same frequency bands
- SS has excellent discrimination of signals in multipath environments
- SS is less interference prone than other techniques particularly in manufacturing environments where “noise” can be severe
- SS in the ISM Bands do not need licensing
- SS combined with TDMA has nearly unlimited capacity
## Data Rates Manufacturing Solutions

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 MHz UHF NB</td>
<td>4.8-19.2 Kbps</td>
</tr>
<tr>
<td>900 MHz SS</td>
<td>100-400 Kbps</td>
</tr>
<tr>
<td>2.4 GHz SS</td>
<td>1-2 Mbps</td>
</tr>
<tr>
<td>2.4 GHz SS (802.11b+)</td>
<td>10 Mbps+</td>
</tr>
<tr>
<td>5.7 GHz (Future)</td>
<td>20 Mbps++</td>
</tr>
</tbody>
</table>

Guide to Wireless LAN Technologies, Intermec Tech Corp
# Ranges of RF Manufacturing Solutions

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Indoor Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 MHz UHF</td>
<td>300-400 ft.</td>
</tr>
<tr>
<td>900 MHz SS</td>
<td>220-350 ft.</td>
</tr>
<tr>
<td>2.4 GHz SS 100mW US, Asia, Pacific, Latin America</td>
<td>150-200 ft.</td>
</tr>
<tr>
<td>2.4 GHz SS 500mW US, Asia, Pacific, Latin America</td>
<td>200-250 ft.</td>
</tr>
<tr>
<td>2.4 GHz SS 100mW Europe</td>
<td>125-150 ft.</td>
</tr>
</tbody>
</table>
Factors Effecting Range

• **Transmitter Power**
  – The FCC regulations permit radiated RF power for unlicensed operation of up to 1 watt (+30dBm) when spread spectrum modulation techniques are used. All ISM band wireless modem and wireless LAN products must adhere to these requirements.

• **Receive Sensitivity**
  – Receiver sensitivity quantifies the ability of a receiver to respond to weak signal levels. Typically stated as Maximum Bit Error Rate at a certain RF level, e.g., $10^{-6}$ BER @ -70dBm

• **Path Loss**
  – Signal attenuation between the transmitter and the receiver.

• **Antenna Gain**
  – Apparent increase in signal strength due to beam forming.

Slide Courtesy of Robert Haller, Grayhill
Wireless Attenuation

- Freespace Attenuation
- Rain Loss -1dB/mile
- Water Vapor
- O2 Absorption -.01dB/mile
- Multipath Losses

Transmitter

Receiver
Range - Link Budget

Where:
- $T_p$ = Transmitter Power
- $G_t$ = TX Antenna Gain
- $L$ = Path Loss
- $G_r$ = RX Antenna Gain
- $N_i$ = Thermal Noise
- $F$ = Noise Floor

Slide Courtesy of Robert Haller, Grayhill
Antenna Fundamentals

• Omnidirectional (Isotropic Source)
  – An isotropic source is a source radiating energy equally in all directions.

• Directivity
  – Directivity is the ratio between the maximum radiation intensity from a transmitter and the radiation intensity from an isotropic source radiating the same power.

• Gain
  – The gain of an antenna is a function of the antenna’s directivity – as the antenna’s beam is focused it’s Effective Radiated Power (ERP) is increased.
Multipath
Ray Tracing

- Software modeling of 2D or 3D ray tracing is the most reliable.
- System using only free-space path loss are the least reliable
- Modeling has limited value within a manufacturing plant
Applications

- **Retail**
  - Wireless link to database
  - Transaction based
  - Inventory control
- **Warehouses**
  - Handheld devices improve efficiency
  - Eliminate paper
  - USPS logs trucks in and out of distribution centers
- **Healthcare**
  - Patient monitoring
  - Tracking pharmaceuticals
Applications (Cont.)

- Restaurants
- Utilities
  - Meter reading
    - Handheld devices improve efficiency
    - Eliminates paper
    - Kansas City Power & Light system monitors 150,000 customers, automatically tracks usage and issues bills – no meter readers
  - Monitor electrical distribution
- Vending
  - Typically utilize existing cellular networks
Applications (Cont.)

- Traffic Monitoring
- Industrial Process Plants
  - Tank Farms
    - Monitor fluid levels, flow rates, temperatures
  - LOS 2 miles
- Ship/Transportation Crane Controls (Omnex)
- Manufacturing Cells
**Bluetooth Link Budget for Max Power TX**

- 20 dBm: Tx power (100mW)
- 0 dBm: Rx power @ 1-3m (Rx Pmax)
- -20 dBm: Rx power @ 100m
- -70 dBm: Noise floor
- -91 dBm: Noise floor
- -114 dBm: kTB

- Near Rx w/Power Control (may not be relevant for Industrial)
  - SNR 21 dB
  - NF 23 dB
**Operational States**

- **Standby**
- **Inquiry-Paging**
- **Connections**
  - **Active**
  - **Power Conserving**
    - Hold (delta t)
    - Sniff (Poling)
    - Park (Listen but do not disturb master)
- **Synchronous Connection-Oriented (SCO) Link** (primarily used for voice)
- **Asynchronous Connection-Less (ACL) Link** (primarily used for packet data)
Features

- Regulations
  - FCC Part 15 compliance
  - ETSI 300 328
- Frequencies
  - covers all of the 2.4GHz ISM band
- Time Division Duplex
- Stand-by Modes
  - Park
  - Hold
  - Sniff
  - Standby
Operational States

- **Master** – sets the hopping sequence
- **Active Slave** – 3-bit MAC address for immediate communication → only 7 slaves in a piconet
- **Parked Slave** – synchronized but has no MAC address
- **Standby** – Unconnected
Making a Connection

- Standby
- Inquiry
- Page
- Connected
Inquiry
Making a Connection

- Standby
- Inquiry
- Page
- Connected
Creating a Piconet

Piconet: A collection of devices connected in an ad hoc fashion

“By Invite Only”

slave D

slave C

master A

slave B

slave A
FH with TDD Channel

- For every repetition, the master transitions between two frequencies while the slave remains in the same frequency.
- The master uses frequencies $f(2k)$, $f(2k+1)$, and $f(2k+2)$.
- The slave remains in $f(2k+1)$.
- The time period is 625 ms.
Frequency Hopping

2.402 2.480

master

slave

time

freq
**Synchronisation of Physical Channel**

- master BD_ADDR → hop sequence
- master CLOCK → phase

*Master Unit is the device in a piconet whose clock and hopping sequence are used to synchronize all other devices in the piconet*
Mixed Link Example

MASTER

SLAVE 1

SLAVE 2

SLAVE 3
### Data Rates (kb/s)

<table>
<thead>
<tr>
<th>Type</th>
<th>Symmetric</th>
<th>Asymmetric</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM1</td>
<td>108.8</td>
<td>108.8</td>
</tr>
<tr>
<td>DH1</td>
<td>172.8</td>
<td>172.8</td>
</tr>
<tr>
<td>DM3</td>
<td>258.1</td>
<td>387.2</td>
</tr>
<tr>
<td>DH3</td>
<td>390.4</td>
<td>585.6</td>
</tr>
<tr>
<td>DM5</td>
<td>286.7</td>
<td>477.8</td>
</tr>
<tr>
<td>DH5</td>
<td>433.9</td>
<td>723.2</td>
</tr>
</tbody>
</table>

Master unit controls the link bandwidth, decides how much is given to each slave, and sets the symmetry of the link.
Automatic Repeat Request (ARQ) Scheme
Sniff Mode

MASTER

ACL

SLAVE 1
(listens every n cycles)

ACL

ACL

SLAVE 2

LOST

SNIFF INTERVAL
(n = 4)
Park & Hold Modes

PARK INTERVAL

MASTER

Parked SLAVE X
(wakes to synchronize)

SLAVE 2

SLAVE 2 in Hold

Loses ADDR but Keeps Hop Sequence
Scatternet

Multiple non-synchronized piconets form a scatternet
Bluetooth Today (242 products)
Information

- http://www.bluetooth.com
- http://news.zdnet.co.uk/0,,t294,00.html
- Any Search on “bluetooth”