Bluetooth for 1451

Sensor Area Networks (SANs)

Thurston Brooks
IEEE P1451.4 & P1453.3 Member
Bluetooth IA SG Vice Chair

with contributions by
Ericsson Mobile Communications AB
Wireless 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
- Spread spectrum technology is now available for low cost
- Mobile connections
- Real-time dynamic range is expensive
  - Power
  - Cost $
- Immediate alert of alarm conditions and follow-up data dumps are also feasible
Machinery Monitoring Implementation with NCAP

e-Devices

- Wireless machinery monitoring (802.11, Bluetooth, Ethernet)

e-Infrastructures

- WAN, LAN and IT
- Remote sites
- WAN / LAN
- Wireless LAN
- Satellite Communication
- Ultra-Wide Band
- Ad Hoc Network

e-Applications

- Web-sensing
- Monitoring
- Session Manager

- ERP Database IDE
- AME Suite
- IETM, IETP, Diagnostician Maintainix

Wireless machinery monitoring (802.11, Bluetooth, Ethernet)
Wireless 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) have been stimulated by Standards
  - IEEE 802.11 (2.4GHz @1-2Mbps) LAN
  - Bluetooth (2.4GHz @ .75Mbps) PAN
  - Potential Interference between 802.11 and Bluetooth
Bluetooth Features

- Low-Cost
  - Highly Integrated ASICs
- Low-Power
- Small Size
- Frequencies
  - covers all of the 2.4GHz ISM band
- Time Division Duplex
- Stand-by Modes
  - Park
  - Hold
  - Sniff
  - Standby
### Bluetooth Link Budget for Max Power TX

<table>
<thead>
<tr>
<th>dBm</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Tx power (100mW)</td>
</tr>
<tr>
<td>0</td>
<td>Rx power @ 1-3m (Rx Pmax)</td>
</tr>
<tr>
<td>-20</td>
<td></td>
</tr>
<tr>
<td>-70</td>
<td>Rx power @ 100m</td>
</tr>
<tr>
<td>-91</td>
<td>Noise floor</td>
</tr>
<tr>
<td>-114</td>
<td>kTB</td>
</tr>
</tbody>
</table>

- **SNR**: 21 dB
- **NF**: 23 dB
- **Near Rx w/Power Control** (may not be relevant for Industrial)
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 – could be used for deterministic link)
- Asynchronous Connection-Less (ACL) Link (packet data)
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”
FH with TDD Channel

- f(2k)
- f(2k+1)
- f(2k+2)

- master
- slave

625 ms
Frequency Hopping

2.402

master

slave

2.480

freq
time
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
### 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**
- **SLAVE 1** (listens every n cycles)
- **SLAVE 2**

ACL

LOST

SNIFF INTERVAL (n = 4)
**Park Mode**

- **PARK INTERVAL**
  - **MASTER**
    - **BC**
    - **ACL**
  - **SLAVE X**
    - Parked
    - (wakes to synchronize)
    - **Loses ADDR but Keeps Hop Sequence**
    - **DO NOT DISTURB**
  - **SLAVE 2**
    - **ACL**
    - **BC**
Scatternet

Multiple non-synchronized piconets form a scatternet
Wireless NCAP Unit

- Watertight
- Small size (8W x 10H x 5D)
- IEEE 802.11b or Bluetooth with Antenna diversity
- Connectorized
- LabView HMI
  Eight 1451 smart sensor inputs using modular plug-in design
  - Vibration
  - Temperature
  - Pressure
  - Flow
  - Etc
- Future Revisions
  - V.90 Modem
NCAP Block Diagram

MODULAR sensor interface: TEDS data decoupling, sensor selection, amplifiers & filter

analog to digital Conversion 16 bit 200kHz

DS microLAN Controller (FPGA?)

x86 Microprocessor (NCAP)

Compact Flash

PCMCIA

COTS Sensors or IEEE 1451.4 compliant Smart Sensors

TEDS data (could be DOT4 or DOT2 TEDS) is passed thru and decoded by NCAP and properly formatted for use by applications such as ICAS
Bluetooth Today (242 products)