Introduction to Vehicular Wireless Networks

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Audio/Video recordings of this class lecture are available at:
http://www.cse.wustl.edu/~jain/cse574-16/

Vehicular Ad-Hoc Networks (VANET):
- Dynamic Topology with nodes moving at a fast speed
- More processing power, storage, and energy than handhelds
- Location based information: Accidents ahead
- Delay constraint
- Varying environments: City streets with tall buildings vs. open high-way roads
- Sensors: GPS, Speed, Proximity, engine sensor, etc.

VANET Architectures
- Vehicle to Infrastructure (V2I)
- Vehicle to Vehicle (V2V)
- Road-Side Unit (RSU)
- On-Board Unit (OBU)

Overview
1. Vehicular Ad-Hoc Networks (VANET):
   Architecture, Applications, Requirements, Routing
2. Dedicated short Range Communication (DSRC) and Wireless Access for Vehicular Environment (WAVE)
   - Spectrum
   - Protocol Components
   - PHY, MAC
   - Products
Applications

- **Infotainment**: Entertainment + Navigation + Telecom
  - Minimize driver distraction: Bluetooth, Voice recognition
- **Traffic Control**: Reduce congestion and fuel consumption
  - Highway advisory radio about congestion
  - Warn before dangerous curves, road conditions
  - Navigation based on congestion
- **Safety**: Car crashes are major cause of deaths of children aged 5 and above.
  - **Adaptive Cruise Control**: Maintain a distance from vehicle ahead
  - **Forward Collision Warning**: Warn and automatically activate brakes
  - **Speed Regulation**: Maintain speed limit

Requirements

- **Highly Critical Messages**: Warnings about collision require low delay (20 ms), Electronic Toll collection (50 ms), roadside service locator (500 ms)
- **Non-Critical**: Video entertainment
- **Short Range**: <300 ft
- **Mobility**
- **Security**: Denial of service, Impersonation, Privacy (location, ID, e-payment), tempering (change sensor readings)

Security Requirements

- **Collaboration**: Multi-hop communication
- **Autonomy**: Vehicles should be able to reject participation or a message
- **Authentication**: Originator and/or location
- **Accountability**: Messages that impact network functions should be audited. Deliberate disruption could be penalized.
- **Privacy**: Location, name of driver, vehicle type, etc should not be disclosed
- **Availability**: Vehicles should be usable even if the network is down

Routing Types

- **Broadcast**: Traffic, weather, emergency, road conditions, …
- **Geocast**: Within an area. Accidents.
- **Forwarding**: Point-to-point via multi-hop
- **Clustering**: Within a specified group. Police, Fire, Safety, ... 
- **Beaconing**: Periodic exchange of information. Receivers integrate received info with their own and beacon.
- **Position Based**: Geographical routing based on positions of routers
- **Delay-Tolerant**: Stored and forwarded when another car is seen.
- **Ad-Hoc**: Address based mobile ad-hoc network routing
VANET Technologies

- **Dedicated Short Range Communication (DSRC):**
  - IEEE 802.11p, IEEE 1609.1-4
  - Up to 1km at 200 km/h
- **WiMAX:** Better for long distance. V2I
- **3G:** Seamless handoff, high latency
- **Satellite:** Ubiquitous. High Cost. Large propagation delay.

DSRC Spectrum

- Dedicated short-range communications (DSRC) band allocated by FCC: 5.850-5.925 GHz
- Seven 10 MHz channels in 5.9 GHz band
- Channel 178 used as **Control Channel (CCH)**
- Channels 174, 176, 180, 182 used as **service channels (SCH)**
- Channel 184 is reserved for future High Availability Low Latency (HALL)
- Channel 172 is unused
- Different EIRP for 4 Classes:
  - OBU: 33 dBm, RSU: 43dBm (Govt), 33 dBm (others)

DSRC Protocol Components

Management Plane

- **WAVE Management Entity (WME):** IEEE 1609.3/1609.4
  - UDP/TCP
  - TCP not advised
  - IPv6 Only

Data Plane

- **Logical Link Layer (LLC):**
  - IEEE 802.2
- **WAVE Short Message Protocol (WSMP):**
  - ASTM E17.51
- **WAVE MAC Layer:**
  - IEEE 1609.3/1609.4
- **MAC Layer Management Entity (MLME):**
  - IEEE 802.11
- **Physical Layer Management Entity (PLME):**
  - IEEE 802.11p

WAVE Security Entity (WSE)

- IEEE 1609.2
  - Data Encryption and Key management

DSRC Protocol Components (Cont)

- **Wireless Access for Vehicular Environment (WAVE):**
- **WAVE Short Message Service (WSMP):** ASTM E17.51
  - Packets contain Priority, data rate, and power (how far should it go). Developed by American Society for Testing and Materials (ASTM) E17.
- **WAVE Management Entity (WME):** IEEE 1609.3 and IEEE 1609.4
  - Registers Priority, data rate, and power for different applications
- **WAVE Security Entity (WSE):** IEEE 1609.2
  - Data Encryption and Key management
IEEE 802.11p PHY

- A Variation of IEEE 802.11a 5.8 GHz PHY
- OFDM with 64 subcarriers is used in 10 MHz
  - 48 data, 4 pilots, and 12 guard subcarriers as in 802.11a
  - Subcarrier spacing is half of that in 802.11a
  - All time parameters are doubled
  - Symbol size is twice of that in 802.11a
  - Guard Interval is also twice of that in 802.11a
    - Allows larger multi-path delay spread
  - Data rate is half of that in 802.11a
    - $27 \text{ Mbps}$ max

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IEEE 802.11a</th>
<th>IEEE 802.11p</th>
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<tbody>
<tr>
<td>Frequency Band</td>
<td>5.8 GHz</td>
<td>5.9 GHz</td>
</tr>
<tr>
<td>FFT Size</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Number of Subcarriers</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Data Subcarriers</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Pilot Subcarriers</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Channel Width</td>
<td>20 MHz</td>
<td>10 MHz</td>
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<tr>
<td>Symbol Duration</td>
<td>4 us</td>
<td>8 us</td>
</tr>
<tr>
<td>Guard Time</td>
<td>0.8 us</td>
<td>1.6 us</td>
</tr>
<tr>
<td>FFT Period</td>
<td>3.2 us</td>
<td>6.4 us</td>
</tr>
<tr>
<td>Preamble</td>
<td>16 us</td>
<td>32 us</td>
</tr>
</tbody>
</table>

DSRC Devices

- Two Channels: Control channel (CCH) for safety messages and network control. Service channel (SCH) for all other messages
- All devices use CCH and one or more SCH
- Two types of devices:
  - Multi-Channel: Can use CCH and SCH continuously
  - Single Channel: Single Radio for both CCH and SCH
    - Need time to switch between two channels
    - Guard time between switching
- All devices must monitor CCH for a common CCH Interval
- All devices should synchronize clocks to UTC time
  - Generally RSU’s will have GPS clocks and transmit it in their beacons
- WAVE Basic Service Set (WBSS): Set of stations in one 802.11p network
- Neighboring WBSS use different Service Channels

WAVE QoS

- Two types of traffic: IPv6 and WSM. No IPv4 because of address issues
- WSMP packets contain channel #, data rate, power level and priority
- IPv6 streams need to inform MLME about their profile that includes channel #, data rate, and power level
- IEEE 802.11e is extended to support 4 queues for each channel
- Channel Router: Directs the packet to the right channel and queue
- Channel Selector: Monitors channels and schedules transmission with the specified power and data rate
**802.11p Channel Coordination Function**

- **Channel Router**
  - LLC
  - CCH (WSMP Packets only)
  - SCH (IPv6, WSMP Packets)
  - Internal Scheduling
  - External Contention

**Channel Selector**

**WBSS Formation**

- Any WAVE device can start a WBSS when requested by an application.
- **Provider**: Device that starts WBSS (OBU or RSU). Generates announcements.
- **Users**: Devices that join WBSS
- **Persistent WBSS**: Announced every sync interval
- **Non-Persistent WBSS**: Short lived. Announced at formation only, e.g., to support on-demand file download
- Server applications register with WME with a Provider Service Identifier (PSID) – like port numbers.
- A WBSS is initiated when first application registers.
- The Provider Service Table (PST) is broadcast periodically

**WBSS Formation (Cont)**

- User applications register their interests with their WME.
- WME monitors announcements and check to see if PST of a WBSS is of interest.
- WBSS are shutdown when there is no active application

**Non-WBSS Communication**

- **Outside the context of a BSS (OCB) Mode:**
  - Stations do not have to be a member of a BSS to transmit
  - A WAVE device can send a WSMP message to a broadcast address on CCH
  - Another WAVE device can respond to this WSMP message on the CCH
  - No BSS advertisement or synchronization
  - Timing Advertisements from provider: Default parameter values and a timestamp indicating local time
  - Authentication handled by higher layers
- OCB stations use slightly higher AIFS than WBSS members.
- OCB stations use wild card in the BSS ID field in MAC frames
802.11p Products

- Arada Systems: OBU and RSU
- Cohda Wireless: WAVE-DSRC Radio
- NXP: Software Defined Radios for Cohda’s radios
- Unex: OBUs
- Ittiam: HDL implementation (IP)
- Card Access Engineering: Product designs
- LITEPOINT: Test platform
- Rohde & Schwarz: Spectrum analyzers and signal generators

Future

- DSRC is designed for short range communication
- Good for the city but long-range communication is also required on highways using cellular technology
- Will require multi-channel OBUs

Summary

1. VANETs have a dynamic topology, very tight delay constraint for critical messages. V2V and V2I Communication between RSU and OBU.
2. DSRC uses **10MHz** Channels with OFDM in 5.9 GHz. CCH for Control and safety critical messages. SCH for all other messages.
3. ASTM started WAVE with **WAVE Short message Service Protocol**. IEEE 1609.1-4 standards extended 802.11 MAC management and security for DSRC.
4. IEEE 802.11p PHY **OFDM** is similar to 802.11a but with double symbols durations.
5. **QoS** similar to IEEE 802.11e but four queues for each channel.

Homework 8

1. Broadcast within a limited area is called _________________.
2. In ________________ in VANETs, receivers integrated their own information and forward.
3. DSRC spectrum is in ________________ GHz band.
4. DSRC spectrum is divided into ________________ channels of ________________ MHz each.
5. The middle channel is used as ________________ channel while the two channels on each side are used as ________________ channels.
6. WAVE PHY layer is ________________
7. DSRC allows only IP version ________________ traffic.
8. DSRC PHY uses ________________ data carriers in a ________________ MHz band.
9. WAVE uses ________________ QoS queues for each channel.
10. Any WAVE device can start a ________________ and become a provider.
Reading List


Wikipedia Links


References


References (Cont)

References (Cont)


Acronyms (Cont)

- AIFS Arbitrated Inter-Frame Spacing
- ASTM American Society for Testing and Materials
- BPSK Binary Phase Shift Keying
- BSS Basic Service Set
- CCH Control Channel
- dBm Decibel mill watt
- DSRC Dedicated short-range communications
- EIRP Equivalent Isotropically Radiated Power
- FCC Federal Communications Commission
- FFT Fast Fourier Transform
- GHz Giga Hertz
- GPS Global Positioning System
- HALL High Availability Low Latency
- HDL Hardware Description Language
- ID Identifier
- IEEE Institution for Electrical and Electronic Engineers
- IPv4 Internet Protocol version 4
- IPv6 Internet Protocol version 6
- LAN Local Area Network
- LLC Logical Link Control
- MAC Media Access Control
- MHz Mega Hertz
- MLME MAC Layer Management Entity
- OBU On-board Unit
- OCB Outside the context of a BSS
- OFDM Orthogonal Frequency Division Multiplexing
- PHY Physical Layer
- PLCP Physical Layer Convergence Protocol
- PLME Physical Layer Management Entity
- PSID Provider Service Identifier
- PST Provider Service Table
- QoS Quality of Service
- RSU Roadside Unit
- SCH Service Channel
- SDR Software Defined Radio
- SWG Standards Working Group
- TCP Transmission Control Protocol
- UDP User Datagram Protocol
- UTC Coordinated Universal Time
- VANET Vehicular Ad-Hoc Networks
- WAVE Wireless Access for Vehicular Environment
- WBSS WAVE Basic Service Set
- WME WAVE Management Entity
- WSM WAVE Security Management Entity
- WSMP WAVE Short Message Protocol