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/cse574-24/

Student Questions

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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

Student Questions

❑ Is the WAVE protocol part of the DSRC protocol?
Yes. See Slide 8-11.

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.
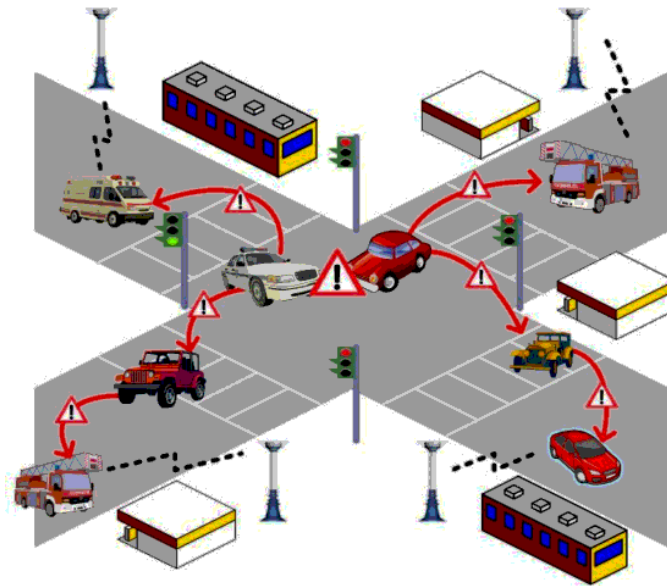
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Student Questions

- Are road side units required? Or are they just optional to assist as part of the network?

Some types of communications require RSUs, and others don't. For example, you can't do a Google search without a roadside unit. These types of communications are defined as V2I later.

VANET Architectures

- Vehicle to Infrastructure (V2I)

- Vehicle to Vehicle (V2V)

- Road-Side Unit (RSU)

- On-Board Unit (OBU)

V2I RSU

V2V OBU

inter-vehicle communication

vehicle-to-roadside communication

inter-roadside communication
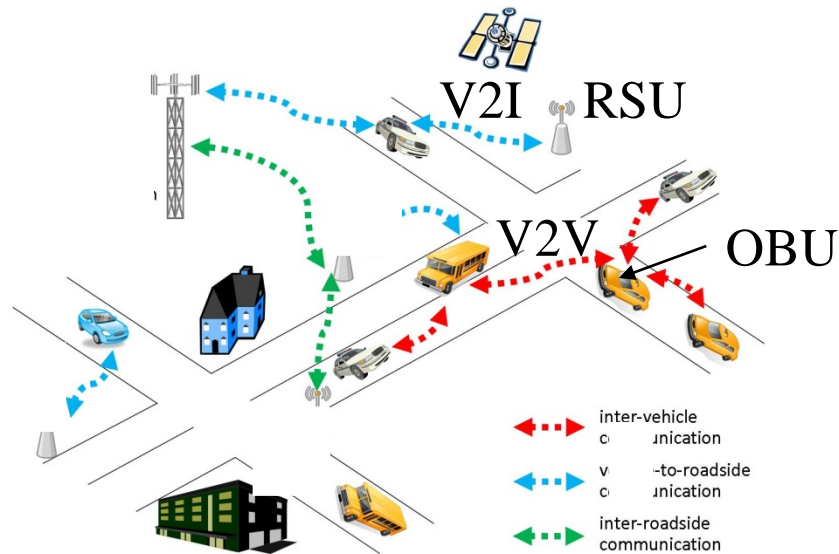
Ref: R. Aquino-Santos, A. Edwards, and V. Rangel-Licea, "Wireless Technologies in Vehicular Ad-Hoc Networks,"
IGI Global, Feb 2012, 382 pp., ISBN:1466602090, Safari Book.

Student Questions

- Is VANET intended to only be used between a car and an external device, or could it be used between multiple devices within a single car?

Cars can use and use existing protocols for in-car communications. E.g. Bluetooth, Ethernet.

- To what extent is V2V VANET implemented today? To what extent do cars communicate directly with one another?

It is mostly a concept so far. Some experimental systems exist. Some toll collection systems use DSRC.

- Can you give us some examples of RSU and OBU?

The original idea was to install a dedicated infrastructure, but that did not happen.
RSU = 5G tower, Satellite
OBU = 5G SIM, Satellite receiver
Toyota Sienna 2024 and other cars have "cloud-based navigation," possibly using satellites. Similar to XM Radio.

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 a major cause of death of children aged five and above.
   ➢ **Adaptive Cruise Control**: Maintain a distance from the vehicle ahead
   ➢ **Forward Collision Warning**: Warn and automatically activate brakes
   ➢ **Speed Regulation**: Maintain the speed limit

Student Questions

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)

Student Questions

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 the driver, vehicle type, etc. should not be disclosed

❑ **Availability**: Vehicles should be usable even if the network is down

Student Questions

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 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 distances. V2I

- **3G**: Seamless handoff, high latency

- **Satellite**: Ubiquitous. High Cost. Large propagation delay.

Student Questions

DSRC Spectrum

- Dedicated short-range communications (DSRC) band allocated by FCC: 5.850-5.925 GHz

- Seven 10 MHz channels in the 5.9 GHz band

- Channel 178 used as **Control Channel (CCH)**

- Channels 174, 176, 180, and 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)

- Due to lack of adoption, the FCC has reallocated all of DSRC's spectrum. 45 MHz to 5.8 GHz ISM band and 30 MHz to Cellular V2X.

Ref: Y. L. Morgan, "Notes on DSRC & WAVE Standards Suite: Its Architecture, Design and Characteristics,"
IEEE Communications Surveys and Tutorials, Vol 12, No. 4, 2010, pp. 504-518, https://ieeexplore.ieee.org/arnumber=5462975
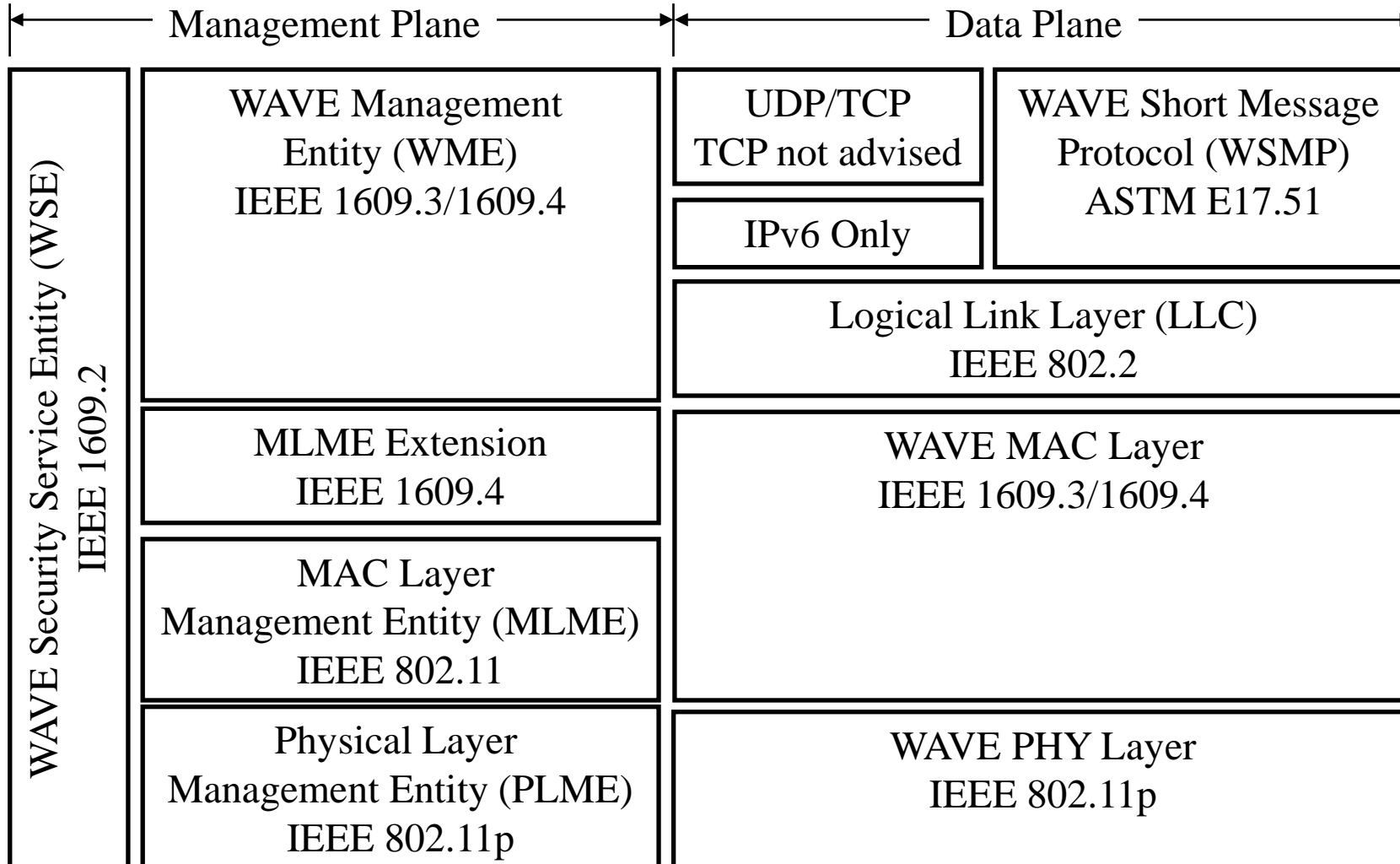http://www.cse.wustl.edu/~jain/cse574-24/

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- Why is channel 172/173 unused?
  Don't really know. Som possible answers:
  - *Reserved for future use.*
  - *Not available in most countries.*
  - *Excessive interference with some existing application*
- 4 Classes: OBU, RSU, 33 dBm. There are only three classes?
  These are devices, not classes. Each device can have four classes, like IEEE 802.11e.

DSRC Protocol Components

Management Plane	Data Plane

WAVE Security Service Entity (WSE) IEEE 1609.2	WAVE Management Entity (WME) IEEE 1609.3/1609.4	UDP/TCP TCP not advised / IPv6 Only	WAVE Short Message Protocol (WSMP) ASTM E17.51

WAVE Security Service Entity (WSE) IEEE 1609.2

WAVE Management Entity (WME) IEEE 1609.3/1609.4

UDP/TCP TCP not advised

IPv6 Only

WAVE Short Message Protocol (WSMP) ASTM E17.51

Logical Link Layer (LLC) IEEE 802.2

MLME Extension IEEE 1609.4

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 PHY Layer IEEE 802.11p

Student Questions

❑ Can you mention which parts of this diagram are IPv6 and which are IPv4?

No IPv4 because of address issues. IPv6 is used only in that one part indicated.

❑ Will any communication be either on the management plane or on the data plane?

Four planes: Data, Control, Management, and Service. Covered in CSE473 Software Defined Networking Module.

http://www.cse.wustl.edu/~jain/cse473-22/i_4nld.htm (Slide 4-46)

❑ How do WSMP nodes create a routing table to forward messages w/o a networking layer?

Point-to-point (one hop)

❑ You mention inline and offline in the video. Can you please explain what you were pointing to?

WSMP allows the node to indicate power level (inline0. When you use IPv6, there is no field in IP or MAC to indicate power level, etc. This is done offline via the management plane.

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

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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
$\Rightarrow$ Allows larger multi-path delay spread

➢ Data rate is half of that in 802.11a $\Rightarrow$ 27 Mbps max

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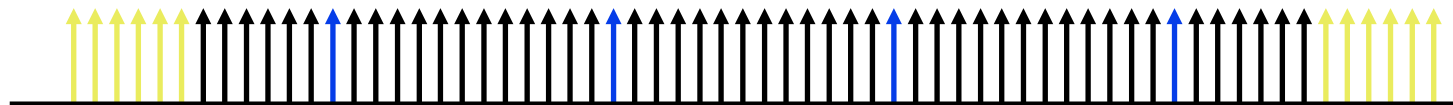
IEEE 802.11p PHY (Cont)

Parameter	IEEE 802.11a	IEEE 802.11p
Frequency Band	5.8 GHz	5.9 GHz
FFT Size	64	64
Data Subcarriers	48	48
Pilot Subcarriers	4	4
Channel Width	20 MHz	5, 10, 20 MHz
Symbol Duration	4 us	16, 8, 4 us
Guard Time	0.8 us	3.2, 1.6, 0.8 us
Subcarrier Spacing	312.5 kHz	78.125, 156.25, 312.5 kHz
Preamble	16 us	64, 32, 16 us

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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.
   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

Student Questions

❑ Does the device only have one CCH, or may it have multiple CCH?

One CCH

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, including channel #, data rate, and power level

- IEEE 802.11e to support four 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

LLC

↓

Channel Router

CCH (WSMP Packets only)   SCH (IPv6, WSMP Packets)

Internal Scheduling   Internal Scheduling

Channel Selector

External Contention

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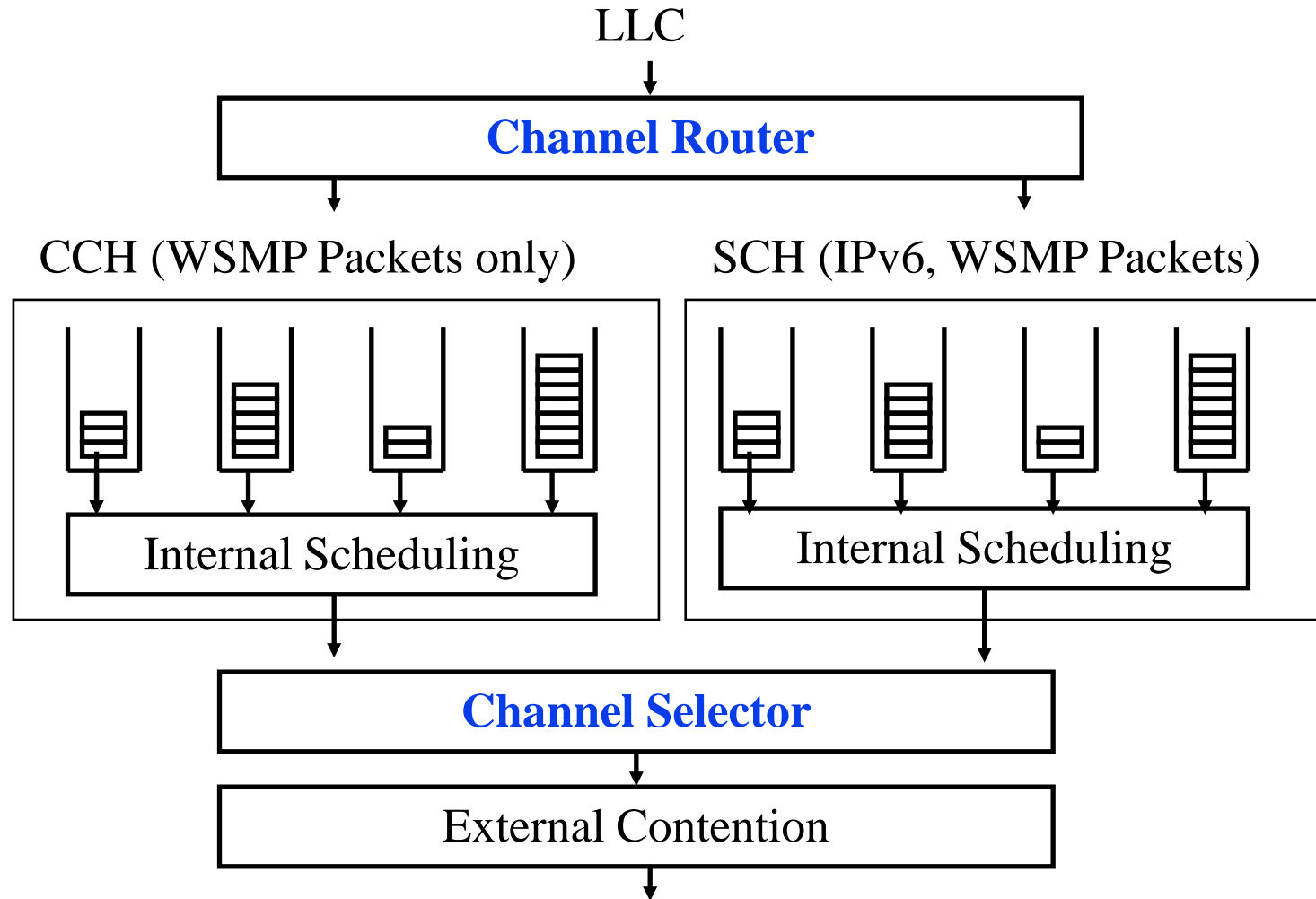
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❑ An 802.11p device listens to all five channels at once? Is that why there is a channel selector?
No, the devices listen only to the control channel and then to the channel allocated to them for communication.

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 the 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 checks to see if the PST of a WBSS is of interest.

❑ WBSS are shutdown when there is no active application

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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 cards in the BSS ID field in MAC frames

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802.11p Products

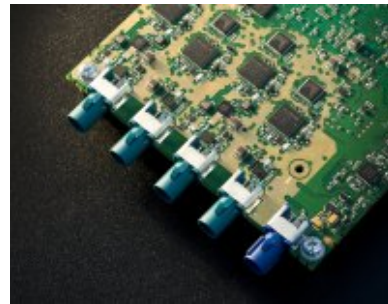- Arada Systems: OBU and RSU
- Cohda Wireless: WAVE-DSRC Radio
- NXP: Software Defined Radios for Cohda's radios
- Unex: OBUs
- Ittiam: HDL implementation (IP)
- Card Access Engineering: Product designs
- LITEPOINT: Test platform
- Rohde & Schwarz: Spectrum analyzers and signal generators
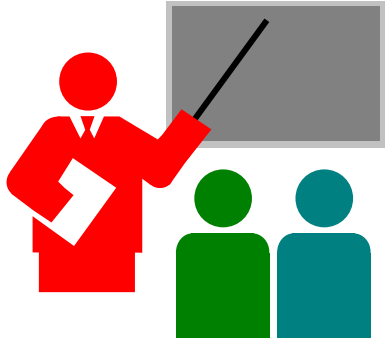

| OBU | RSU | Radio | SDR+Radio |

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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

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Summary

1. VANETs have a dynamic topology and tight delay constraints 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

❑ Your Name: _____

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.
11. A _____ WBSS is announced every sync interval.

Reading List

❑ Christoph Sommer, Falko Dressler, "Vehicular Networking," Cambridge University Press, November 2014, 384 pp., ISBN:978-1-107-04671-9 (Safari Book).

❑ Karagiannis, G.; Altintas, O.; Ekici, E.; Heijenk, G.; Jarupan, B.; Lin, K.; Weil, T., "Vehicular Networking: A Survey and Tutorial on Requirements, Architectures, Challenges, Standards and Solutions," in *Communications Surveys & Tutorials, IEEE* , vol.13, no.4, pp.584-616, Fourth Quarter 2011, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5948952 (Must Read)

Student Questions

Wikipedia Links

- http://en.wikipedia.org/wiki/IEEE_802.11p
- http://en.wikipedia.org/wiki/Wireless_Access_for_the_Vehicular_Environment
- http://en.wikipedia.org/wiki/Dedicated_short-range_communications
- http://en.wikipedia.org/wiki/Vehicular_ad_hoc_network
- http://en.wikipedia.org/wiki/Intelligent_vehicular_ad-hoc_network
- http://en.wikipedia.org/wiki/Vehicular_communication_systems
- http://en.wikipedia.org/wiki/Abiding_Geocast_/_Stored_Geocast
- http://en.wikipedia.org/wiki/Geocast
- http://en.wikipedia.org/wiki/Vehicle_infrastructure_integration

Student Questions

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- Hadded, M.; Muhlethaler, P.; Laouiti, A.; Zagrouba, R.; Saidane, L.A., "TDMA-Based MAC Protocols for Vehicular Ad Hoc Networks: A Survey, Qualitative Analysis, and Open Research Issues," in Communications Surveys & Tutorials, IEEE , vol.17, no.4, pp.2461-2492, Fourth quarter 2015, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7117340&isnumber=7331734

- Suthaputchakun, C.; Zhili Sun, "Routing protocol in intervehicle communication systems: a survey," in Communications Magazine, IEEE , vol.49, no.12, pp.150-156, December 2011, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6094020

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- Araniti, G.; Campolo, C.; Condoluci, M.; Iera, A.; Molinaro, A., "LTE for vehicular networking: a survey," in Communications Magazine, IEEE , vol.51, no.5, pp.148-157, May 2013, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6515060

- ASTM, "ASTM E2213 - 03(2010) Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems — 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications," http://www.astm.org/Standards/E2213.htm Available for purchase.

Student Questions

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- IEEE, "IEEE standard 802.11p: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications: Amendment 6- Wireless access in vehicular environments," 2010, http://standards.ieee.org/getieee802/download/802.11p-2010.pdf

- IEEE P1609.1 SWG, "IEEE 1609.1 Trial-Use Standard for Wireless Access in Vehicular Environment (WAVE) Resource Manager," 2009

- IEEE P1609.2 SWG, "IEEE 1609.2 Trial Use Standard for Wireless Access in Vehicular Environments – Security services for Applications and Management Messages," June 2009

- IEEE P1609.3 SWG, "IEEE 1609.3-2010: IEEE standard for wireless access in vehicular environments (WAVE) – Networking services," 2010.

- IEEE P1609.4 SWG, "IEEE 1609.4-2010: IEEE standard for wireless access in vehicular environments (WAVE) – Multi-channel operation," 2010.

Student Questions

Acronyms

- 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

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Acronyms (Cont)

- 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

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Acronyms (Cont)

- 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

Student Questions

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Thank You

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Student Questions

Related Modules

CSE567M: Computer Systems Analysis (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

Recent Advances in Networking (Spring 2013),

https://www.youtube.com/playlist?list=PLjGG94etKypLHyBN8mOgwJLHD2FFIMGq5

CSE571S: Network Security (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u

Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw

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