

# 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/cse574-20/>

**Student Questions**

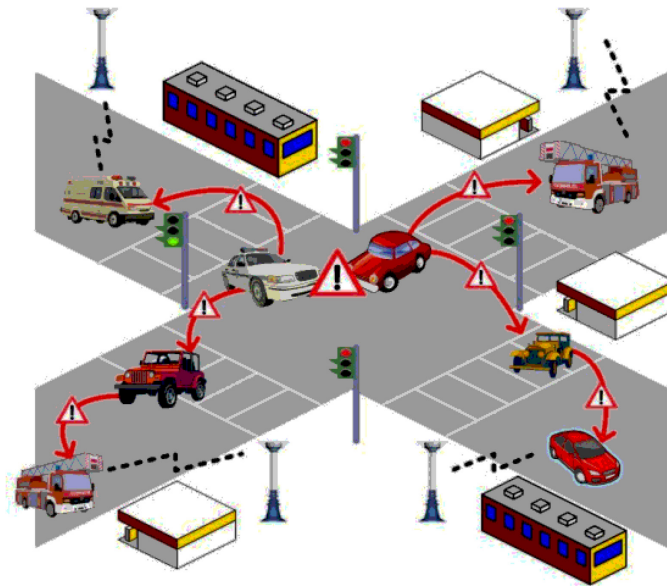


1. Vehicular Ad-Hoc Networks (VANET):  
Architecture, Applications, Requirements, Routing
2. Dedicated short Range Communication (DSRC) and  
Wireless Access for Vehicular Environment (WAVE)
  - Spectrum
  - Protocol Components
  - PHY, MAC
  - Products

## Student Questions

# 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.



## Student Questions

Ref: Christoph Sommer, Falko Dressler, "Vehicular Networking," Cambridge University Press, November 2014, 384 pp.,

ISBN:978-1-107-04671-9 (Safari Book).

R. Aquino-Santos, A. Edwards, and V. Rangel-Licea, "Wireless Technologies in Vehicular Ad-Hoc Networks,"

IGI Global, Feb 2012, 382 pp., ISBN:1466602090 (Not a Safari Book).

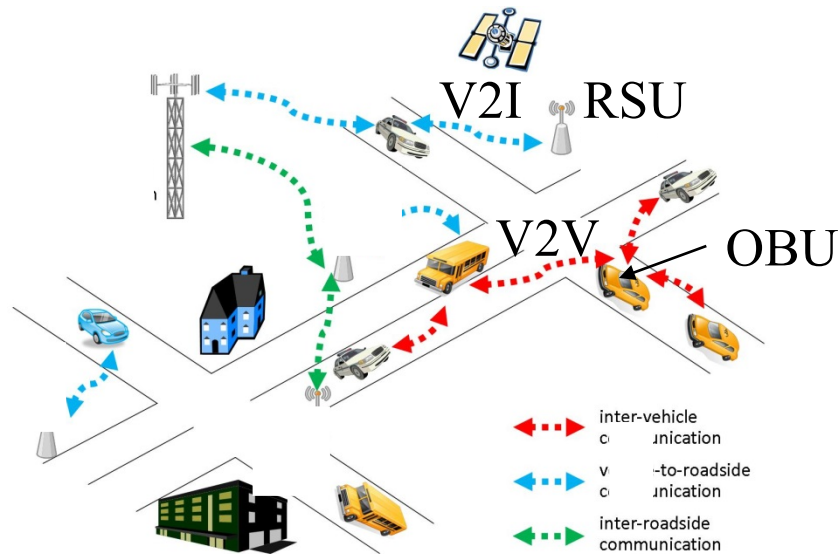
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# VANET Architectures

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



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

# 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

## 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 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 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

## Student Questions



# 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.

## Student Questions

# DSRC Spectrum

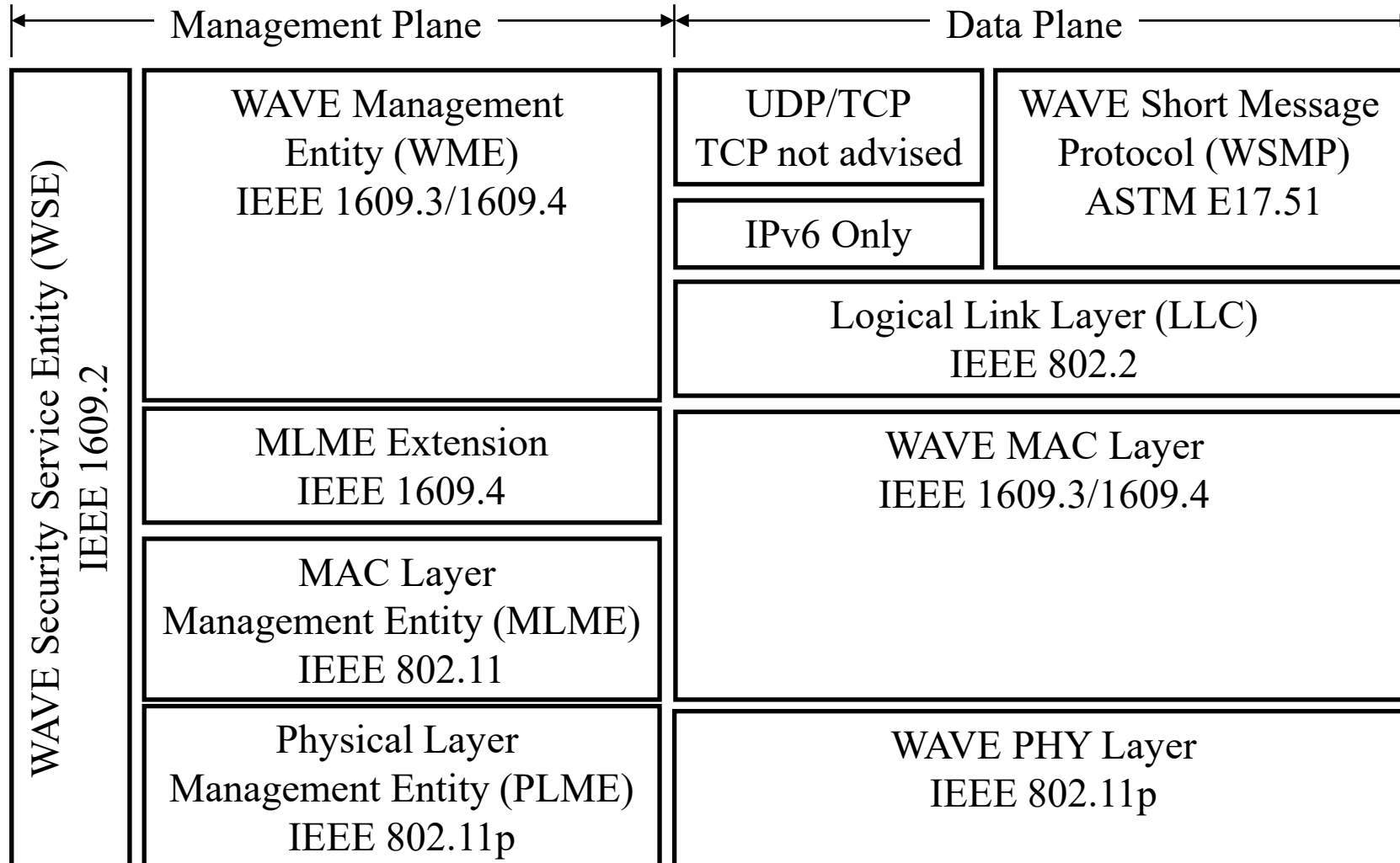
- ❑ Dedicated short-range communications (DSRC) band allocated by FCC: 5.850-5.925 GHz
- ❑ Seven 10 MHz channels in 5.9 GHz band
- ❑ Channel 178 used as **Control Channel (CCH)**
- ❑ Channels 174, 176, 180, 182 used as **service channels (SCH)**
- ❑ Channel 184 is reserved for future High Availability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



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.

## Student Questions

# DSRC Protocol Components



## Student Questions

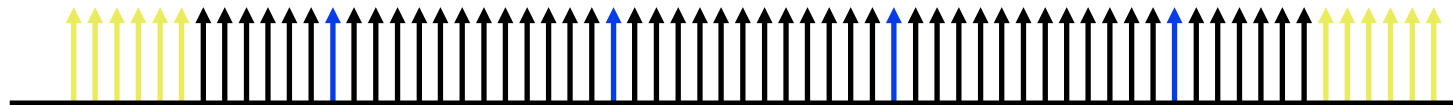
# DSRC Protocol Components (Cont)

- ❑ 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

## Student Questions

# 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 Mbps max



## Student Questions

# IEEE 802.11p PHY (Cont)

<b>Parameter</b>	<b>IEEE 802.11a</b>	<b>IEEE 802.11p</b>
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

## Student Questions

# 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

## Student Questions

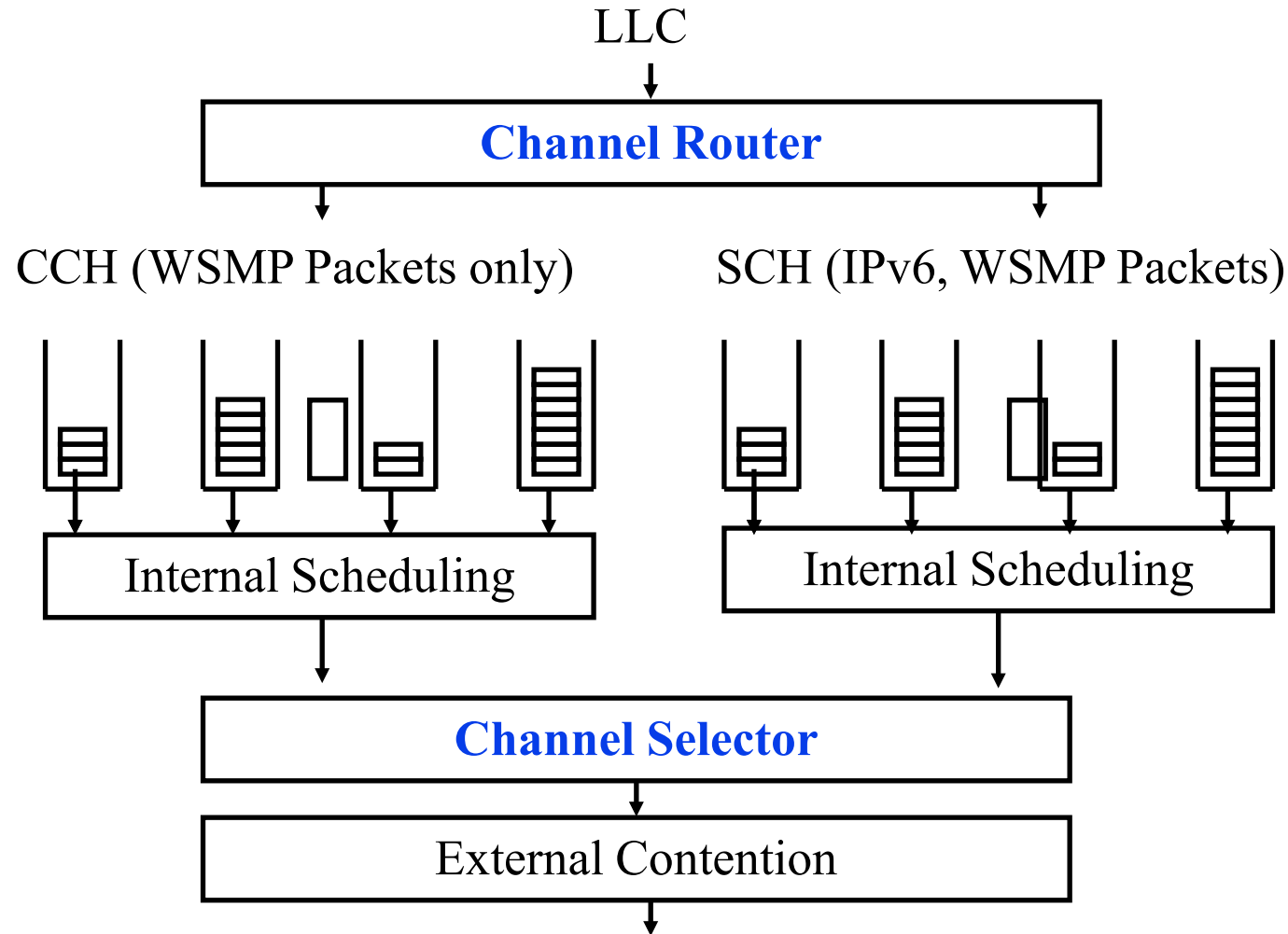
# WAVE QoS

- ❑ **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

## Student Questions



# 802.11p Channel Coordination Function



## Student Questions

# 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

## Student Questions

## 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

### Student Questions

# 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

## Student Questions

# 802.11p Products

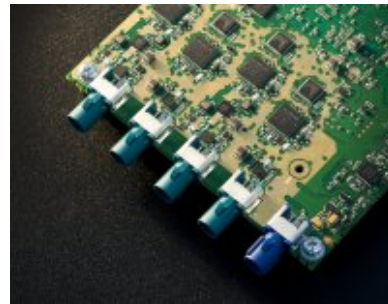
- ❑ Arada Systems: OBU and RSU
- ❑ Cohda Wireless: WAVE-DSRC Radio
- ❑ NXP: Software Defined Radios for Cohda's radios
- ❑ Unex: OBUs
- ❑ Ittiam: HDL implementation (IP)
- ❑ Card Access Engineering: Product designs
- ❑ LITEPOINT: Test platform
- ❑ Rohde & Schwarz: Spectrum analyzers and signal generators



OBU



RSU



Radio



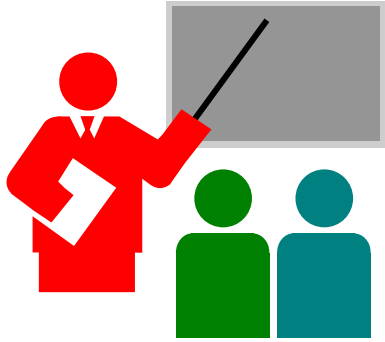
SDR+Radio

## Student Questions

# 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

## Student Questions



## 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.

## Student Questions

# 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.

## Student Questions



# 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/IEEE_802.11p)
- ❑ [http://en.wikipedia.org/wiki/Wireless\\_Access\\_for\\_the\\_Vehicular\\_Environment](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/Dedicated_short-range_communications)
- ❑ [http://en.wikipedia.org/wiki/Vehicular\\_ad\\_hoc\\_network](http://en.wikipedia.org/wiki/Vehicular_ad_hoc_network)
- ❑ [http://en.wikipedia.org/wiki/Intelligent\\_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/Vehicular_communication_systems)
- ❑ [http://en.wikipedia.org/wiki/Abiding\\_Geocast / Stored\\_Geocast](http://en.wikipedia.org/wiki/Abiding_Geocast / Stored_Geocast)
- ❑ <http://en.wikipedia.org/wiki/Geocast>
- ❑ [http://en.wikipedia.org/wiki/Vehicle\\_infrastructure\\_integration](http://en.wikipedia.org/wiki/Vehicle_infrastructure_integration)

## Student Questions

# References

- ❑ 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, <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5462975>
- ❑ R. Aquino-Santos, A. Edwards, and V. Rangel-Licea, "Wireless Technologies in Vehicular Ad-Hoc Networks," IGI Global, Feb 2012, 382 pp., ISBN:1466602090.
- ❑ 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>

## Student Questions

# References (Cont)

- Cailean, A.-M.; Cagneau, B.; Chassagne, L.; Popa, V.; Dimian, M., "A survey on the usage of DSRC and VLC in communication-based vehicle safety applications," in Communications and Vehicular Technology in the Benelux (SCVT), 2014 IEEE 21st Symposium on , vol., no., pp.69-74, 10-10 Nov. 2014,  
<http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7046710>
- 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

# References (Cont)

- ❑ 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

## Student Questions

# 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

## Student Questions

# 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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[http://www.cse.wustl.edu/~jain/cse574-20/j\\_08vwn.htm](http://www.cse.wustl.edu/~jain/cse574-20/j_08vwn.htm)

# Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),  
[https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n\\_1X0bWWNyZcof](https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof)

CSE473S: Introduction to Computer Networks (Fall 2011),  
[https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e\\_10TiDw](https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e_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>

## Student Questions

# Quiz 8B

Your Name: \_\_\_\_\_

T F

1. Autonomy of a VANET node refers to its ability to reject a message or participation.
2. VANET nodes are very short on energy and storage compared to other mobile nodes.
3. VANETs may have some highly time critical messages.

## Student Questions