

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

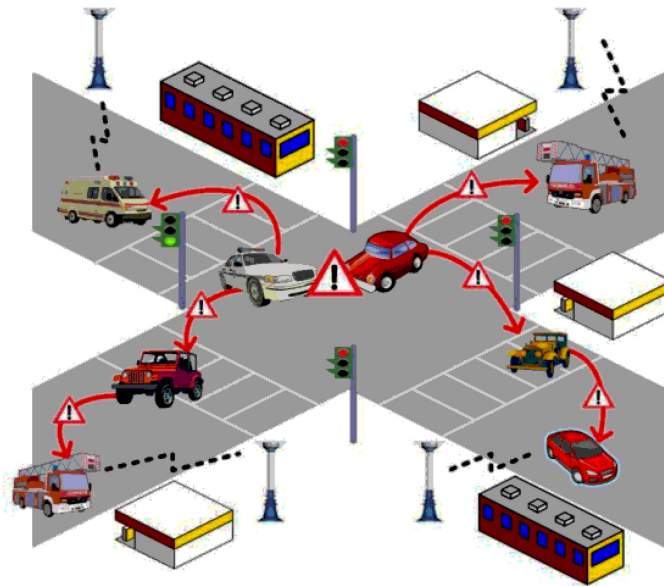


1. Vehicular Ad-Hoc Networks (VANET):
Architecture, Applications, Requirements, Routing
2. Dedicated short Range Communication (DSRC) and
Wireless Access for Vehicular Environment (WAVE)
 - Spectrum
 - Protocol Components
 - PHY, MAC
 - Products

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

- ❑ 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.

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).

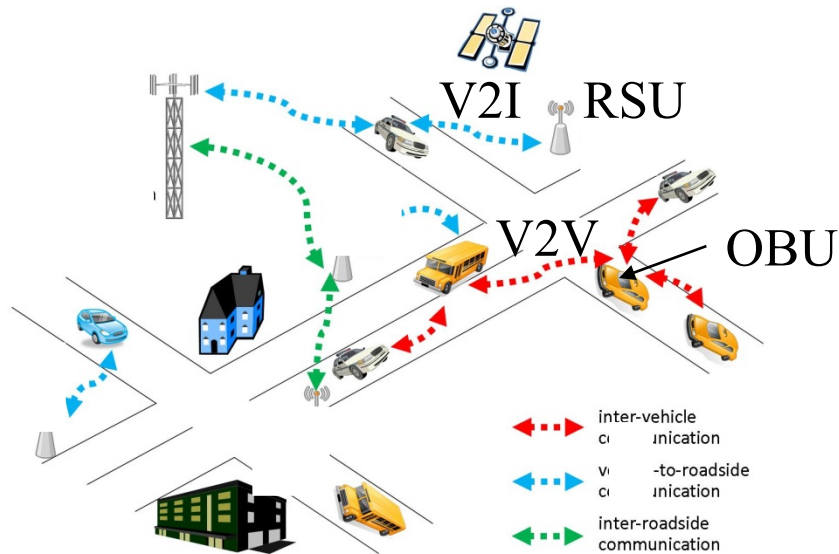
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VANET Architectures

- ❑ 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

- ❑ 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.

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

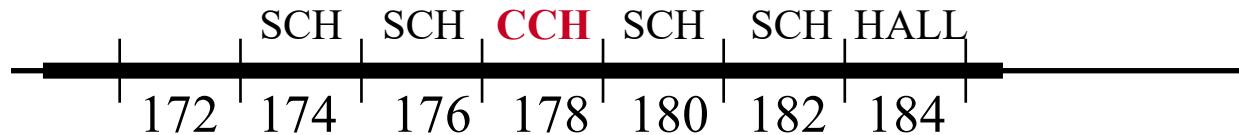
VANET Technologies

- ❑ **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, <https://ieeexplore.ieee.org/arnumber=5462975>

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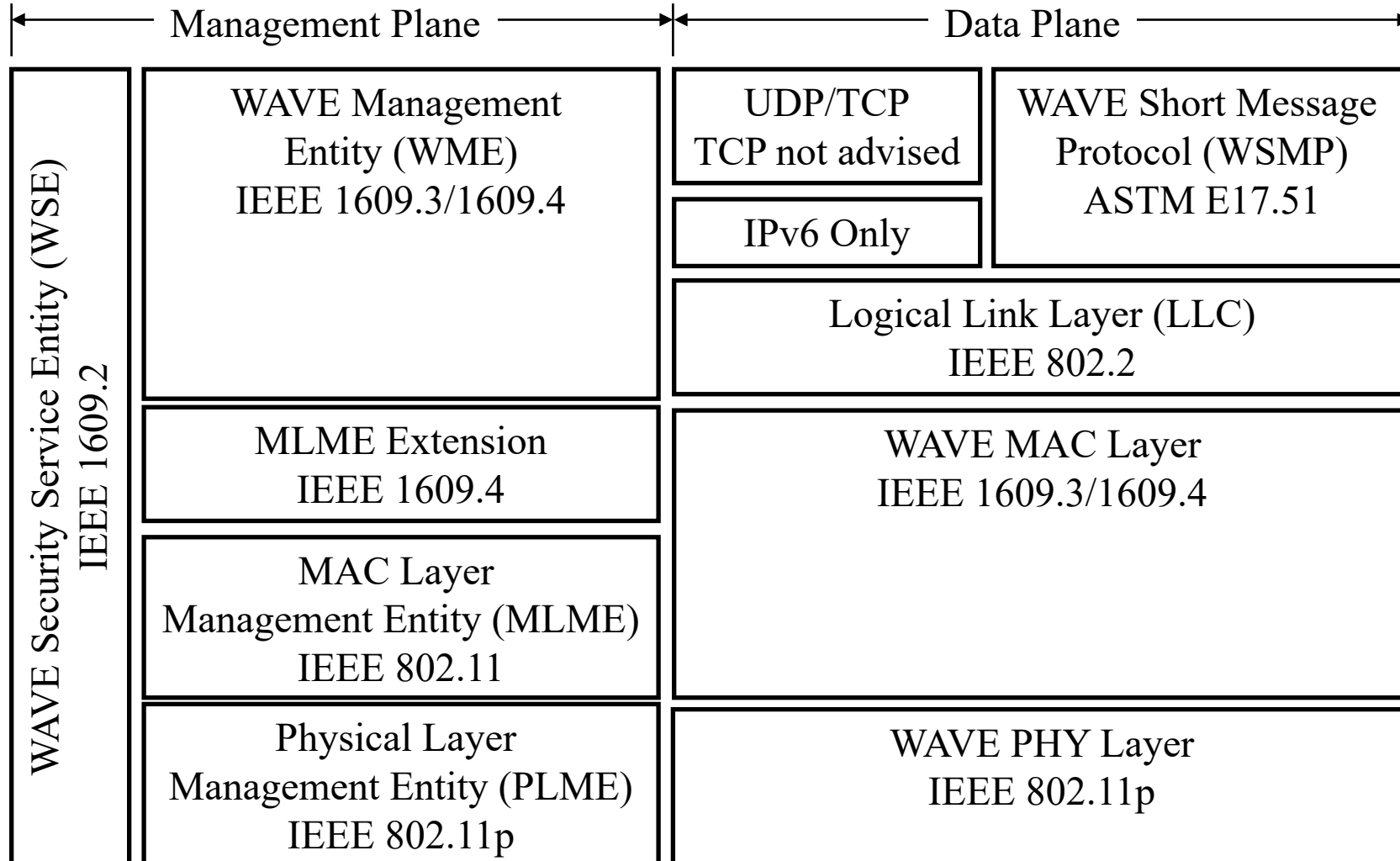
Student Questions

- ❑ 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*

DSRC Protocol Components



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.

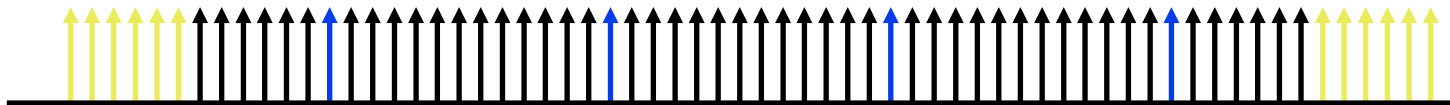
DSRC Protocol Components (Cont)

- ❑ 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)

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

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

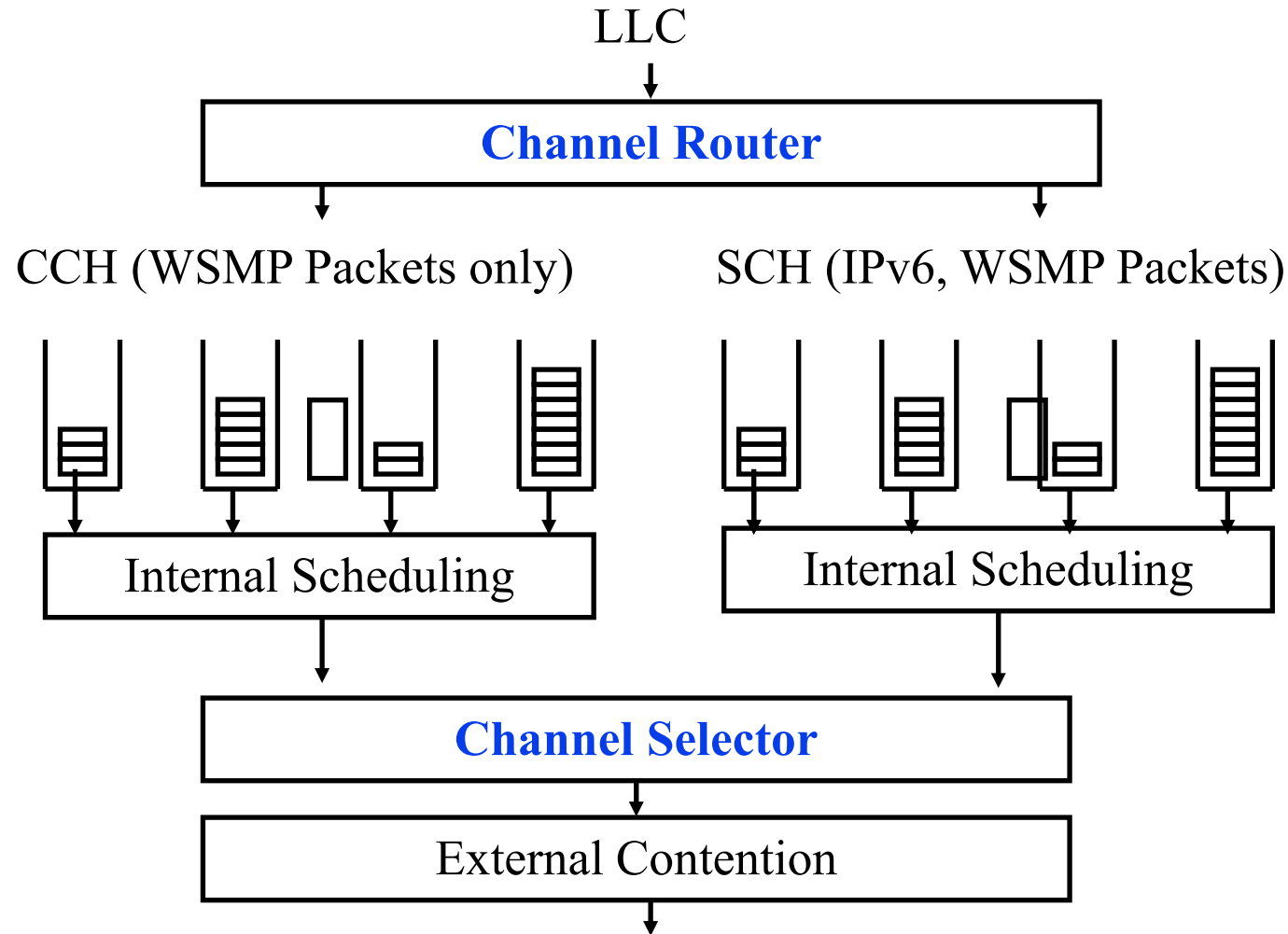
- ❑ **Two types of traffic:** IPv6 and WSM. No IPv4 because of address issues
- ❑ WSMP packets contain channel #, data rate, power level and priority
- ❑ IPv6 streams need to inform MLME about their profile that includes channel #, data rate, and power level
- ❑ IEEE 802.11e is extended to support 4 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

- ❑ Which traffic is the IPv6 vs WSM traffic? You show slide 11 but don't indicate which is which.

IPv6 and WSMP are two L3 alternatives. Any application can use either alternative. Both can carry all traffic. These are designed by different organizations.

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

- ❑ Why does the PST need to be periodically broadcasted?
Similar to Beacons in Bluetooth, Wi-Fi, etc. You can either passively listen to what is available or broadcast a request to find out what services are available. Both are allowed.

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

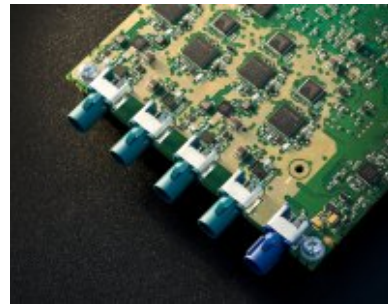
- ❑ Arada Systems: OBU and RSU
- ❑ Cohda Wireless: WAVE-DSRC Radio
- ❑ NXP: Software Defined Radios for Cohda's radios
- ❑ Unex: OBUs
- ❑ Ittiam: HDL implementation (IP)
- ❑ Card Access Engineering: Product designs
- ❑ LITEPOINT: Test platform
- ❑ Rohde & Schwarz: Spectrum analyzers and signal generators



OBU



RSU



Radio



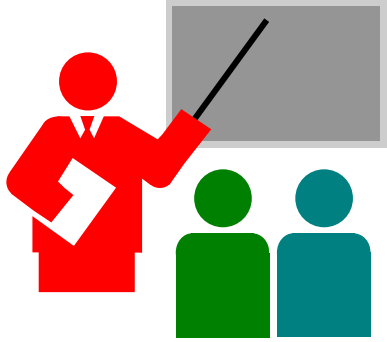
SDR+Radio

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

- When are we supposed to turn in HW8?

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/Abiding_Geocast/_/_Stored_Geocast)
- ❑ <http://en.wikipedia.org/wiki/Geocast>
- ❑ 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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Student Questions

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

CSE473S: Introduction to Computer Networks (Fall 2011),
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