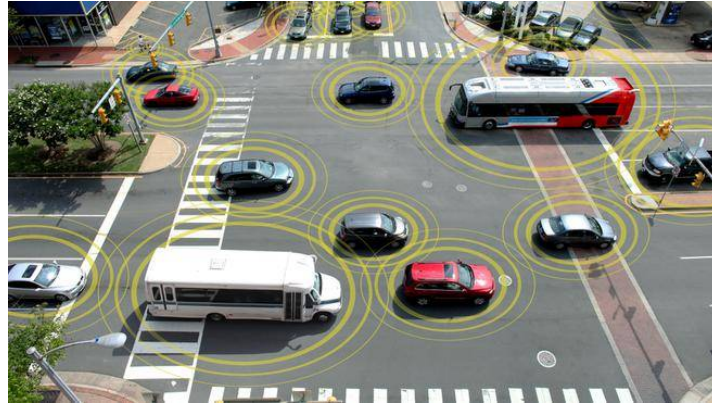# Introduction to Vehicular Wireless Networks

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Audio/Video recordings of this class lecture are available at:

http://www.cse.wustl.edu/~jain/cse574-18/

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

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.
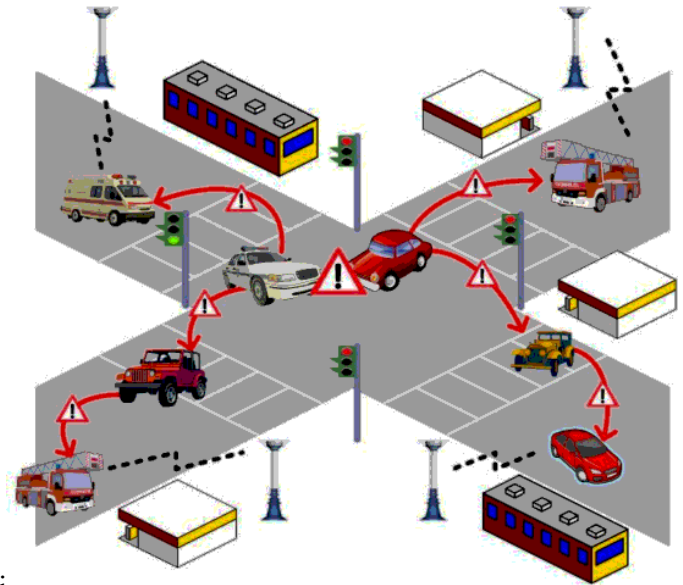
Ref: Christoph Sommer, Falko Dressler, "Vehicular Networking," Cambridge Uni
ISBN:978-1-107-04671-9 (Safari Book).
R. Aquino-Santos, A. Edwards, and V. Rangel-Licea, "Wireless Technologies in Vehicular Ad-Hoc Networks,"
IGI Global, Feb 2012, 382 pp., ISBN:1466602090 (Not a Safari Book).

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VANET Architectures

❑ Vehicle to Infrastructure (V2I)

❑ Vehicle to Vehicle (V2V)

❑ Road-Side Unit (RSU)

❑ On-Board Unit (OBU)
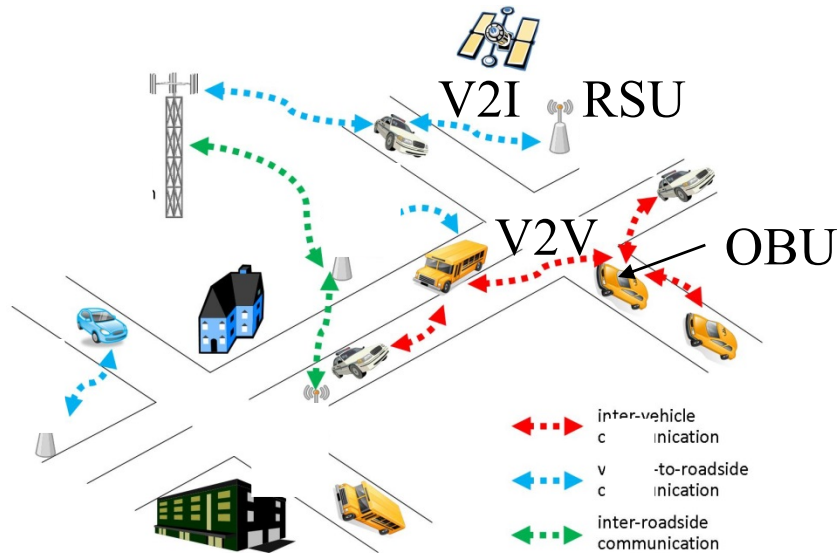
Ref: R. Aquino-Santos, A. Edwards, and V. Rangel-Licea, "Wireless Technologies in Vehicular Ad-Hoc Networks,"
IGI Global, Feb 2012, 382 pp., ISBN:1466602090, Safari Book.

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

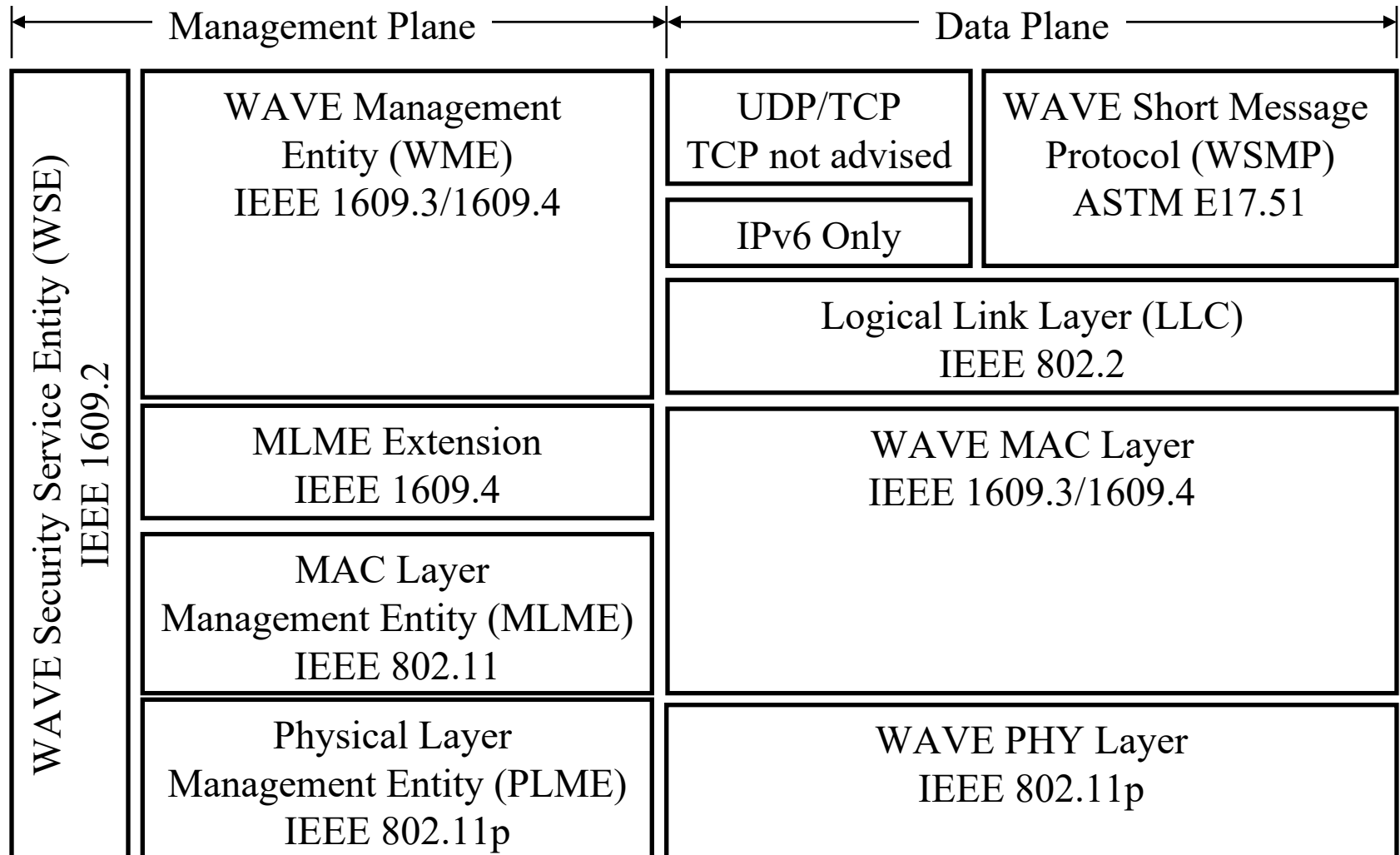❑ **Satellite**: Ubiquitous. High Cost. Large propagation delay.

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)

```
          SCH   SCH   CCH   SCH   SCH  HALL
   ───┼────┼────┼────┼────┼────┼────┼────┼───
      172  174  176  178  180  182  184
```

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.

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 |

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

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
    Þ Allows larger multi-path delay spread

  ➢ Data rate is half of that in 802.11a Þ 27 Mbps max
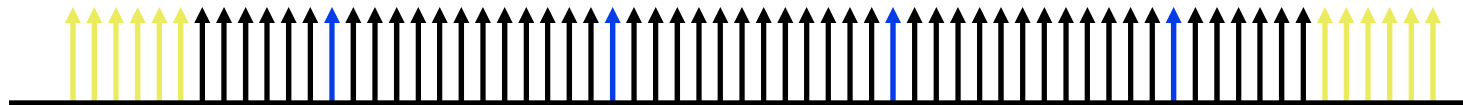
IEEE 802.11p PHY (Cont)

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

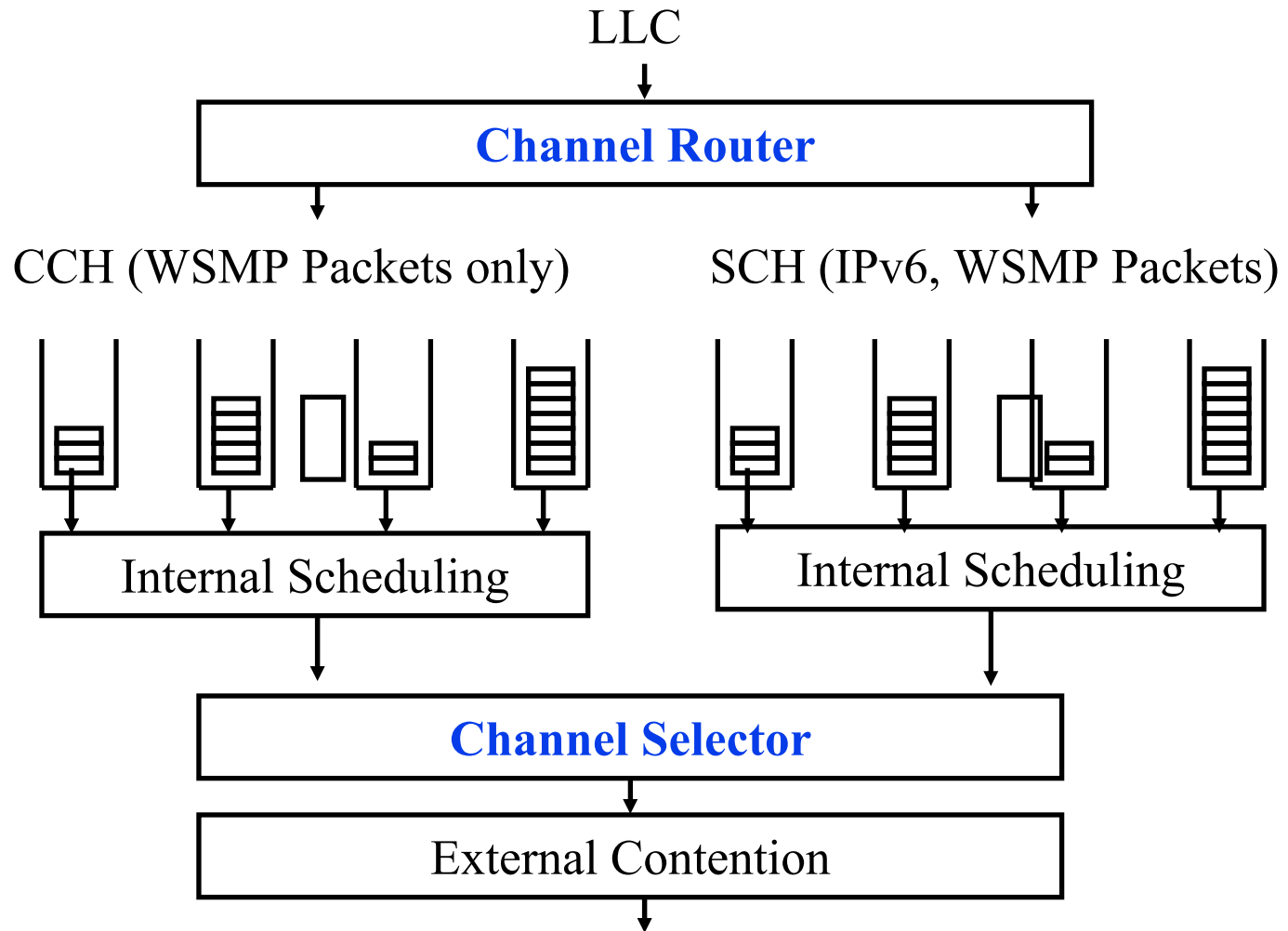# DSRC Devices

❑ **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
    Þ Need time to switch between two channels
    Þ 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

LLC

| Channel Router |

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

| Internal Scheduling | | Internal Scheduling |

| Channel Selector |

| External Contention |

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.

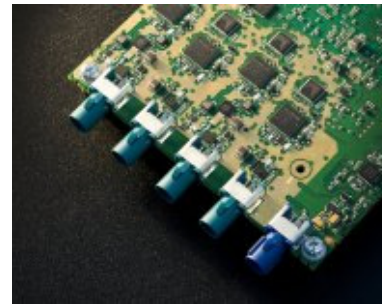❑ OCB stations use wild card in the BSS ID field in MAC frames

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

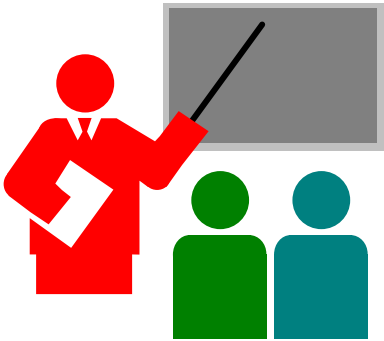❑ Rohde & Schwarz: Spectrum analyzers and signal generators

| OBU | RSU | Radio | SDR+Radio |

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

❑ 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.

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)

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

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

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.

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.

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

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

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

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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