Introduction to Vehicular Wireless Networks

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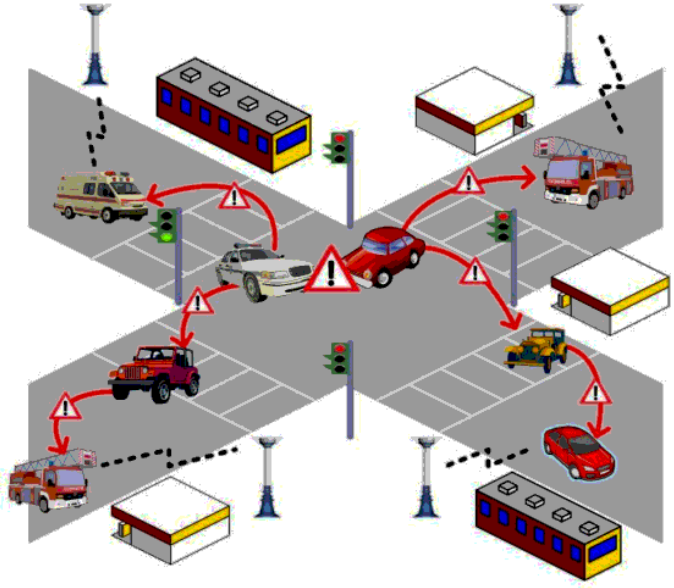
Overview

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

Vehicular Ad-Hoc Networks (VANET)

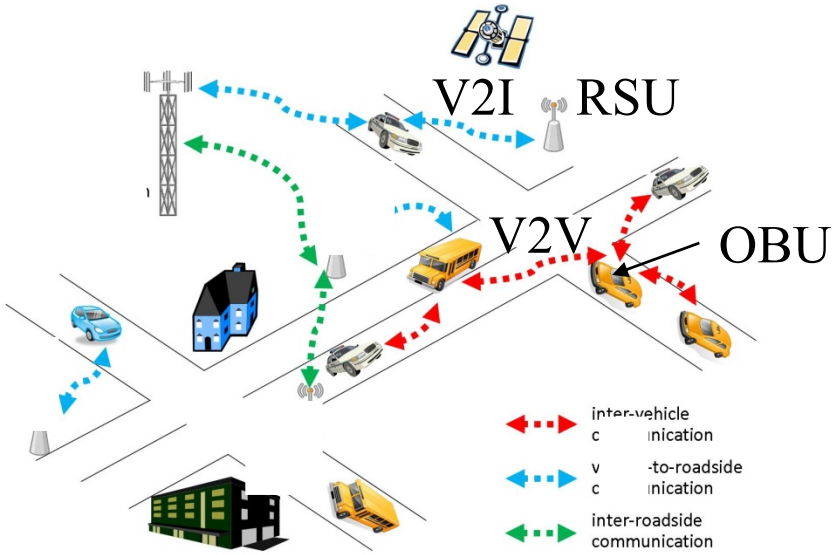
- Dynamic Topology with nodes moving at a fast speed
- More processing power, storage, and energy than handhelds
- Location based information: Accidents ahead
- Delay constraint
- Varying environments: City streets with tall buildings vs. open high-way roads
- Sensors: GPS, Speed, Proximity, engine sensor,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

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

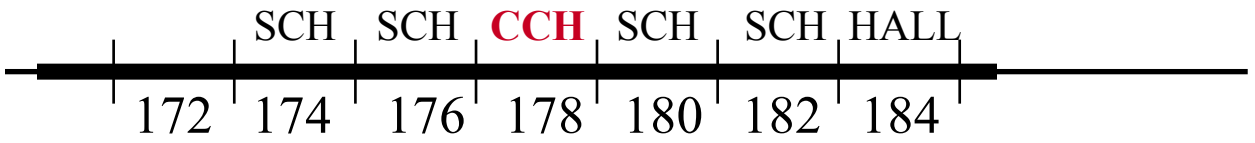
- **Broadcast**: Traffic, weather, emergency, road conditions, …
- **Geocast**: Within an area. Accidents.
- **Forwarding**: Point-to-point via multi-hop
- **Clustering**: Within a specified group. Police, Fire, Safety,
- **Beaconing**: Periodic exchange of information. Receivers integrate received info 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.

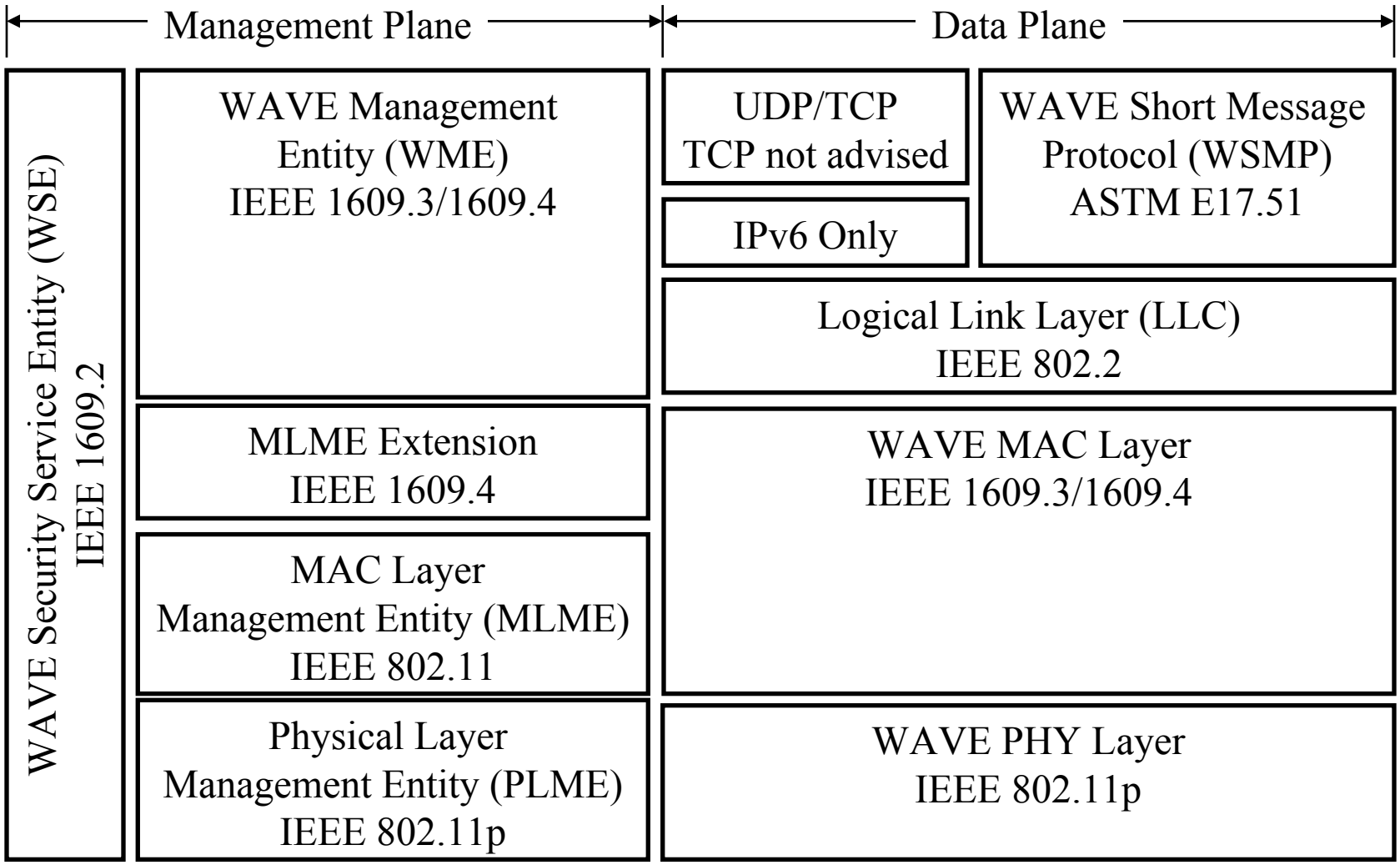
DSRC Spectrum

- 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)



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

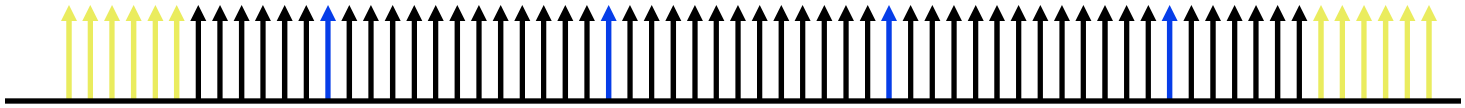


DSRC Protocol Components (Cont)

- 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
Number of Subcarriers	64	64
Data Subcarriers	48	48
Pilot Subcarriers	4	4
Channel Width	20 MHz	10 MHz
Symbol Duration	4 us	8 us
Guard Time	0.8 us	1.6 us
FFT Period	3.2 us	6.4 us
Preamble	16 us	32 us

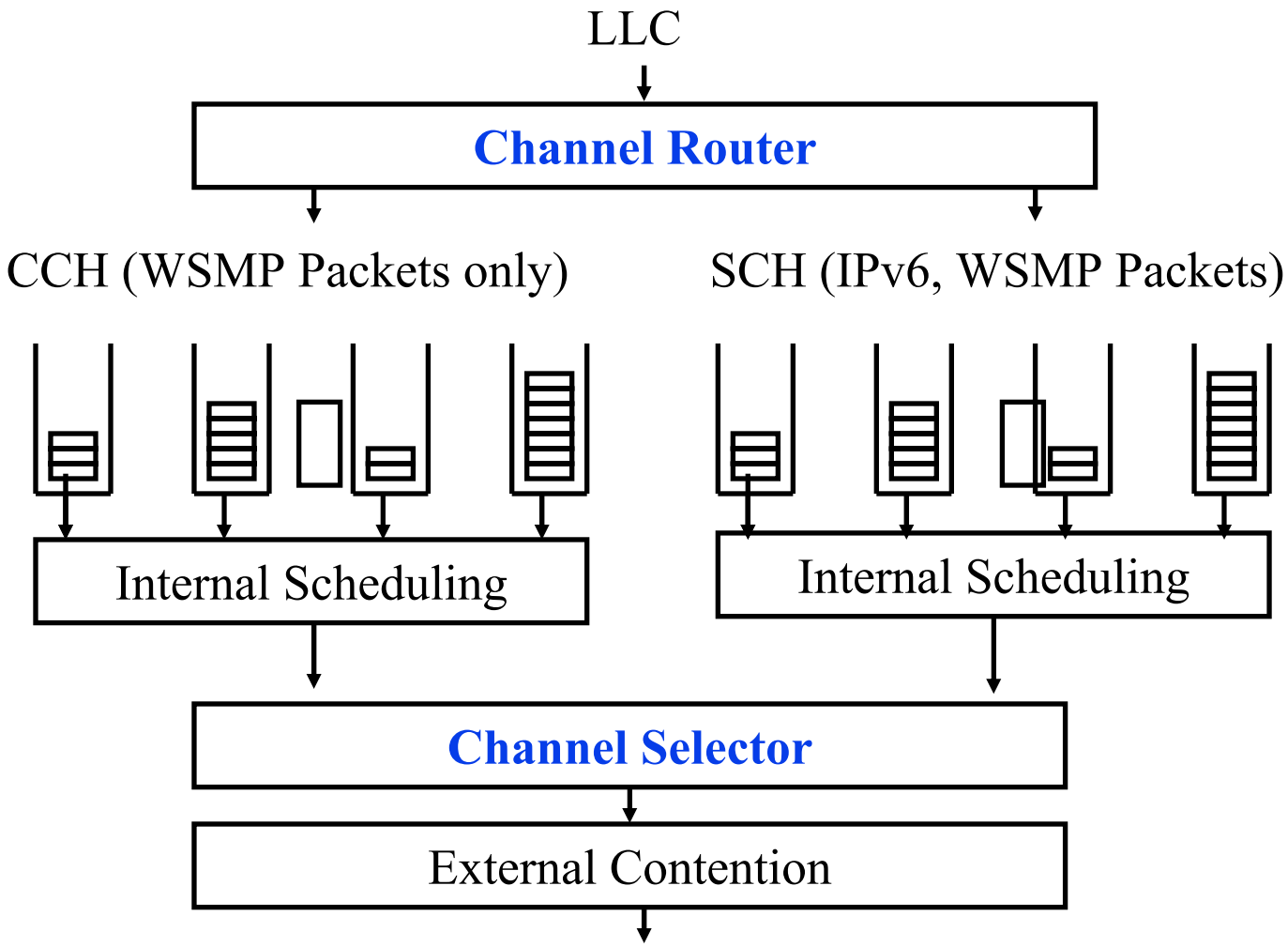
DSRC Devices

- **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



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

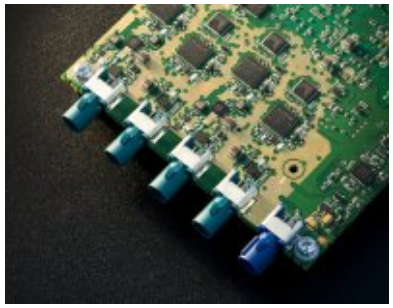
- **Outside the context of a BSS (OCB)** Mode:
  - Stations do not have to be a member of a BSS to transmit
  - A WAVE device can send a WSMP message to a broadcast address on CCH
  - Another WAVE device can respond to this WSMP message on the CCH
  - No BSS advertisement or synchronization
  - Timing 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

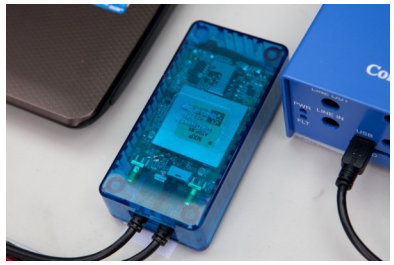
- Arada Systems: OBU and RSU
- Cohda Wireless: WAVE-DSRC Radio
- NXP: Software Defined Radios for Cohda's radios
- Unex: OBUs
- Ittiam: HDL implementation (IP)
- Card Access Engineering: Product designs
- LITEPOINT: Test platform
- Rohde & Schwarz: Spectrum analyzers and signal generators

OBU

RSU



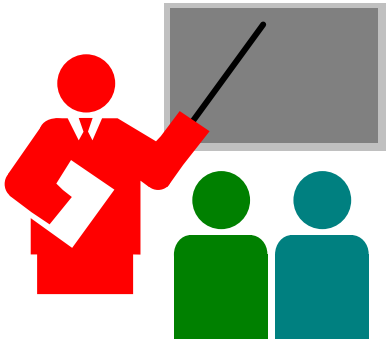
Radio



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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Introduction to 60 GHz millimeter Wave Gigabit Wireless Networks,
http://www.cse.wustl.edu/~jain/cse574-16/j_07sgh.htm

Internet of Things,
http://www.cse.wustl.edu/~jain/cse574-16/j_10iot.htm

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