VII/DSRC Protocols Overview

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5.9 GHz DSRC/WAVE System Objectives

- Leverage existing technology
  - E.g., 802.11
- Future-proof technology
  - E.g., IPv6
- Account for freeway-speed units
  - Short and intermittent mobile-roadside connectivity
- Provide mobile-mobile as well as mobile-roadside communication
  - Support a range of traffic types including high priority/low latency and general Internet
- Provide security
  - ECC used for signing and authentication

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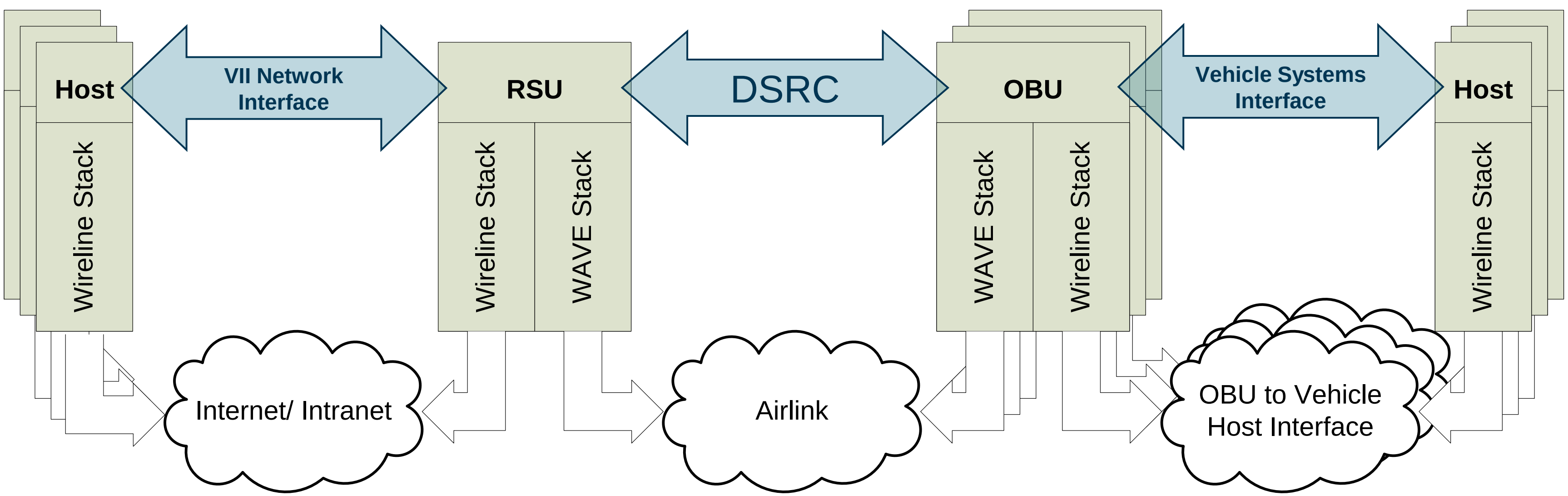
System Architecture

- The DSRC portion of the RSE is the Road Side Unit (RSU)
  - Interconnects DSRC Networks with VII Networks
- The DSRC portion of the OBE is the On Board Unit (OBU)
  - Interconnects Vehicle Systems with DSRC Networks



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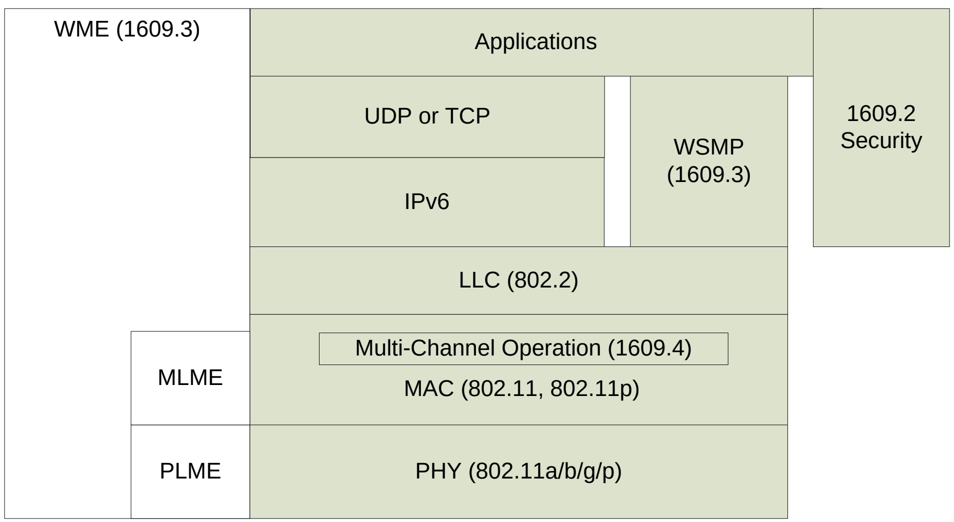
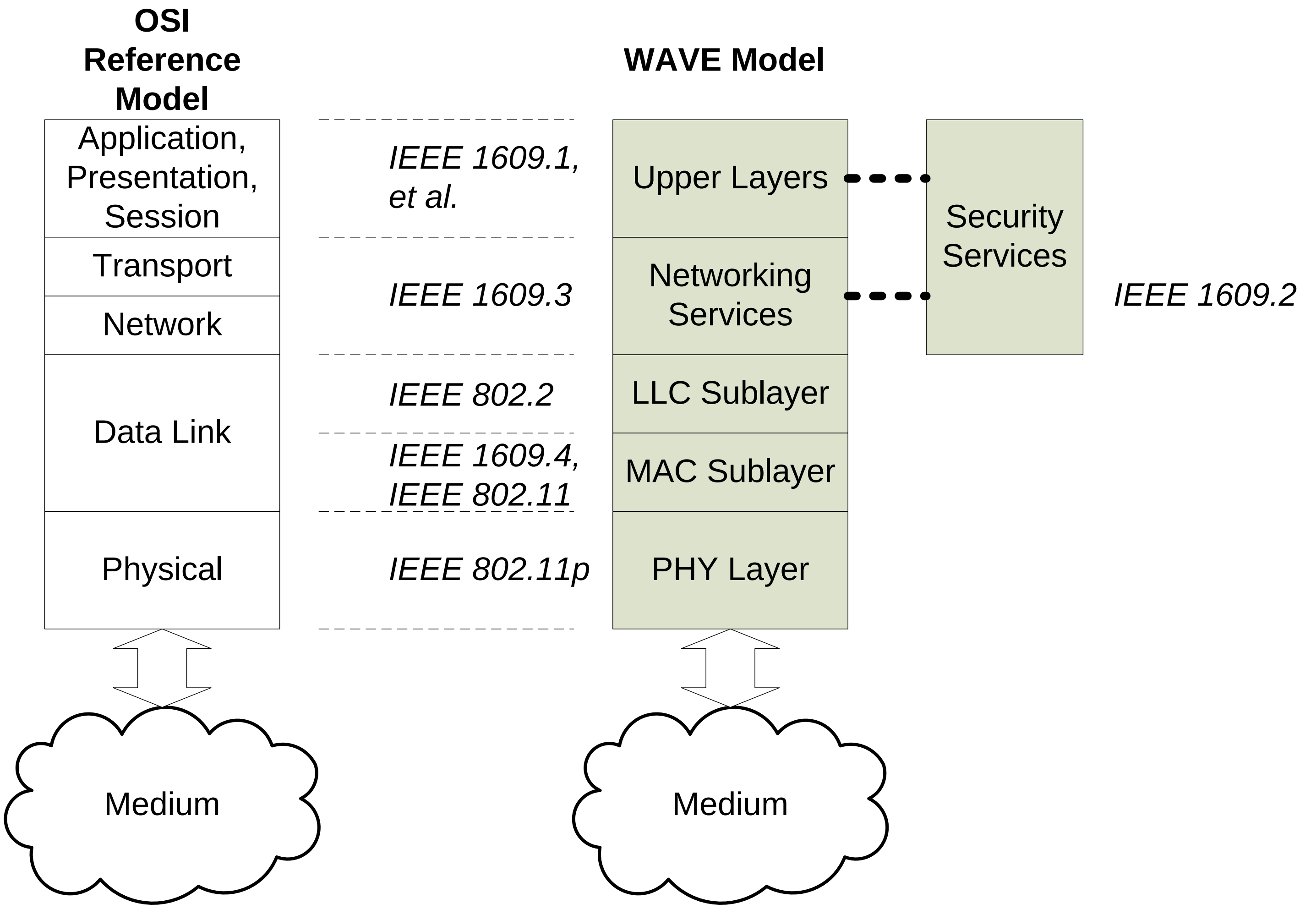
Protocol Architecture Overview

- Open Systems Interconnection Based DSRC Protocol Stack



Key:
WSMP: WAVE Short Message Protocol
UDP: User Datagram Protocol
TCP: Transmission Control Protocol
IPv6 Internet Protocol Version 6
LLC: Logical Link Control
MAC: Medium Access Control
MLME: MAC Layer Management Entity
PHY: Physical Layer
PLME: Physical Layer Management Entity
WME: WAVE Management Entity

5.9 GHz DSRC/WAVE Standards



5.9 GHz DSRCWAVE Standards

- IEEE 1609.2: 5.9 GHz Intelligent Transportation System (ITS) Radio Service Security
  - Defines 5.9 GHz DSRC Security
    - Privacy, Confidentiality and Anonymity
- IEEE 1609.3: WAVE Networking Services
  - Provides description and management of the DSRC Protocol Stack
    - Application interfaces
    - Network configuration management
    - WAVE Short Message (WSM) transmission and reception

Standards (cont'd)

- IEEE 1609.4: WAVE Multi-Channel Operation
  - Provides DSRC frequency band coordination and management
    - Manages Lower Layer usage of the seven DSRC channels
    - Integrates tightly with IEEE 802.11p
- IEEE 802.11p: Wireless LAN Medium Access Control (MAC) and physical layer (PHY) specifications: Wireless Access in Vehicular Environments (WAVE)
  - Defines the Lower Layers of the communications stack
    - Radio wave forms and wireless medium access procedures

Current Standards Status

- 802.11p recently passed letter ballot
- 1609 family implemented and in trial use phase
  - Vehicle Infrastructure Integration (VII) initiative
  - Standards valid approximately through 2008
  - Revision process is under way
  - Resource Manager (1609.1) not used in current TechnoCom offering
    - Little industry interest

MAC and PHY

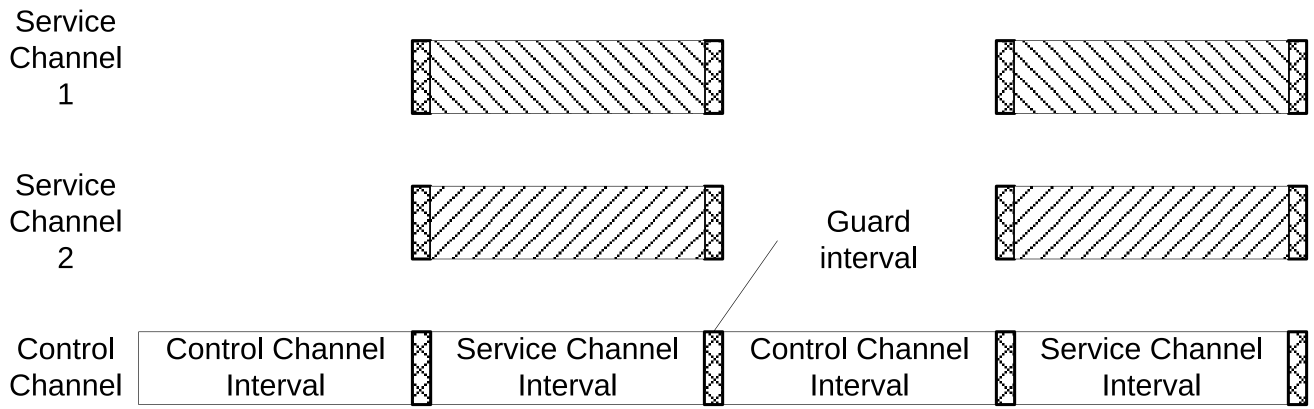
- 802.11p defines the Physical and MAC layer for a single channel system
  - Uses Orthogonal Frequency Division Multiplexing (OFDM)
  - Uses basic EDCA medium access mechanism to support priority queuing
- 1609.4 defines the multi-channel operation
  - Channel switching mechanism between control and service channels

IEEE 802.11p

- Defines band use at 5.9 GHz with 10 and 20 MHz channels
- Permits operation without Authentication and Association
  - Allows access to a Distribution System (e.g. Ethernet based LAN) without the traditional Association based process
    - To/From DS bits can be set to 1
    - Reduces latency related to link establishment

Channel Switching

- Default receive on predefined Control Channel
- Switch to a Service Channel when participating in a WAVE Basic Service Set (WBSS)
- Control and Service Channel intervals are 50 ms



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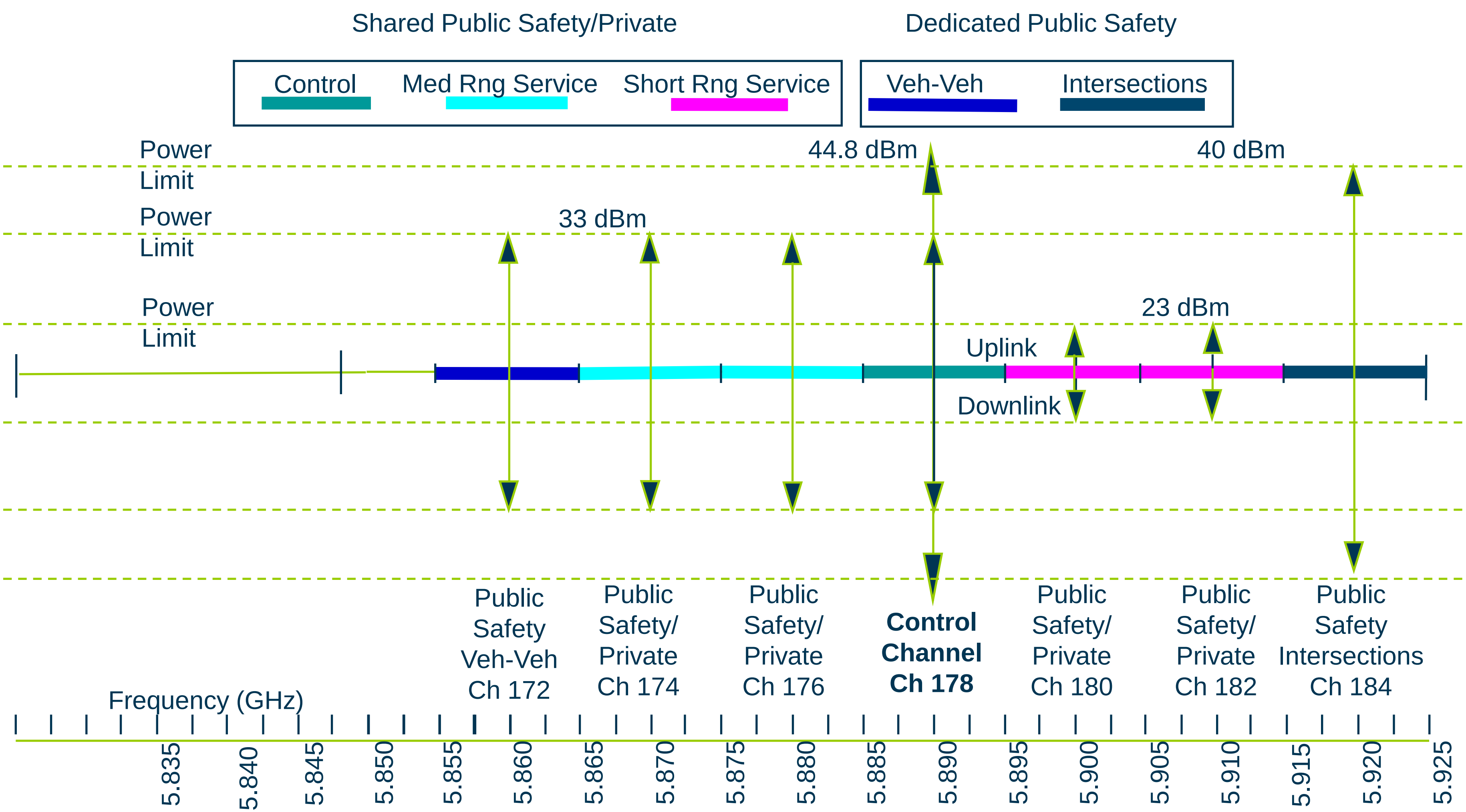
Typical Band Use Plan in the US



Messaging and Network Services

- IEEE 1609.3 Defines how to use IPv6 and the WAVE Short Message Protocol (WSMP)
  - WSMP may be used on both the control and service channels
  - IPv6 can only be used on service channels

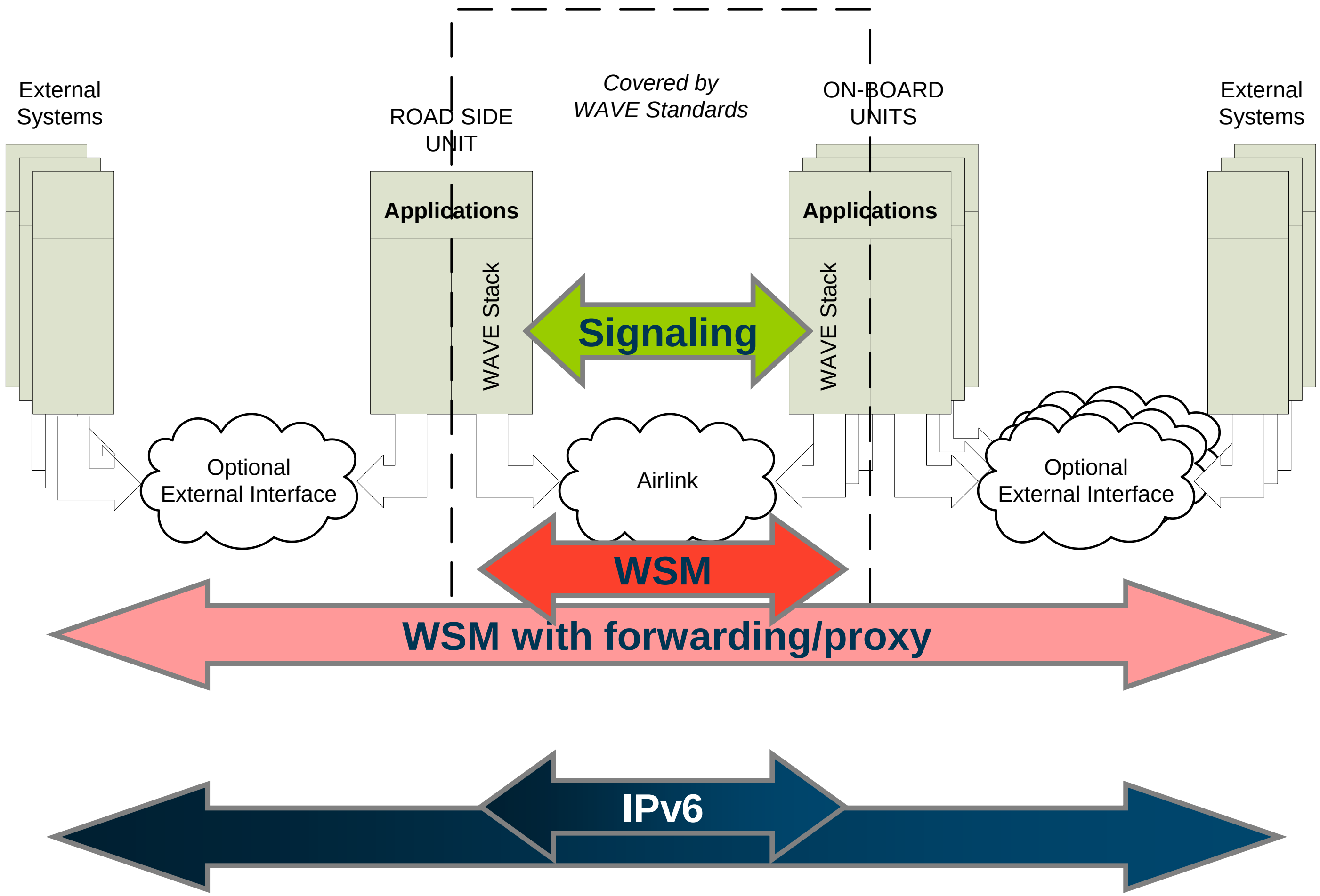
Types of DSRC Data Communication

- WAVE Short Message (WSM)
  - Useful for broadcast applications and applications that do not require infrastructure or extensive routing and addressing mechanisms
    - Does not require continuous access to the VII network infrastructure
    - Facilitates the majority of vehicle to vehicle safety communications
  - Primarily supports the instant exchange of safety information, generally localized to a collection of two or more vehicles or between a specific RSU and vehicles (OBUs) nearby
    - E.g. Intersection Collision Avoidance, Traffic Signal Warning, Emergency Electronic Brake Lights

Types of DSRC Data Communication

- Internet Protocol (IPv6) Datagrams
  - Internet Protocol is the most common means for end-to-end routing of information through an extensive infrastructure network such as VII
    - Facilitates VII network build-out out using COTS equipment
    - Provides robust mechanisms for network addressing and network management
  - Supports exchange of safety and other content provider data over a rapidly established network
    - E.g. Traffic Information, Electronic Payment Systems (parking lots or electronic tolls) and other Applications

Scope of User Communications



Service Identification

- PSC is a multi-byte field with PSID-specific format
- OBU/User identifies services of interest by matching PSID and PSC
- PSID and PSC is used in the WAVE Service Advertisement and the WSMP header

Communication in the Absence of a WBSS

- WSMs can be transmitted on the control channel in the absence of a WBSS
- Use case examples
  – SPAT messages (signal violation warning), in vehicle signing messages, basic safety message
- Service channel usage requires “joining” a WBSS

Communication within a WBSS

- Using a service channel requires “joining” a WBSS via the reception of a WAVE Service Advertisement (WSA)
  - Provider transmits WSA (contained in 802.11 Beacon)
  - User receives WSA and joins WBSS based on matching PSID/PSC
    - Each PSID/PSC pair may correspond to a unique service (e.g. PSID → “electronic payment system”, PSC → “parking”, “tolling”, etc.)
    - Used for general IP based services
    - Other use cases include transmission/reception of the GID message

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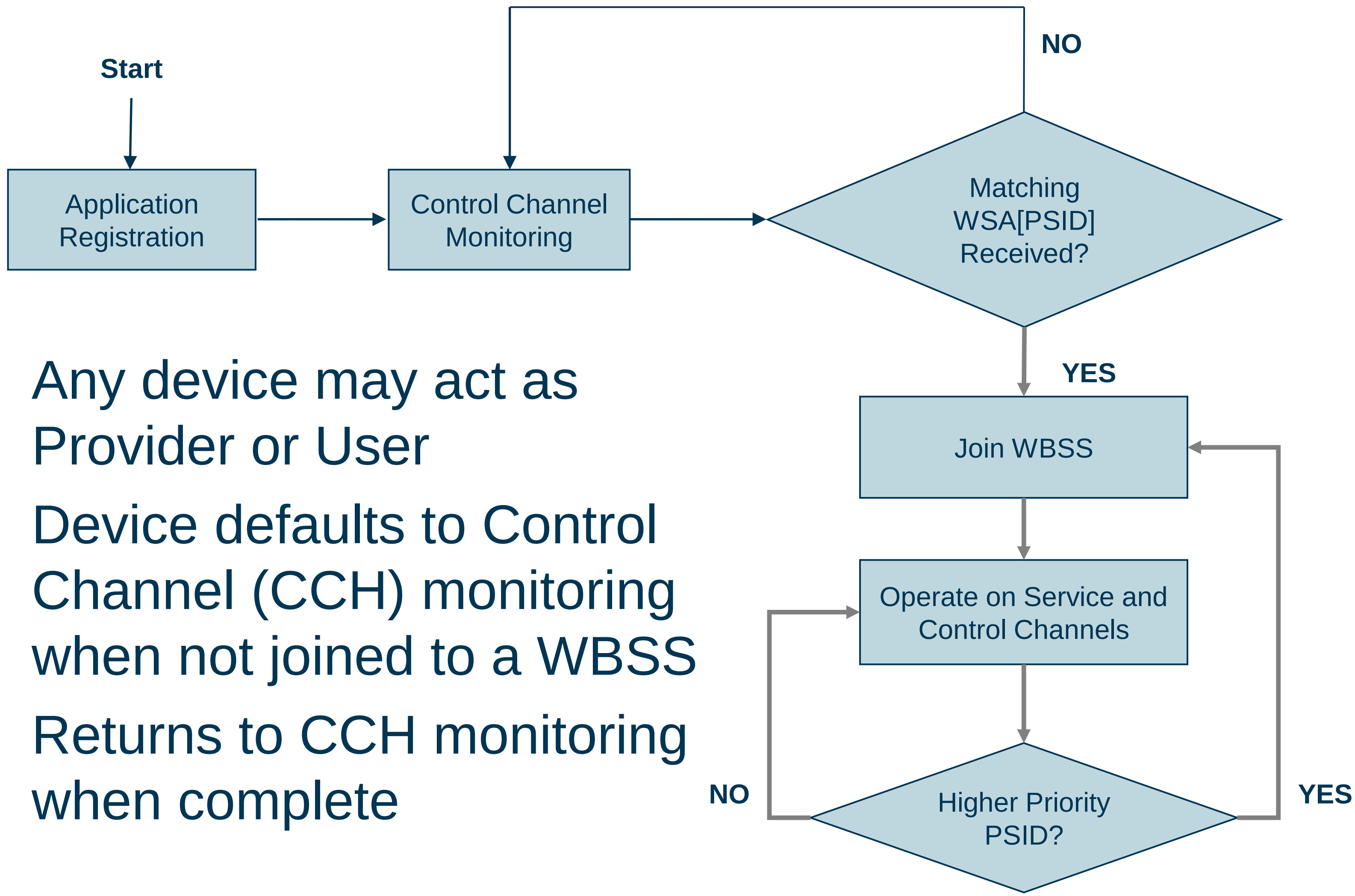
Simplified User-Side Process Flow



- Any device may act as Provider or User
- Device defaults to Control Channel (CCH) monitoring when not joined to a WBSS
- Returns to CCH monitoring when complete

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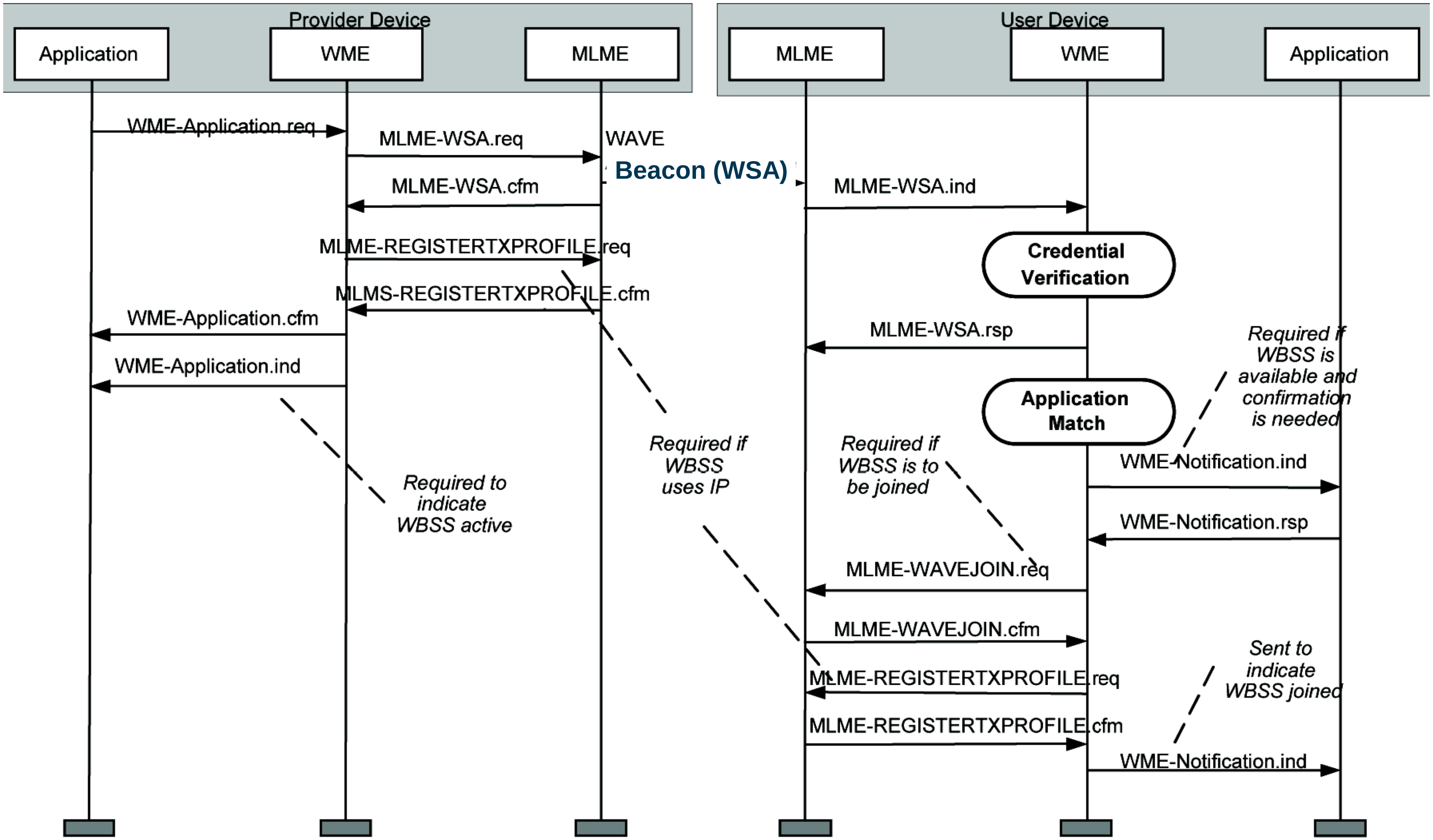
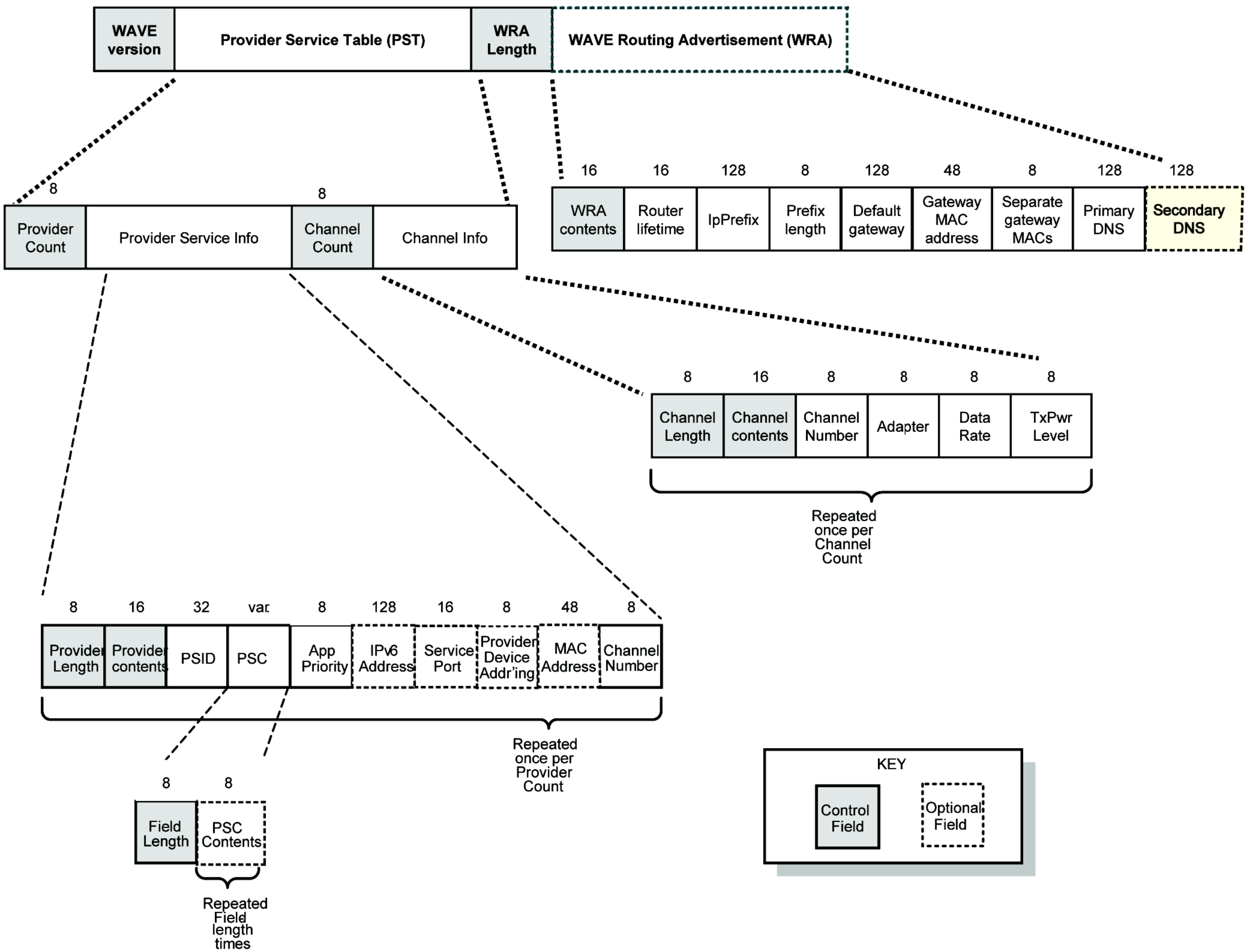
Communication within a WBSS



WSA Format



WAVE version
Provider Service Table (PST)
WRA Length
WAVE Routing Advertisement (WRA)
8
Provider Count
Provider Service Info
8
Channel Count
Channel Info
16 16 128 8 128 48 8 128 128
WRA contents
Router lifetime
IpPrefix
Prefix length
Default gateway
Gateway MAC address
Separate gateway MACs
Primary DNS
Secondary DNS
8 16 8 8 8 8
Channel Length
Channel contents
Channel Number
Adapter
Data Rate
TxPwr Level
Repeated once per Channel Count
8 16 32 var 8 128 16 8 48 8
Provider Length
Provider contents
PSID
PSC
App Priority
IPv6 Address
Service Port
Provider Device Addr'ing
MAC Address
Channel Number
Repeated once per Provider Count
8 8
Field Length
PSC Contents
Repeated Field length times
KEY
Control Field
Optional Field

Options for Service Channel Communications

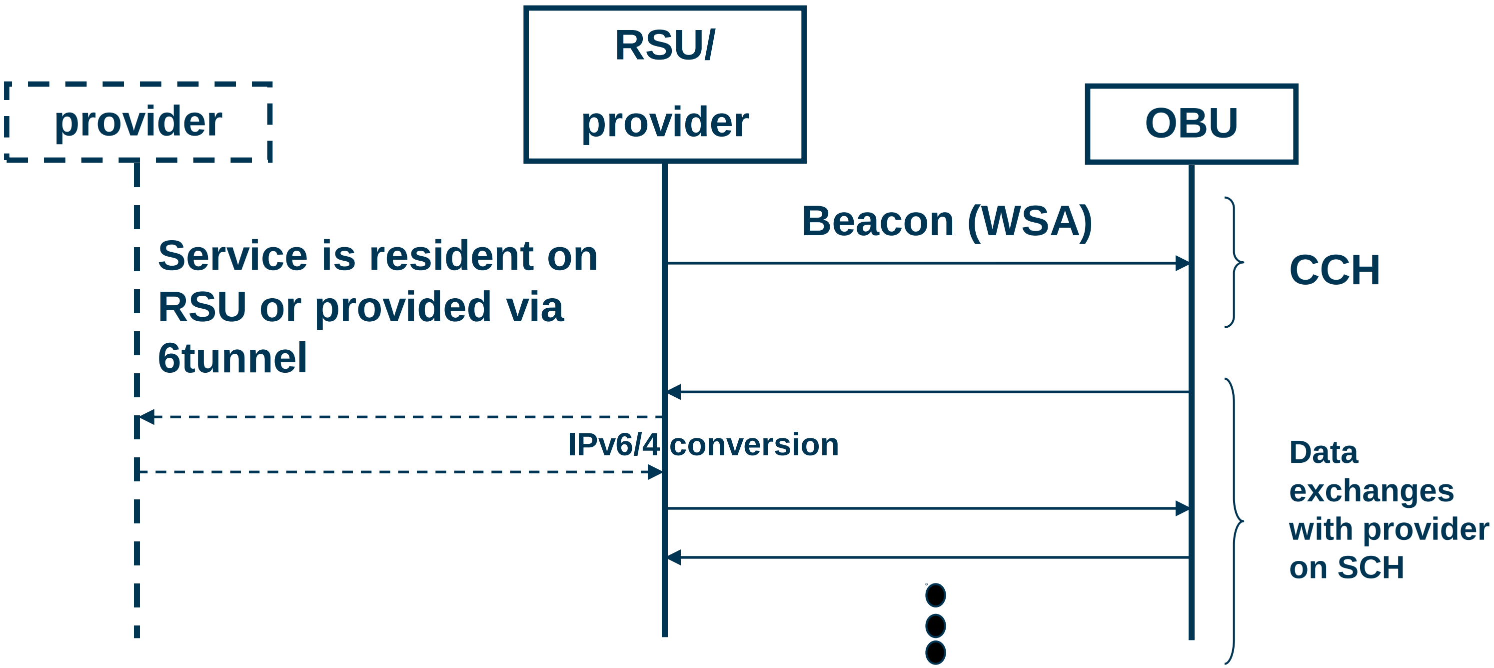
- Example: an PSID indicating “General Internet” could contain PSC value indicating the backhaul uplink/downlink data rates, so OBE could decide whether to connect
- Example: could have PSC indicating network identifier for true Internet, VII Network or Private Network

Option 1

- IP-Based services that require IPv6 addressing and routing information inside the WAVE Service Advertisement (Beacon Frame contains a WAVE Service Advertisement and optional WAVE Router Advertisement)

- Need Destination Address
- Service may reside on the RSU (option 1A) or supported via 6 to 4 tunnel capability
- Service may be external to the RSU (option 1B: RSU is a gateway)
  - WAVE Router Advertisement required

Option 1A (WRA not required)



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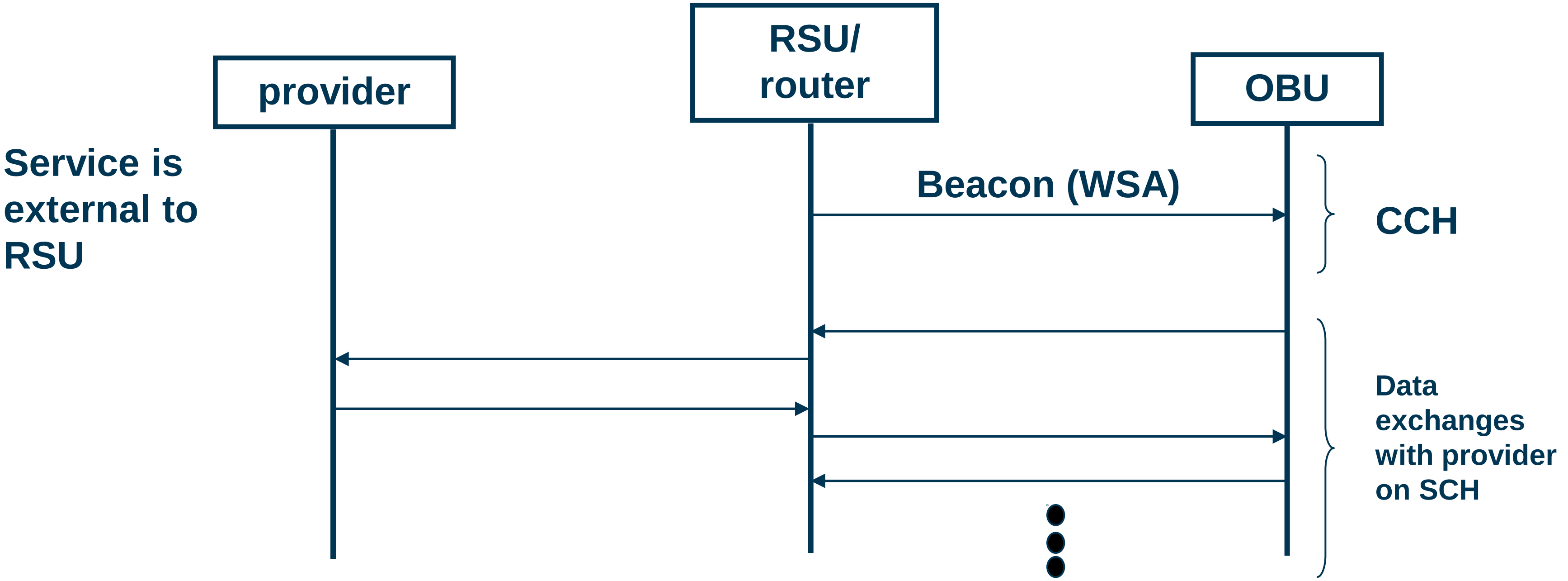
Option 1B (WRA required)

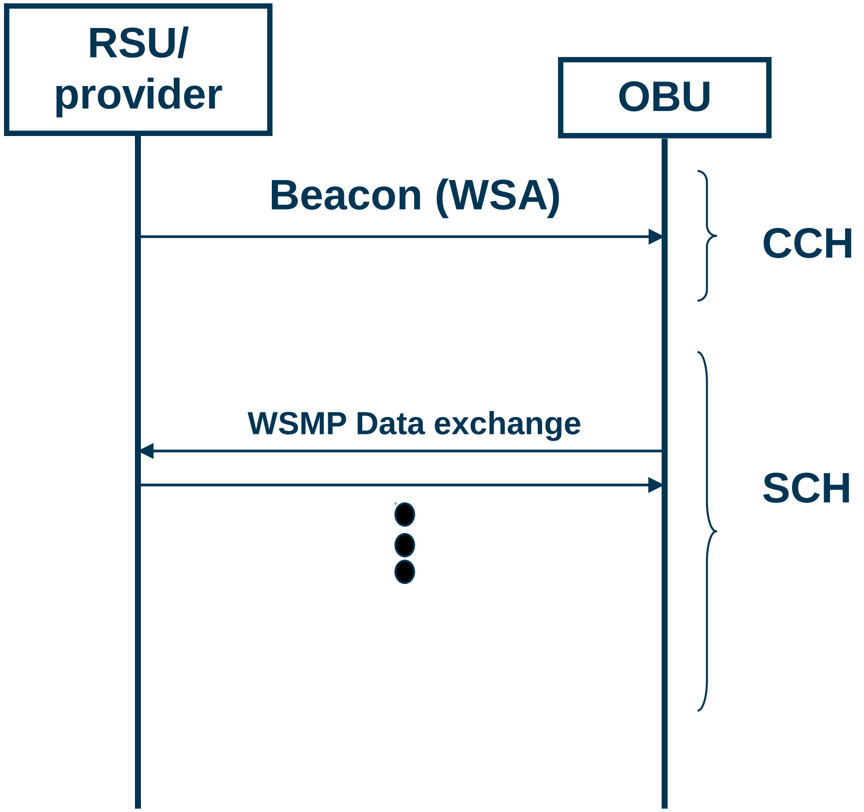


Option 2

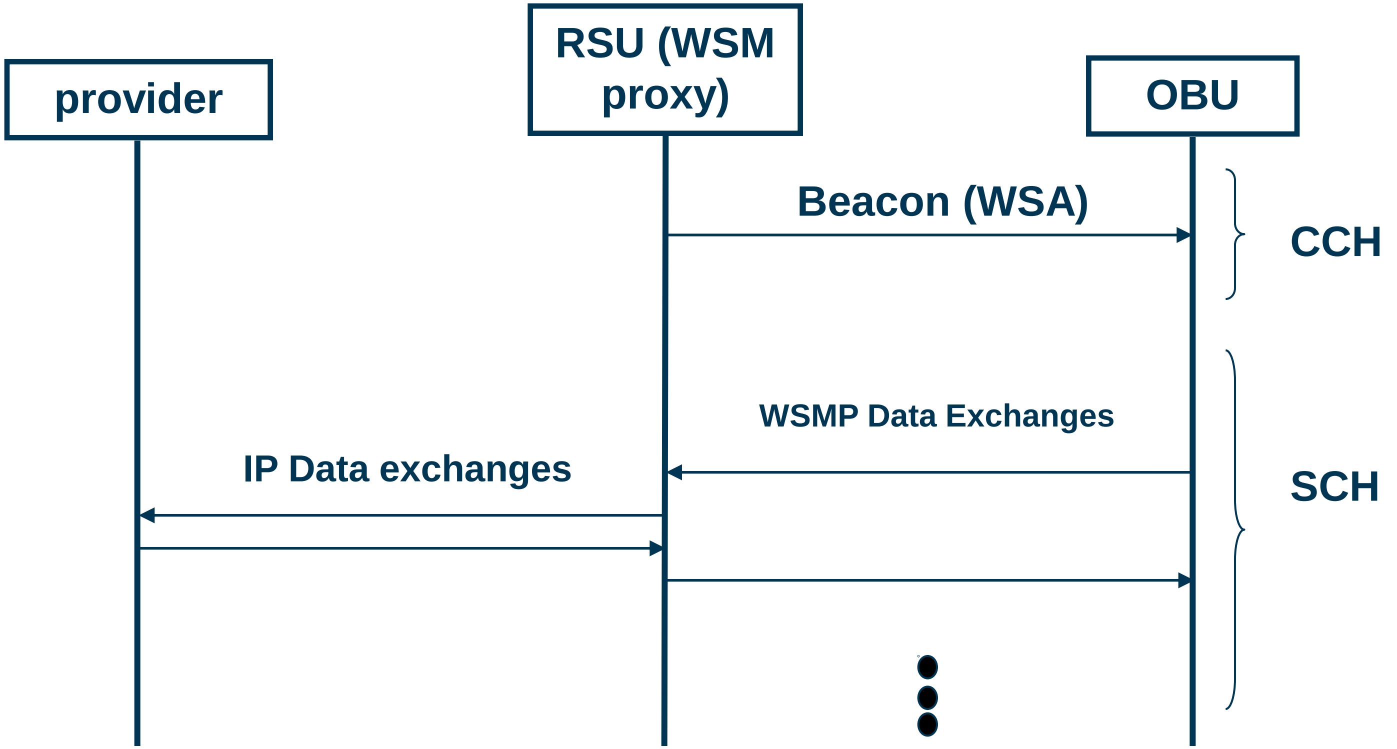
- WSMP-Based services without IPv6 addressing and routing information inside the Beacon Frame containing a WAVE Service Advertisement (WSA)

- No IPv6 addressing information in PST
- No WRA required
- RSU can act as WSMP to IP proxy for external services
  - WSMP cannot be used directly on backhaul

Option 2A



Option 2B

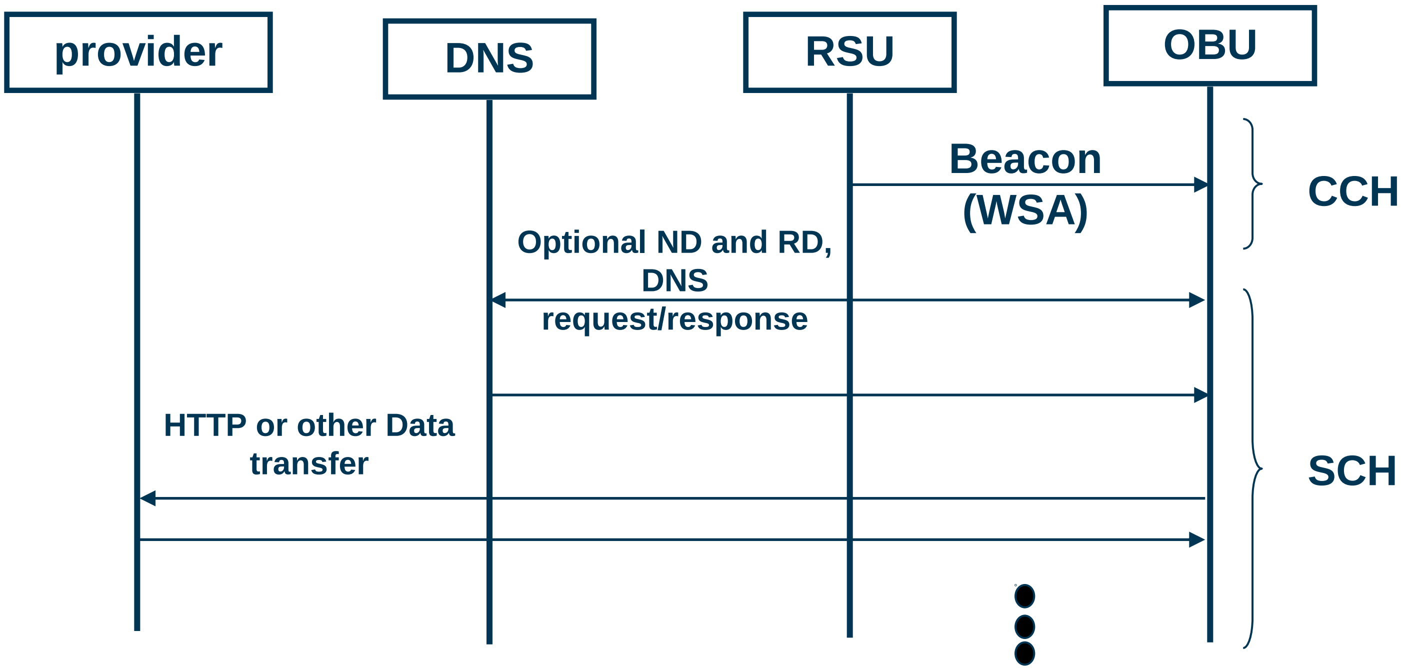

provider
RSU (WSM proxy)
OBU
Beacon (WSA)
CCH
WSMP Data Exchanges
IP Data exchanges
SCH

Option 3

- URL-Based Services
- Can use WRA for DNS configuration, or traditional discovery may be used
  - – OBU receives DNS address in WRA thru RSU, or use neighbor and router discovery
    - ND and RD approach is standard IPv6 solution, but adds additional service channel overhead latency
  - – OBU makes DNS request
  - – DNS responds to OBU after lookup

Option 3

URL Based Transaction



Current TechnoCom WAVE Stack Implementation

- PHY, MAC, WME, WSMP and IPv6 development complete
  - Working implementation of 802.11 and 1609
- Service Channel (WBSS) Options
  - Option 1: Complete
  - Option 2A: Complete
  - Option 2B: In development
  - Option 3: Complete, optional ND and RD not yet supported (WRA is currently required)

Detailed Simulation Examples

- EDCA performance optimization
- TCP/IP performance optimization (available via white paper)

Simulation Platform

- 2.8 GHz, 1GB RAM Pentium PC
- Microsoft Windows™ 2000 SP4
- Cygwin (GNU Windows™ based Unix™ emulator)
- The Network Simulator research tool, version 2.27 (NS-2)
- Empirical propagation model based on testing in San Francisco

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NS-2 802.11 MAC and PHY Settings

Characteristics	**802.11p Value**	**Comments**
SlotTime	13μs	
SIFSTime	32μs	Doubled from standard 802.11a value
CWMin	15	Same as standard 802.11a value
CWMax	1023	Same as standard 802.11a value
Preamble Length	40μs	Doubled from standard 802.11a value
PLCP Header Length	8μs	Doubled from standard 802.11a value
MAC Short Retry Limit	7	Determines max number of retransmissions
RTS/CTS Threshold	3000	(RTS/CTS disabled)

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EDCA Performance - General Simulation Setup

- OBUs are arranged in a rectangular array in simulated space
- Each OBU broadcasts messages of a fixed AC on the CCH every 100 ms
- Each OBU is within range of every other OBU

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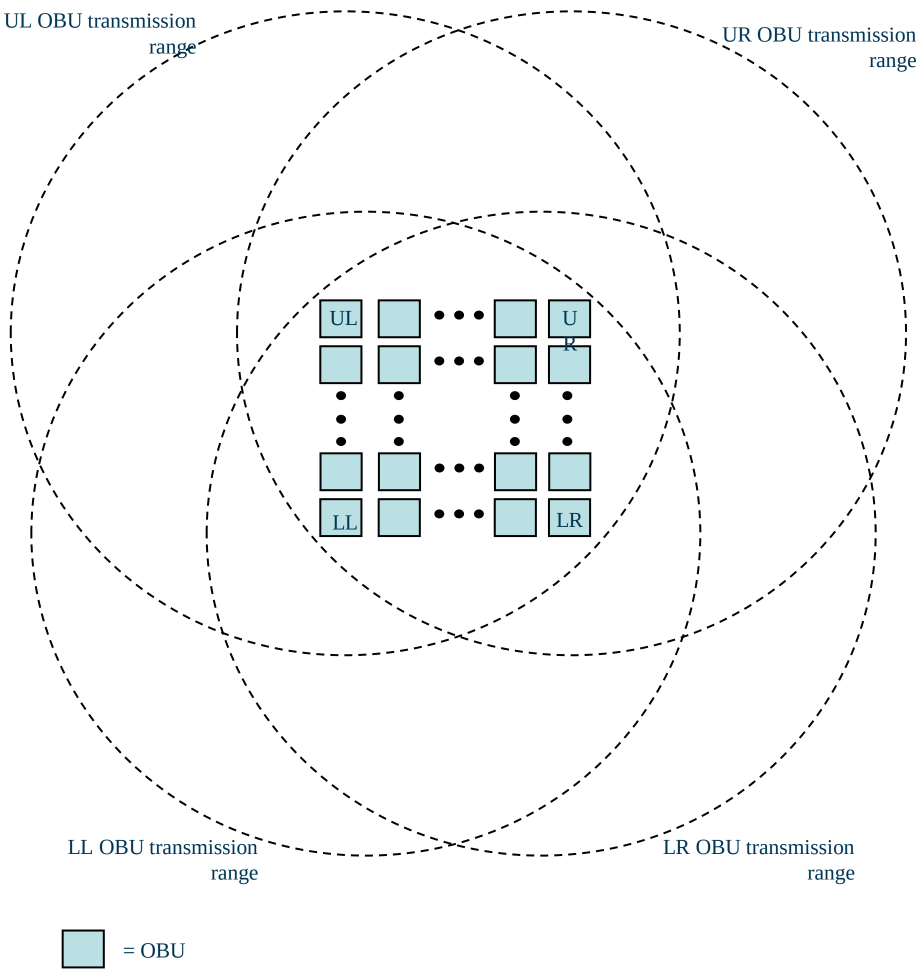
General Simulation Setup



Scenario 1: EDCA Parameter Optimization

- Addresses 11p draft comments such as 418
- Simulations were performed in 12/2006 for VIIC Proof of Concept system
- 150 simulated OBUs in the array
- Vary AIFSN, CWmin, CWMax
- Compare message delivery success rate (MDSR) and packet latency for each AC
- Optimization criteria
  - Higher-priority messages should be received faster
  - Packet latencies should be minimum

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Scenario 1 Results

Settings					Results Message Delivery Success Rate (MDSR), Mean and Maximum Latency for each AC											
AIFSN (AC=3,2,1,0)	CWmin, CWmax				AC = 3			AC = 2			AC = 1			AC = 0		
	AC = 3	AC = 2	AC = 1	AC = 0	MDSR (%)	Mean (ms)	Max (ms)	MDSR (%)	Mean (ms)	Max (ms)	MDSR (%)	Mean (ms)	Max (ms)	MDSR (%)	Mean (ms)	Max (ms)
2,3,6,9	3,7	3,7	7,15	15, 1023	96	0.9	1.8	96	0.9	1.9	92	1.5	4.5	81	3.3	12.7
2,4,7, 10	3,7	3,7	7,15	15, 1023	100	0.9	1.2	100	0.8	1.8	90	1.2	3.7	75	2.4	11.5
2,3,4,5	3,7	3,7	7,15	15, 1023	96	0.8	1.2	92	1.0	1.8	89	1.1	3.9	80	1.8	8.3
2,3,6,9	7,15	7,15	15,31	31, 1023	97	0.8	1.3	96	0.9	1.9	91	1.5	4.2	76	3.6	14.5

200 byte packets, one OBU at AC = 3 (1%), 6 at AC =2 (4%), 23 at AC =1 (15%) and 120 at AC = 0 (80%)

Scenario 1 Results

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AIFSN (AC=3,2,1,0)	CWmin, CWmax				AC = 3			AC = 2			AC = 1			AC = 0		
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2,3,6,9	3,7	3,7	7,15	15, 1023	100	1.3	1.7	98	1.2	2.5	83	1.9	5.4	45	5.0	19
2,4,7, 10	3,7	3,7	7,15	15, 1023	100	1.2	1.8	99	1.3	2.2	84	2.0	5.0	41	6.1	18
2,3,4,5	3,7	3,7	7,15	15, 1023	88	1.3	2.4	85	1.4	3.3	75	2.3	6.0	53	4.5	15
2,3,6,9	7,15	7,15	15,31	31, 1023	95	1.3	2.5	92	1.4	3.3	84	2.6	7.0	42	10	28

400 byte packets, one OBU at AC = 3 (1%), 6 at AC =2 (4%), 23 at AC =1 (15%) and 120 at AC = 0 (80%)

Scenario 1 Results

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2,4,7, 10	3,7	3,7	7,15	15, 1023	100	0.7	1.2	100	0.9	1.3	95	1.0	2.2	73	2.5	10.4
2,3,4,5	3,7	3,7	7,15	15, 1023	93	0.9	1.7	96	0.9	1.7	89	1.2	3.2	83	1.7	8.1
2,3,6,9	7,15	7,15	15,31	31, 1023	98	0.9	1.7	97	0.9	1.9	93	1.3	3.8	78	3.3	15.0

200 byte packets, 3 OBUs at AC = 3 (2%), 5 at AC =2 (3%), 7 at AC =1 (5%) and 135 at AC = 0 (90%)

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Scenario 1 Results

Settings					Results Message Delivery Success Rate (MDSR), Mean and Maximum Latency for each AC											
AIFSN (AC=3,2,1,0)	CWmin, CWmax				AC = 3			AC = 2			AC = 1			AC = 0		
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2,3,6,9	3,7	3,7	7,15	15, 1023	100	1.2	1.8	96	1.3	2.6	86	1.8	5.4	46	5.2	18
2,4,7, 10	3,7	3,7	7,15	15, 1023	100	1.2	1.8	100	1.3	1.9	86	1.8	3.8	44	5.6	16
2,3,4,5	3,7	3,7	7,15	15, 1023	95	1.1	2.2	83	1.5	2.7	76	2.2	6.0	53	4.4	15
2,3,6,9	7,15	7,15	15,31	31, 1023	94	1.3	2.5	92	1.3	2.7	84	2.5	6.3	46	9.2	27

400 byte packets, 3 OBUs at AC = 3 (2%), 5 at AC =2 (3%), 7 at AC =1 (5%) and 135 at AC = 0 (90%):

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Scenario 1 Results

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2,4,7, 10	3,7	3,7	7,15	15, 1023	91	0.9	1.7	91	1.0	2.7	86	1.4	5.7	68	3.2	12.5
2,3,4,5	3,7	3,7	7,15	15, 1023	92	0.8	1.7	90	0.9	2.3	85	1.2	4.7	80	1.9	10.7
2,3,6,9	7,15	7,15	15,31	31, 1023	95	0.9	2.3	94	0.9	3.0	86	1.8	7.8	73	4.3	20.8

200 byte packets, 15 OBUs at AC = 3 (10%), 30 at AC =2 (20%), 45 at AC =1 (30%) and 60 at AC = 0 (40%)

Scenario 1 Results

Settings					Results Message Delivery Success Rate (MDSR), Mean and Maximum Latency for each AC											
AIFSN (AC=3,2,1,0)	CWmin, CWmax				AC = 3			AC = 2			AC = 1			AC = 0		
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2,3,6,9	3,7	3,7	7,15	15, 1023	98	1.2	3.4	82	1.5	4.2	66	2.6	10	33	5.6	22
2,4,7, 10	3,7	3,7	7,15	15, 1023	84	1.4	4.1	90	1.5	3.9	70	2.7	14	29	6.3	32
2,3,4,5	3,7	3,7	7,15	15, 1023	85	1.4	3.4	77	1.6	4.8	66	2.6	8.8	45	4.8	21
2,3,6,9	7,15	7,15	15,31	31, 1023	87	1.6	4.0	85	1.7	5.0	66	4.1	15	36	11	36

400 byte packets, 15 OBUs at AC = 3 (10%), 30 at AC =2 (20%), 45 at AC =1 (30%) and 60 at AC = 0 (40%):

Scenario 1 Results

Settings					Results Message Delivery Success Rate (MDSR), Mean and Maximum Latency for each AC											
AIFSN (AC=3,2,1,0)	CWmin, CWmax				AC = 3			AC = 2			AC = 1			AC = 0		
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2,4,7, 10	3,7	3,7	7,15	15, 1023	93	0.9	2.3	93	1.0	2.9	83	1.6	6.9	74	2.8	23.3
2,3,4,5	3,7	3,7	7,15	15, 1023	92	0.8	2.2	90	0.9	3.0	87	1.2	5.1	79	2.1	12.8
2,3,6,9	7,15	7,15	15,31	31, 1023	90	1.0	3.6	90	1.0	4.6	87	2.0	12.5	81	3.9	21.8

200 byte packets, 37 OBUs at AC = 3 (25%), 38 at AC =2 (25%), 37 at AC =1 (25%) and 38 at AC = 0 (25%)

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Scenario 1 Results

Settings					Results Message Delivery Success Rate (MDSR), Mean and Maximum Latency for each AC											
AIFSN (AC=3,2,1,0)	CWmin, CWmax				AC = 3			AC = 2			AC = 1			AC = 0		
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2,4,7, 10	3,7	3,7	7,15	15, 1023	87	1.3	4.0	76	1.8	5.2	62	3.3	13	19	7.5	53
2,3,4,5	3,7	3,7	7,15	15, 1023	75	1.5	4.1	69	1.8	5.0	56	3.2	11	38	5.9	34
2,3,6,9	7,15	7,15	15,31	31, 1023	79	1.8	6.4	73	2.1	11	59	4.4	25	34	11	60

400 byte packets, 37 OBUs at AC = 3 (25%), 38 at AC =2 (25%), 37 at AC =1 (25%) and 38 at AC = 0 (25%)

Scenario 1 Conclusions

- The results verify that the parameters given in Table p4 (also the first row in each of the preceding results tables) give the best compromise among the optimization criteria.
  - Good prioritization even at low channel loading
  - Good message delivery success rate throughout the ACs
  - Reasonable packet latencies, even at high loading and low priorities

Scenario 1 Conclusions

AC	CWmin	CWmax	AIFSN	TXOP Limit OFDM PHY (WAVE mode)
AC_BK	**aCWmin = 15**	**aCWmax = 1023**	**9**	**0**
AC_BE	**(aCWmin+1)/2 – 1 = 7**	**aCWmin = 15**	**6**	**0**
AC_VI	**(aCWmin+1)/4 – 1 = 3**	**(aCWmin+1)/2 – 1 = 7**	**3**	**0**
AC_VO	**(aCWmin+1)/4 – 1 = 3**	**(aCWmin+1)/2 – 1 = 7**	**2**	**0**

Scenario 2: More than 200 Vehicles

- Simulations were performed in 5/2007 to address 11p draft comments such as 415, 420, etc.
- Set AIFSN, CWmin, CWMax as in Table p4
- 200 byte packets
- Vary the total number of simulated OBUs in the array
- Same number of OBUs for each AC (i.e. 25% of the OBUs are broadcasting highest priority messages)

Scenario 2 Results

Number of vehicles	Highest priority (AC = AC_VO) messages		
	MDSR (%)	Mean latency (ms)	Max latency (ms)
250	**85**	**0.4**	**1.3**
300	**78**	**0.4**	**1.5**
350	**75**	**0.5**	**1.7**

Scenario 2 Conclusions

- The results verify that the parameters given in Table p4 give good results for more than 200 vehicles
  - Message delivery success rate is good, despite small contention window
  - Packet latencies are good