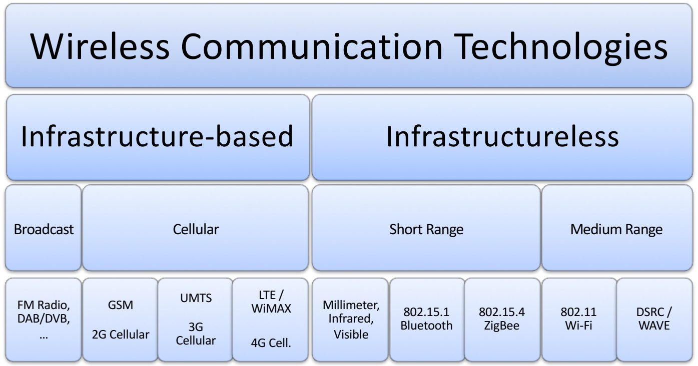
Technology

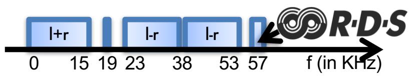
Communication paradigms and media



[1] Dar, K. et al., "Wireless Communication Technologies for ITS Applications," IEEE Communications Magazine, vol. 48 (5), pp. 156-162, May 2010

Broadcast Media

- Traffic Message Channel (TMC)
  - Central management of traffic information
  - Data sources are varied
    - Federal/local/city police, road operator, radio, ...
  - Transmission in RDS channel of FM radio
    - BPSK modulated signal at 57 KHz, data rate 1.2 kBit/s
    - RDS group identifier 8A (TMC), approx. 10 bulletins per minute



[1] ISO 62106, „Specification of the radio data system (RDS) for VHF/FM sound broadcasting in the frequency range from 87,5 to 108,0 MHz"

Broadcast Media

- Traffic Message Channel (TMC)
  - Contents (ALERT-C coded):
    - Validity period
    - Re-routing required?
    - North-east or south-west?
    - Spatial extent
    - Code in event table
      - International
    - Code in location table
      - Country/region specific
      - Must be installed in end device
  - No (real) security measures

101	Standing traffic (generic)
102	1 km of standing traffic
103	2 km of standing traffic
394	Broken down truck
1478	Terrorist incident

1	Deutschland
264	Bayern
12579	A8 Anschlussstelle Irschenberg

[1] ISO 14819-1, „Traffic and Traveller Information (TTI) - TTI messages via traffic message coding - Part 1: Coding protocol for Radio Data System (RDS-TMC) using ALERT-C"
[2] ISO 14819-2, „Traffic and Traveller Information (TTI) - TTI messages via traffic message coding - Part 2: Event and information codes for Radio Data System - Traffic Message Channel (RDS-TMC)"

Broadcast Media

- Traffic Message Channel (TMC)
  - Regional value added services
    - *Navteq Traffic RDS* (U.S.), *trafficmaster* (UK), *V-Trafic* (France)
  - Ex: TMCpro
    - Private service of Navteq Services GmbH
    - Financed by per-decoder license fee
    - Data collection and processing
      - Fully automatic
      - Deployment of 4000+ sensors on overpasses
      - Use of floating car data
      - Downlink from traffic information centers
    - Event prediction
      - Expert systems, neuronal networks
      - Early warnings of predicted events
    - Restricted to major roads

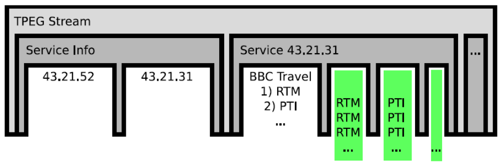
Broadcast Media

- Transport Protocol Experts Group (TPEG)
  - Planned successor of RDS-TMC/Alert-C
  - Published April 2000
  - Principles:
    - Extensibility
    - Media independence
  - Goals:
    - Built for “Digital Audio Broadcast” (DAB)
    - Unidirectional, byte oriented stream
    - Modular concept
    - Hierarchical approach
    - Integrated security

[1] ISO 18234-x, „Traffic and Travel Information (TTI) — TTI via Transport Protocol Experts Group (TPEG) data-streams“

Broadcast Media

- Transport Protocol Experts Group (TPEG)
  - Information types defined by “TPEG Applications”
    - RTM - Road Traffic Message
    - PTI - Public Transport Information
    - PKI - Parking Information
    - CTT - Congestion and Travel-Time
    - TEC - Traffic Event Compact
    - WEA - Weather information for travelers
  - Modular concept:



Transport Protocol Experts Group (TPEG)

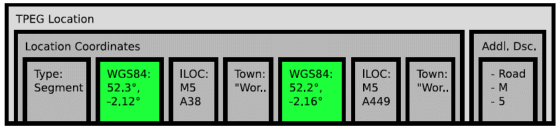
- tpegML: XML variant of regular (binary) TPEG

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<!DOCTYPE tpeg_document PUBLIC "-//EBU/tpegML/EN"
      "http://www.bbc.co.uk/travelnews/xml/tpegml_en/tpegML.dtd">
<tpeg_document generation_time="2007-09-19T07:22:44+0">
        <tpeg_message>
                <originator country="UK" originator_name="BBC Travel News"/>
                <summary xml:lang="en">M5 Worcestershire - Earlier accident
                      southbound between J5, Droitwich and J6, Worcester, heavy
                      traffic.</summary>
                <road_traffic_message>
                        <!-- ... tpeg-rtmML ... -->
                </road_traffic_message>
        </tpeg_message>
        <tpeg_message>
                <originator country="UK" originator_name="BBC Travel News"/>
                <summary xml:lang="en">A420 Oxfordshire - The Plain closed westbound
                      at the A4158 Iffley Road junction in Oxford, delays expected.
                      Diversion in operation.</summary>
                <road_traffic_message>
                        <!-- ... tpeg-rtmML ... -->
                </road_traffic_message>
        </tpeg_message>
</tpeg_document>
```

[1] ISO 24530-x, „Traffic and Travel Information (TTI) — TTI via Transport Protocol Experts Group (TPEG) Extensible Markup Language (XML)“

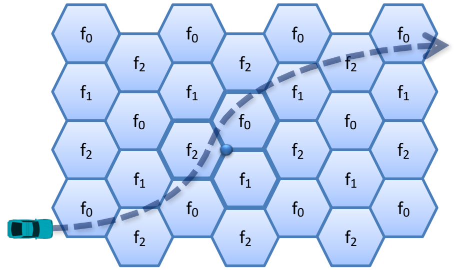
Transport Protocol Experts Group (TPEG)

- Hybrid approach to geo-referencing: one or more of
  - WGS84 based coordinates
  - ILOC (Intersection Location)
    - Normalized, shortened textual representation of street names intersecting at desired point
  - Human readable plain text
  - Code in hierarchical location table



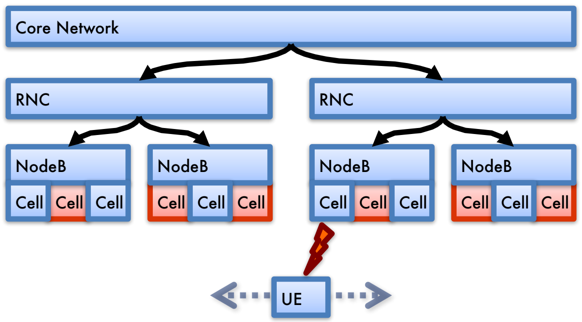
Cellular Networks

- Concept
  - Divide world into cells, each served by base station
  - Allows, e.g., frequency reuse in FDMA



Concept

- Strict hierarchy of network components



Cellular Networks

- Can UMTS support Car-to-X communication?
  - Ex: UTRA FDD Release 99 (W-CDMA)
  - Speed of vehicles not a limiting factor
    - Field operational tests at 290 km/h show signal drops only after sudden braking (⇨ handover prediction failures)
  - Open questions
    - Delay
    - Capacity
- Channels in UMTS
  - Shared channels
    - E.g. Random Access Channel (RACH), uplink and Forward Access Channel (FACH), downlink
  - Dedicated channels
    - E.g. Dedicated Transport Channel (DCH), up-/downlink

Cellular Networks

- FACH
  - Time slots managed by base station
  - Delay on the order of 10 ms per 40 Byte and UE
  - Capacity severely limited (in non-multicast networks)
  - Need to know current cell of UE
- RACH
  - Slotted ALOHA – random access by UEs
    - Power ramping with Acquisition Indication
  - Delay approx. 50 ms per 60 Byte and UE
  - Massive interference with other UEs

Cellular Networks

- DCH
  - Delay: approx. 250 ms / 2 s / 10 s for channel establishment
    - Depends on how fine-grained UE position is known
  - Maintaining a DCH is expensive
    - Closed-Loop Power Control (no interference of other UEs)
    - Handover between cells
    - ...
  - Upper limit of approx. 100 UEs

Cellular Networks

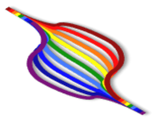
- So: can UMTS support Car-to-X communication?
  - At low market penetration: yes
  - Eventually:
    - Need to invest in much smaller cells (e.g., along freeways)
    - Need to implement multicast functionality (MBMS)
  - Main use case for UMTS: centralized services
    - Ex.: Google Maps Traffic
      - Collect information from UMTS devices
      - Storage of data on central server
      - Dissemination via Internet (⇨ ideal for cellular networks)

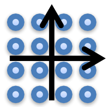
IEEE 802.11p

- IEEE 802.11{a,b,g,n} for Car-to-X communication?
  - Can't be in infrastructure mode and ad hoc mode at the same time
  - Switching time consuming
  - Association time consuming
  - No integral within-network security
  - (Massively) shared spectrum (⇨ ISM)
  - No integral QoS
  - Multi-path effects reduce range and speed

IEEE 802.11p

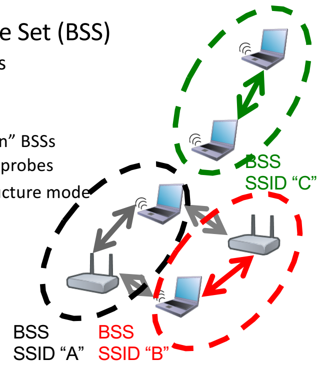
- IEEE 802.11p
  - PHY layer mostly identical to IEEE 802.11a
    - Variant with OFDM and 16 QAM
    - Higher demands on tolerances
    - Reduction of inter symbol interference because of multi-path effects
      - Double timing parameters
      - Channel bandwidth down to 10 MHz (from 20 MHz)
      - Throughput down to 3 ... 27 Mbit/s (from 6 ... 54 Mbit/s)
      - Range up to 1000 m, speed up to 200 km/h
  - MAC layer of IEEE 802.11a plus extensions
    - Random MAC Address
    - QoS (EDCA priority access, cf. IEEE 802.11e, ...)
    - Multi-Frequency and Multi-Radio capabilities
    - New Ad Hoc mode
    - ...





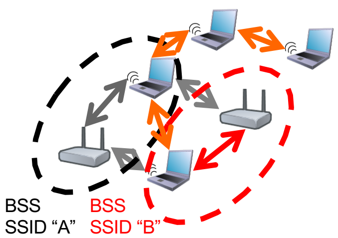
IEEE 802.11p

- Classic IEEE 802.11 Basic Service Set (BSS)
  - Divides networks into logical units
    - Nodes belong to (exactly one) BSS
    - Packets contain BSSID
    - Nodes ignore packets from “foreign” BSSs
    - Exception: Wildcard-BSSID (-1) for probes
    - Ad hoc networks emulate infrastructure mode
  - Joining a BSS
    - Access Point sends beacon
    - Authentication dialogue
    - Association dialogue
    - Node has joined BSS



IEEE 802.11p

- New: 802.11 WAVE Mode
  - Default mode of nodes in WAVE
  - Nodes may always use Wildcard BSS in packets
  - Nodes will always receive Wildcard BSS packets
  - May join BSS and still use Wildcard BSS

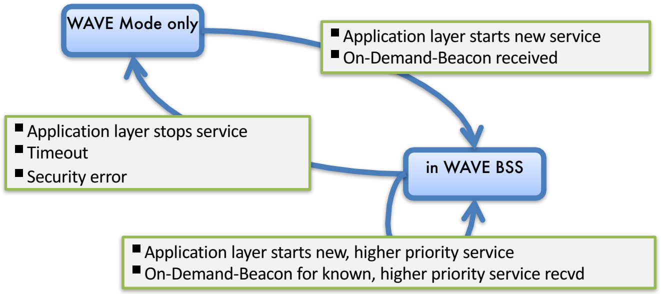


IEEE 802.11p

- New: 802.11 WAVE BSS
  - No strict separation between Host and Access Point (AP)
  - Instead, loose classification according to:
    - Equipment: Roadside Unit (RSU) / On-Board Unit (OBU)
    - Role in data exchange: Provider / User
  - No technical difference between Provider and User
  - Provider sends On-Demand Beacon
    - Analogous to standard 802.11-Beacon
    - Beacon contains all information and parameters needed to join
  - User configures lower layers accordingly
    - Starts using provided service
    - No additional exchange of data needed
  - BSS membership now only implied
    - BSS continues to exist even after provider leaves

WAVE BSS Internal state machine

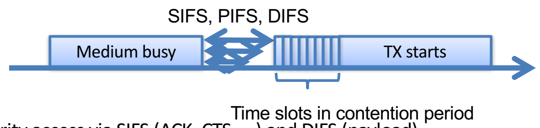
- Node will not join more than one WAVE BSS



[1] IEEE Vehicular Technology Society, "IEEE 1609.3 (Networking Services)," IEEE Std, April, 2007

IEEE 802.11p

- IEEE 802.11 Distributed Coordination Function (DCF)
  - aka "Contention Period"



  - Priority access via SIFS (ACK, CTS, ...) and DIFS (payload)
  - Wait until medium has been free for duration of DIFS
  - If medium busy, wait until idle, then wait DIFS plus random backoff time

SIFS= Short Inter-frame Space, DIFS= DCS Inter-frame Space,
CTS= Clear to Send, RTS= Request to Send
PIFS= Point Coordination Function Inter-frame Space

IEEE 802.11p

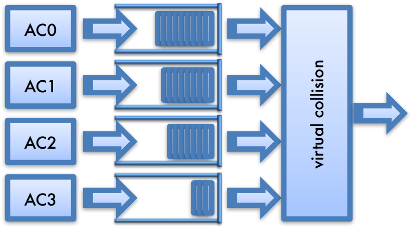
- IEEE 802.11 Distributed Coordination Function (DCF)
  - Backoff if
    a) Node is ready to send and channel becomes busy
    b) A higher priority queue (⇨ next slides) becomes ready to send
    c) Unicast transmission failed (no ACK)
    d) Transmission completed successfully
  - Backoff: Random slot count from interval [0, CW]
  - Decrement by one after channel was idle for one slot (only in contention period)
  - In cases b) and c), double CW (but no larger than CW_{max})
  - In case d), set CW to CW_{min}

IEEE 802.11p

- QoS in 802.11p (Hybrid Cordination Funct.)
  - cf. IEEE 802.11e EDCA
  - DIFS ⇨ AIFS (Arbitration Inter-Frame Space)
    - DCF ⇨ EDCA (Enhanced Distributed Channel Access)
  - Classify user data into 4 ACs (Access Categories)
    - AC0 (lowest priority)
    - ...
    - AC3 (highest priority)
  - Each ACs has different...
    - CW_{min}, CW_{max}, AIFS, TXOP limit (max. continuous transmissions)
  - Management data uses DIFS (not AIFS)

IEEE 802.11p

- QoS in 802.11p (HCF)
  - Map 8 user priorities ➪ 4 access categories ➪ 4 queues
  - Queues compete independently for medium access



IEEE 802.11p

- QoS in 802.11p (HCF)
  - Parameterization

Parameter	Value
SlotTime	13µs
SIFS	32µs
CW_{min}	15
CW_{max}	1023

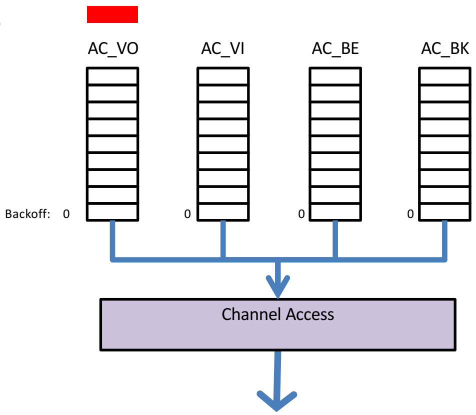
Default EDCA Parameters for each AC

AC	CWmin	CWmax	AIFSN	Max TXOP
Background (AC_BK)	15	1023	7	0
Best Effort (AC_BE)	15	1023	3	0
Video (AC_VI)	7	15	2	3.008ms
Voice (AC_VO)	3	7	2	1.504ms
Legacy DCF	15	1023	2	0

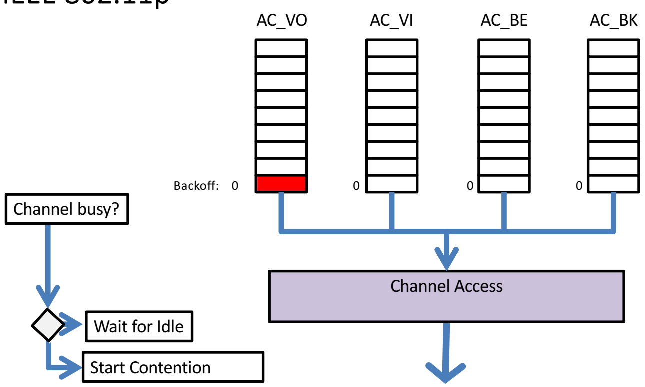
Parameter	
CW_{min}	4-1
CW_{max}	2-1
AIFSn	

AIFS= Arbitration Int

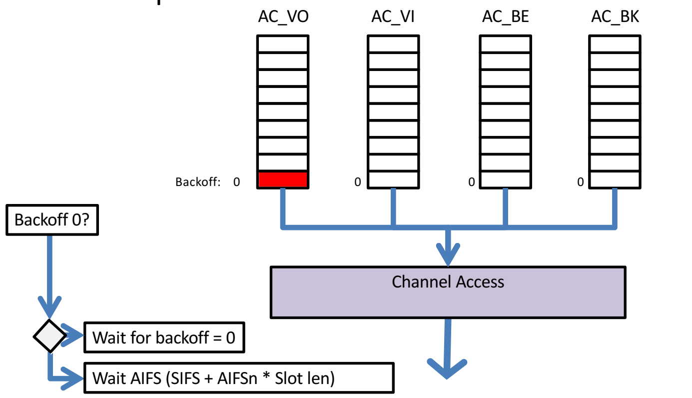
IEEE 802.11p



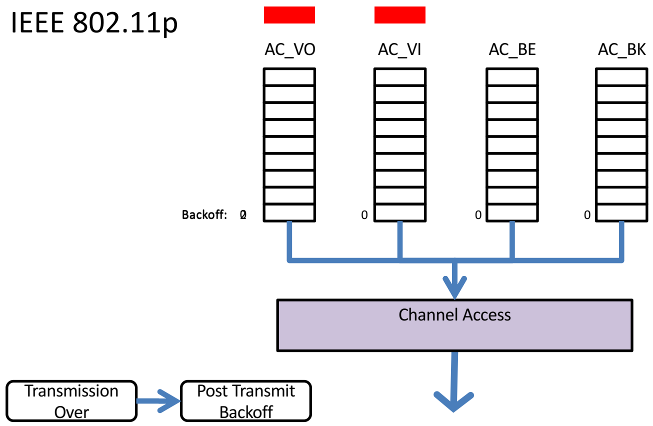
IEEE 802.11p



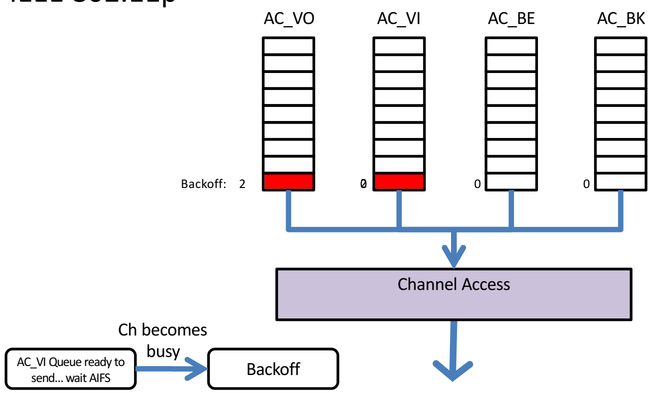
IEEE 802.11p



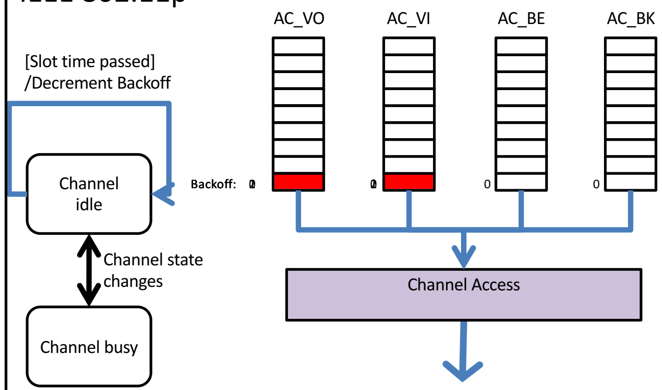
IEEE 802.11p



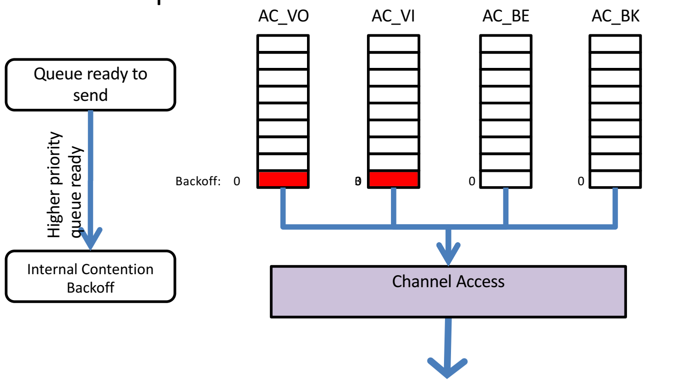
IEEE 802.11p



IEEE 802.11p



IEEE 802.11p



IEEE 802.11p

- QoS in WAVE
  - mean waiting time for channel access, given sample configuration (and TXOP Limit=0 ➪ single packet)
  - when channel idle:
  - when channel busy:

AC	CW_{min}	CW_{max}	AIFS	TXOP	t_w (in µs)
0	15	1023	9	0	264
1	7	15	6	0	152
2	3	7	3	0	72
3	3	7	2	0	56

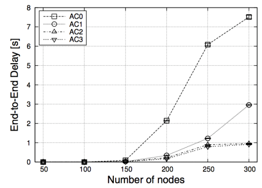


Figure Source: Eichler, S., "Performance evaluation of the IEEE 802.11p WAVE communication standard," Proceedings of 66th IEEE Vehicular Technology Conference (VTC2007-Fall), Baltimore, USA, October 2007, pp. 2199-2203

UMTS/LTE vs. 802.11p

- Pros of UMTS/LTE
  - \+ Easy provision of centralized services
  - \+ Quick dissemination of information in whole network
  - \+ Pre-deployed infrastructure
  - \+ Easy migration to (and integration into) smartphones
- Cons of UMTS/LTE
  - \- High short range latencies (might be too high for safety)
  - \- Network needs further upgrades (smaller cells, multicast service)
  - \- High dependence on network operator
  - \- High load in core network, even for local communication

UMTS/LTE vs. IEEE 802.11p

- Pros of 802.11p/Ad hoc
  - \+ Smallest possible latency
  - \+ Can sustain operation without network operator / provider
  - \+ Network load highly localized
  - \+ Better privacy (➪ later slides)
- Cons of 802.11p/Ad hoc
  - \- Needs gateway for provision of central services (e.g., RSU)
  - \- No pre-deployed hardware, and hardware is still expensive
- The solution?
  - hybrid systems:
    deploy both technologies to vehicles and road,
    decide depending on application and infrastructure availability

Higher Layer Standards: CALM

- Mixed-media communication
  - „Communications access for land mobiles“
  - ISO TC204 Working Group 16
  - Initiative to transparently use best possible medium
  - Integrates:
    - GPRS, UMTS, WiMAX
    - Infrared, Millimeter Wave
    - Wi-Fi, WAVE
    - Unidirectional data sources (DAB, GPS, ...)
    - WPANs (BlueT, W-USB, ...)
    - Automotive bus systems (CAN, Ethernet, ...)

[1] ISO 21210, “Intelligent transport systems -- Communications access for land mobiles (CALM) -- IPv6 Networking“

Higher Layer Standards for IEEE 802.11p

- Channel management
  - Dedicated frequency band at 5.9 GHz allocated to WAVE
    - Exclusive for V2V und V2I communication
    - No license cost, but strict rules
    - 1999: FCC reserves 7 channels of 10 MHz (“U.S. DSRC”)
      - 2 reserved channels, 1+4 channels for applications
    - ETSI Europe reserves 5 channels of 10 MHz

U.S. allocation	...	Critical Safety of Life	SCH	SCH	Control Channel (CCH)	SCH	SCH	Hi-Power Public Safety	...
European allocation		SCH	SCH	SCH	SCH	CCH	SCH	SCH	
IEEE Channel		172	174	176	178	180	182	184	
Center frequency		5.860 GHz	5.870 GHz	5.880 GHz	5.890 GHz	5.900 GHz	5.910 GHz	5.920 GHz	

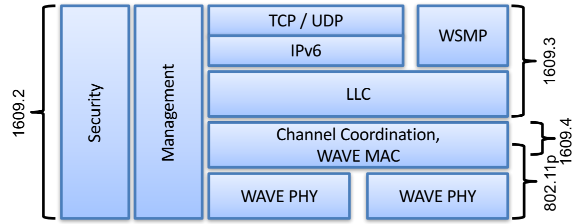
[1] ETSI ES 202 663 V1.1.0 (2010-01) : Intelligent Transport Systems (ITS); European profile standard for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band

Higher Layer Standards for IEEE 802.11p

- Need for higher layer standards
  - Unified message format
  - Unified interfaces to application layer
- U.S.
  - IEEE 1609.*
  - WAVE („Wireless Access in Vehicular Environments“)
- Europe
  - ETSI
  - ITS G5 (“Intelligent Transportation Systems”)

IEEE 1609.* upper layers (building on IEEE 802.11p)

- IEEE 1609.2: Security
- IEEE 1609.3: Network services
- IEEE 1609.4: Channel mgmt.
- IEEE 1609.11: Application “electronic payment”

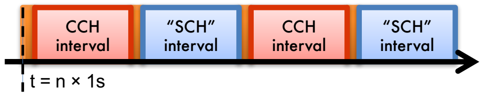


[1] Jiang, D. and Delgrossi, L., "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments," Proceedings of 67th IEEE Vehicular Technology Conference (VTC2008-Spring), Marina Bay, Singapore, May 2008

[2] Uzcátegui, Roberto A. and Acosta-Marum, Guillermo, "WAVE: A Tutorial," IEEE Communications Magazine, vol. 47 (5), pp. 126-133, May 2009

IEEE 1609

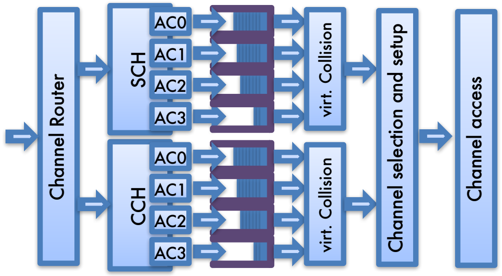
- Channel management
  - WAVE allows for both single radio devices & multi radio devices
  - Dedicated Control Channel (CCH) for mgmt and safety messages
    ➪ single radio devices need to periodically listen to CCH
  - Time slots
    - Synchronization envisioned via GPS receiver clock
    - Standard value: 100ms sync interval (with 50ms on CCH)
    - Short guard interval at start of time slot
      - During guard, medium is considered busy (➪ backoff)



[1] IEEE Vehicular Technology Society, "**IEEE 1609.4 (Multi-channel Operation)**," IEEE Std, November, 2006

IEEE 1609

- Packet transmission
  - Sort into AC queue, based on WSMP (or IPv6) EtherType field, destination channel, and user priority
  - Switch to desired channel, setup PHY power and data rate
  - Start medium access

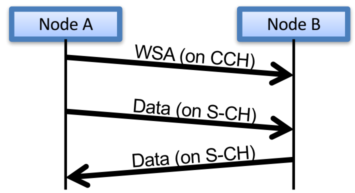


IEEE 1609

- Channel management
  - Control Channel (CCH):
    - Default channel upon initialization
    - WAVE service advertisements (WSA), WAVE short messages (WSM)
    - Channel parameters take fixed values
  - Service Channel (SCH):
    - Only after joining WAVE BSS
    - WAVE short messages (WSM), IP data traffic (IPv6)
    - Channel parameters can be changed as needed

IEEE 1609

- WAVE service advertisement (WSA)
  - Broadcast on Control Channel (CCH)
  - Identifies WAVE BSSs on Service Channels (SCHs)
  - Can be sent at arbitrary times, by arbitrary nodes
  - Only possibility to make others aware of data being sent on SCHs, as well as the required channel parameters to decode them



IEEE 1609

- WAVE service advertisement (WSA)
  - WAVE Version (= 0)
  - Provider Service Table (PST)
    - n × Provider Service Info
      - Provider Service Identifier (PSID, max. 0x7FFF FFFF)
      - Provider Service Context (PSC, max. 31 chars)
      - Application priority (max priority: 63)
      - (opt.: IPv6 address and port, if IP service)
      - (opt.: Source MAC address, if sender ≠ data source)
      - Channel number (max. 200)
    - 1..n × Channel Info (for each channel used in PST table)
      - Data rate (fixed or minimum value)
      - Transmission power (fixed or maximum value)
  - (opt.: WAVE Routing Announcement)

[1] IEEE Vehicular Technology Society, "**IEEE 1609.3 (Networking Services)**," IEEE Std, April, 2007

WAVE service advertisement (WSA)

- Provider Service Identifier (PSID) defined in IEEE Std 1609.3-2007

0x000 0000	system	0x000 000D	private
0x000 0001	automatic-fee-collection	0x000 000E	multi-purpose-payment
0x000 0002	freight-fleet-management	0x000 000F	dsrc-resource-manager
0x000 0003	public-transport	0x000 0010	after-theft-systems
0x000 0004	traffic-traveler-information	0x000 0011	cruise-assist-highway-system
0x000 0005	traffic-control	0x000 0012	multi-purpose-information system
0x000 0006	parking-management	0x000 0013	public-safety
0x000 0007	geographic-road-database	0x000 0014	vehicle-safety
0x000 0008	medium-range-preinformation	0x000 0015	general-purpose-internet-access
0x000 0009	man-machine-interface	0x000 0016	onboard diagnostics
0x000 000A	intersystem-interface	0x000 0017	security manager
0x000 000B	automatic-vehicle-identification	0x000 0018	signed WSA
0x000 000C	emergency-warning	0x000 0019	ACI

IEEE 1609

- WAVE Short Message (WSM)
  - Header (11 Byte)
    - Version (= 0)
    - Content type: plain, signed, encrypted
    - Channel number (max. 200)
    - Data rate
    - Transmission power
    - Provider Service Identifier (Service type, max. 0x7FFF FFFF)
    - Length (max. typ. 1400 Bytes)
  - Payload

IEEE 1609

- IP traffic (UDP/IPv6 or TCP/IPv6)
  - Header (40+n Byte)
    - Version
    - Traffic Class
    - Flow Label
    - Length
    - Next Header
    - Hop Limit
    - Source address, destination address
    - (opt.: Extension Headers)
  - Payload

  - No IPv6-Neighbor-Discovery (High overhead)
  - All OBUs listen to host multicast address,
    all RSUs listen to router multicast address

IEEE 1609

- Channel quality monitoring
  - Nodes store received WSAs, know SCH occupancy
  - Received Channel Power Indicator (RCPI) polling
    - Nodes can send RCPI requests
    - Receiver answers with Received Signal Strength (RSS) of packet
  - Transmit Power Control (TPC)
    - Nodes can send TPC requests
    - Receiver answers with current transmission power and LQI
  - Dynamic Frequency Selection (DFS)
    - Nodes monitor transmissions on channel (actively and passively)
    - If higher priority third party use (e.g., RADAR) is detected, nodes cease transmitting

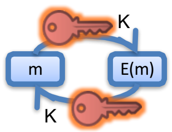
IEEE 1609

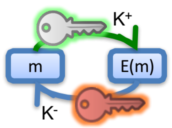
- Security in WAVE
  - Nature of WAVE messages mandates trust between nodes
    - Ex: Green wave for emergency vehicles
  - Security is built into WAVE (IEEE 1609.2)
  - WAVE can transparently sign, verify, encrypt/decrypt messages when sending and receiving
    - Ex: WSA → Secure WSA
  - Authorization of messages needed
    - By role: CA, CRL-Signer, RSU, Public Safety OBU (PSOBU), OBU
    - By application class (PSID) and/or instance (PSC)
    - By application priority
    - By location
    - By time

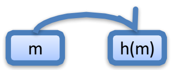
[1] IEEE Vehicular Technology Society, "**IEEE 1609.2 (Security Services)**," IEEE Std, July, 2006

IEEE 1609

- Security concepts
  - Basic security goals
    - Integrity, Confidentiality, Authenticity
    - Non-Repudiation
  - Mechanisms
    - Symmetric encryption
      - Secret Key Cryptography
      - Ex: Caesar cipher, Enigma, AES
    - Asymmetric encryption
      - Public Key Cryptography
      - Ex: RSA, ElGamal, ECC
    - (cryptographic) hashing
      - Ex: MD5, SHA-1

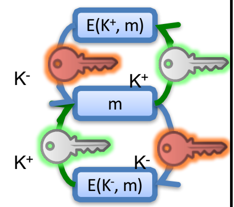






IEEE 1609

- Asymmetric Cryptography
  - Relies on certain mathematical procedures being very hard to invert
    - Product ⇔ factorization (RSA)
    - Nth power ⇔ Nth logarithm (DH, ElGamal)
  - Two keys: Public Key (K^+), Private Key (K^-)
  - Can be used in both directions
  - Encryption: E(K^+, m), Signing: E(K^-, h(m))
  - Drawback:
    - Much slower than symmetric cryptography



IEEE 1609

- Asymmetric Cryptography Example: RSA
  - Chose two primes: q, p with q != p
  - Calculate n = p · q
  - Calculate ϕ(n) = (p – 1) · (q – 1)
    ϕ(x) gives number of (smaller) co-primes for x.
    Based on ϕ(a · b) = ϕ(a) · ϕ(b) · (d/ϕ(d)) with d = gcd(a, b)
    If x is prime, this is x – 1.
  - Choose e co-prime to ϕ(n) with 1 < e < ϕ(n)
  - Calculate d using EEA, so that e · d mod ϕ(n) = 1
  - Public Key: $K^+ = \{e, n\}$, Private Key: $K^- = \{d, n\}$.
  - En/Decryption:
    $M^e \bmod n = C$
    $C^d \bmod n = M$

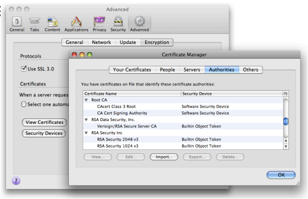
IEEE 1609

- Certificates
  - Encryption is useless without authentication
    - Alice ⇔ Eve ⇔ Bob
    - Eve can pretend to be Alice,
      replace K^+_A with own key K^+_E
  - Solution: use Trusted Third Party (TTP) and certificates
    - TTP signs (Name, Key) tuple, vouches for validity and authorization:
      "Alice has Public Key K^+_A, may participate as OBU until 2019"
    - not: "~~whoever sends this packet is Alice~~"
    - not: "~~whoever sends this packet has Public Key~~ K^+_A"
  - Send K^+_A together with certificate vouching for tuple

IEEE 1609

- Implementation in WAVE
  - Certificate signature chains
    - Root certificate ⇨ certificate ⇨ certificate ⇨ payload
    - Root certificates pre-installed with system
    - Other certificates cannot be assumed to be present
  - Nodes must download certificates a
    - Include chain of certificates
    - …or SHA-256 of first certificate in chain

      (if receiver can be assumed to have all required certificates)



IEEE 1609

- Implementation in WAVE
  - X.509 formats too large ⇨ new WAVE certificate format
    - Version
    - Certificate
      - Role (RSU, PSOBU, OBU, …)
      - Identity (dependent on role)
      - Restrictions (by application class, priority, location, …)
      - Expiration date
      - Responsible CRL
      - Public Keys
    - Signature
  - New: Restriction by location
    e.g.: none, inherited from CA, circle, polygon, set of rectangles
  - Public Key algorithms (motivated by key size):
    ECDSA (NIST p224), ECDSA (NIST p256), ECIES (NIST p256), …

Complete packet format of a WSM:

Ex: Signed WSM of an OBU, Certificate issuer is known

Length	Field			
1	WSM version			
1	Security Type = signed(1)			
1	Channel Number			
1	Data Rate			
1	TxPwr_Level			
4	PSID			
1	PSC Field Length			
7	PSC			
2	WSM Length			
1	WSM Data	signer	type = certificate	
125			certificate	
2		unsigned_wsm	message flags	
32			application_data	
8			transmission_time	
4			transmission_location	latitude
4				longitude
3				elevation_and_confidence
28		signature	ecdsa_signature	r
28				s

➪ next slide

Complete packet format of a WSM (certificate part):

Length	Field			
1	certificate_version = 1			
1	unsigned_certificate	subject_type = obu_identified		
8		signer_id		
1		scope	subject_name length	
8			subject_name	
2			applications	length of applications field
1				type = from_issuer
4		expiration		
4		crl_series		
1		public_key	length of public key field	
1			algorithm = ecdsa nistp224..	
29			public_key	point
32	signature	ecdsa_signature	r	
32			s	