Mobile Networking

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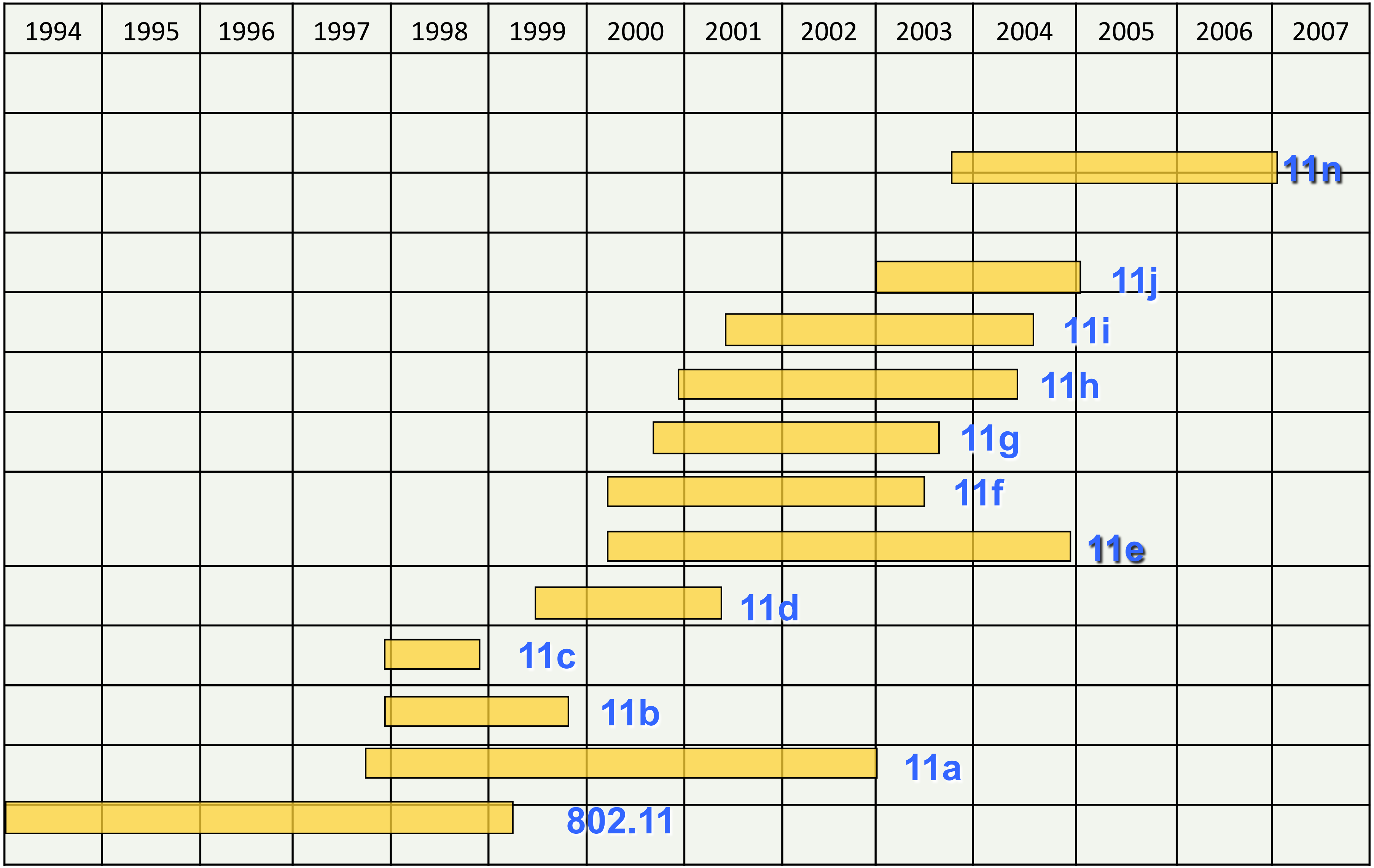
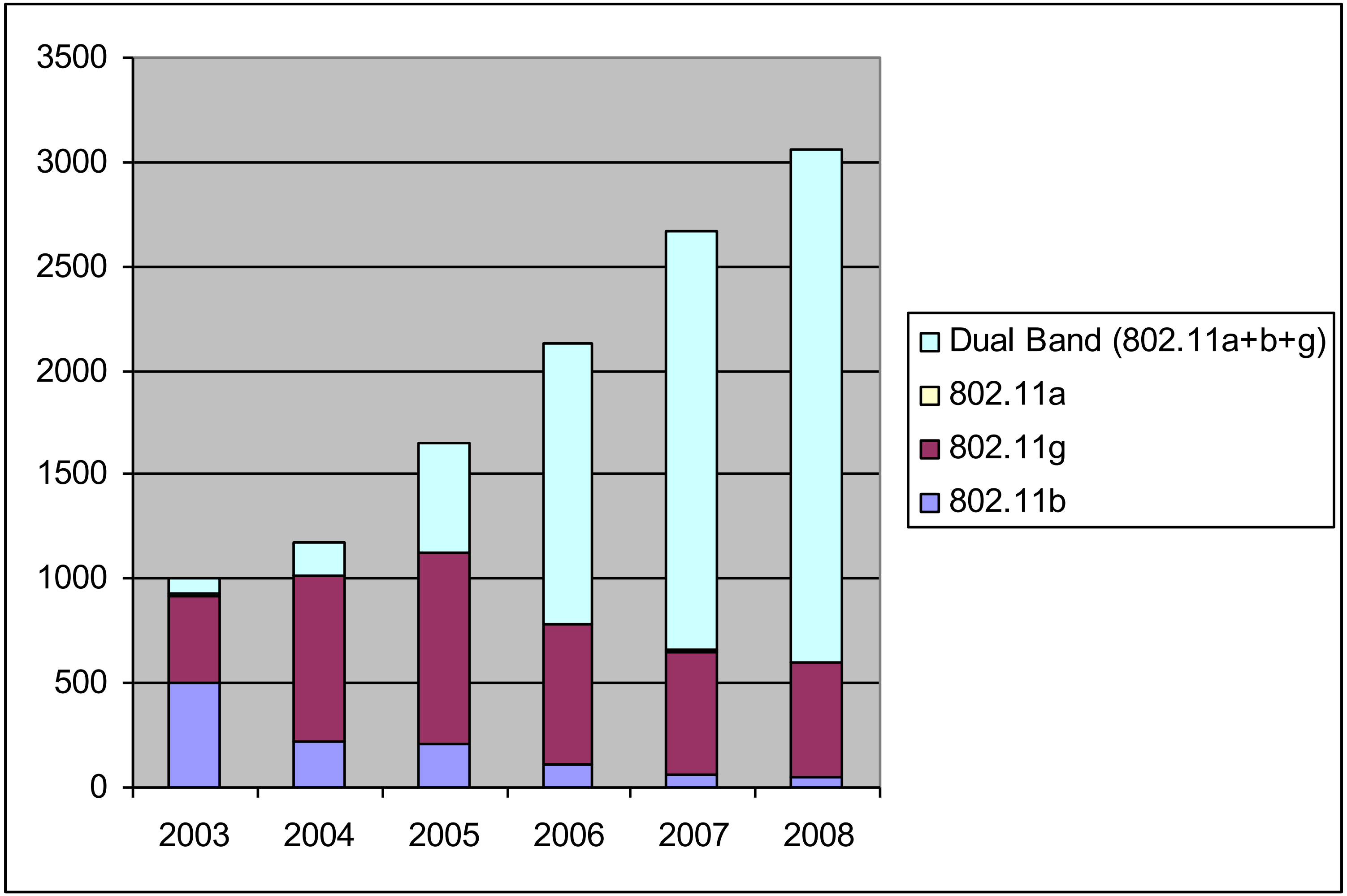
802.11g, 802.11n, 802.11ac, 802.11p

MORE ON 802.11 PHYSICAL LAYERS

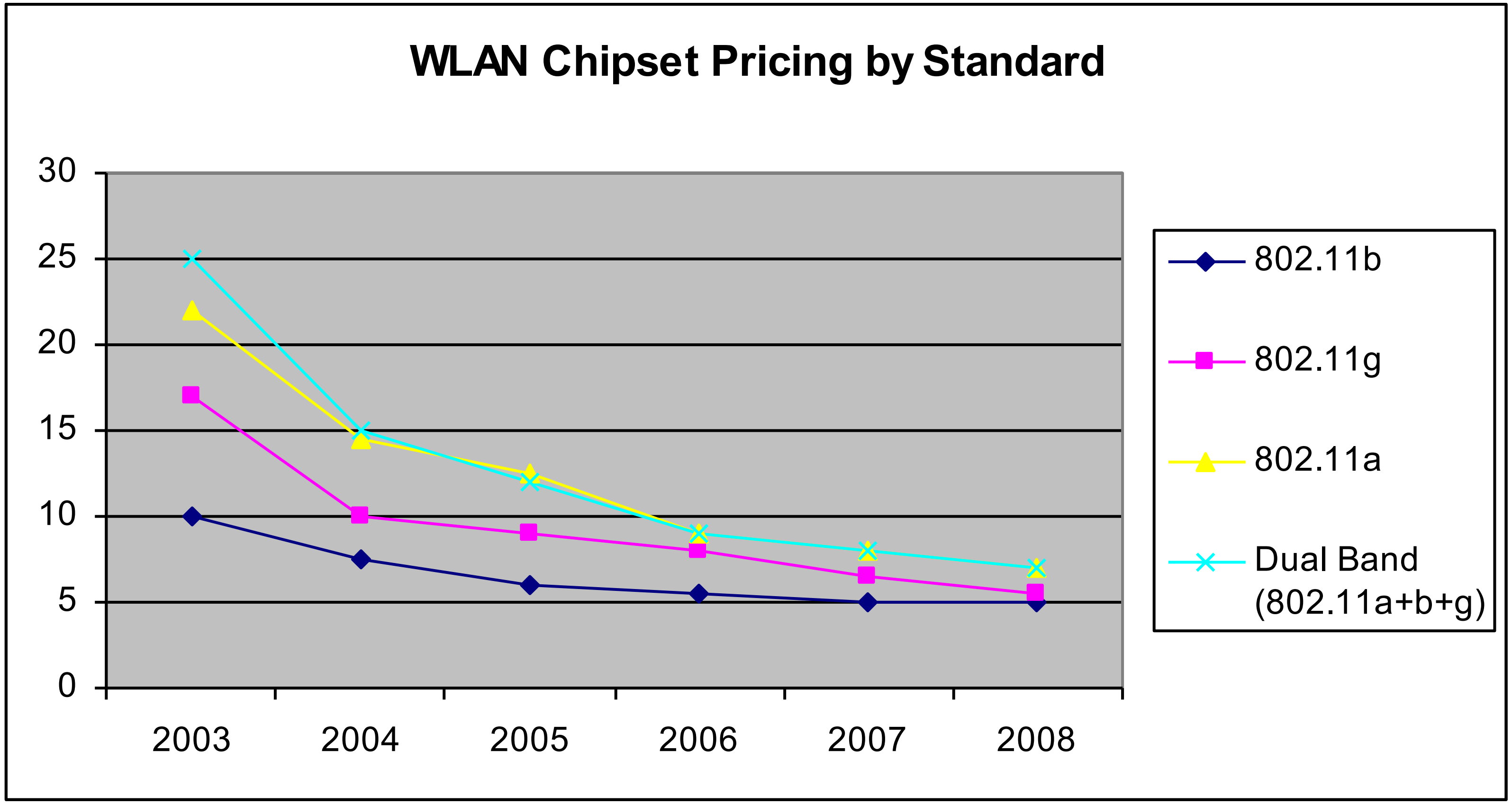
Growing 802.11 Standards



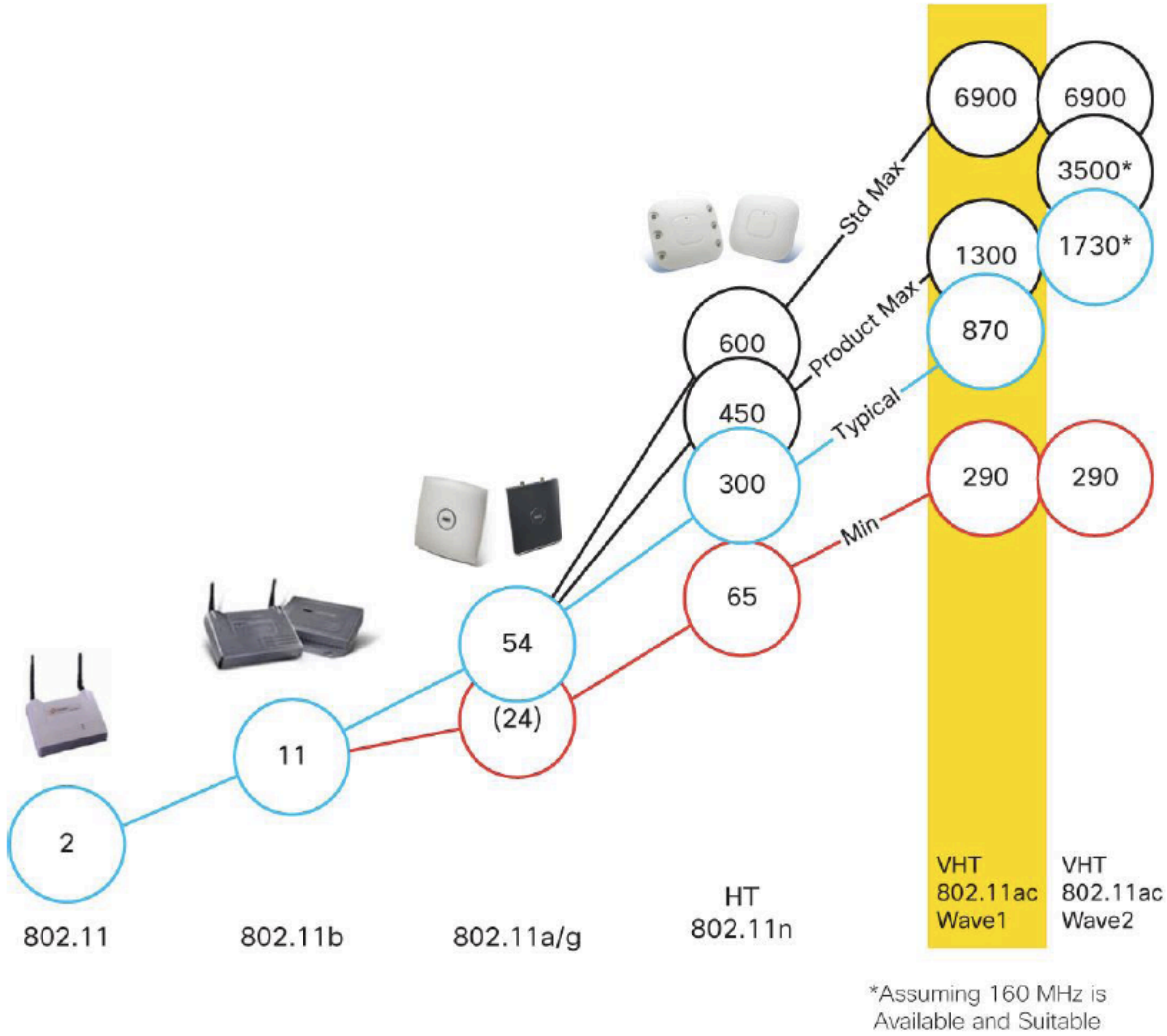
Worldwide WLAN Semiconductor Revenues by Standard, 2003 - 2008 ($M)



WLAN Chipset Pricing by Standard



Data Rates in 802.11a, b, g, n, ac



Contents

- IEEE 802.11g
- IEEE 802.11n
- IEEE 802.11ac
- IEEE 802.11p
- Physical Data Rates Adaptation

Having11b and 11a together → 11g

IEEE 802.11g

802.11g: Introduction

- Officially approved by IEEE in June 2003
- Products conforming to the draft were made available in late 2002
- Increase speed and range while maintaining compatibility with 802.11b
- Use OFDM and CCK modulations
- 802.11b operating at 5Ghz provide high data rate, but had low range, so, it is important that 802.11g should operate in 2.4Ghz frequency band
- 802.11g is an exciting technology that offers the performance of 802.11a and the range of 802.11b

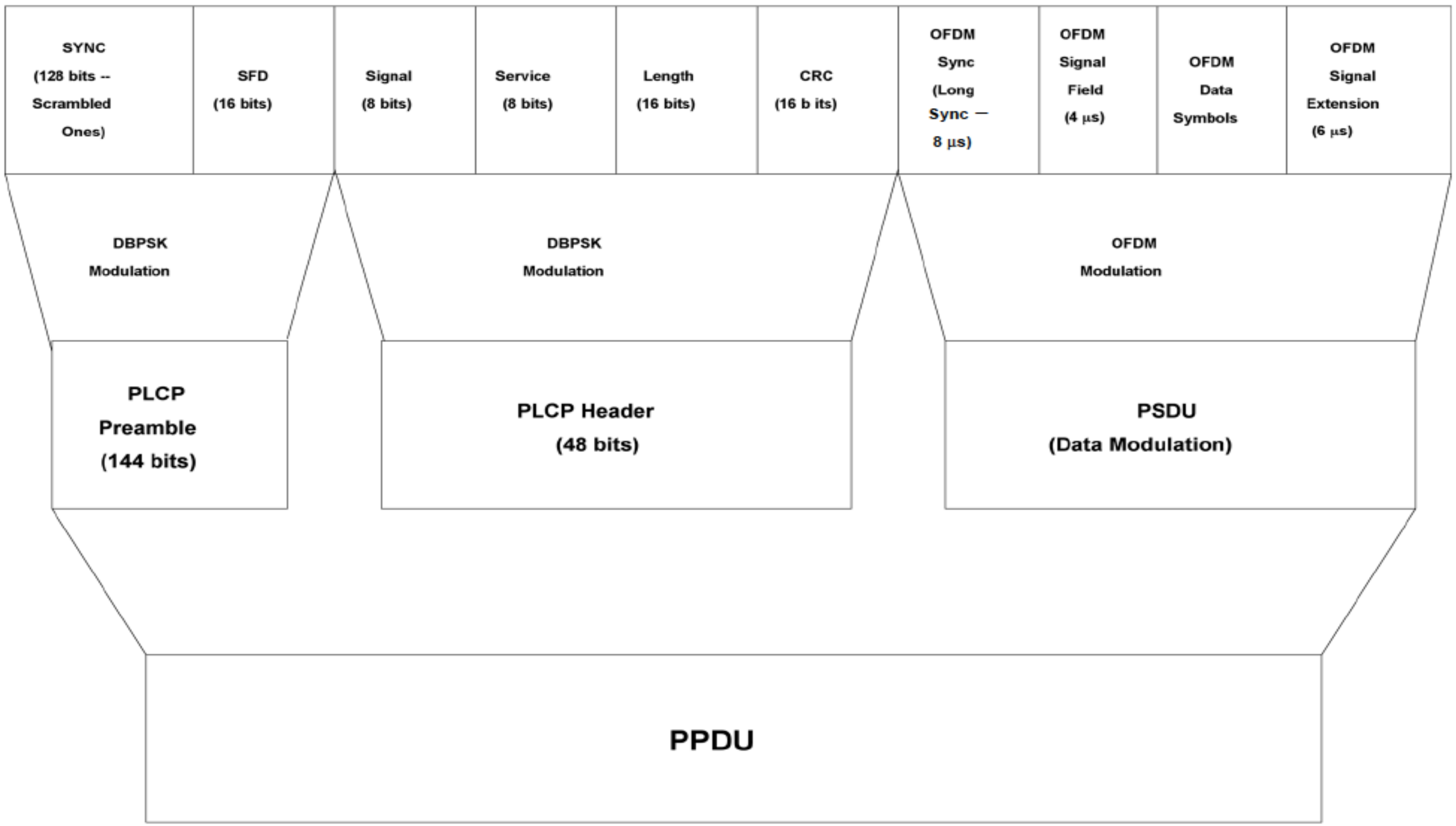
IEEE 802.11g Operational Modes: Extended Rate PHY (ERP)

1. **ERP-DSSS/CCK**
2. **ERP-OFDM**
3. **ERP- PBCC (Optional)**
   – ERPPBCC modes with payload data rates of 22 and 33 Mbit/s
4. **DSSS-OFDM (Optional)**
   – This is a hybrid modulation combining a DSSS preamble and header with an OFDM payload transmission. DSSS-OFDM modes with payload data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s

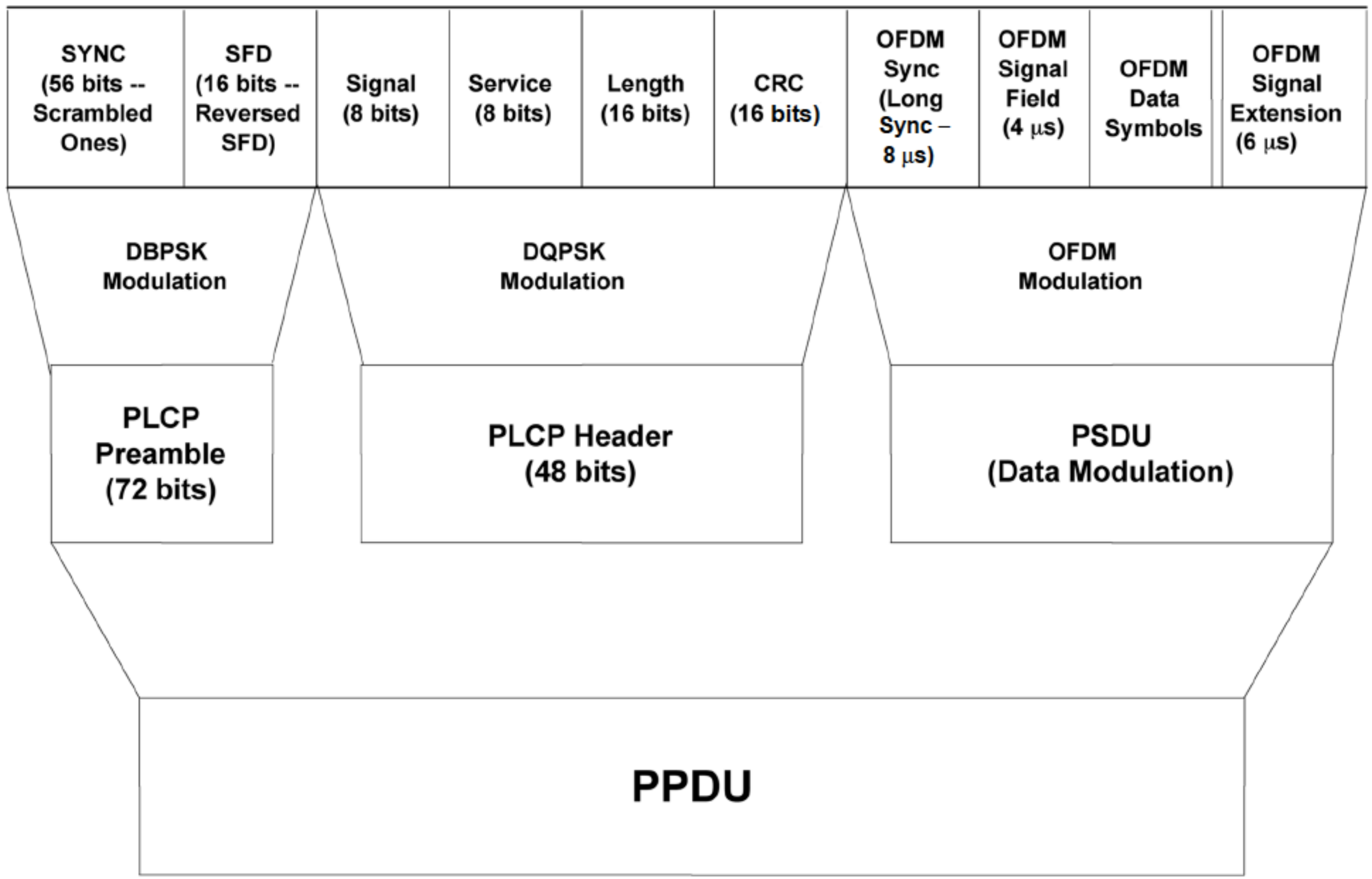
802.11g Available Data Rates

Parameter	Value
DATARATE	The rate used to transmit the PSDU in Mbit/s Allowed value depends on value of MODULATION parameter: ERP-DSSS: 1 and 2 ERP-CCK: 5.5 and 11 ERP-OFDM: 6, 9, 12, 18, 24, 36, 48, and 54 ERP-PBCC: 5.5, 11, 22, and 33 DSSS-OFDM: 6, 9, 12, 18, 24, 36, 48, and 54.
LENGTH	The length of the PSDU in octets Range: 1–4095.
PREAMBLE_TYPE	The preamble used for the transmission of the PPDU Enumerated type for which the allowed value depends on value of MODULATION parameter: ERP-OFDM: null ERP-DSSS, ERP-CCK, ERP-PBCC, DSSS-OFDM: SHORTPREAMBLE, LONGPREAMBLE.
MODULATION	The modulation used for the transmission of this PSDU Enumerated type: ERP-DSSS, ERP-CCK, ERP-OFDM, ERP-PBCC, DSSS-OFDM.
SERVICE	The scrambler initialization vector When the modulation format selected is ERP-OFDM or DSSS-OFDM, seven null bits are used for scrambler initialization as described in 17.3.5.1. The remaining bits are reserved. For all other ERP modulations that all start with ERP-DSSS short or long preamble, the bits of the SERVICE field are defined in Table 123C and the SERVICE field is not applicable in the TXVECTOR, so the entire field is reserved.
TXPWR_LEVEL	The transmit power level. The definition of these levels is up to the implementer. 1–8.

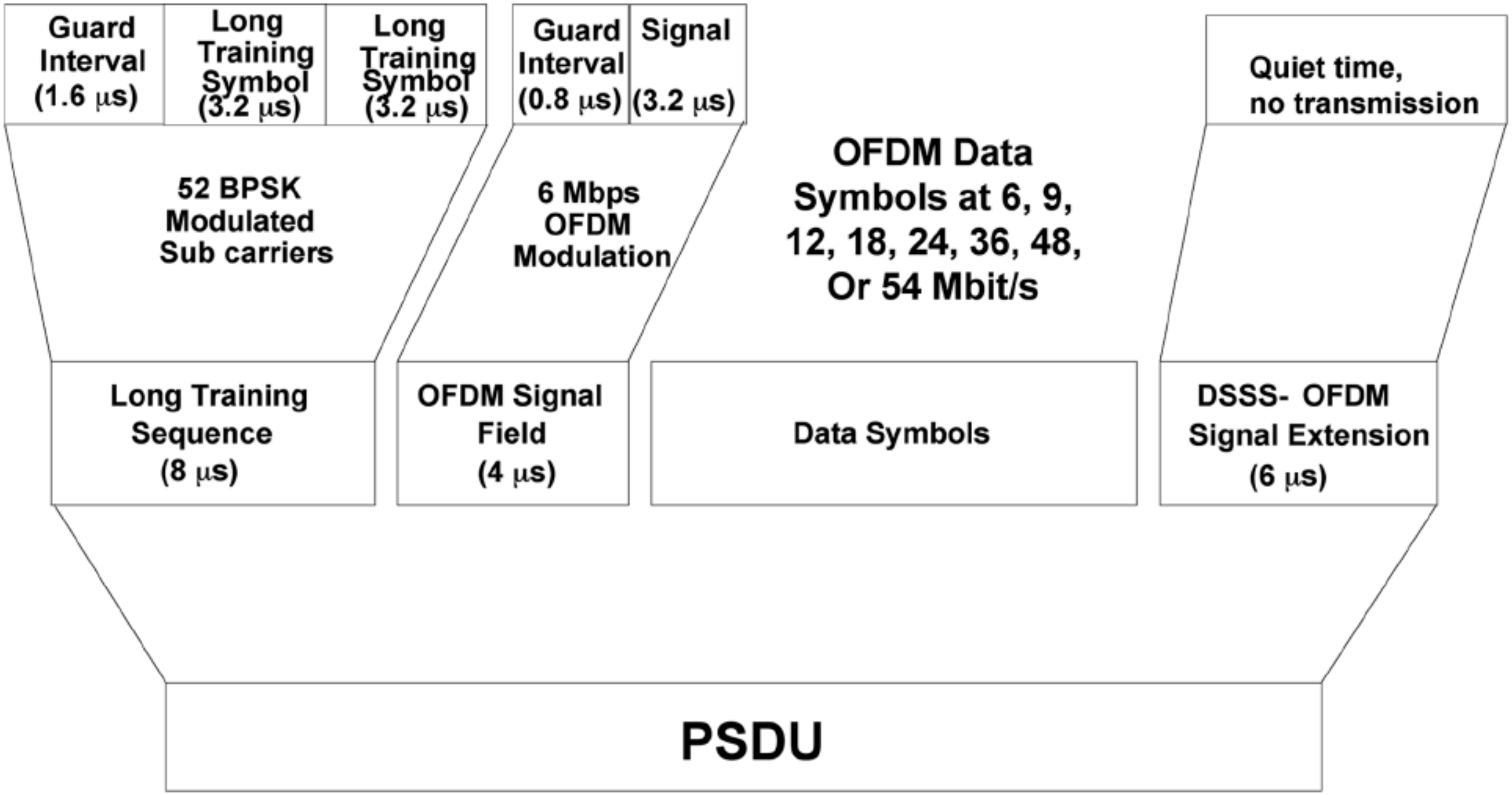
Long Preamble for DSSS-OFDM



Short Preamble for DSSS-OFDM



DSSS-OFDM PSDU Format



802.11 Data Rate and Range

Data Rate (Mbps)	802.11a (40 mW with 6 dBi gain diversity patch antenna) Range	802.11g (30 mW with 2.2 dBi gain diversity dipole antenna)	802.11b (100 mW with 2.2 dBi gain diversity dipole antenna)
54	45 ft (13 m)	90 ft (27 m)	-
48	50 ft (15 m)	95 ft (29 m)	-
36	65 ft (19 m)	100 ft (30 m)	-
24	85 ft (26 m)	140 ft (42 m)	-
18	110 ft (33 m)	180 ft (54 m)	-
12	130 ft (39 m)	210 ft (64 m)	-
11	-	160 ft (48 m)	160 ft (48 m)
9	150 ft (45 m)	250 ft (76 m)	-
6	165 ft (50 m)	300 ft (91 m)	-
5.5	-	220 ft (67 m)	220 ft (67 m)
2	-	270 ft (82m)	270 ft (82m)
1	-	410 ft (124 m)	410 ft (124 m)

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MIMO arrives!

IEEE 802.11n

802.11n: A Brief History

- In January 2004, new IEEE 802.11 Task Group (TGn) to develop a new amendment to the 802.11 standard with the real data throughput is estimated to reach a theoretical **540 Mbit/s**, i.e. , **802.11n**
- Two competing proposals of the 802.11n standard, by companies including **Broadcom**, **Intel** and **Philips**

802.11n: A Brief History

- Built upon previous 802.11 standards by adding **MIMO** (multiple-input multiple-output).
  - Increased data throughput through **spatial multiplexing** and increased range by exploiting **the spatial diversity**

- The Enhanced Wireless Consortium (EWC) was formed to help accelerate the IEEE 802.11n development process

802.11n Main Elements

1. Use of MIMO-OFDM
2. 20 and 40 MHz Channels
3. Packet Aggregation Techniques

Mandatory Modulation and Coding Schemes (MSC)

MCS	Code rate	Modulation	Number of spatial streams	Data rate in 20 MHz	Data rate in 40 MHz
0	1/2	BPSK	1	6.5	13.5
1	1/2	QPSK	1	13	27
2	3/4	QPSK	1	19.5	40.5
3	1/2	16-QAM	1	26	54
4	3/4	16-QAM	1	39	81
5	2/3	64-QAM	1	52	108
6	3/4	64-QAM	1	58.5	121.5
7	5/6	64-QAM	1	65	135
8	1/2	BPSK	2	13	27
9	1/2	QPSK	2	26	54
10	3/4	QPSK	2	39	81
11	1/2	16-QAM	2	52	108
12	3/4	16-QAM	2	78	162
13	2/3	64-QAM	2	104	216
14	3/4	64-QAM	2	117	243
15	5/6	64-QAM	2	130	270

MCS Parameters

MCS Index	Modulation	R	$N_{BPSCS}(i_{SS})$	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate (Mb/s)	
								800 ns GI	400 ns GI (see NOTE)
0	BPSK	1/2	1	52	4	52	26	6.5	7.2
1	QPSK	1/2	2	52	4	104	52	13.0	14.4
2	QPSK	3/4	2	52	4	104	78	19.5	21.7
3	16-QAM								
4	16-QAM								
5	64-QAM								
6	64-QAM								
7	64-QAM								

NOTE—Support of 400

MCS Index	Modulation	R	$N_{BPSCS}(i_{SS})$	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	N_{ES}	Data rate (Mb/s)	
									800 ns GI	400 ns GI
24	BPSK	1/2	1	108	6	432	216	1	54.0	60.0
25	QPSK	1/2	2	108	6	864	432	1	108.0	120.0
26	QPSK	3/4	2	108	6	864	648	1	162.0	180.0
27	16-QAM	1/2	4	108	6	1728	864	1	216.0	240.0
28	16-QAM	3/4	4	108	6	1728	1296	2	324.0	360.0
29	64-QAM	2/3	6	108	6	2592	1728	2	432.0	480.0
30	64-QAM	3/4	6	108	6	2592	1944	2	486.0	540.0
31	64-QAM	5/6	6	108	6	2592	2160	2	540.0	600.0

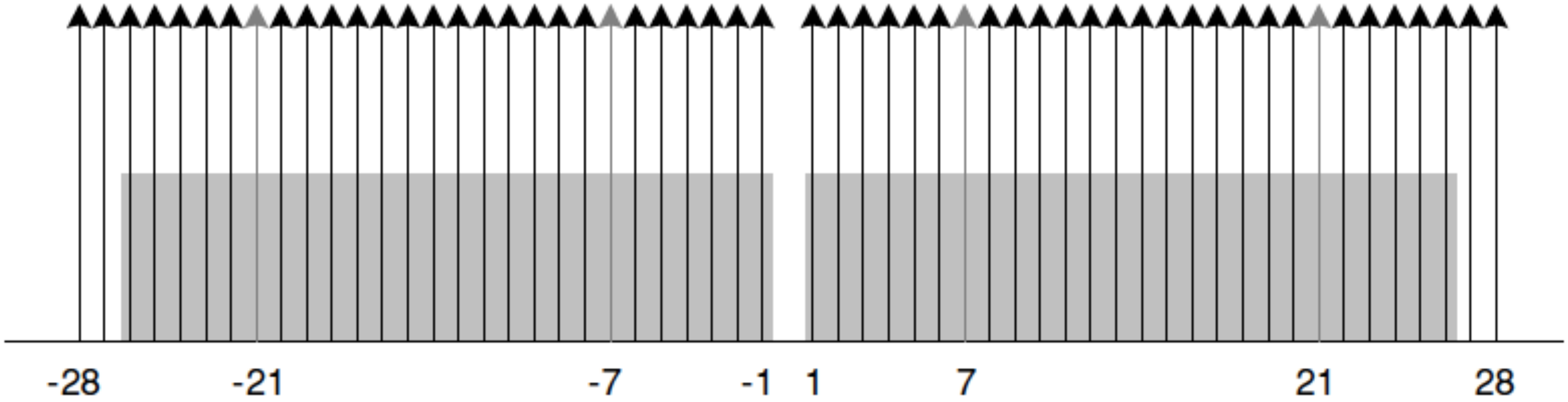
MCS Parameters (Cont.)

Symbol	Explanation
N_{CBPS}	Number of coded bits per symbol
$N_{CBPSS}(i)$	Number of coded bits per symbol per the *i*-th spatial stream
N_{DBPS}	Number of data bits per symbol
N_{BPSC}	Number of coded bits per single carrier
$N_{BPSCS}(i)$	Number of coded bits per single carrier for spatial stream *i*
N_{RX}	Number of receive chains
N_{STS}	Number of space-time streams
N_{SS}	Number of spatial streams
N_{ESS}	Number of extension spatial streams
N_{TX}	Number of transmit chains
N_{ES}	Number of BCC encoders for the Data field
N_{HTLTF}	Number of HT Long Training fields (see 20.3.9.4.6)
N_{HTDLTF}	Number of Data HT Long Training fields
N_{HTELTF}	Number of Extension HT Long Training fields
R	Coding rate

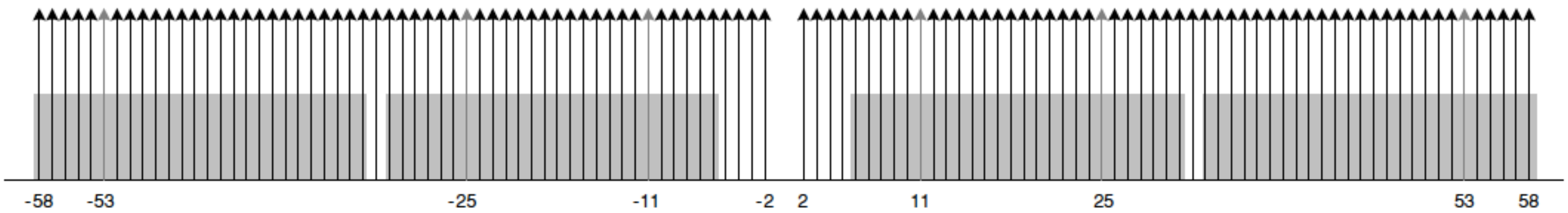
Optional Rates

- **Reduced guard interval** of 400 ns instead of 800 ns, which increases the maximum data rate for 2 spatial streams in a 40MHz channel to 300 Mbps
- Other optional rates use **3 or even 4 spatial streams**
- The **highest** optional data rate defined by 802.11n is **600 Mbps**, which is achieved by using **4 spatial streams in a 40MHz** channel with a 400 ns guard interval.

802.11n Frequency Allocations: 20 MHz



802.11n Frequency Allocations: 40 MHz



802.11n PHY Operating Modes

1. **Legacy Mode:** Packets are transmitted in the legacy 802.11a/g format.

2. **Mixed Mode:** Packets are transmitted with a **preamble compatible with the legacy 802.11a/g** – the legacy Short Training Field (STF), the legacy Long Training Field (LTF) and the legacy signal field are transmitted so they can be decoded by legacy 802.11a/g devices. Receiver can decode both the Mixed Mode packets and legacy packets.

3. **Green Field:** *High throughput* (HT) packets are transmitted without a legacy compatible part. It is not compatible with legacy 802.11a or 802.11g devices as such devices will not be able to decode the signal field of a greenfield preamble

802.11n PHY in frequency domain

1. **LM: (Legacy Mode)** – equivalent to 802.11a/g
2. **HT-Mode:** Device operates in either 40MHz bandwidth or 20MHz bandwidth and with **one to four spatial streams**. This mode includes the HT-duplicate mode.
3. **Duplicate Legacy Mode:** The device operates in a 40MHz channel composed of two adjacent 20MHz channel. The packets to be sent are in the legacy 11a format in each of the 20MHz channels
4. **40 MHz Upper Mode –** used to transmit a legacy or HT packet in the upper 20MHz channel of a 40MHz channel.
5. **40 MHz Lower Mode –** used to transmit a legacy or HT packet in the lower 20 MHz channel of a 40MHz channel

Note: LM and HT-Mode for 1 and 2 spatial streams are mandatory.

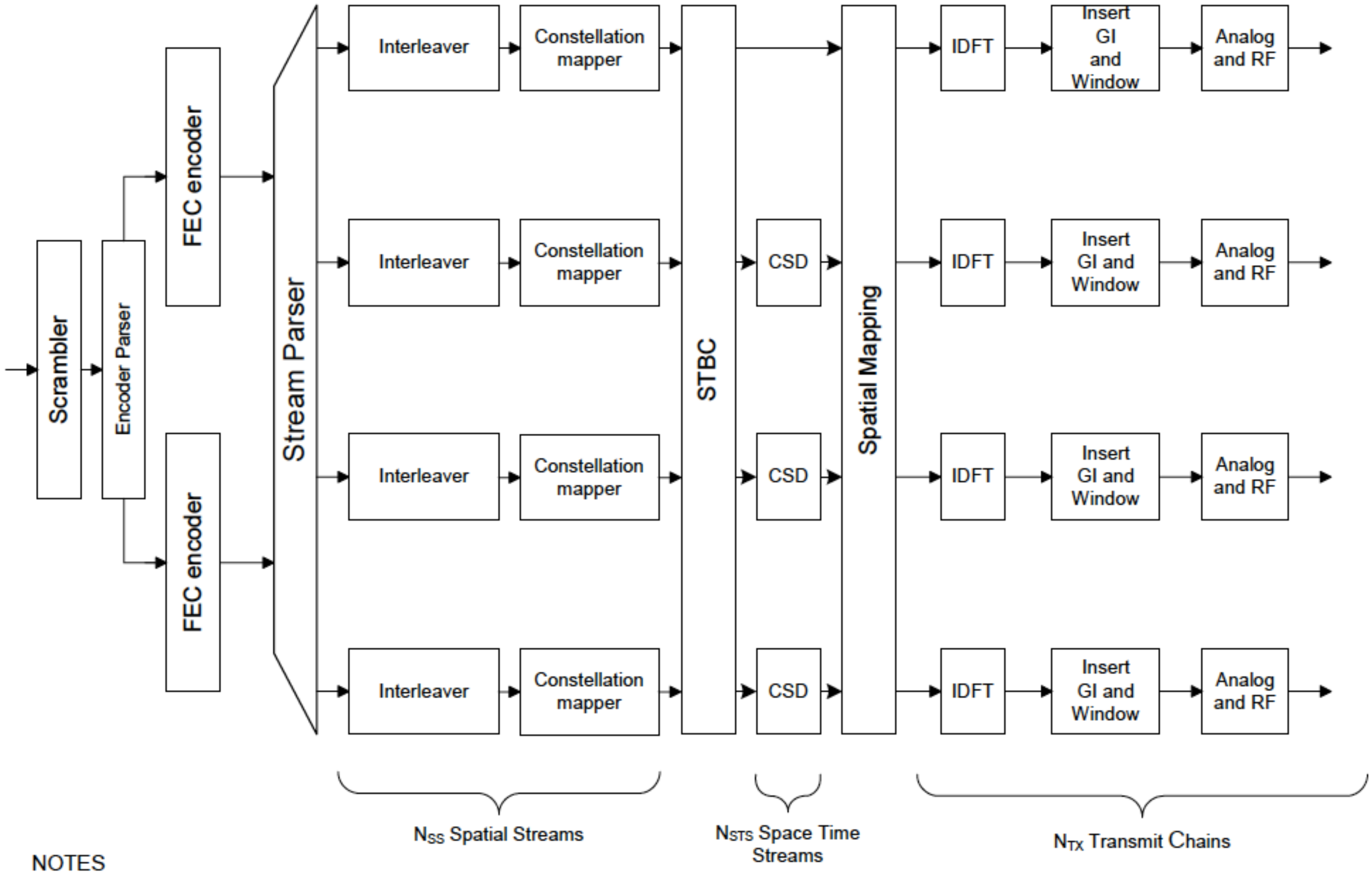
802.11n Frame Aggregation

1. **Aggregation of MAC service data units** (MSDUs) at the top of the MAC (referred to as A-MSDU)
2. **Aggregation of MAC protocol data units** (MPDUs) at the bottom of the MAC (referred to as A-MPDU)

- Frame aggregation is a process of packing multiple MSDUs or MPDUs together to reduce the overheads

- A-MPDU aggregation requires the use of **block acknowledgement**, which was introduced in 802.11e and has been optimized in 802.11n.

Transmitter Block Diagram: HT-Greenfield



NOTES

802.11n Transmitter block

- **Scrambler** – scrambles the data to prevent long sequences of zeros or ones.
- **Encoder Parser** – if BCC encoding is to be used, de-multiplexes the scrambled bits among FEC encoders, in a round robin manner.
- **FEC encoders** – encodes the data to enable error correction
- **Stream Parser** – divides the output of the encoders into blocks that will be sent to different interleaver and mapping devices. The sequences of the bits sent to the interleaver are called **spatial streams**.
- **Interleaver** – interleaves the bits of each spatial stream (changes order of bits) to prevent long sequences of noisy bits from entering the FEC decoder.
- **Constellation mapper** – maps the sequence of bit in each spatial stream to constellation points (complex numbers).

802.11n Transmitter block

- **Spatial Mapping** – maps spatial streams to different transmit chains. This may include one of the following:
  - **Direct mapping** – each sequence of constellation points is sent to a different transmit chain.
  - **Spatial expansion** – Vectors of constellation points from all the space-time streams are expanded via matrix multiplication to produce the input to all the transmit chains.
  - **Beam Forming -** similar to spatial expansion, each vector of constellation points from all the sequences is multiplied by a matrix of steering vectors to produce the input to the transmit chains.
- **Inverse Fast Fourier Transform** – converts a block of constellation points to a time domain block.

802.11n Transmitter block

- **Cyclic shift insertion** – inserts the cyclic shift into the time domain block.
- **Guard interval insertion** – inserts the guard interval.
- **Optional windowing** – smoothing the edges of each symbol to increase spectral decay

802.11n Time and Frequency Parameters

Parameter	TXVECTOR CH_BANDWIDTH			
	NON_HT_CBW20	HT_CBW_20	HT_CBW40 or NON_HT_CBW40	
			HT format	MCS 32 and non-HT duplicate
N_{SD}: Number of complex data numbers	48	52	108	48
N_{SP}: Number of pilot values	4	4	6	4
N_{ST}: Total number of subcarriers See NOTE 1	52	56	114	104
N_{SR}: Highest data subcarrier index	26	28	58	58
Δ_F : Subcarrier frequency spacing	312.5kHz (20 MHz/64)	312.5kHz	312.5kHz (40 MHz/128)	
T_{DFT}: IDFT/DFT period	3.2 μs	3.2 μs	3.2 μs	
T_{GI}: Guard interval duration	0.8 μs= $T_{DFT}/4$	0.8 μs	0.8 μs	
T_{GI2}: Double guard interval	1.6 μs	1.6 μs	1.6 μs	
T_{GIS}: Short guard interval duration	N/A	0.4 μs = $T_{DFT}/8$	0.4 μs See NOTE 2	
$T_{L\text{-}STF}$: Non-HT short training sequence duration	8 μs=10× $T_{DFT}/4$	8 μs	8 μs	
$T_{HT\text{-}GF\text{-}STF}$: HT-greenfield short training field duration	N/A	8 μs=10× $T_{DFT}/4$	8 μs See NOTE 2	
$T_{L\text{-}LTF}$: Non-HT long training field duration	8 μs=2× $T_{DFT}+T_{GI2}$	8 μs	8 μs	
T_{SYM}: Symbol interval	4 μs= $T_{DFT}+T_{GI}$	4 μs	4 μs	
T_{SYMS}: Short GI symbol interval	N/A	3.6 μs = $T_{DFT}+T_{GIS}$	3.6 μs See NOTE 2	
$T_{L\text{-}SIG}$: Non-HT SIGNAL field duration	4 μs= T_{SYM}	4 μs	4 μs	
$T_{HT\text{-}SIG}$: HT SIGNAL field duration	N/A	8 μs= $2T_{SYM}$	8 μs See NOTE 2	
$T_{HT\text{-}STF}$: HT short training field duration	N/A	4 μs	4 μs See NOTE 2	
$T_{HT\text{-}LTF1}$: First HT long training field duration	N/A	4 μs in HT-mixed format, 8 μs in HT-greenfield format	4 μs in HT-mixed format, 8 μs in HT-greenfield format See NOTE 2	
$T_{HT\text{-}LTFs}$: Second, and subsequent, HT long training fields duration	N/A	4 μs	4 μs See NOTE 2	

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New Generation

IEEE 802.11ac

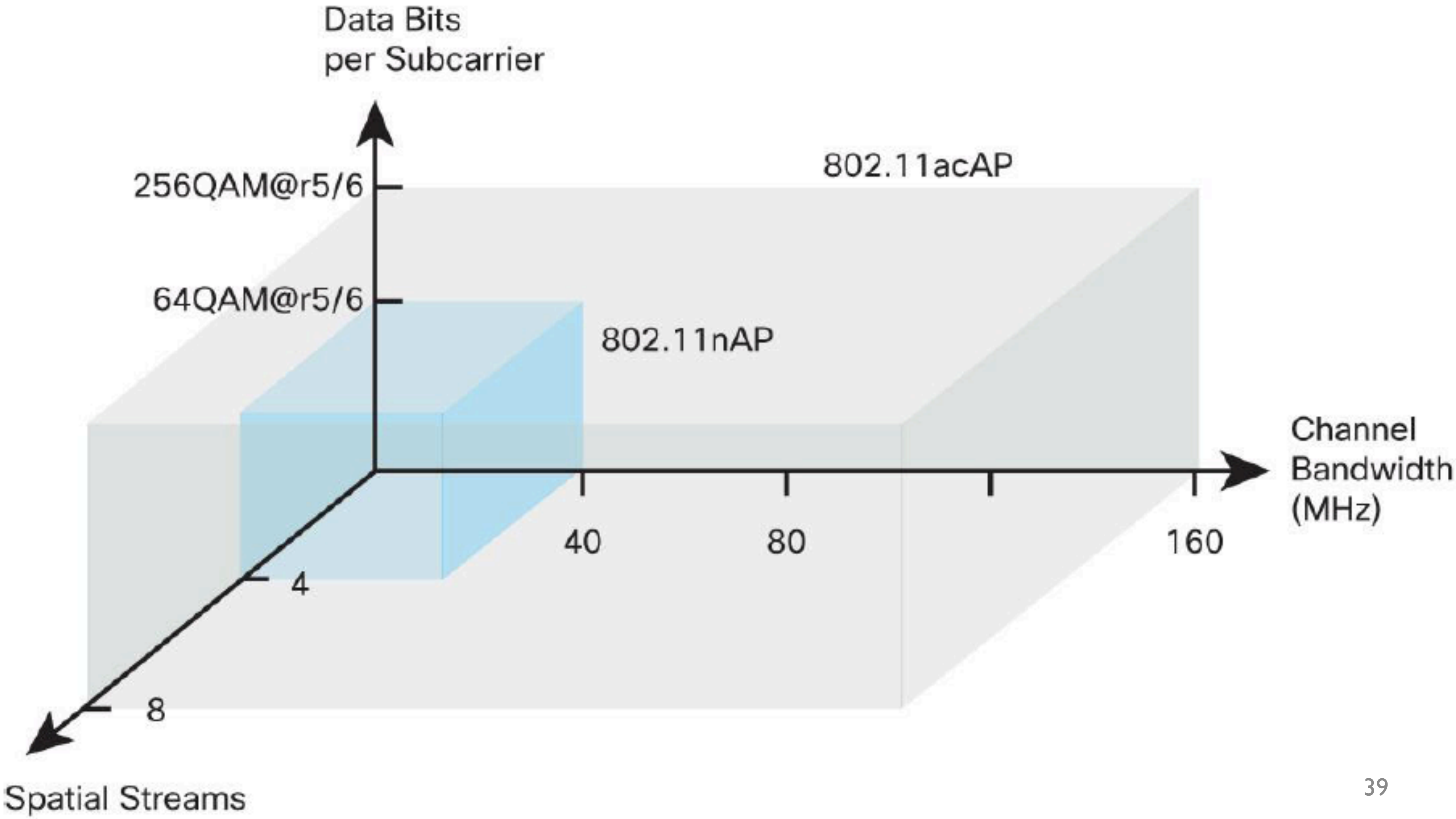
802.11ac: Introduction

- IEEE 802.11ac works in 5 GHz band
- The standard was developed from 2011 through 2013, with final 802.11 Working Group approval and publication scheduled for early 2014
- Devices with the 802.11ac specification are expected to be common by 2015 with an estimated one billion spread around the world.
- This specification has expected multi-station WLAN throughput of at least 1 gigabit per second and a single link throughput of at least 500 Mbit/s.

802.11ac: Main Elements

1. Wider RF bandwidth (up to 160 MHz)
2. More MIMO spatial streams (up to 8)
3. High-density modulation (up to 256-QAM)

802.11ac vs 11n



802.11ac: New Technologies

- **Extended channel binding**
  - Mandatory 80 MHz channel bandwidth for stations (vs. 40 MHz maximum in 802.11n), 160 MHz available optionally
- **More MIMO spatial streams**
  - Support for up to eight spatial streams (vs. four in 802.11n)
- **Multi-user MIMO (MU-MIMO)**
  - Multiple STAs, each with one or more antennas, transmit or receive independent data streams simultaneously
    - "Space Division Multiple Access" (SDMA): streams not separated by frequency, but instead resolved spatially, analogous to 11n-style MIMO
  - Downlink MU-MIMO (one transmitting device, multiple receiving devices) included as an optional mode

802.11ac: New Technologies

- **Modulation**
  - 256-QAM, rate 3/4 and 5/6, added as optional modes (vs. 64-QAM, rate 5/6 maximum in 802.11n)
  - Controversy has been raised that this modulation rate is not suitable for any architecture other than extremely small cells and would be completely useless to 3GPP
- **Other elements/features**
  - Beamforming with standardized sounding and feedback for compatibility between vendors (non-standard in 802.11n made it hard for beamforming to work effectively between different vendor products)
  - MAC modifications (mostly to support above changes)

Commercial laptops

- On June 7, 2012, ASUS had unveiled its ROG G75VX gaming notebook, which will be the first consumer-oriented notebook to be fully compliant with 802.11ac

- Apple announced in June 2013 that the new MacBook Air features 802.11ac wireless networking capabilities.

Commercial handsets

- HTC announced the first 802.11ac-enabled handset, the HTC One on February 19, 2013.
  The phone uses the Broadcom BCM4335 chipset.

- The Samsung Galaxy S4, announced on March 14, 2013, also uses the BCM4335.
- The Samsung Galaxy Round, announced on October 09, 2013, also use
  the 802.11ac-enabled handset.

Example Configuration for 802.11ac

Scenario	Typical Client Form Factor	PHY Link Rate	Aggregate Capacity
1-antenna AP, 1-antenna STA, 80 MHz	Handheld	433 Mbit/s	433 Mbit/s
2-antenna AP, 2-antenna STA, 80 MHz	Tablet, Laptop	867 Mbit/s	867 Mbit/s
1-antenna AP, 1-antenna STA, 160 MHz	Handheld	867 Mbit/s	867 Mbit/s
2-antenna AP, 2-antenna STA, 160 MHz	Tablet, Laptop	1.69 Gbit/s	1.69 Gbit/s
4-antenna AP, four 1-antenna STAs, 160 MHz (MU-MIMO)	Handheld	867 Mbit/s to each STA	3.39 Gbit/s
8-antenna AP, 160 MHz (MU-MIMO) -- one 4-antenna STA -- one 2-antenna STA -- two 1-antenna STAs	Digital TV, Set-top Box, Tablet, Laptop, PC, Handheld	3.39 Gbit/s to 4-antenna STA 1.69 Gbit/s to 2-antenna STA 867 Mbit/s to each 1-antenna STA	6.77 Gbit/s
8-antenna AP, four 2-antenna STAs, 160 MHz (MU-MIMO)	Digital TV, Tablet, Laptop, PC	1.69 Gbit/s to each STA	6.77 Gbit/s

802.11ac Data Rates

Theoretical throughput for single Spatial Stream (in Mb/s)										
MCS index	Modulation type	Coding rate	20 MHz channels		40 MHz channels		80 MHz channels		160 MHz channels	
			800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	BPSK	1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	65
1	QPSK	1/2	13	14.4	27	30	58.5	65	117	130
2	QPSK	3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195
3	16-QAM	1/2	26	28.9	54	60	117	130	234	260
4	16-QAM	3/4	39	43.3	81	90	175.5	195	351	390
5	64-QAM	2/3	52	57.8	108	120	234	260	468	520
6	64-QAM	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
7	64-QAM	5/6	65	72.2	135	150	292.5	325	585	650
8	256-QAM	3/4	78	86.7	162	180	351	390	702	780
9	256-QAM	5/6	N/A	N/A	180	200	390	433.3	780	866.7

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VANETs

IEEE 802.11p

802.11p: Main Features

- 802.11p is an approved amendment to the IEEE 802.11 standard to add *wireless access in vehicular environments (WAVE)*
- Data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz).
- IEEE 1609 is a higher layer standard based on the IEEE 802.11p

802.11p vs DSRC in US

802.11p was considered for **dedicated short-range communications (DSRC)**, a **U.S**. Department of Transportation project based on the Communications, Air-interface, Long and Medium range (**CALM**) architecture of the International Organization for Standardization for vehicle-based communication networks, particularly for applications such as **toll collection, vehicle safety services, and commerce transactions via cars**.

802.11p vs ITS-G5 in EU

In Europe, 802.11p was used as a basis for **the ITS-G5 standard**, supporting the **GeoNetworking** protocol for vehicle to vehicle and vehicle to infrastructure communication. ITS G5 and GeoNetworking is being standardized by the European Telecommunications Standards Institute group for Intelligent Transport Systems.

What is Dedicated Short Range Communication (DSRC)?

- A short to medium range communications service
- Aimed as a replacement to the 802.11 wireless standards
  - 802.11 a/b/g
- Older DSRC systems such as toll tags operate in the 900 MHz spectrum
  - No standard, several proprietary systems are in place
- FCC has authorized 75 MHz of spectrum from 5.850 to 5.925 GHz for DSRC (incl. Canada and Mexico)
  - Standardization, Interoperability
  - Europe and Japan use the 5.8 GHz spectrum
  - European organization – CEN – Different Physical and MAC layer standards
  - Japan – ARIB T55

DSRC Overview

- Supports both Public Safety and Private operations
- Both roadside to vehicle and vehicle to vehicle communication environments
- Meant to be a complement to cellular communications
  - provides very high data transfer rates and minimal latency
  - Range – upto 1000 m
  - Data Rate – 6 to 27 Mbps
  - Channels – 7 Licensed Channels

DSRC

- Key Issue – QoS – Prioritization of Safety messages
- If a neighboring car is in the middle of a streaming movie application, and I need to communicate about an accident, how to prioritize the message?
- DSRC has 1 control channel and other service channels. Safety messages are expected to use the control channel

DSRC Protocol Stack

- IEEE P1609.1, Resource Manager
- IEEE P1609.2, Application Services
- IEEE P1609.3, IP Network Services
- IEEE P1609.4, Medium Access Control (MAC) Extension Services
- [Vehicle Safety Data Dictionary/Message Sets (SAE)]

IEEE P1609.1 Scope

- Modified version of the Resource Manager standard originally defined in IEEE Std 1455-1999
- P1609 Resource Manager supports DSRC applications using the IEEE 802.11a communication technology

IEEE P1609.2 Scope

- An Application Services (Layer 7) standard for 5.9 GHz DSRC applications
- Supports several protocol stacks, including one representing traditional DSRC systems, TCP/IP, and streaming audio/video
- Describes interfaces with the lower layer standards being developed by ASTM

IEEE P1609.3 Scope

- Defines interfaces between the multiple communication stacks and the lower layer services of ASTM 2213-02 (IEEE 802.11a R/A)
- Support multiple protocol stacks, one for the traditional DSRC, one for streaming audio/video, and another for TCP/IP
- The North American DSRC Architecture is evolving

IEEE P1609.4 Scope

- Standard for the Media Access Control Extension sub-layer (Layer 2) that defines interfaces between these multiple applications and communication stacks that interface with ASTM 2213-02 (IEEE 802.11a)
- Interface with the public safety applications community through National Public Safety Telecommunication Council (NPSTC)
- NPSTC cooperation is expected to result in potential use of the ITS Radio (DSRC) by ITS and public safety

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- IEEE 802.11g
- IEEE 802.11n
- IEEE 802.11ac
- IEEE 802.11p
- Physical Data Rates Adaptation

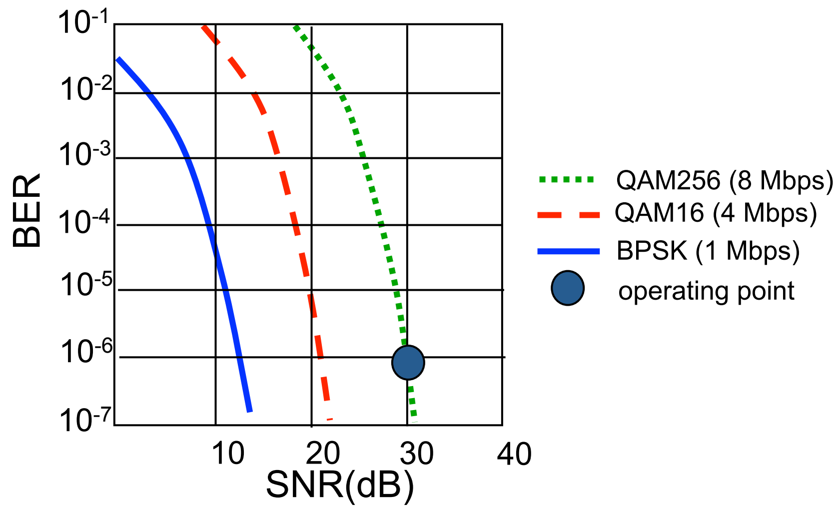
Physical Data Rates Adaptation

ADVANCE FEATURES IN 802.11

802.11: Advanced Capabilities

Rate adaptation

- base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies



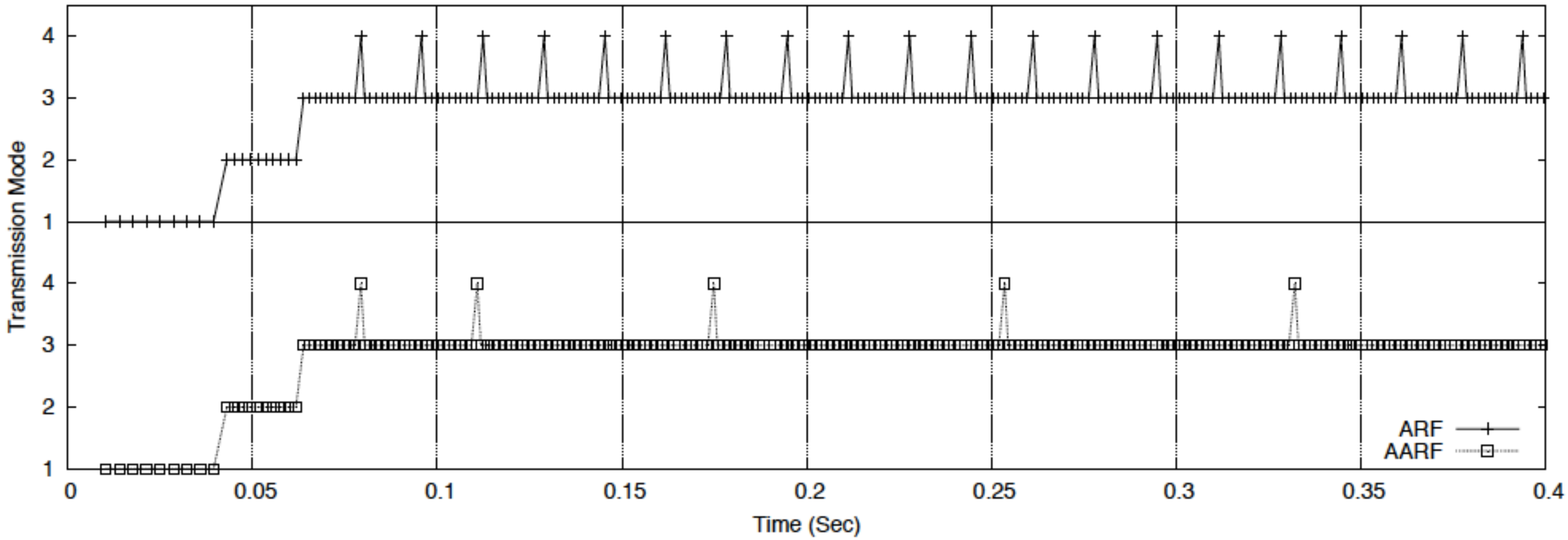
1. SNR decreases, BER increase as node moves away from base station

2. When BER becomes too high, switch to lower transmission rate but with lower BER

Main Protocols

- Auto Rate Fallback: ARF
  - Try to increase rate at periodic times
  - Decrease rate if it is not successful
- Receiver Based Auto Rate: RBAR
  - Get feedback from the receiver to select the best rate
- Adaptive Auto Rate Fallback: AARF
  - Conservative rate increase
- Full Auto Rate: FAR
- Opportunistic Auto Rate: OAR
- Medium Access Diversity: MAD

ARF vs AARF



Transmission Mode
4
3
2
1
4
3
2
1
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Time (Sec)
ARF
AARF