SYSC 4700

Lecture 13

Wireless LAN / Wi-Fi I

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Who Is This Guy ?!

Stephen Rayment is a VP of Technology at Ericsson where he is responsible for new technologies in the North America region.

He has more than 30 years of product and technology experience in the telecommunications industry - most of that focussed on wireless.

He led the Wi-Fi business at Ericsson and before that was CTO and co-founder of BelAir Networks. Prior to that he led the development of broadband fixed wireless products, broadband multimedia satcom equipment and the industry's first wireless PBX at Bell-Northern Research and Nortel Networks.

Stephen is author of over 30 US patents, and is active in industry standardization, having served as an officer in IEEE 802.11 and Wi-Fi Alliance.

Stephen holds a B.Sc and M.Sc in Electrical Engineering from Queen's University, a Diploma in Administration from the University of Ottawa, is a graduate of the MIT Sloan School's Management of Technology program, and is a Senior Member of the IEEE.

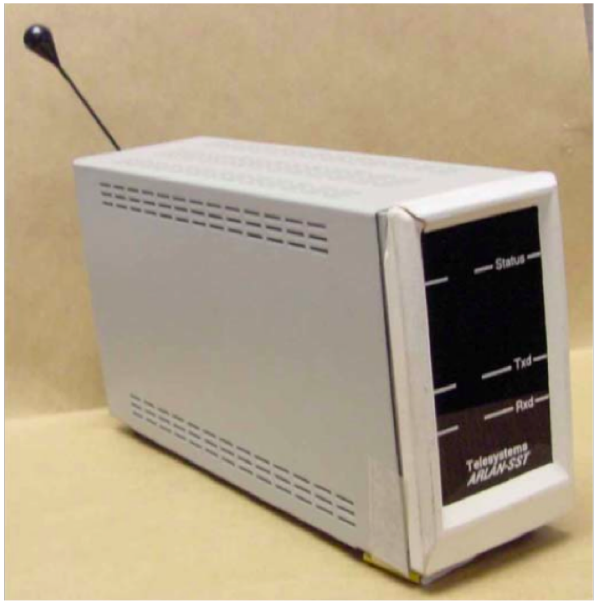
Quiz Time

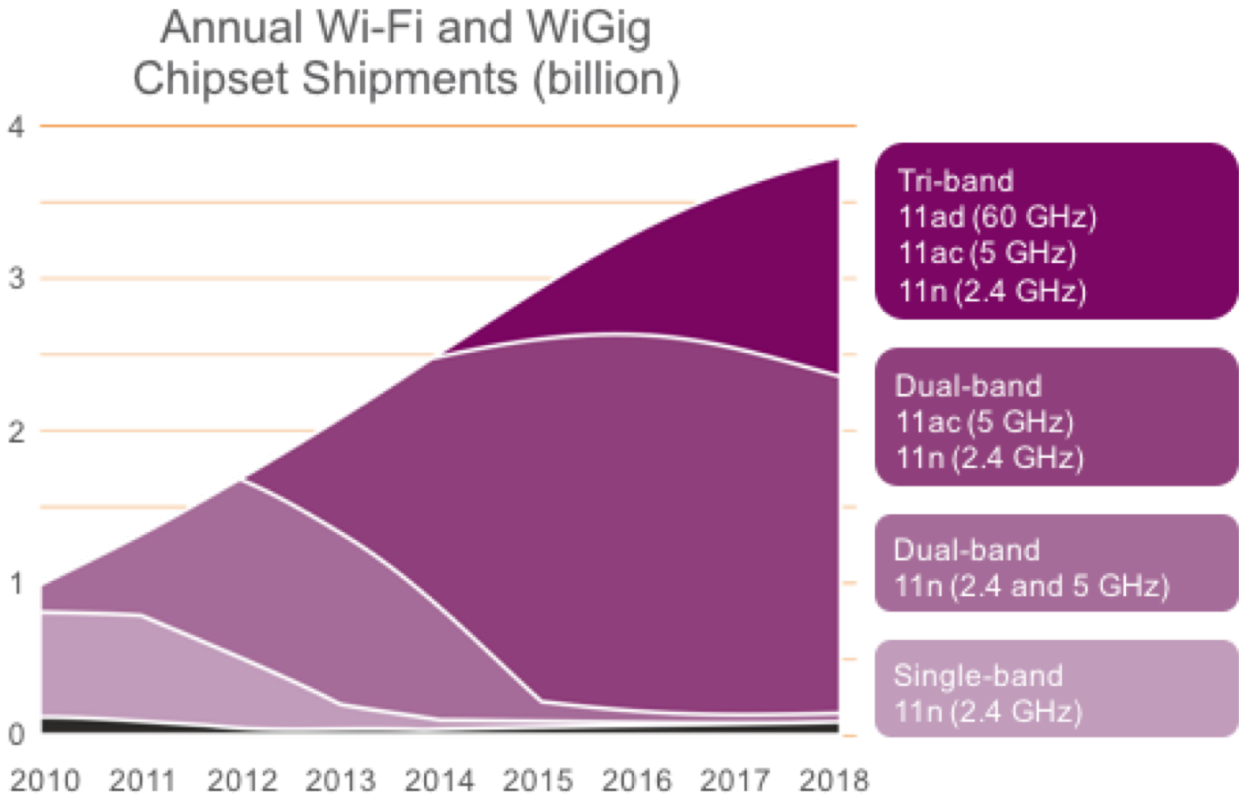
- What is Wi-Fi short for?
- For what application was WLAN first used?
- How may Wi-Fi chipsets have been shipped to end of 2017?
- What percentage of homes have Wi-Fi world-wide?
- What standard does Wi-Fi use?
- What does the Wi-Fi Alliance do?

Outline

1. Applications and History
2. Architecture
3. Physical Layer – PHY
4. Medium Access Control – MAC

WLAN Progress!





Telesystems ARLAN-SST (circa 1988)

~ 200kbps

Dual band 802.11ac USB

> 1Gbps

You Can't Buy a Laptop or Smartphone Without Wi-Fi

Intel began to include Wi-Fi in all its Centrino laptops in 2003

Starting with iPhone 1 in 2007

Residential Wi-Fi

Home Routers
- Tri-band
- Over 2Gbps
- HDTV streaming
- Mesh "whole home"
- Voice control, e.g. Alexa

Smart TV
with built-in Wi-Fi

Digital Cameras
- Upload to computer, and web applications wirelessly
- Full remote control

Wi-Fi Security Cameras

Enterprise Wi-Fi

SME/Branch Office WLANs

Eliminating the cost and complexity of centrally managed wireless LANs, but with all the features and benefits, and then some.

Hospitality

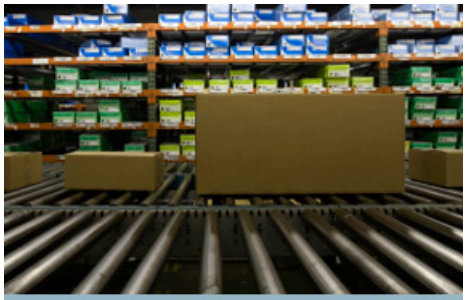
See how Wi-Fi delivers reliable high-speed connectivity that guests will gladly check in for.

Retail

Research how companies leverage better Wi-Fi technology to increase efficiency and the satisfaction of the customers.

Enterprise WLANs

Robust, secure, scalable and reliable centrally managed WLANs that fit within any existing network structure.



Warehousing

Find out how companies are getting Wi-Fi to function in the rugged remote reaches of their warehouses.

Healthcare

Discover how our solutions connect clinicians to information and people, to improve the quality of care.

Education

Learn how schools and districts are getting better coverage with fewer access points and less Ethernet cabling.

Mobile employee productivity

Wire replacement 802.11ac

BYOD

Applications in the "cloud"

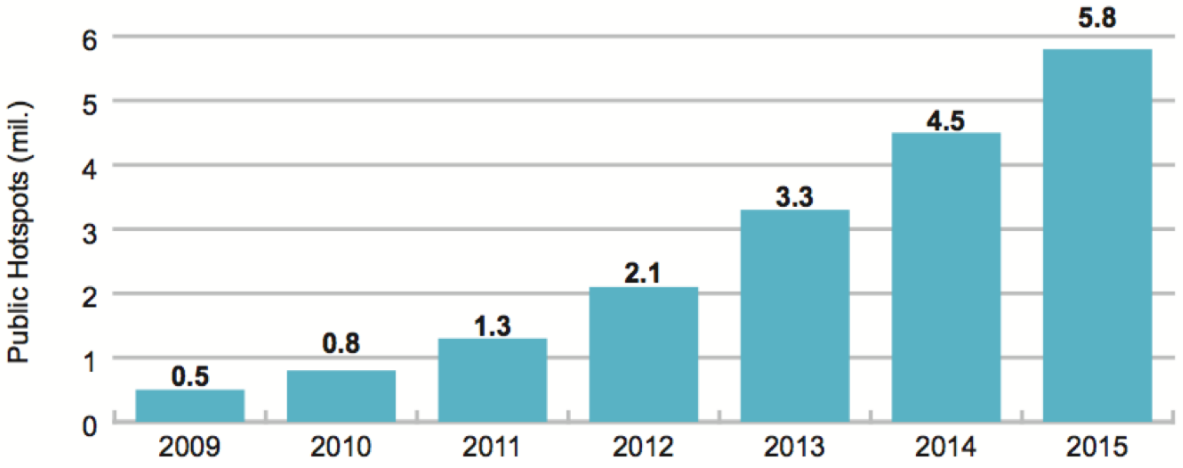
Security, security, security

Source: Ruckus Wireless

Wi-Fi Hotspots

- Over 10M public hotpots around the world by 2018
  - –China, S Korea, FR, UK, US
- AT&T has over 45K hotspots
  - –including McDonald's
- KT has over 200K hotspots
- China Mobile has deployed over 5M APs
- Community Wi-Fi
  - –Hotspot in your home

Fig. 4: Global number of public Hotspots, 2009-2015



Source: Informa Telecoms & Media

Wi-Fi on Trains

- Wi-Fi is a key tool to compete with the airlines
  - –Heathrow Express in London was one of the first
  - –National Express East Coast 43 trains between London and Inverness, Scotland
  - –Deutsche Bahn in Dortmund, Cologne, Frankfurt, Stuttgart, Munich, Frankfurt, Hamburg
  - –San Francisco Bay Area Rapid Transit District (BART) with Wi-Fi Rail
  - –Comcast and Cablevision offer Wi-Fi service in 100 commuter train stations in NJ
  - –Via Rail offers service on 98% of the the Windsor-Quebec Corridor
- Usually cellular "backhaul" to the Internet
  - –Aggregate multiple networks

VIA Rail Canada

national express

THALYS

SNCF

DB BAHN

T··Mobile·HotSpot

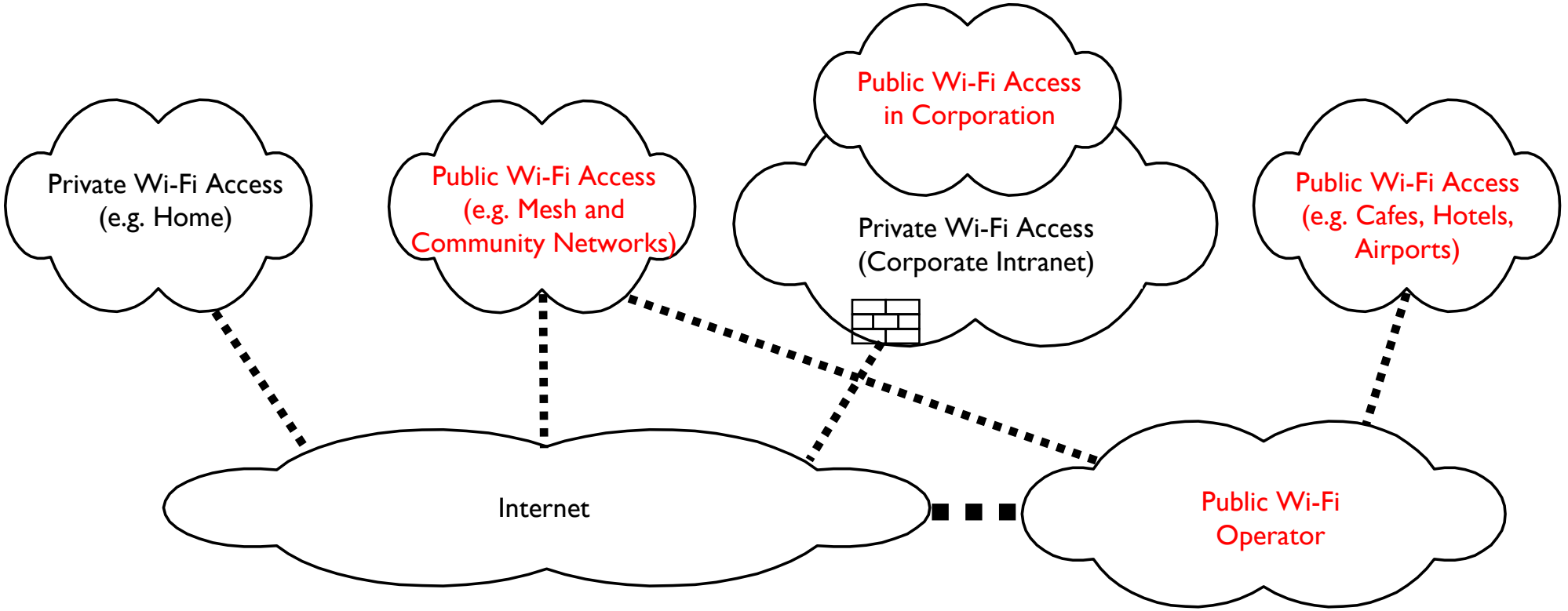
Wi-Fi on Airplanes

- NA and international airlines
  - –Air Canada, Air Tran, Alaska Airlines, American Airlines, Delta, Frontier, United, US Airways, Virgin America
  - –Currently on over 2000 commercial aircraft
  - –Lufthansa, Emirates, Oman and Gulf also deploying
  - –Typical cost for Wi-Fi services: $12.95 for 24 hours, $39.95 per month
- cdma (EV-DO Rev A) cellular data network – over 100 BTS's pointing to the sky
- Typical 500 kbps

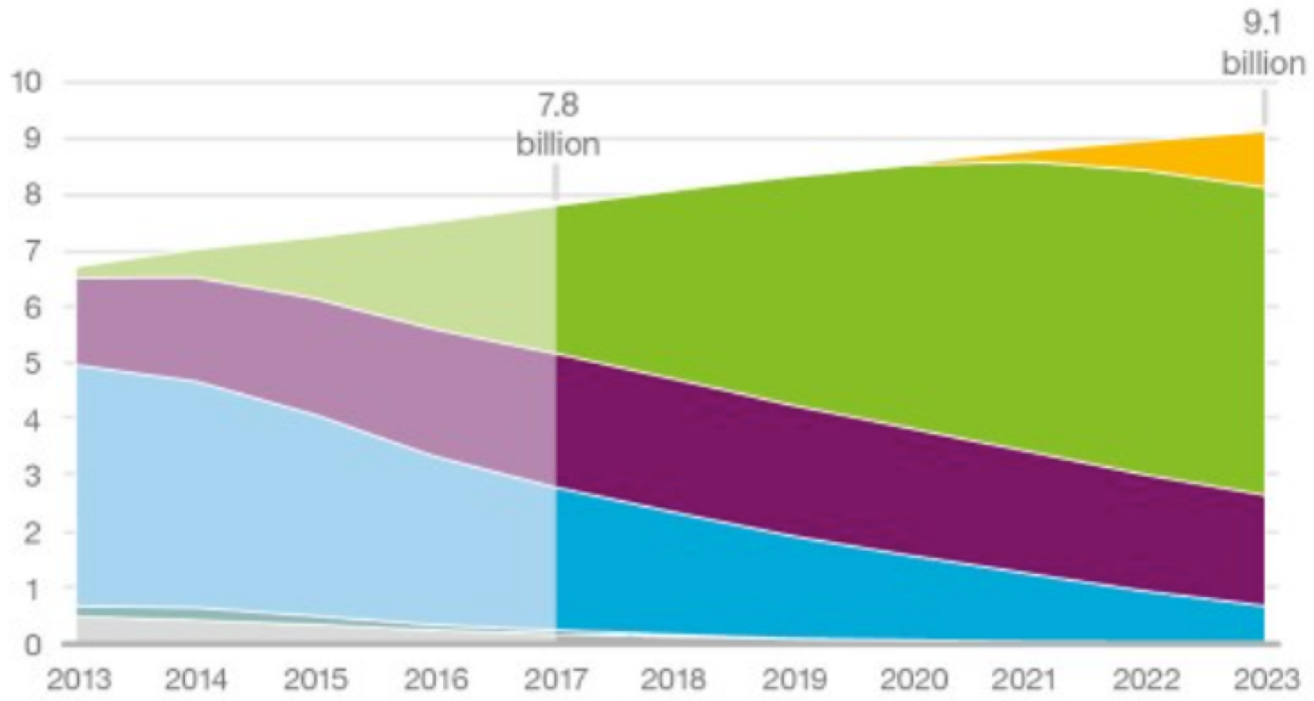
gogo IN AIR. ONLINE.

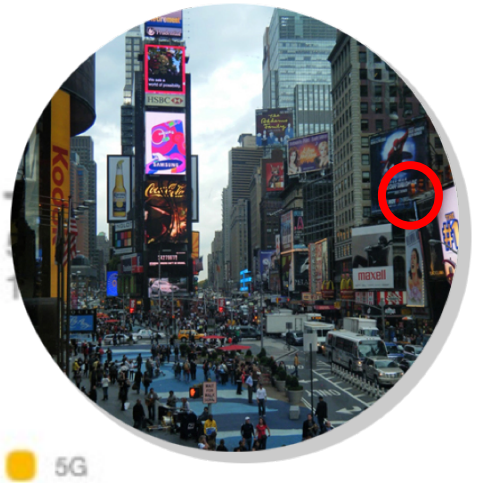
Wi-Fi ONBOARD

Ubiquitous Wi-Fi Access – Muni Wi-Fi



Mobile Broadband – Cellular Data Offload



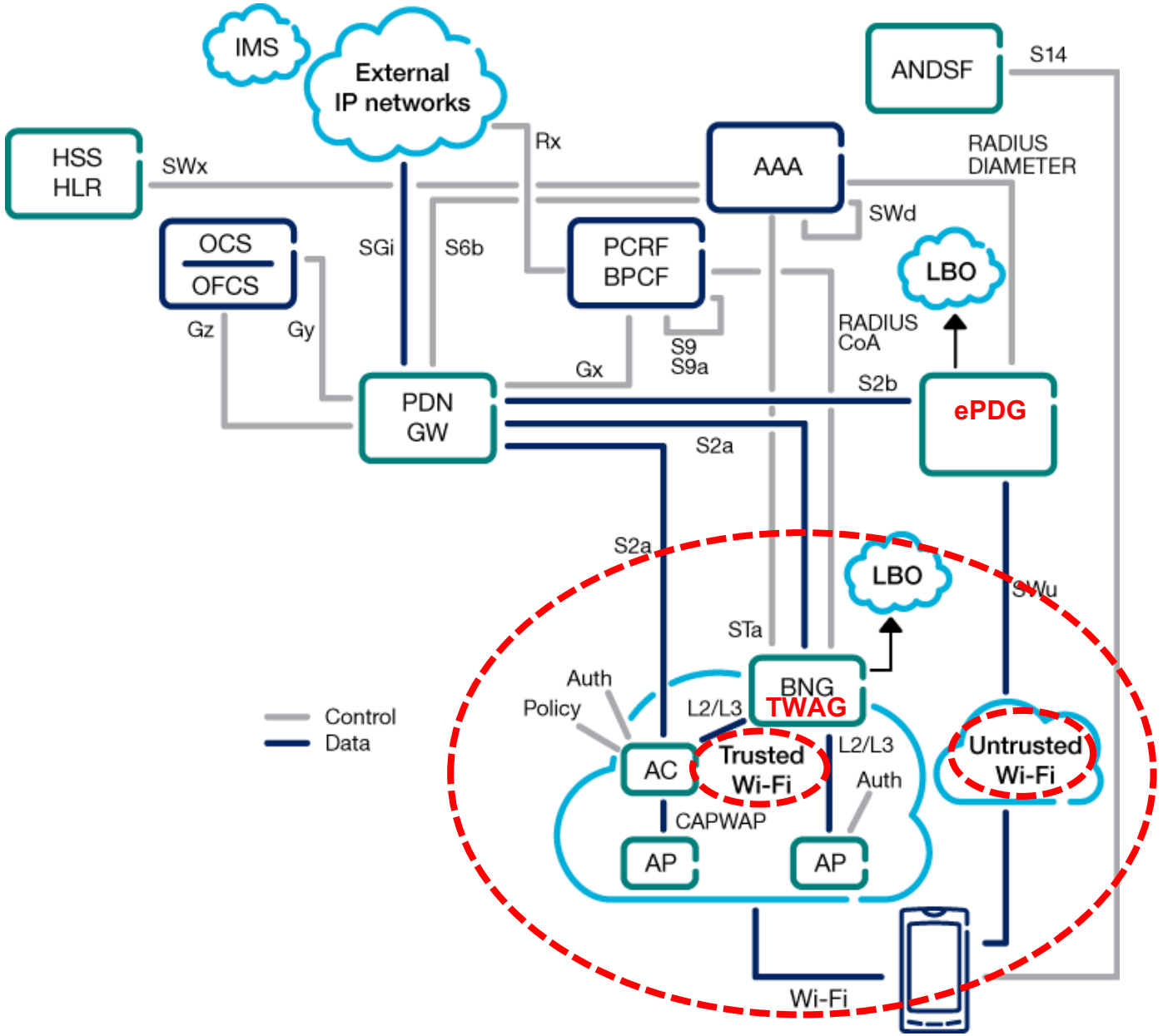


- Over 7.8B smartphone subscriptions 2017 will grow to 9.1B by 2023
- Mobile data traffic will grow by 9x between now and 2023
- Subscribers downloading and watching video content, and using video-communication services
- Wi-Fi (and small cells) in areas of high user concentration

Ericsson Mobility Report

Wi-Fi and Heterogeneous Networks

- Wi-Fi integrated into 3GPP cellular network
- Just another RAT (Radio Access Technology
- Core network integration shown here
- RAN (radio access network) integration



Cable Wi-Fi

- Cable operators add Wi-Fi mobility as part of a "quad" play to retain subscribers
- CableWiFi" roaming consortium enables roaming across five operators, about 300,000 hotspots
- Community Wi-Fi – adding public capability to residential gateways means 10's of millions of hotspots
- Plus outdoor strand mounted nodes

IoT Internet of Things

29 billion connected devices by 2022

Many will be in home - could be Wi-Fi based . . .

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IEEE 802 Standards

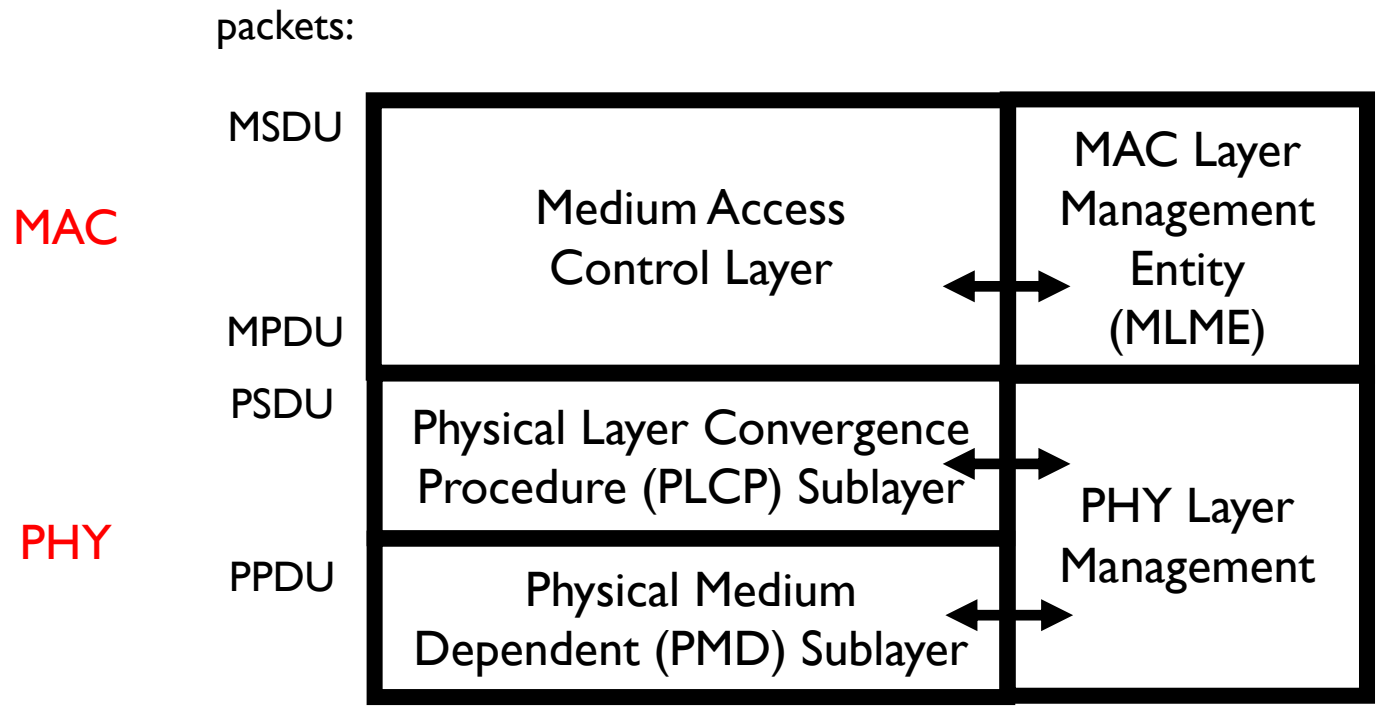
- IEEE 802 is the (Layer 1,2) standard for LANs – i.e. Ethernet
- Includes many broadband wireless access standards:
  - *802.11, 802.15, 802.16, 802.20, 802.22*

<table>
<tr><td colspan="2">Network Layer</td><td rowspan="3">802.1
Overview
Architecture
Management
Internetworking</td><td colspan="6">802.2 Logical Link Control (LLC)</td></tr>
<tr><td rowspan="2">Data Link Layer</td><td>LLC Sublayer</td><td rowspan="2">CSMA CD Wired</td><td rowspan="2">Wireless Local Area Networks</td><td rowspan="2">Wireless Personal Area Networks</td><td rowspan="2">Broadband Wireless Access</td><td rowspan="2">Mobile Broadband Wireless Access</td><td rowspan="2">Wireless Regional Area Networks</td></tr>
<tr><td>MAC Sublayer</td></tr>
<tr><td colspan="2">PHYsical Layer</td><td>802.3</td><td>802.11</td><td>802.15</td><td>802.16</td><td>802.20</td><td>802.22</td></tr>
</table>

- All the 802 wireless standards interface to the same Ethernet LLC and architecture
- The 802.11standard is supplemented by alphabetical amendments (up to 802.11ax now)
- Integrated standard is updated roughly every 4 years (last was 802.11-2016)
- Download 802.11 standard and ratified amendments from:

http://standards.ieee.org/getieee802/802.11.html

802.11 Basic Reference Model



MSDU MAC Service Data Unit

MPDU MAC Protocol Data Unit

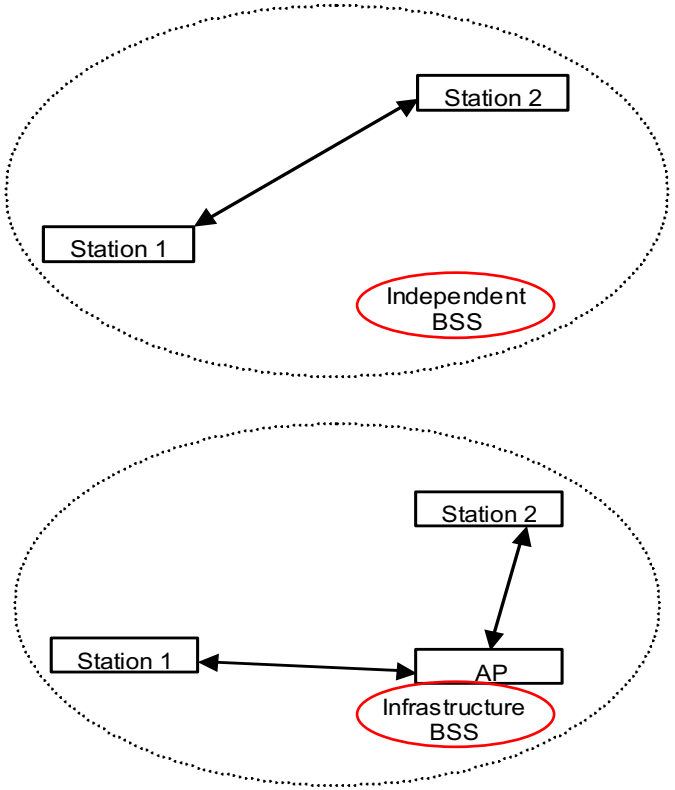
PSDU PHY Service Data Unit

PPDU PLCP Protocol Data Unit

802.11 Architecture and Terminology

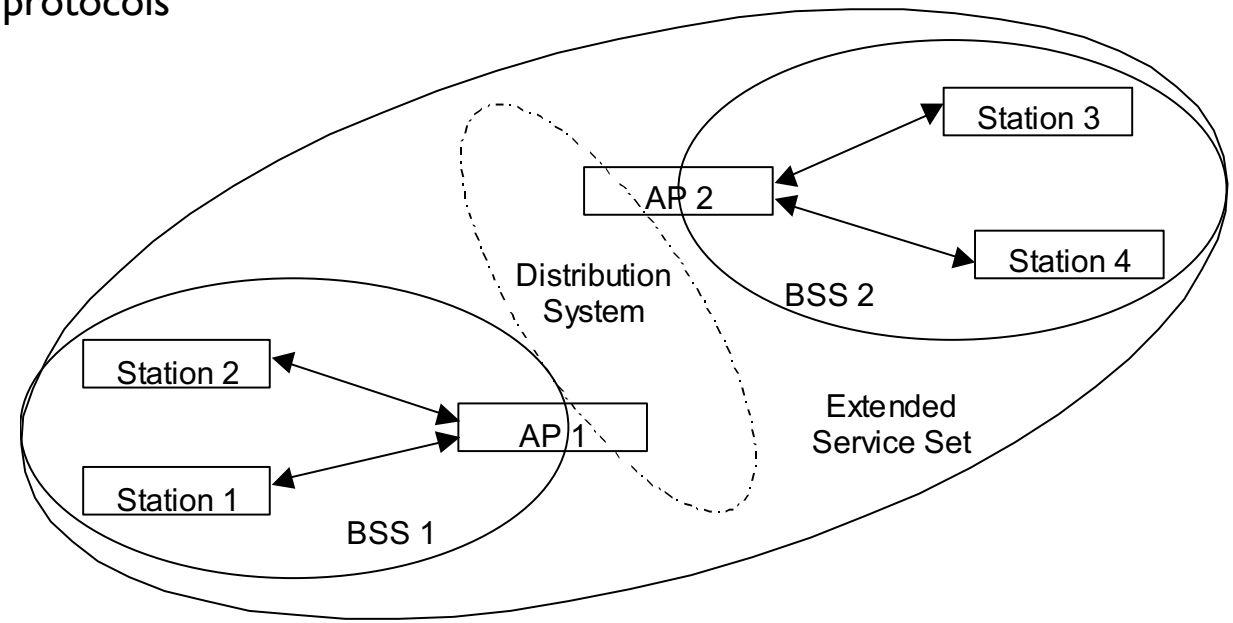
- The Station (STA)
  - A station is the basic building block of the 802.11 WLAN, consisting of a MAC and a PHY
  - A station may be stationary, portable, or mobile
- The Access Point (AP)
  - The access point links a number of stations, even if all the stations cannot communicate directly with each other
- The Basic Service Set (BSS)
  - When two or more stations communicate, they form a basic service set
- The Independent BSS (IBSS)
  - The independent BSS comprises only stations that communicate directly with each other
  - Sometimes referred to as "Adhoc Mode"
- The Infrastructure BSS
  - In an infrastructure BSS, all stations communicate via the AP
  - The AP provides relay functionality so that stations that cannot communicate directly with each other still have a means to exchange information

BSS can be either . . .



802.11 Architecture and Terminology

- The Distribution System (DS)
  - The distribution system links one infrastructure BSS to another, using the AP as the point of connection to each BSS
  - The DS is also where the 802.11 WLAN connects to other LANs, such as Ethernet
  - The DS allows mobility of stations between one BSS and another
- The Extended Service Set (ESS)
  - The extended service set is the set of all BSSs that are connected by a single distribution system
  - To network destinations outside the ESS, the ESS appears as a single LAN segment including all of the stations and APs of the WLAN
  - A station may move anywhere within the ESS and maintain its logical location to higher layer network protocols



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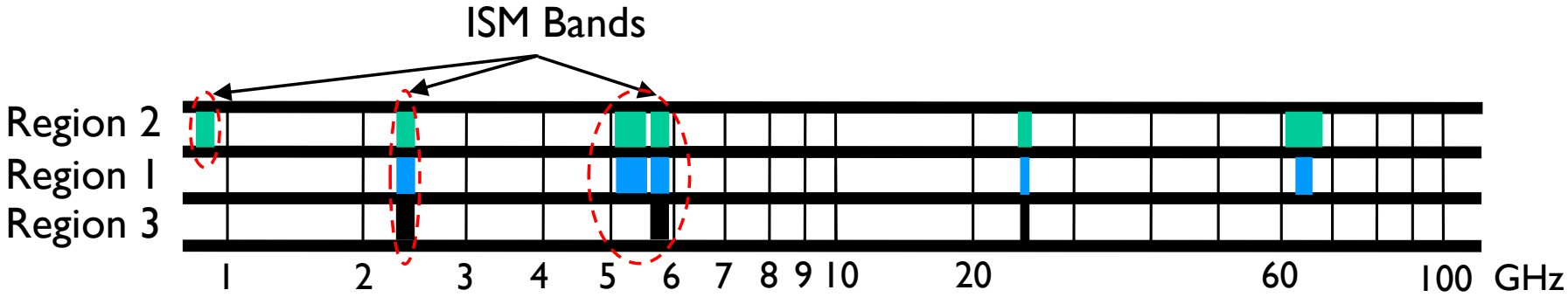
Unlicensed Frequency Bands

- Junk bands that no-one wanted!
- ISM – Industrial Scientific and Medical – 900MHz, 2.4GHz and 5GHz
  - "Landmark" 1985 FCC ruling allowing "type approval"
- 802.11 uses 2.4 GHz, 5 GHz and 60GHz unlicensed frequency bands
  - Other standards and devices also operate in these bands
    - IEEE 802.15.1 (Bluetooth), IEEE 802.15.4 (ZigBee), cordless telephones and microwave ovens operate in 2.4 GHz band
    - IEEE 802.16 (WiMAX), plus proprietary backhaul and cordless telephones operates in 5 GHz band
- To mitigate effects of interference, all devices should observe some sort of etiquette during transmission
  - Allows incompatible systems to co-exist
  - Key elements are listen before transmit, limit transmit time and limit transmit power
  - But regulations vary across regions
  - In addition, at 5GHz, DFS (Dynamic Frequency Section) is a regulated requirement to avoid radar

Unlicensed Frequency Bands

- 2.4 GHz band has become very popular – "tragedy of the commons"
- 5 GHz band offers much more bandwidth (500 MHz versus 83.5 MHz)
- 60 GHz for "in room" networks



2.4GHz Channels, Bandwidth and Power

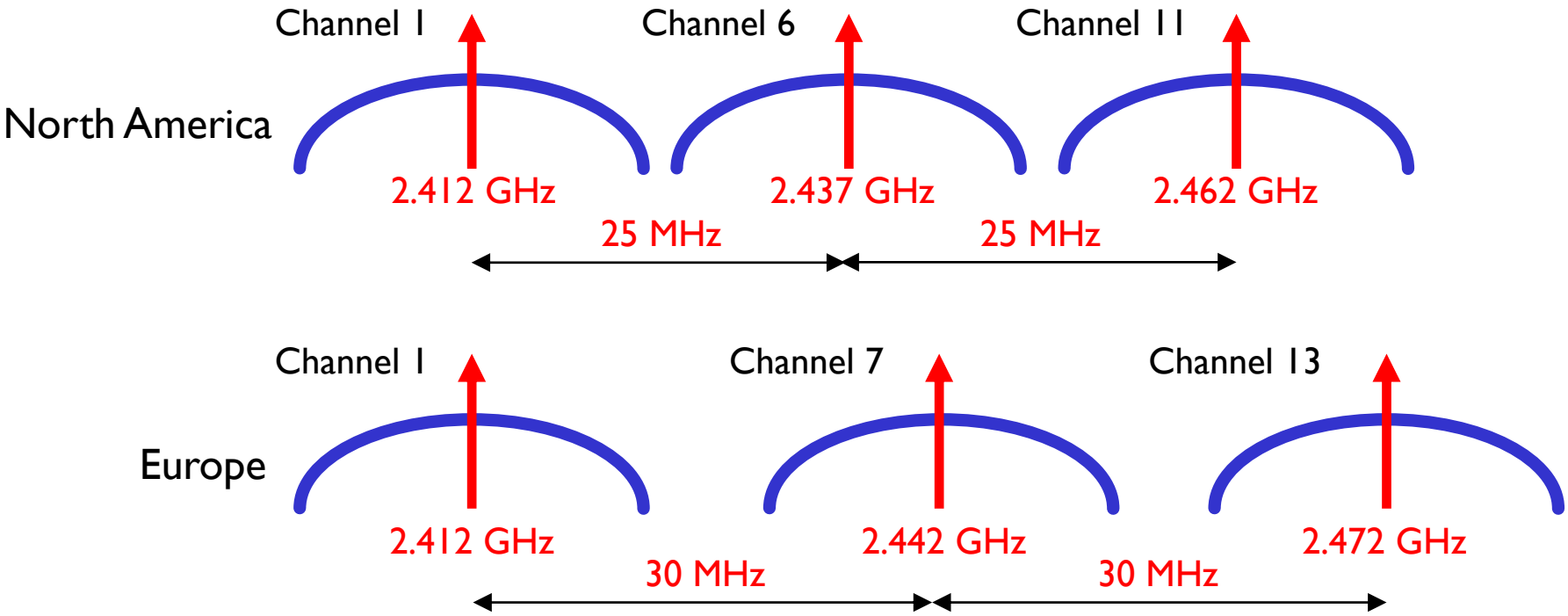
–3 non-overlapping channels

– Channel bandwidth (for -20dB power):

- ~13 MHz for 802.11b DSSS
- ~16 MHz for 802.11g/n OFDM

– EIRP – Effective Isotropic Radiating power – from antenna

- 4W (US), 100mW (Europe), 10mW/MHz (Japan)

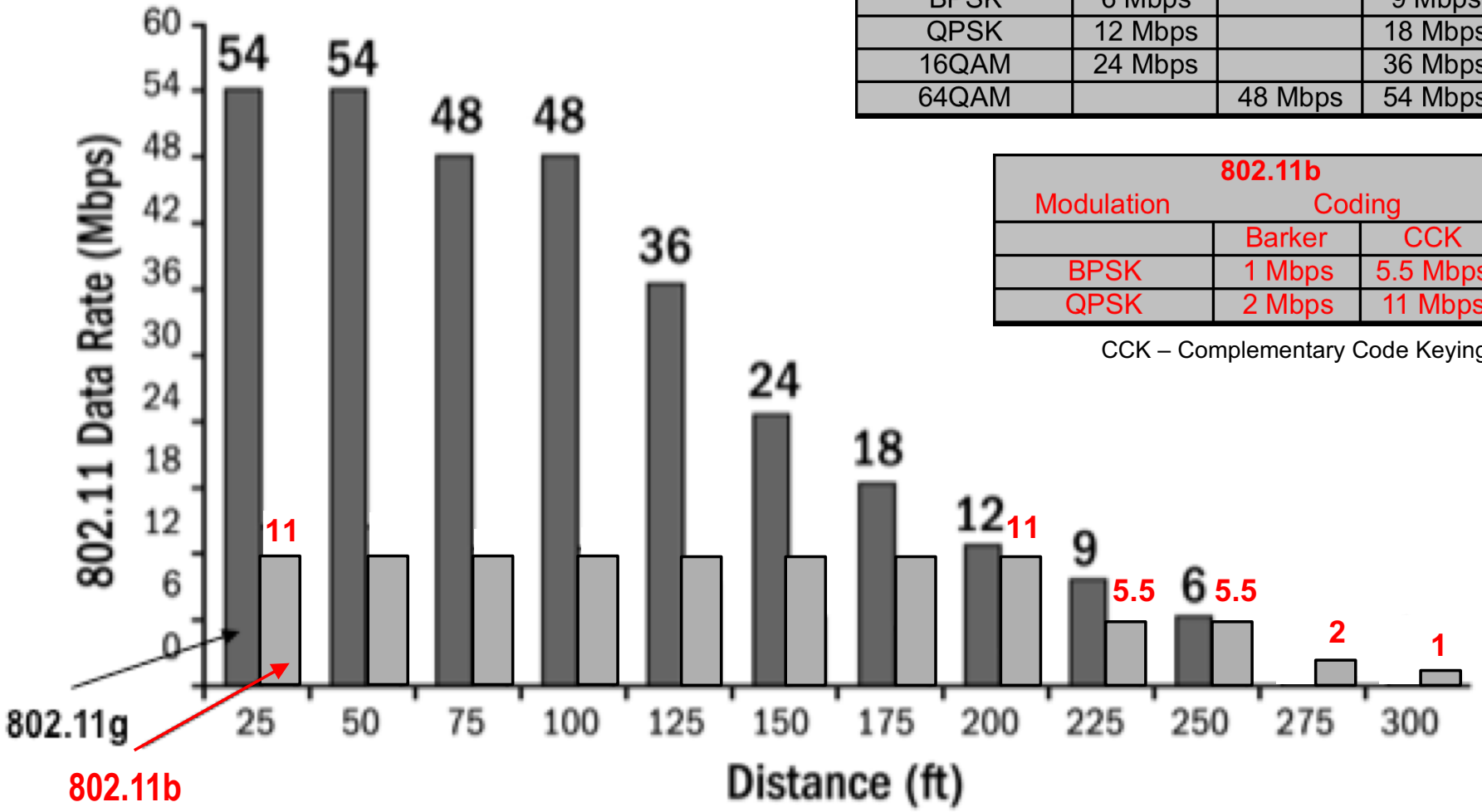


Data Rate vs Range – Indoors

802.11g			
Modulation	Coding Rate		
	R = 1/2	R = 2/3	R = 3/4
BPSK	6 Mbps		9 Mbps
QPSK	12 Mbps		18 Mbps
16QAM	24 Mbps		36 Mbps
64QAM		48 Mbps	54 Mbps

802.11b		
Modulation	Coding	
	Barker	CCK
BPSK	1 Mbps	5.5 Mbps
QPSK	2 Mbps	11 Mbps

CCK – Complementary Code Keying



5GHz Channels and Power

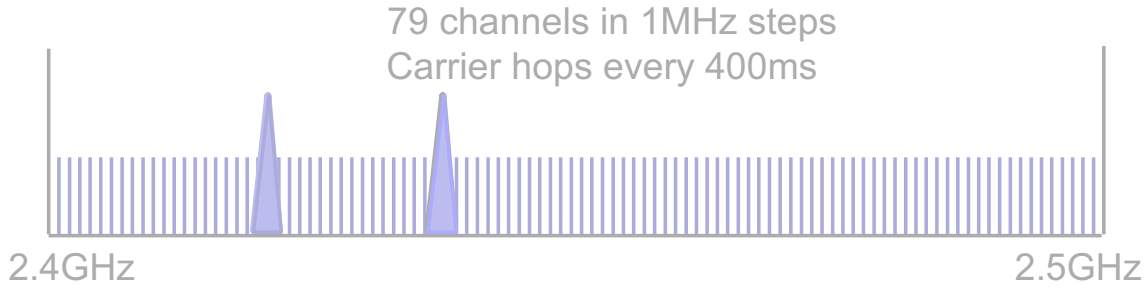
Frequency Band	Channel Numbers	Center Frequency (GHz)	Maximum Output U.S. (Conducted with up to 6 dBi antenna gain)	Maximum Output Europe (EIRP)
5.15-5.25GHz (U-NII 1)	36 40 44 48	5.18 5.20 5.22 5.24	250 mW (12.5 mW / MHz) changed in 2014 to 1W	200 mW
5.25-5.35GHz (U-NII 2A)	52 56 60 64	5.26 5.28 5.30 5.32	250 mW (12.5 mW / MHz)	200 mW
5.470-5.725GHz (U-NII 2C)	100 ~ 144	5.470 ~ 5.725	250 mW (12.5 mW / MHz)	200 mW
5.725-5.825GHz (U-NII 3) note: ISM extends to 5.875	149 153 157 161 165	5.745 5.765 5.785 5.805 5.825	1W (50 mW / MHz)	4 W

420 MHz bandwidth, 21 non-overlapping channels of 20MHz each

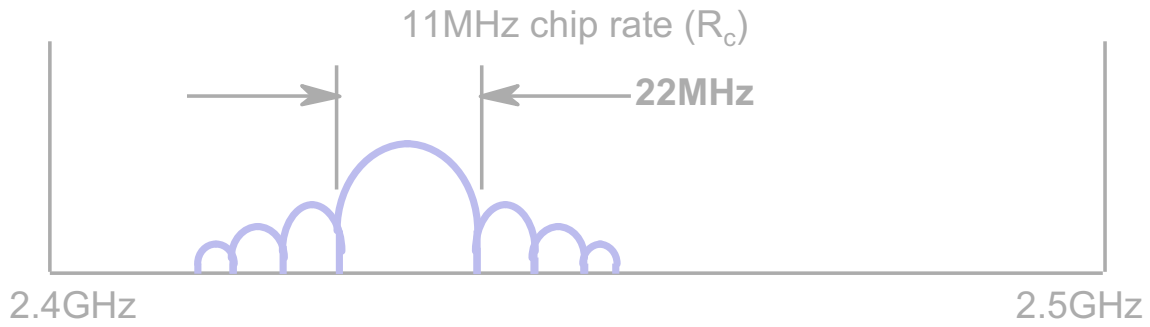
Potential for expansion to over 700MHz (U-NII 2B and U-NII 4)

Modulation Schemes – FHSS, DSSS and **OFDM**

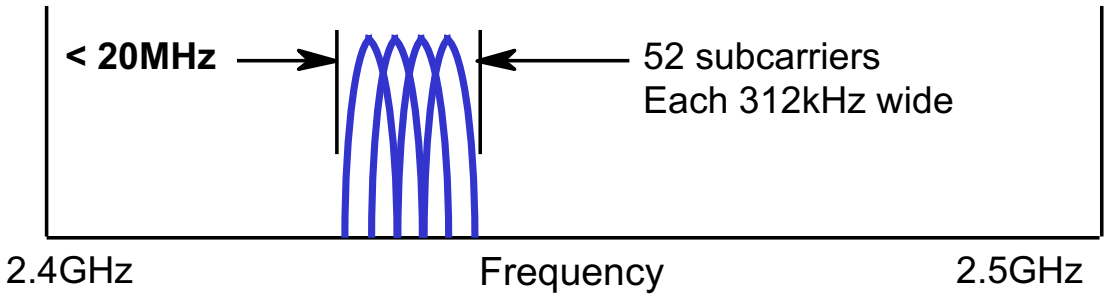
802.11 Frequency Hopping Spread Spectrum – FHSS



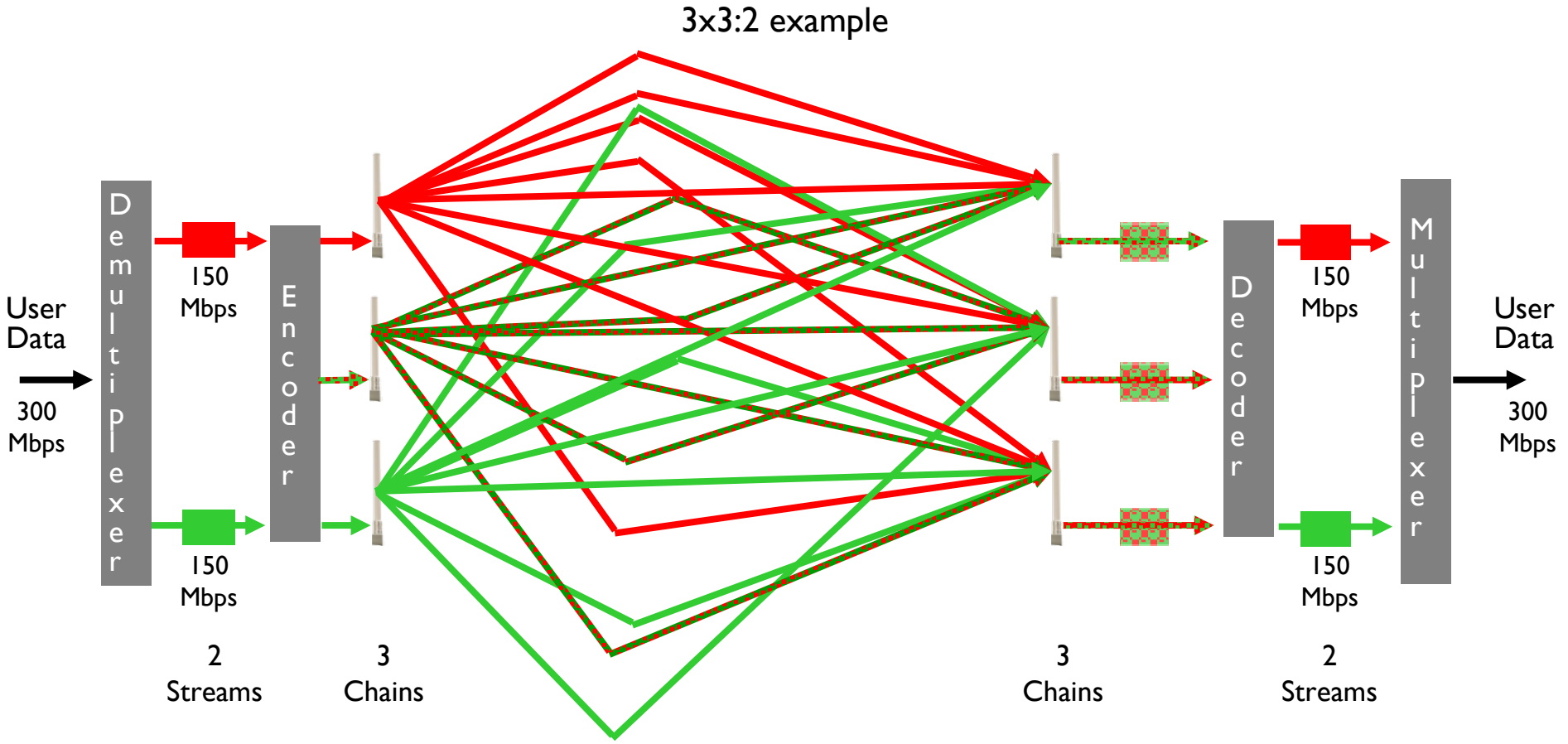
802.11b Direct Sequence Spread Spectrum – DSSS



802.11g/n/ac Orthogonal Frequency Division Multiplexing – OFDM



Multiple Input Multiple Output (MIMO) in 802.11n



- Spectrally efficient
  - –Up to 7.5 bps/Hz for 802.11n – violates Shannon's bound? – not really – this assumes full 2x MIMO gain
- Compared to previous Wi-Fi technologies:
  - –0.5 bps/Hz for 802.11b, 2.7 bps/Hz for 802.11a/g
- Works best in indoor environments
  - –Rich multipath reflections from walls and structures
  - –May not always be present in outdoor environments
  - –Signals must be uncorrelated to get full benefits!

802.11n Data Rates

Modulation and Coding Schemes (MCS) for 1 and 2 spatial streams
20 and 40MHz channels (HT20 and HT40)
Short and Long GI (Guard Interval)

MCS	Code Rate	Modulation	Number of Spatial Streams	Data Rate HT20 800ns GI	Data Rate HT20 400ns GI	Data Rate HT40 800ns GI	Data Rate HT40 400ns GI
0	1/2	BPSK	1	**6.5**	7.2	13.5	15
1	1/2	QPSK	1	**13**	14.4	27	30
2	3/4	QPSK	1	**19.5**	21.7	40.5	45
3	1/2	16-QAM	1	**26**	28.9	54	60
4	3/4	16-QAM	1	**39**	43.3	81	90
5	2/3	64-QAM	1	**52**	57.8	108	120
6	3/4	64-QAM	1	**58.5**	65	121.5	135
7	5/6	64-QAM	1	**65**	72.2	135	150
8	1/2	BPSK	2	**13**	14.4	27	30
9	1/2	QPSK	2	**26**	28.9	54	60
10	3/4	QPSK	2	**39**	43.3	81	90
11	1/2	16-QAM	2	**52**	57.8	108	120
12	3/4	16-QAM	2	**78**	86.7	162	180
13	2/3	64-QAM	2	**104**	115.6	216	240
14	3/4	64-QAM	2	**117**	130	243	270
15	5/6	64-QAM	2	**130**	144.4	270	300

compare to
54 Mbps
802.11a/g
2.7 bps/Hz

7.5 bps/Hz

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What Does the 802.11 MAC Do ?

- Access control of medium
  - CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance)
  - Virtual Collision Avoidance
- Priority of medium access
  - DCF (Distributed Coordination Function)
  - PCF (Point Coordination Function)
- Reliable delivery over noisy medium (ACKs)
- Error correction
- Packet fragmentation, re-assembly and aggregation
- Beacons (SSID=Service Set Identifier) and Probes
- Mobility (Associate, reassociate, disassociate)
- Authentication
- Data encryption
- Power saving

Listen Before Talk

Collision Avoidance

Physical and Virtual

CCA MODE 1 - ENERGY DETECT (ED)

RSSI SIGNAL

REFERENCE THRESHOLD -70 TO -80dBm

- ED > THRESHOLD
  - Back-off for a Set Time Period
- ED < THRESHOLD
  - Clear Channel

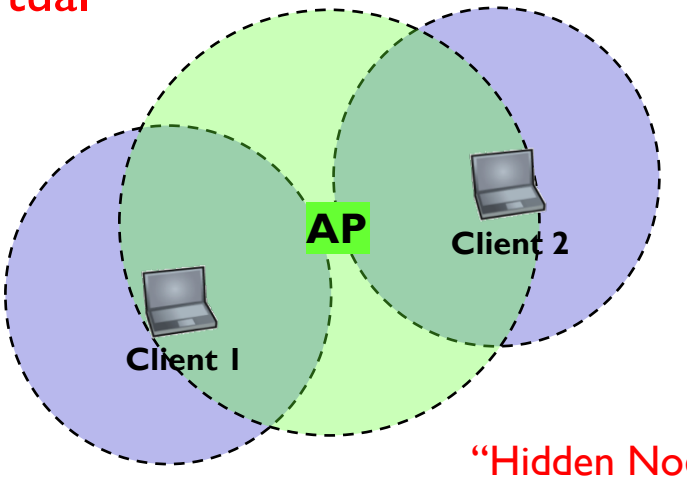
CCA MODE 2 - CARRIER SENSE (CS)

DIGITIZED SERIAL INPUT SIGNAL — 11-BIT PN CODE CORRELATOR

- CORRELATION OR CARRIER SENSE
  - Back-off for a Random Set Time Period
- NO CORRELATION
  - Clear Channel

CCA MODE 3 - ED AND CS

- CCA MODES 1 AND 2 COMBINED

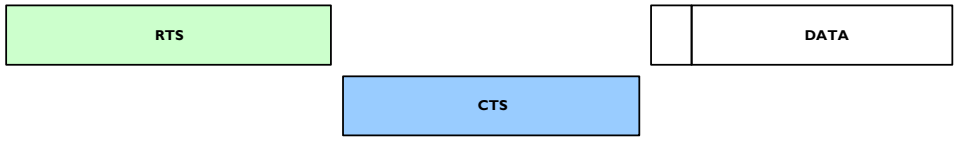


"Hidden Node"

Access Point Coverage Area

Client Coverage Area

Virtual Carrier Sense
RTS/CTS from Client 1 to AP



What Client 2 "hears"

Additional Resources

1. IEEE 802.11 Working Group http://www.ieee802.org/11
2. Wi-Fi Alliance http://www.wi-fi.org
3. Wireless Broadband Alliance http://www.wballiance.com
4. Bob O'Hara and Al Petrick "IEEE 802.11 Handbook: A Designers Companion" IEEE Press Second Edition 2005
5. Eldad Perahia and Robert Stacey "Next Generation Wireless LANs" Cambridge University Press 2008
6. Matthew Gast "802.11 Wireless Networks: The Definitive Guide" O'Reilly Second Edition 2005
7. Jim Geier "Wireless LANs" SAMS Second Edition 2002
8. Guido R. Hiertz, Dee Denteneer, Lothar Stibor, Yunpeng Zang, Xavier Pérez Costa, Bernhard Walke "The IEEE 802.11 Universe" IEEE Communications Magazine 2009
9. Benny Bing ed "Emerging Technologies in Wireless LANs: Theory, Design, and Deployment" Cambridge University Press 2007