Wi-Fi Alliance Member Symposium

November, 2013

Nanjing, China
Guangzhou, China

Welcome!

- We are honored to have you here today.
- Member symposia are a good time to get an update on our organization and learn how you can participate.
- This is also an opportunity to ask questions and provide feedback!
- **Today's materials are available at: https://wi-fi.boxcn.net/symp-201311**
- Thank you to our sponsor today:

SRTC 国家无线电监测中心检测中心 The State Radio_monitoring_center Testing Center

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Today's agenda

Time	Topic
9:30 – 10:15	Keynote: Wi-Fi Alliance® - Seamless Connectivity
10:15 – 10:30	Sponsoring Lab Presentation
10:30 – 11:00	Wi-Fi Alliance Program Roadmap
11:00 – 11:45	Program Status Updates
11:45 – 12:45	Lunch
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Wi-Fi Alliance®: Seamless Connectivity

Wi-Fi Alliance: The worldwide network of companies* that brought you Wi-Fi

*** For a full list of over 600 member companies go to www.wi-fi.org**

Wi-Fi Alliance

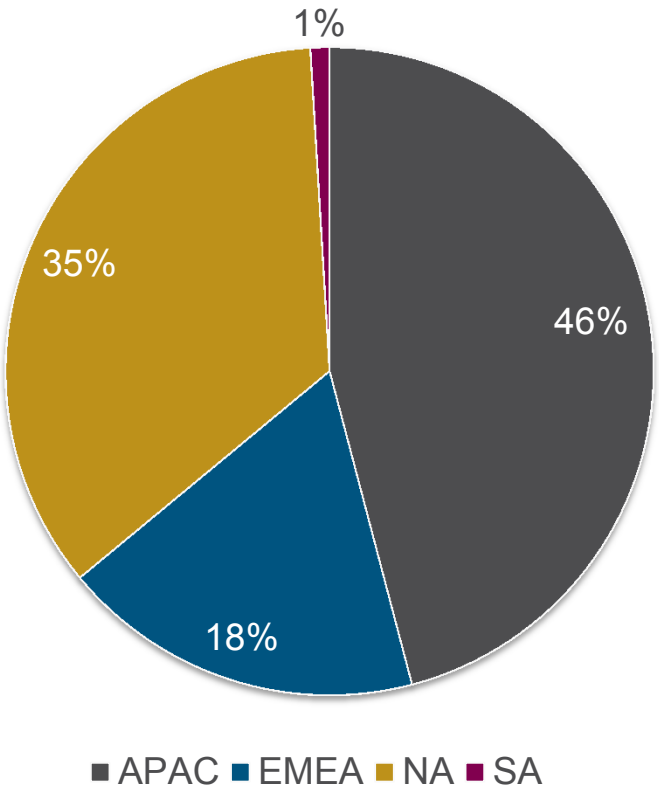
Vision: Seamless connectivity

Summary:

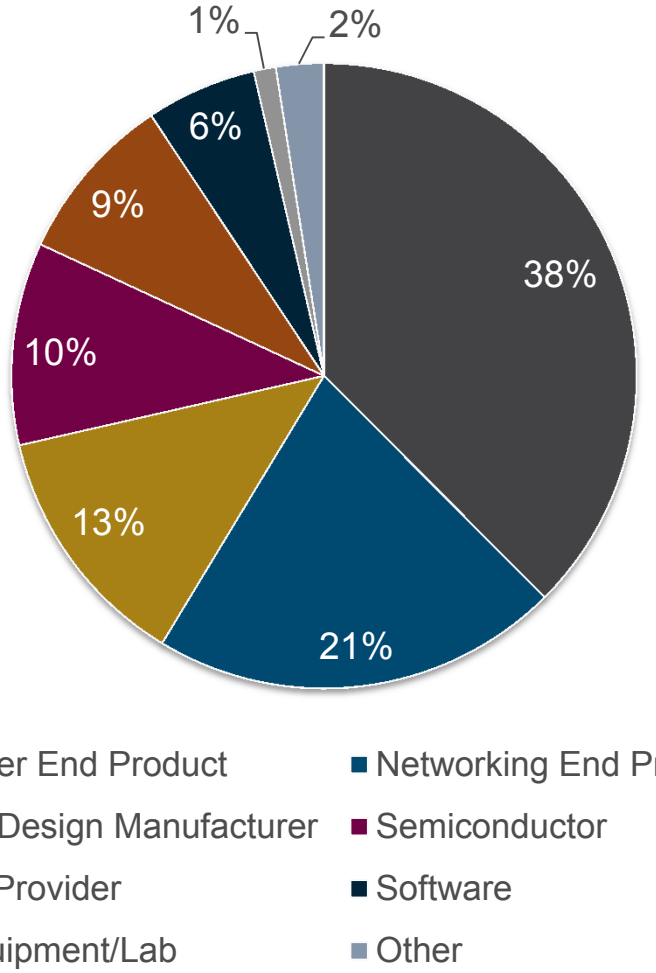
- Enable worldwide Wi-Fi adoption
- Technology and market development
- Regulatory affairs
- Seven new capability programs launched in 2012
- ~550 member companies

Wi-Fi Alliance represents a diverse set of members

Members by Region



Members by Industry



Local member companies continue their commitment to Wi-Fi

2013 Outlook: New technologies, compelling solutions, and a broadening portfolio

One of the world's most loved technologies

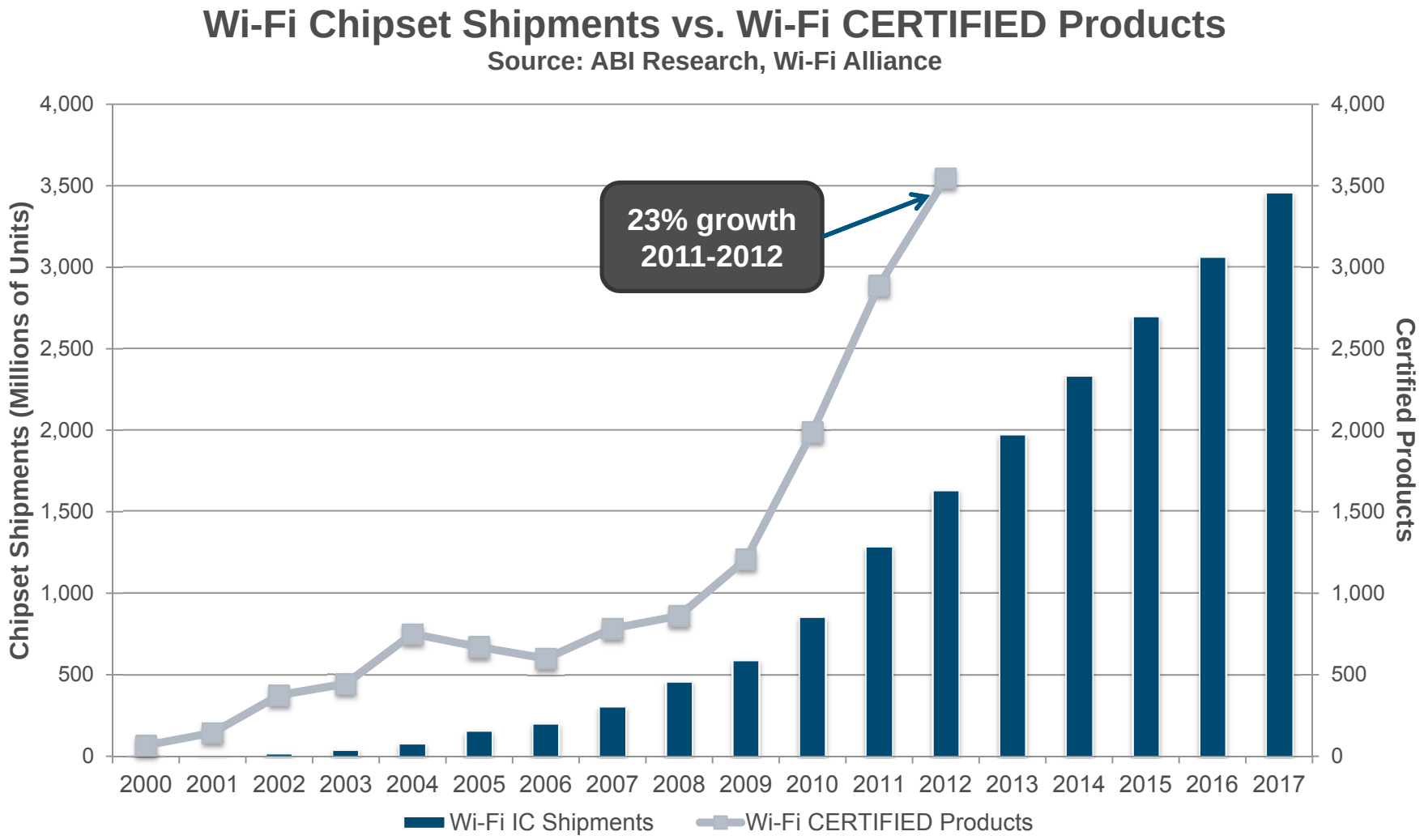
- In 25% of homes*, and most enterprises around the world
- 1.6 billion devices comprise ~30% shipment growth in 2012**
- 12 years to first 5 billion units, 3 years to next 7 billion**

It just keeps getting better

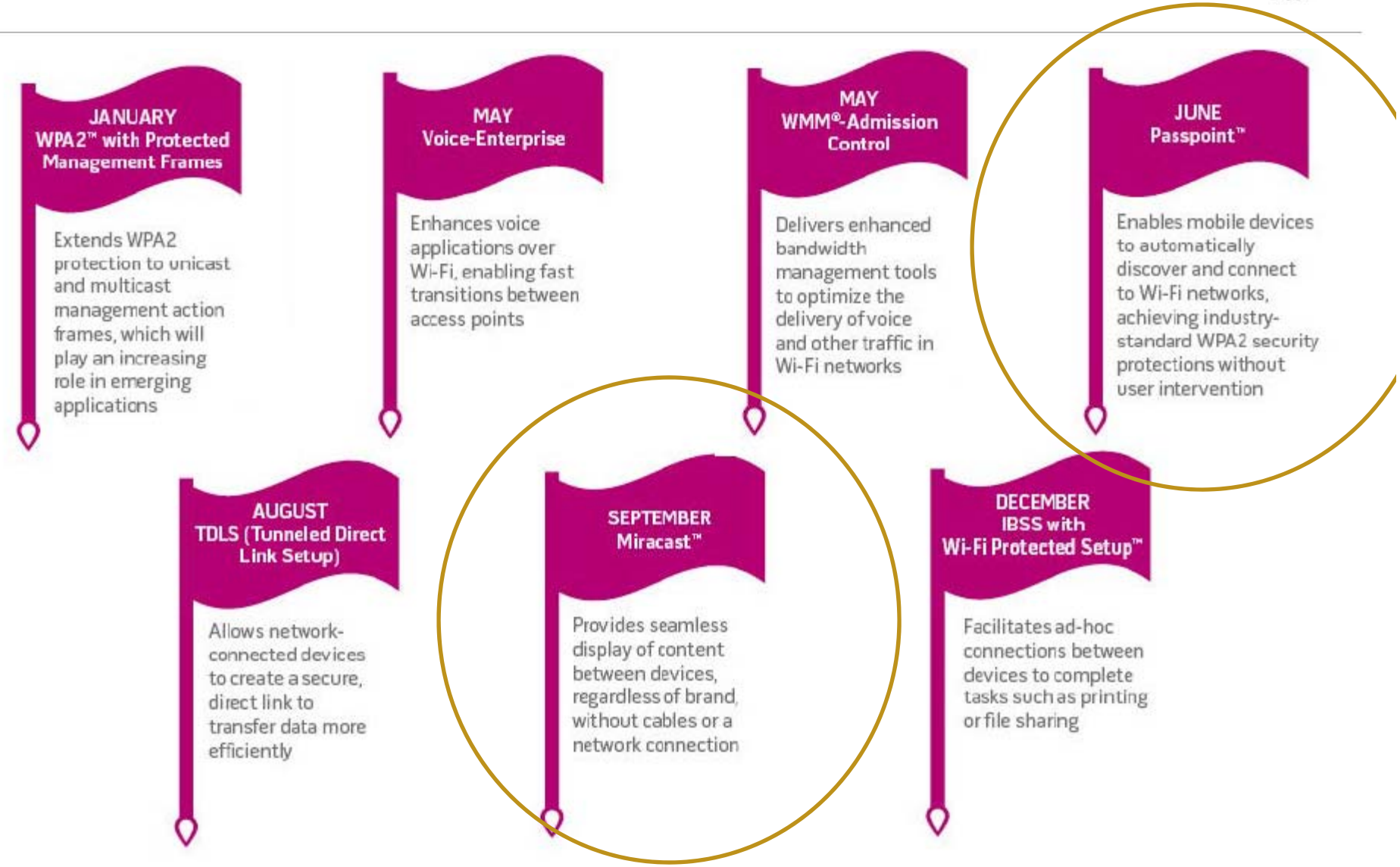
- Market growing at double-digit rates
- Application advancements: Miracast™, Passpoint™, and much more
- New high-performance technologies in 5 GHz and 60 GHz this year

*Strategy Analytics, April 2012.
**ABI, February 2013

Wi-Fi proliferates well into foreseeable future



Seven new Wi-Fi Alliance programs launched in 2012

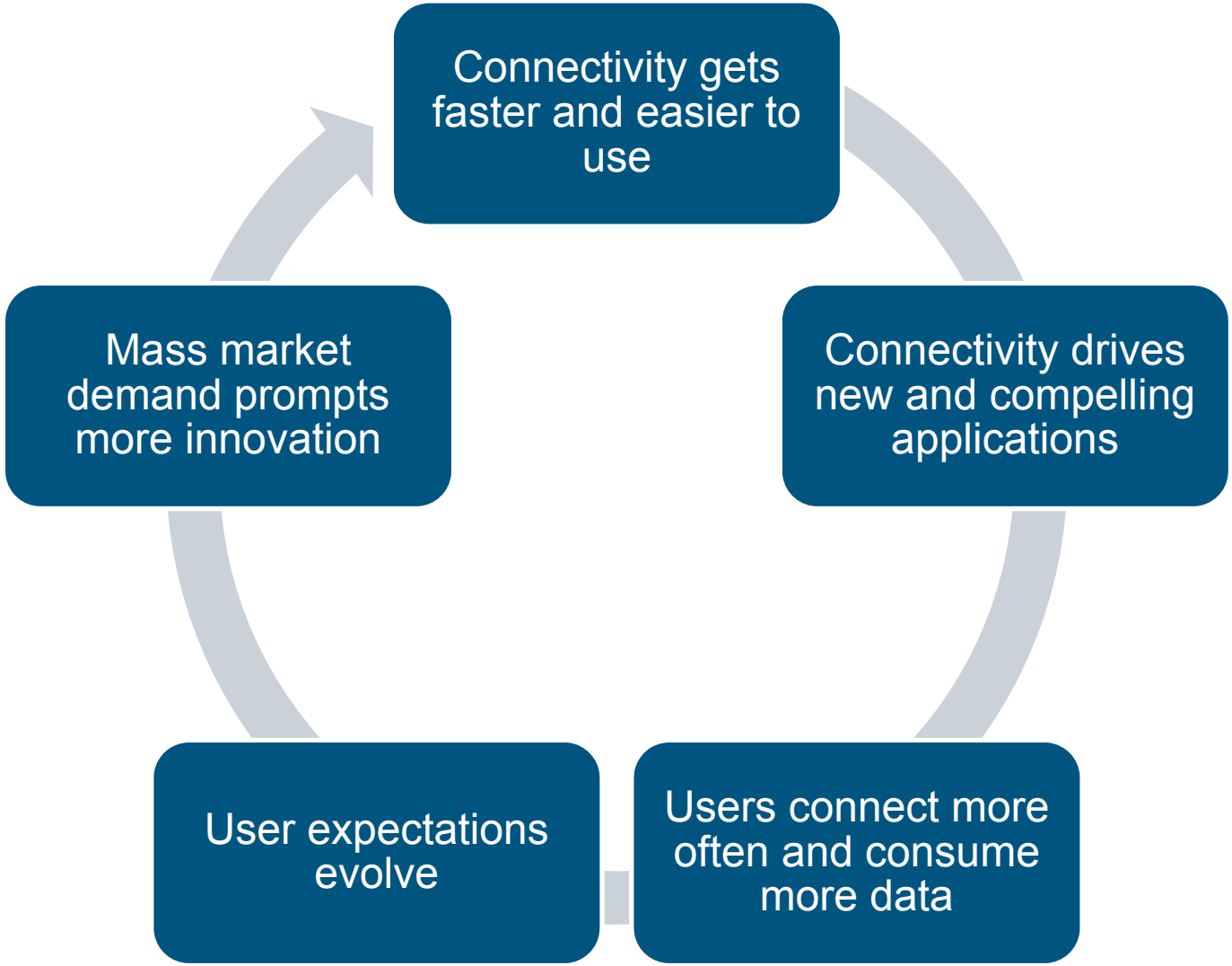


Wi-Fi has transformed connectivity expectations

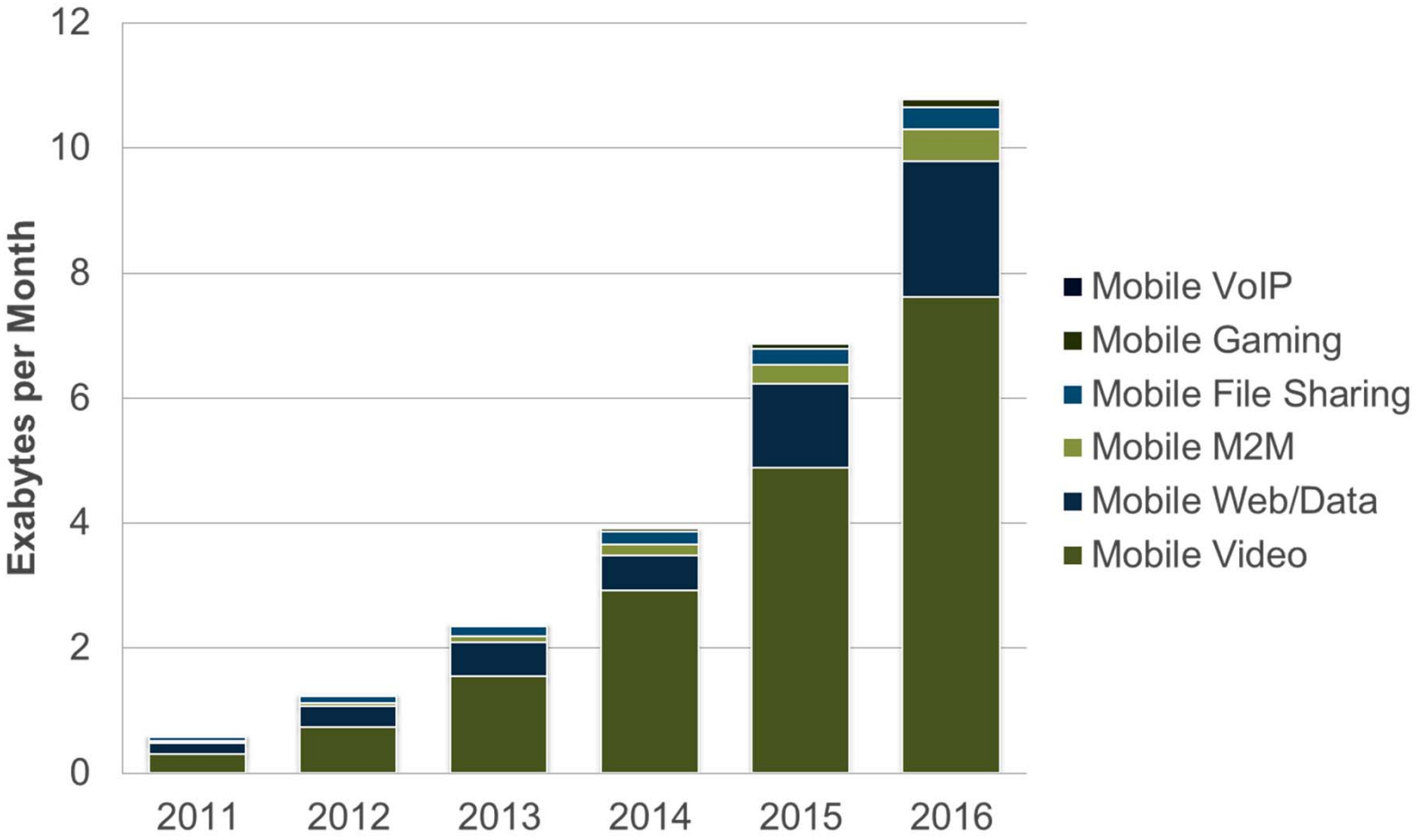
- Wi-Fi is the default connectivity mode across many device types.
- Devices connect anywhere at any time.
  - Connecting to each other to share, sync, print, and play.
  - Connecting to the internet in more than 1M hotspots worldwide (and growing).
- Connected experience is richer than ever: making new innovations such as cloud services a reality.
  - Cloud applications account for 45 percent of mobile data traffic (71 percent by 2016).*
  - "[In 2012,] 80% of new commercial enterprise apps will be deployed on cloud platforms" (IDC).
  - More and more content is processed and stored "off-device", overcoming device limitations.
- Transformed user expectations further stimulate appetite for connectivity.

*Source: Cisco VNI Mobile, 2012 http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

Virtuous cycle of innovation and adoption: Wi-Fi propelling market advancement



Wi-Fi will meet the needs of cloud-based applications

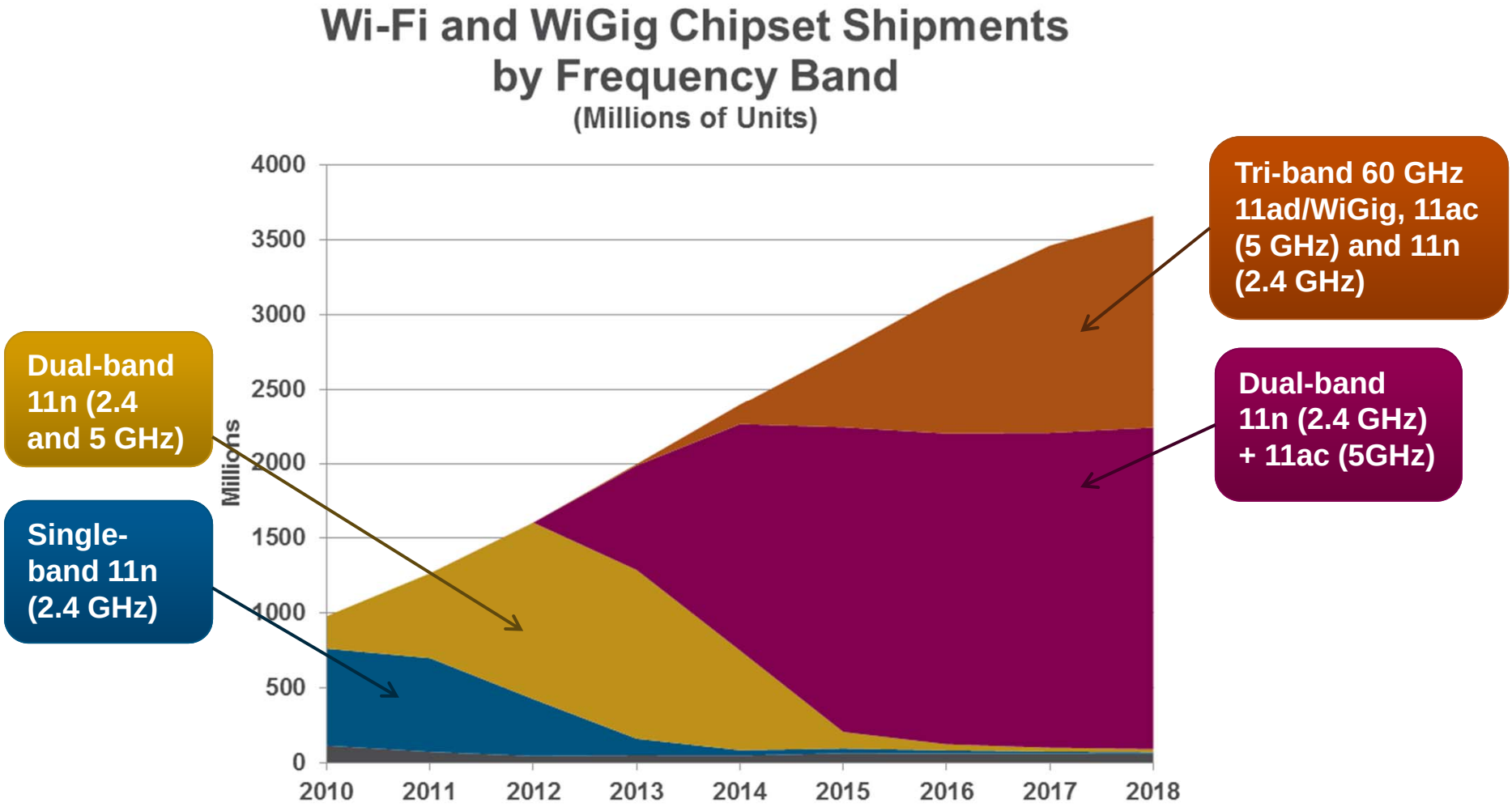


Cloud video services will generate over 70 percent of mobile data traffic and test the limits of mobile network capacity

The next wave of Wi-Fi is coming

- We are on the cusp of an explosion in the number and diversity of Wi-Fi devices.
- New applications require greatly enhanced performance.
  - Core improvements will increase speeds by orders of magnitude.
  - Power management will further improve the endurance of battery-operated devices.
- Wi-Fi will provide more than basic data connectivity.
  - Service interoperability will make Wi-Fi integral to the user experience.
  - Wi-Fi will be increasingly transparent to the user as devices discover and connect to each other more intelligently.

Technology portfolio expanding for an exciting range of applications



Source: ABI Research, February 2013

Wi-Fi will enable a more consistent user experience

- Display devices will provide a rich audio/video experience without cables.

- Mobile devices will seamlessly connect to hotspots.

- Appliances will communicate with utilities and each other to respond to changing energy demands.

- Peripherals such as monitors and keyboards interface directly with laptops to realize the cordless desktop.

The expectations for Wi-Fi are high

"…it's hard to beat Wi-Fi. Thanks to anticipated updates to the standard, when it comes to coverage and the user experience, it may be hard not to choose Wi-Fi."

- Stacey Higginbotham, GigaOm

Together we will enable the next generation of connected devices, applications and users.

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Wi-Fi Alliance Program Roadmap

Wi-Fi Alliance certification and market-enabling programs

Wi-Fi CERTIFIED™ programs	
Wi-Fi CERTIFIED™ a/b/g/n/ac	
WPA2™	Tunneled Direct Link Setup
Voice-Personal	Voice-Enterprise
WMM®-Power Save	WMM®-Admission Control
Wi-Fi Protected Setup™	Passpoint ™
CWG-RF	Miracast™
WMM® (Wi-Fi Multimedia™)	Protected Management Frames
Wi-Fi Direct™	IBSS with Wi-Fi Protected Setup™

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New Wi-Fi programs and capabilities

Wi-Fi CERTIFIED™ ac:
Wi-Fi technology's next generation

- Stream up to three lightly compressed HD video streams, rapidly synch large files, and connect for demanding applications at gigabit data rates.
- Wi-Fi CERTIFIED ac technology builds on Wi-Fi CERTIFIED n and interoperates with legacy 5 GHz devices
- Dual-band (2.4 and 5 GHz) networking products are expected to be very widespread, keeping legacy devices connected
- Includes WPA2™, the latest-generation security technology

WiGig CERTIFIED is an exciting companion to Wi-Fi networking technology

- 60 GHz devices deliver multi-gigabit data rates and low latency to support a range of applications
  - Stream uncompressed HD video
  - Enjoy video gaming with no noticeable latency
  - Dock a range of devices without cables
- Multi-band devices will seamlessly hand over data streams from 60 GHz to Wi-Fi, providing whole-home, high-performance networking, boosted with islands of even higher data rate 60 GHz connections

Wi-Fi CERTIFIED Miracast™: Easy-to-use Wi-Fi display, available now

- Connect devices for a rich audio/video experience without cables or a connection to an existing Wi-Fi network
  - Watch videos from a smartphone on a big screen television
  - Share a laptop screen with the conference room projector
- Miracast certified products entering the market in volume this year
- Find Wi-Fi CERTIFIED Miracast smartphones, TVs, tablets, etc. at wi-fi.org

Wi-Fi CERTIFIED Passpoint™ streamlines connectivity in hotspots

- Passpoint devices deliver an automated, security-protected connection experience in service provider hotspots
- Passpoint is catalyzing carrier Wi-Fi
  - Enables “in pocket” user connection experience
  - Building block for data offload, Wi-Fi roaming, other operator imperatives
  - Specified by GSMA for Wi-Fi terminals

- About 75 mobile devices certified-to-date; growing brand and equipment diversity reflects industry momentum
- An update planned for 2014 adds features to support creation of new accounts, and makes it easier for users to find hotspots recommended by their service provider
- Find Wi-Fi CERTIFIED Passpoint devices at wi-fi.org

Quiet momentum for Passpoint

Brand diversity

- About 75 Passpoint-certified mobile products today
- Certified brands: Samsung, LG, HTC, Fujitsu, Pantech, ASUStek
- White label handsets (Fujitsu for Docomo)
- All major infrastructure vendors

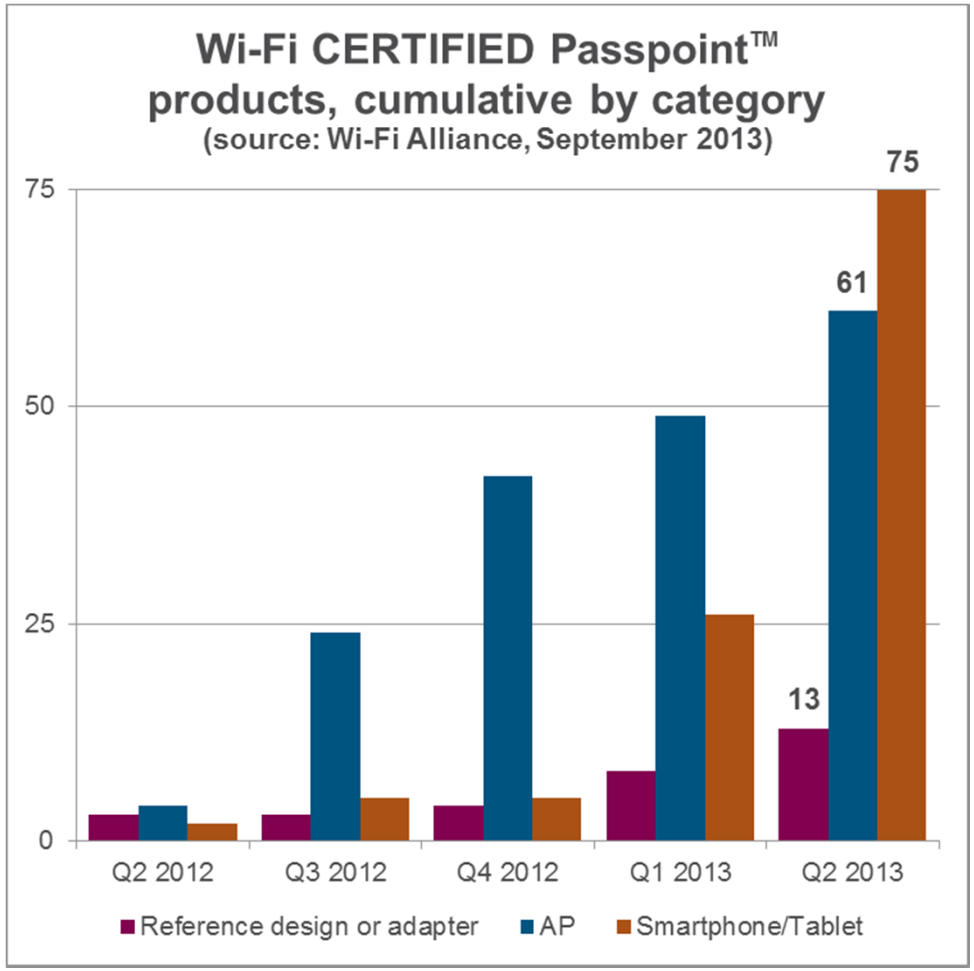
Device diversity: High-end and mid-level smartphones and tablets

Network diversity

- 3G/LTE/LTE-A cellular
- Wi-Fi CERTIFIED n and ac

First Passpoint network: "Boingo Passpoint"

GSMA Recommends Passpoint for Wi-Fi terminals



Wi-Fi CERTIFIED™ Voice-Enterprise: enterprise-grade voice quality, mobility, and security

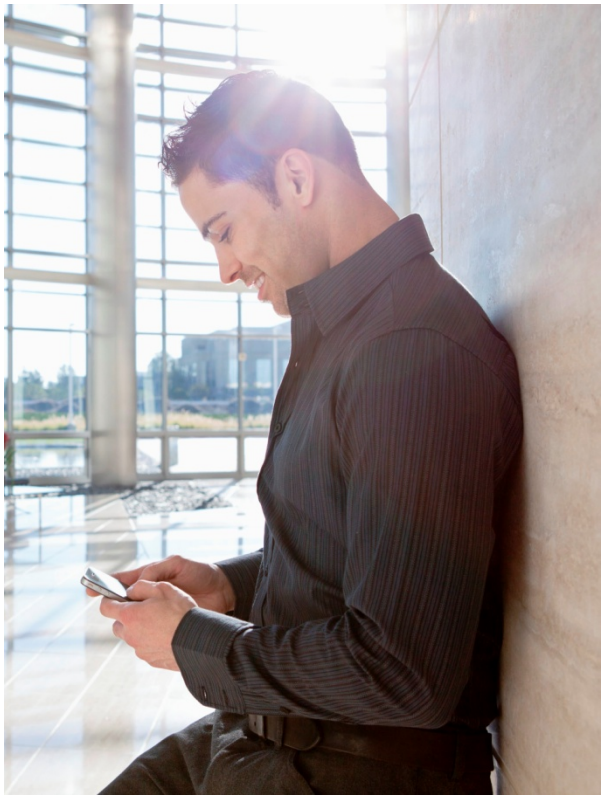
- Priority for voice applications over data packets, optimizing performance in mixed traffic environments where heavy data, voice and video traffic co-exist
- Users experience seamless voice connectivity as the user moves within the enterprise network, from one access point to the next
- Power saving solutions are optimized for battery-operated devices, implementing mechanisms across the system that maximize power efficiency
- WPA2 advanced security protection helps ensure integrity of communication

WMM®-Admission Control: Bandwidth management control tools

- Part of WMM® suite of QoS solutions
- Manages bandwidth by monitoring network load and channel conditions
- Admits only traffic streams that the network can support at a good quality level
- Directs traffic streams that cannot be supported at good quality level to alternative APs or channels

A range of additional programs in pipeline

- Smart grid and sensor networks: new applications, while re-using existing infrastructure and minimizing the amount of new equipment needed
- Additional application specific solutions
- Additional power-saving features based on IEEE 802.11v
- Over 15 new programs currently in development



Other Wi-Fi CERTIFIED Programs on the Horizon and Operational Updates

WFA Task Groups sustain the rate of innovation

Marketing Task Groups with a Technical Task Group	Marketing Task Groups (early stage)
Security	Service Discovery
Wireless Network Management (WNM)	HEW Use Case
Wi-Fi Display	Wi-Fi Docking
Smart Grid	Sensor Net
Hotspot 2.0 (Passpoint™)	White Spaces
60 GHz	Mobile Multimedia
Wi-Fi Direct Services	Multiband Operation
Wi-Fi Protected Setup	**Market Segment Task Groups**
Neighbor Awareness Networking	Enterprise
Wi-Fi Serial Bus	Operator
WiGig Bus Extension	Healthcare
WiGig Display Extension	Automotive
WiGig SD Extension	**Special Task Groups**
VHT 5G	Long Range Planning
	RF Health and Science
	Spectrum and Regulatory
	Certification Oversight Group
	Certification Maintenance Group

Local Authorized Test Labs

SIT

Industry liaisons, to enable collaboration and harmonize work areas

CableLabs® REVOLUTIONIZING CABLE TECHNOLOGY®

CEPT ECC Electronic Communications Committee

PCI SIG®

CARCONNECTIVITY consortium

GSMA

SUPERSPEED CERTIFIED USB®

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CSEP Consortium for SEP 2 Interoperability

HOMEPLUG® ALLIANCE

VESA

CTIA The Wireless Association®

JasPar

Wireless Broadband Alliance

dlna

NFC FORUM

ZigBee® Alliance

Things are going great, but we have a lot of work to do!

- Many new market segments have become important to the Wi-Fi industry.
  - Smart Energy.
  - Machine-to-Machine (IOT).
  - Personal health and fitness monitoring.
  - Vehicular Wi-Fi.
  - Very high performance Wi-Fi for advanced digital home.

- These are ideal markets for Wi-Fi technology, but they will require that we innovate together.
  - Improve power management capabilities for constrained devices.
  - Maintain fail-safe security.
  - Make it easier than ever before.

Contributions and knowledge from member companies will play a critical role in the future of Wi-Fi – please get involved!

Upcoming Wi-Fi Alliance Meetings – please join us!

- **2014 Asia Meeting**
  Bangkok, Thailand, March 4 – 6, 2014
- **2014 North America Meeting**
  Chicago, USA, June 24 – 26, 2014

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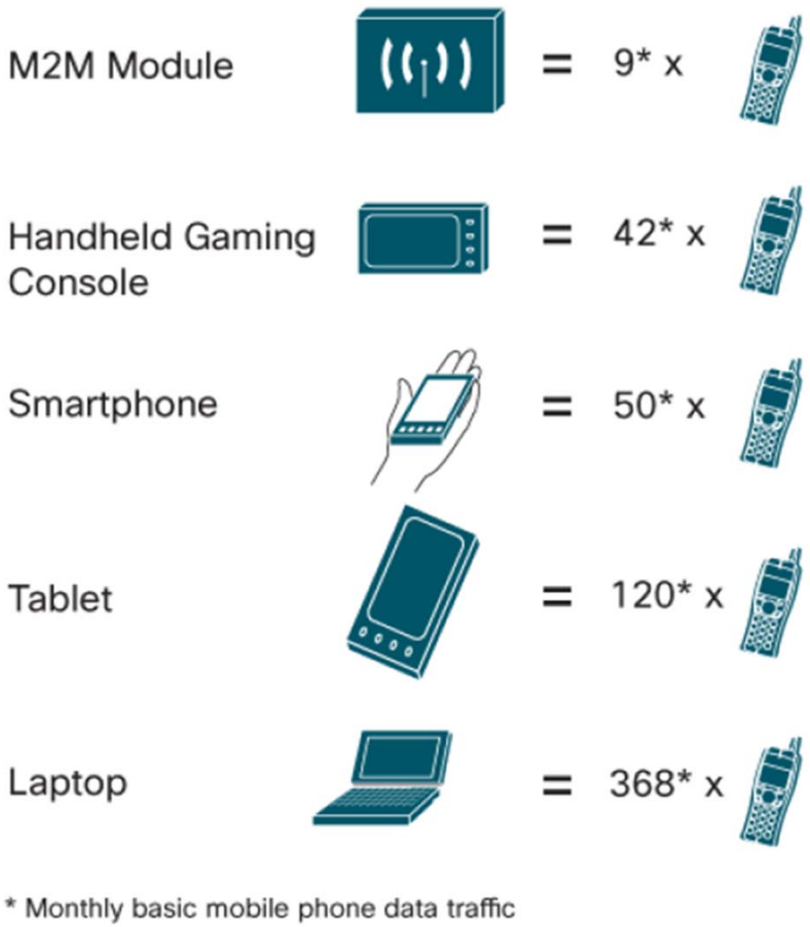
Program Status Update

Enhanced performance and usability for new applications

Today's platforms significantly multiply data traffic as compared to feature phones



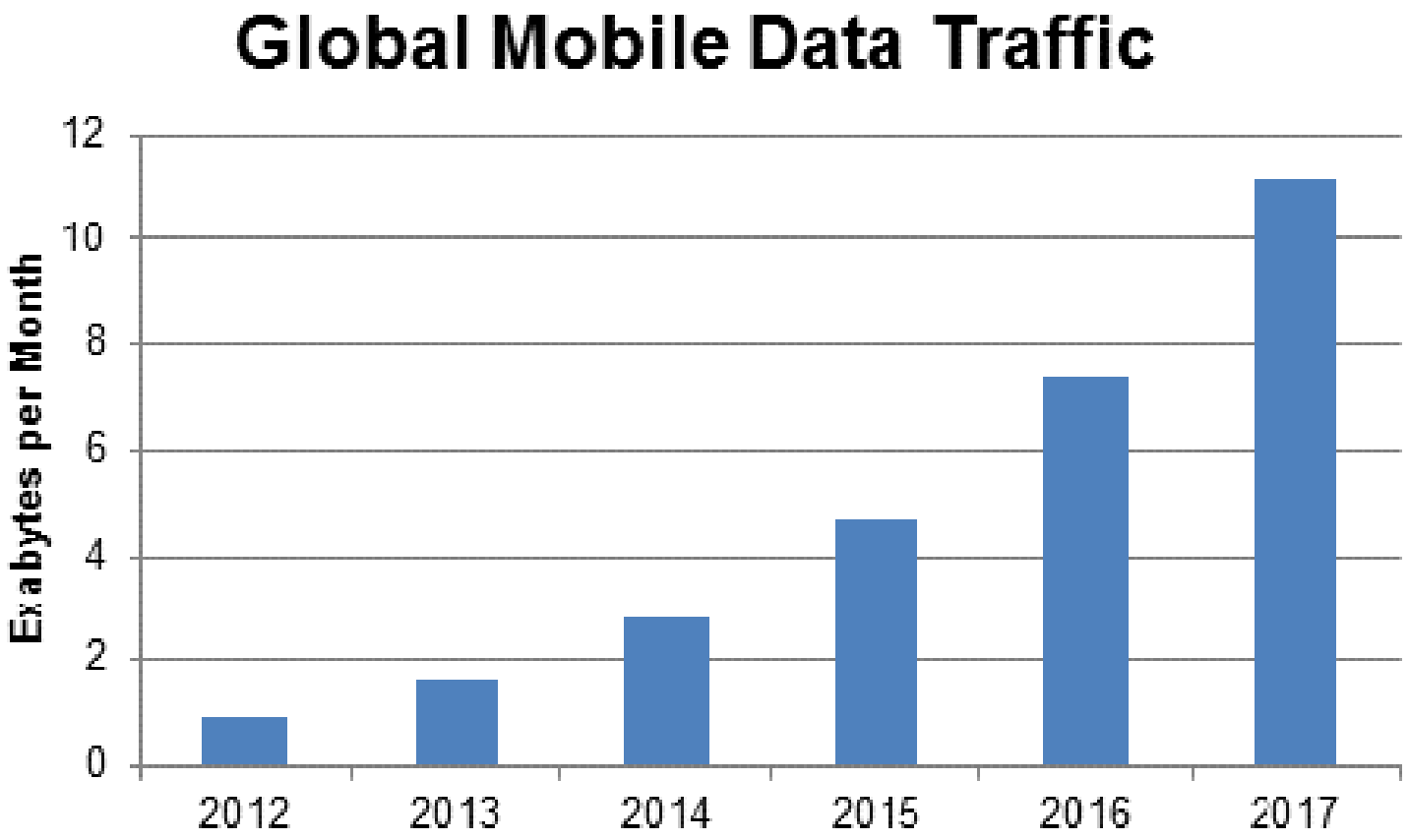
Source: Cisco VNI Mobile Forecast, 2013

There is a fundamental shift in how, when and where users access content

- Devices are easier to carry, with form factors that maximize screen area
- User content and data is increasingly stored off-device to overcome storage capacity limitations and provide ease of access
- Home networks, and Wi-Fi specifically, are utilized for in-home video distribution
- Over-the-top video services offering higher quality content
- New form factors necessitate doing more with fewer ports

"The fidelity of streamed media continues to climb, keeping pace with device capabilities, so even if the total minutes viewed remained constant (which it won't), the byte consumption will increase dramatically." Sandvine

As global data traffic explodes…



Source: Cisco VNI 2013

…Wi-Fi will be ready to meet users' needs

- Easy to use
- Localized traffic concentration
- Dramatic capacity increases with future generations of gigabit performance
- Diversity of new uses and applications enabled with waves of new technologies

Wi-Fi CERTIFIED™ ac

Faster Wi-Fi for today's data intensive applications

Wi-Fi CERTIFIED ac improves Wi-Fi performance for data-intensive applications

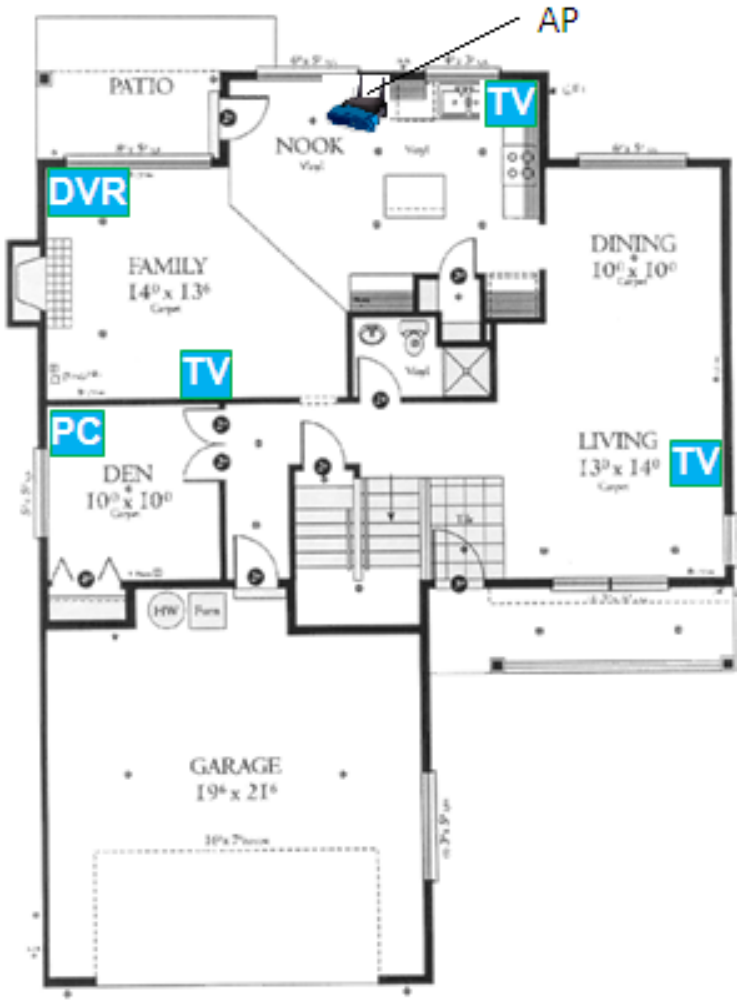
- Rich digital media and content is ubiquitous, but the data is not always stored on the correct device at the correct time
- Streaming and data sharing applications are becoming more important to access content from other devices
- ac-certified devices improve access to content
  - Stream multiple videos simultaneously with additional network capacity
  - Videoconferencing with no noticeable latency
  - Most power-efficient generation of Wi-Fi

Wi-Fi CERTIFIED ac: Technology advancements

Enhancement	Result
Greater capacity (40 and 80 MHz channels)	Up to 1.3Gbps data rate
Better performance (3 multi user MIMO streams, beam forming)	Approximately 3x faster than 802.11n
Efficiency (256 QAM high density modulation)	Better coverage with fewer networks nodes
Meets today's enterprise needs	Better support for BYOD, more devices and more demanding applications

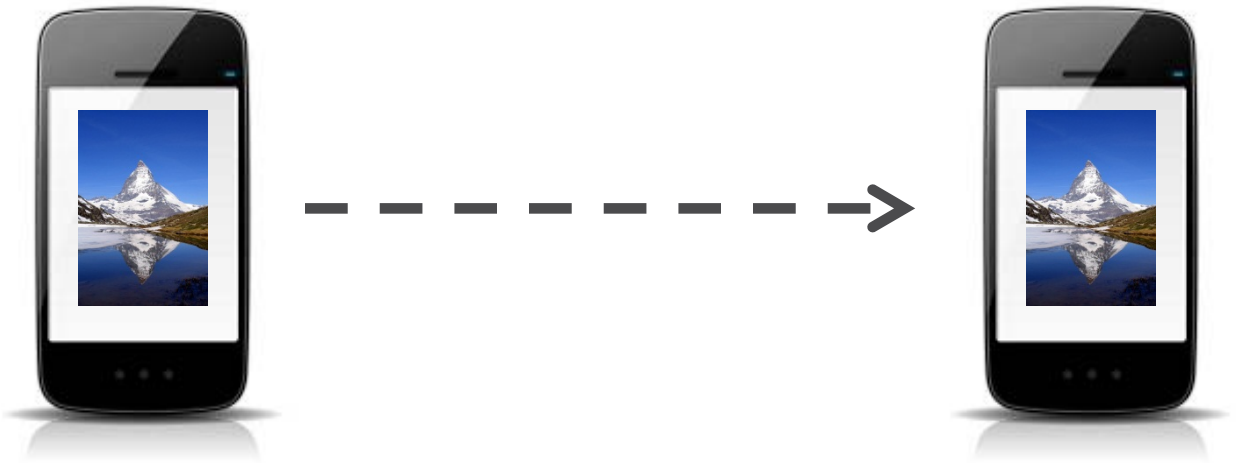
Wi-Fi CERTIFIED ac enables multiple HD quality video streaming

- Reliably stream multiple HD quality videos to multiple devices
- Whole home coverage and improved quality at similar range of Wi-Fi CERTIFIED n
- Compressed video (e.g. ~10 Mbps) is delivered to any of the 3 TVs, originating from DVR or PC
- Videos are delivered reliably despite other network activity and neighboring Wi-Fi networks



ac-certified devices support rapid sync-and-go

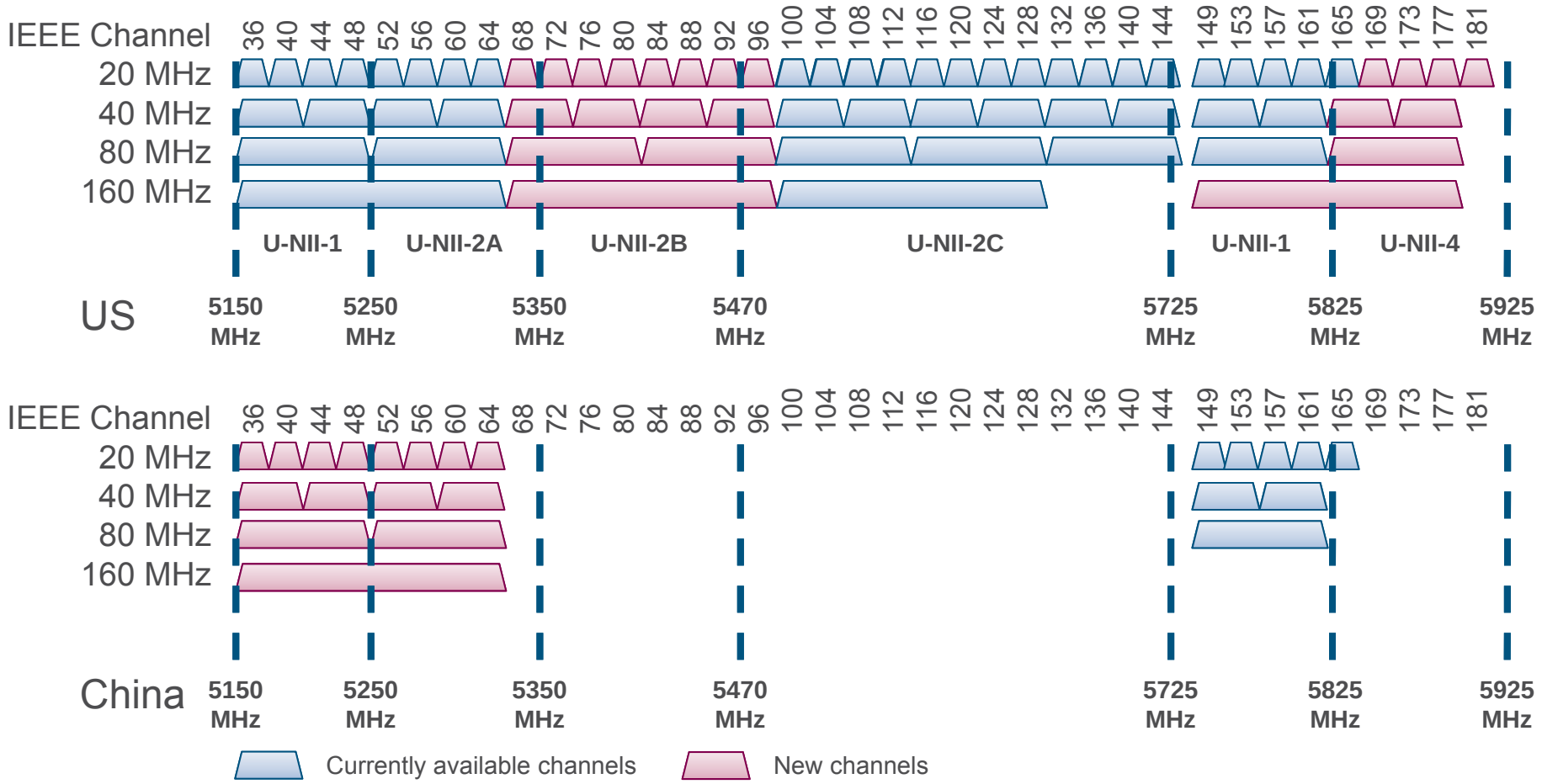
- Jitter and delay are not critical; time spent to do transfer is valuable
- Download HD movies for a trip as you're walking out the door
  - Transfer a 25GB HD movie file in 5 minutes
- Instantly share photo albums with friends
  - 150 JPEG files of 1.25MB each will transfer in less than 2 seconds



ac-certified devices can be utilized for video demonstrations in large auditoriums

- Rate, latency, and range requirements are met by VHT 5GHz
- Project video and audio to a large screen 200 meters away
- HD voice is transmitted in several languages to accommodate a diverse audience with no noticeable latency

Regulators have opened more 5GHz spectrum



Additional spectrum will provide an opportunity for technologies like Wi-Fi to continue to innovate, bringing further social and consumer benefits

WiGig CERTIFIED

Multi-Gigabit Connectivity

WiGig CERTIFIED is a complement to Wi-Fi that supports multi-gigabit data rates

Delivering secure low-latency multi-gigabit connections between nearby devices to enable the next-generation digital home will become a reality

- Together Wi-Fi and 60GHz are bringing to life the vision of a hi-fidelity connected home untethered by cables
- Devices including televisions, set top boxes, laptops, phones, tablets, etc., as well as access points will be certified in the new program
- Certification by the Wi-Fi Alliance of 60GHz devices will give users confidence as they adopt new technology
- 60 GHz devices that also support Wi-Fi will interoperate with the billions of existing Wi-Fi CERTIFIED devices

WiGig certification program will deliver the same great user experience people expect from Wi-Fi

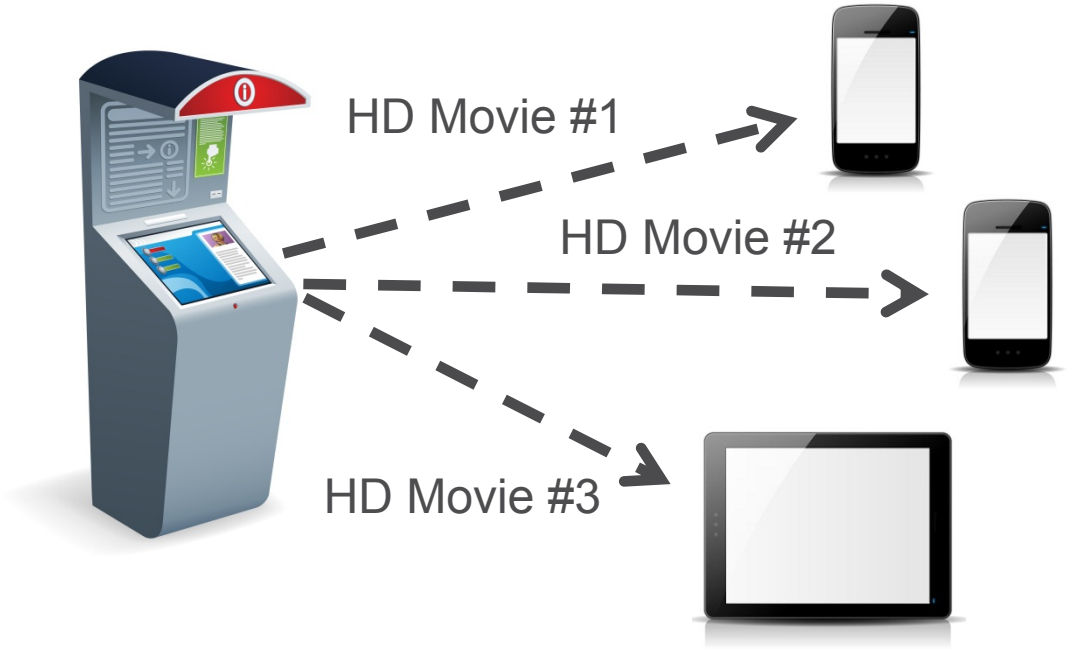
Enhancement	Manifestation
Multi-gigabit Data Rates	Transport low-latency uncompressed high-definition video from device to device
Fast Session Transfer	Seamless handover from 60GHz to 5GHz and 2.4GHz: Whole-home sea of high-performance networking boosted with islands of even higher data rate WiGig
IP Connectivity	Leverage growing number of IP-based technologies, including Wi-Fi Direct and Miracast
Power Management Techniques	Advanced device sleep mechanisms improve mobile device power efficiency
Security	Transmissions using the latest-generation security and encryption technology

Dock peripheral devices without cords with 60GHz

- Computing devices, including laptops and tablets, are being built slimmer, reducing the amount of space for peripherals to connect through cables
- Many types of peripherals are used in close proximity to the device (less than 10 meters), such as a mouse, monitor, or keyboard
- With Wi-Fi CERTIFIED 60GHz products, a device can securely handle multiple peripherals, even if each product is made by a different company

Transfer uncompressed HD movies between devices on the go

- Public kiosks with downloadable movies, such as at an airport, are a great way to make movies available to users with portable devices
- At multi-gigabit download speeds, a user can download an uncompressed, HD movie in one minute, or on the way to an airport gate before boarding
- The kiosk can support multiple simultaneous transfers, which means even less time waiting in line



Place your TV anywhere in a room by streaming HD videos with 60GHz

- Mary has a set-top box (STB) with an HDMI interface placed in a cabinet opposite an HDTV, about 10 meters apart.
- A 10m HDMI cable crossing the room is not an option
- Mary can use a pair of 60GHz dongles with HDMI interfaces to connect to each device
- The Audio/Video content is streamed from the STB to the HDTV wirelessly

Wi-Fi Direct™ Enhancements

Standardized services will make Wi-Fi Direct even more useful

Wi-Fi CERTIFIED Wi-Fi Direct is personal Wi-Fi networking that goes anywhere

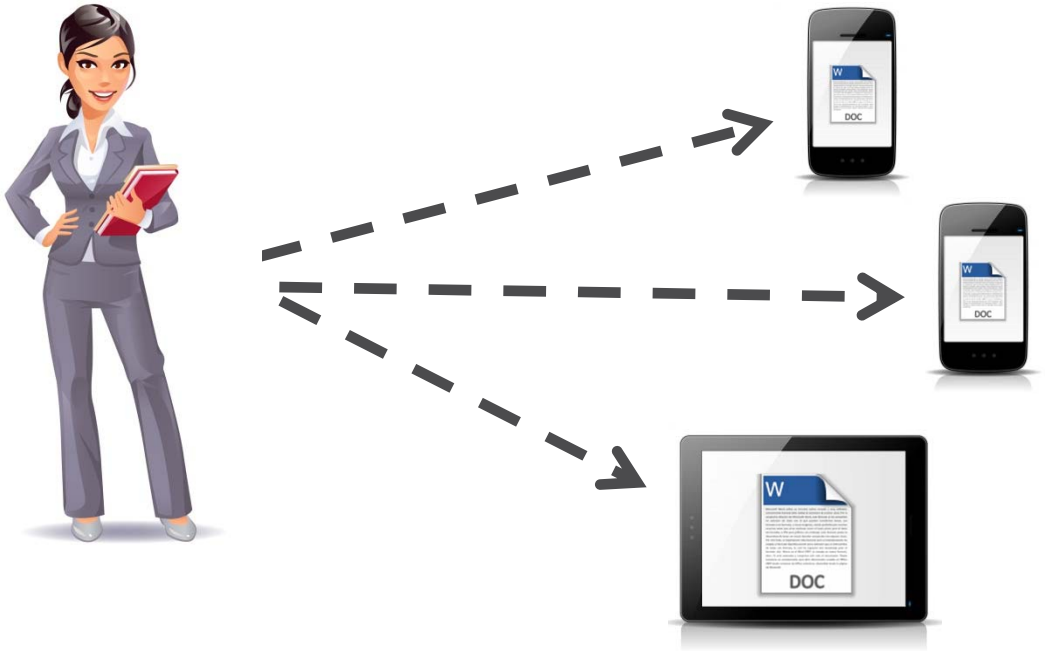
- Connects devices directly, with or without a Wi-Fi network or hotspot available
- Makes the connection to open a world of applications, including content sharing, synch, printing, gaming and more
- Easy to use and secure
- Wide variety of devices from many vendors
- Connects with almost any Wi-Fi CERTIFIED device
- Designed for portable and stationary devices
- By the end of 2012, more than 2,000 products were Wi-Fi Direct certified

Enhancements will enable interoperable services over Wi-Fi Direct

- Wi-Fi Direct is becoming even more useful
- Users will enjoy a consistent user experience across vendors
  - For example, users will no longer need to set up a Wi-Fi Direct group before they can find out whether devices can run compatible apps
- Standardized services will deliver interoperability between vendor applications when carrying out common tasks such as sharing, playing, displaying, and printing
- In the world of “there’s an app for that,” application developers will find it much easier to use Wi-Fi Direct for app connectivity

Service Use Cases: Send to Multiple Devices

- Kate is the company's marketing director. She's having an offsite meeting with her team and wants to send the annual marketing strategy plan document to everyone.
- Kate finds the file, and from the file browser's extended options selects "Send to…" then "Multiple devices…". A menu pops up from which he selects her team member's laptops, tablets and phones before clicking "Go".
- Every team member sees a notification that Kate's device wants to send them the document. The ones that click "Accept" receive the file.
  - *The Wi-Fi Direct Application Service Platform allows the file browser application to find devices that support the Send Service (receive) prior to having a connection and provides a standardized process to initiate connections.*



Service Use Cases: Play via DLNA

- Jane has some photos she wants to show her friend Sid. As Jane starts the slideshow on her phone, in addition to showing photos, nearby devices that are capable of displaying slideshows are also listed.
  - *The Wi-Fi Direct Application Service Platform allows the slideshow app to find capable devices while playing a slideshow and prior to having a connection.*
- Jane selects Sid's tablet, and Sid accepts the request. As Jane thumbs through photos on her phone, they are also played via the DLNA app on Sid's tablet.
  - *The Wi-Fi Direct Application Service Platform provides a standardized process for users to initiate connections between their devices.*
  - *The Play service, built on the Wi-Fi Direct Application Service Platform, enables a DLNA connection that allows the user to have a control interface to play encoded media to other devices.*
- Later Jane selects some videos and they are also played on Sid's tablet. As their friend Anne walks up, her phone is also included on the list of devices Jane's phone can play to. Jane selects Anne's phone. After she accepts the connection request, Anne can also see the photos and videos that Jane selects on her phone.
  - *The Play service, built on the Wi-Fi Direct Application Service Platform, enables a DLNA connection that allows the user to play content to multiple devices.*

Service Use Cases: Display via Miracast™

- Jake is editing a document in an office using his phone. He would like to display the screen to a colleague's wide monitor, so that the colleague, Charlie can give him some feedback. As Jake starts his screen mirroring app on his phone, devices near him that are capable of displaying mirroring streams are listed.
  - *The Wi-Fi Direct Application Service Platform allows the screen mirroring app to find Display (receive) capable devices prior to having a connection.*
- Jake selects Charlie's monitor from the list. Charlie accepts the request and he can see the document on his monitor.
- As both Jake's phone and Charlie's monitor have the User Input Back Channel capability, Charlie can also edit the document interactively through his monitor as well, using the keyboard and mouse connected to Charlie's monitor.
  - *The Wi-Fi Direct Application Service Platform provides a standardized process for users to initiate connections between their devices. The Display service, built on the Wi-Fi Direct Application Service Platform, enables a Miracast connection that allows the user to have a control interface to other devices.*

Service Use Cases: Print

- Lauren has a photo printer in her family room, used by her family and friends at different times with different devices.
- Lauren is hanging out with some of her friends and Natalie is showing them pictures that she took at their entrepreneurs' club.
  - *Lauren uses the Play service on the Wi-Fi Direct Application Service Platform to show the photo on the TV.*
- Lauren asks Natalie to print out a copy of the photo for her to keep. Lauren says "you can use our family photo printer and you can print it yourself".
  - *The Wi-Fi Direct Application Service Platform allows the slideshow app to find capable devices prior to having a connection.*

- Lauren says "if you see a Printer Icon, just click on it and the photo will print".
  - *The Printer Icon is an indication that the printer supports a compatible protocol and page description language. Clicking the Icon creates the connection and prints the photo. The printer's policy is to automatically accept connections; it could alternatively require a user to manually accept connections.*
  - *The Wi-Fi Direct Application Service Platform provides a standardized process for users to initiate connections between their devices.*
  - *The Print Service provides a way for the slideshow app to check compatibility with printers and print documents and images.*
- They continue to look at other photos while it prints.
  - *The Wi-Fi Direct Application Service Platform allows Applications and Services to run in parallel.*

Service Use Cases: Enable

- Klaus has a Jukebox home sound system from Company X. When friends come around they can queue up music to play from their phones, even though they are using different media applications on phones from different manufacturers.
- Company X developed and published their proprietary Jukebox service on top of the Wi-Fi Direct Application Service Platform. Developers of media applications already use the Wi-Fi Direct Application Service Platform as it enables an easy way for them to enhance their products with peer to peer features.
  - *The application interface on the Wi-Fi Direct Application Service Platform reduces the complexity of building an application on Wi-Fi Direct by abstracting the details of the underlying technology.*
- Company X is happy that all of the popular media applications incorporate support for their Jukebox service. Customers love Jukebox because they can use their favorite media application to interact with it.
  - *OEMs can enable developers to provide innovative applications on their products by supporting the application interface on the Wi-Fi Direct Application Service Platform and optionally promoting proprietary services built on top of the platform.*

Today's agenda

Time	Topic
9:30 – 10:15	Keynote: Wi-Fi Alliance® - Seamless Connectivity
10:15 – 10:30	Sponsoring Lab Presentation
10:30 – 11:00	Wi-Fi Alliance Program Roadmap
11:00 – 11:45	Program Status Updates
11:45 – 12:45	**Lunch**
12:45 – 14:45	Program Focus: WiGig CERTIFIED™
14:45 – 15:00	Break
15:00 – 16:00	Program Focus: Wi-Fi CERTIFIED ac
16:00 – 17:00	Q&A and Wrap-Up

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WiGig CERTIFIED™ Program Focus

Focus topics

- 60 GHz technology overview
- Media Access Control (MAC)
- Physical layer (PHY)
- WiGig CERTIFIED™ program
- Protocol Adaptation Layers (PALs) overview
- WiGig Display Extension PAL
- WiGig Bus Extension PAL
- WiGig SD Extension PAL

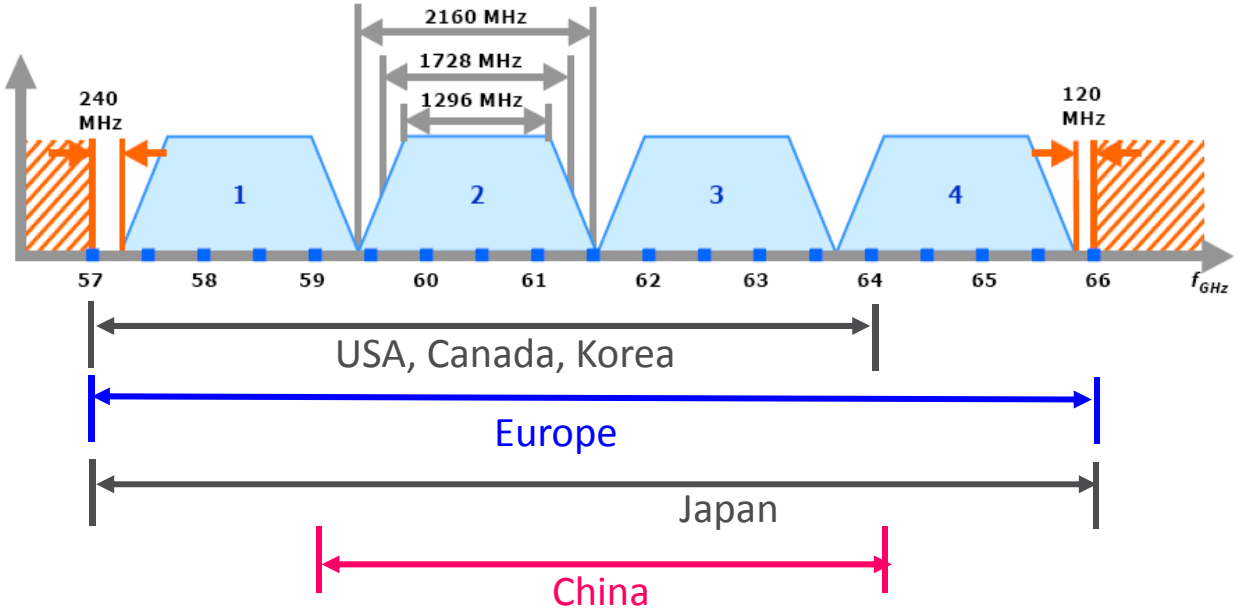
WiGig CERTIFIED™ Program Focus

60 GHz technology overview

Worldwide 60 GHz spectrum allocations

- The unlicensed 60 GHz band is the key to realize multi-Gbps wireless
- The 60 GHz spectrum is well harmonized around the world, thus easing worldwide adoption of 60 GHz products

Channel Number	Low Freq. (GHz)	Center Freq. (GHz)	High Freq. (GHz)	3 dB BW (MHz)	Roll-Off Factor
1	57.240	58.320	59.400	1728	0.25
2	59.400	60.480	61.560	1728	0.25
3	61.560	62.640	63.720	1728	0.25
4	63.720	64.800	65.880	1728	0.25



60 GHz characteristics

- Significantly different from 2.4 and 5 GHz
- Much poorer path loss in 1 meter range
  - Propagation loss 20 to 30 dB higher than 2 – 5 GHz
  - Penetration loss also higher
- Higher Link Budget loss ~32dB (or more)
  - Free space loss increase (-21 dB)
  - Decrease in TX power (~ -6 dB)
  - Factor of 50 increase in bandwidth (-17 dB)
  - Increase in RX noise figure (-3 dB)
  - Decrease in maximum range (+10 dB)
  - Decrease in bps/Hz (+5 dB)
- Compensated with directional antenna gains supported by beamforming protocol, to achieve multi-Gbps throughput
- 802.11ad WiGig specifications to bring the standard to support the technologies

802.11ad features added to 802.11

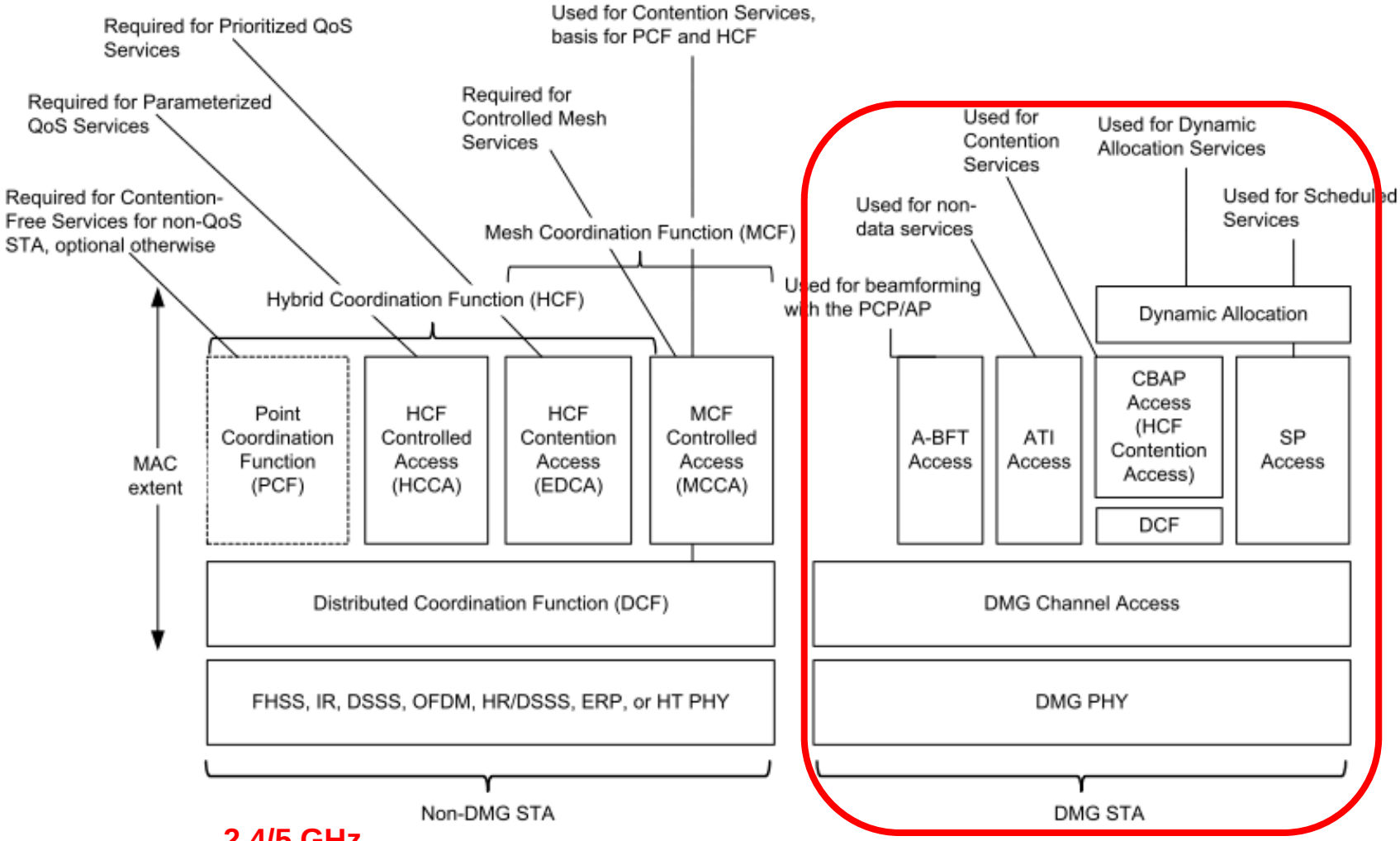
Item	802.11ad	Technical details
Network architecture	Infra-BSS, IBSS, PBSS	Backward compatibility to 802.11 + native WPAN support
Medium access	Scheduled access and contention access	Enables both the low power and the high performance devices, EDCA with directional antenna
Power saving	Advanced power saving techniques	More power efficiency with PCP PS, PSC-REQ/RSP wakeup schedule
Security mechanism	GCMP	Secure communication at Gbps rates
PHY	SC, low-power SC and OFDM, with common preamble and coding	• Up to 7Gbps with OFDM • Up to 4.6Gbps with SC
Beamforming	Unified and flexible beamforming scheme (SLS/BRP)	Enables robust communication at ranges beyond 10m
Fast session transfer	Multi-band operation across 2.4/5/60 GHz	Built-in efficient and seamless support for multi-band radios

WiGig CERTIFIED™ Program Focus

Media Access Control (MAC)

802.11ad architecture changes from 802.11

- From [IEEE 802.11ad-2012]:



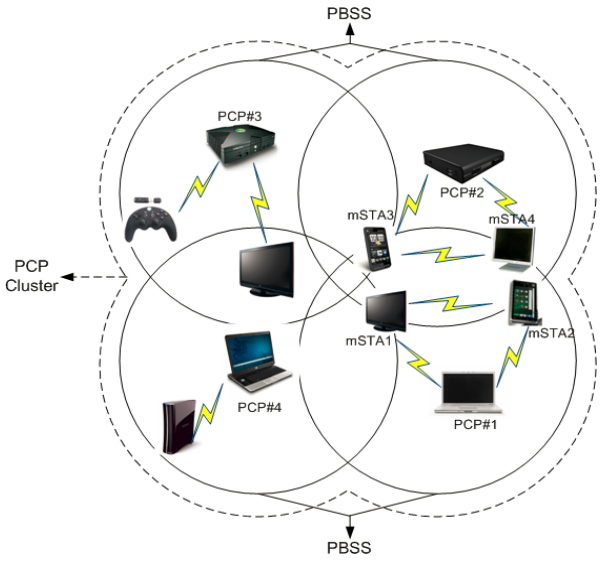
MAC architecture

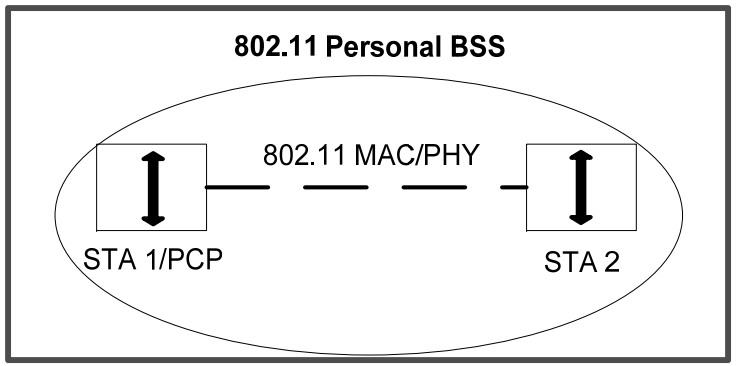
New features to 802.11 MAC

- Personal Basic Service Set (PBSS) which retains the existent 802.11 network architectures
- Channel access supports directionality and spatial frequency reuse, including both random access and scheduled access
- A unified and flexible beamforming scheme that can be tuned to simple, low power devices as well as complex devices
- Enhanced security (GCMP), link adaptation and power saving
- Multi-band support (fast session transfer)

The Personal BSS (PBSS)

- New network architecture in addition to infrastructure BSS and IBSS, which are also supported
- PBSS is defined to address some unique usages and challenges of 60 GHz communication
  - Usages: Rapid sync-n-go file transfer, projection to TV/projector, etc.
  - Challenges: directional channel access, power saving, etc.
  - Ad hoc network similar to the IBSS, but a STA assumes the role of the PBSS Central Point (PCP) and only the PCP transmits beacon frames



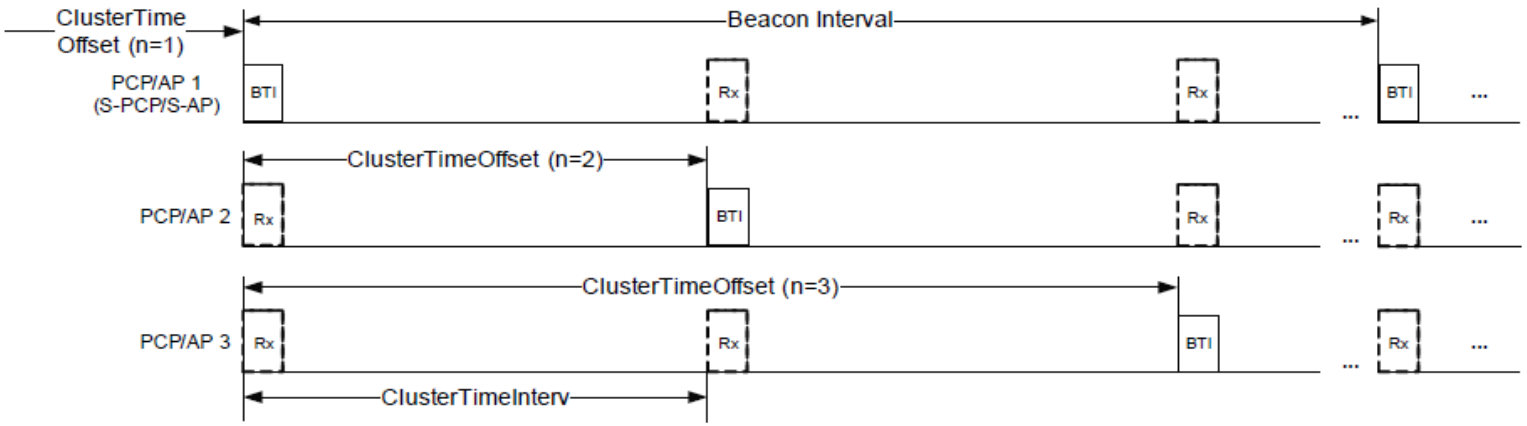


Understanding PCP clustering

- Synchronization(S)-PCP/AP with member PCPs/APs to improve spatial sharing and interference mitigation
- Schedule transmissions in non-overlapping time periods within the same cluster
- Member PCPs / APs performs scheduling to minimize interference upon receiving a beacon of adjacent members
- Supports two types of Clustering:
  - Decentralized
  - Centralized

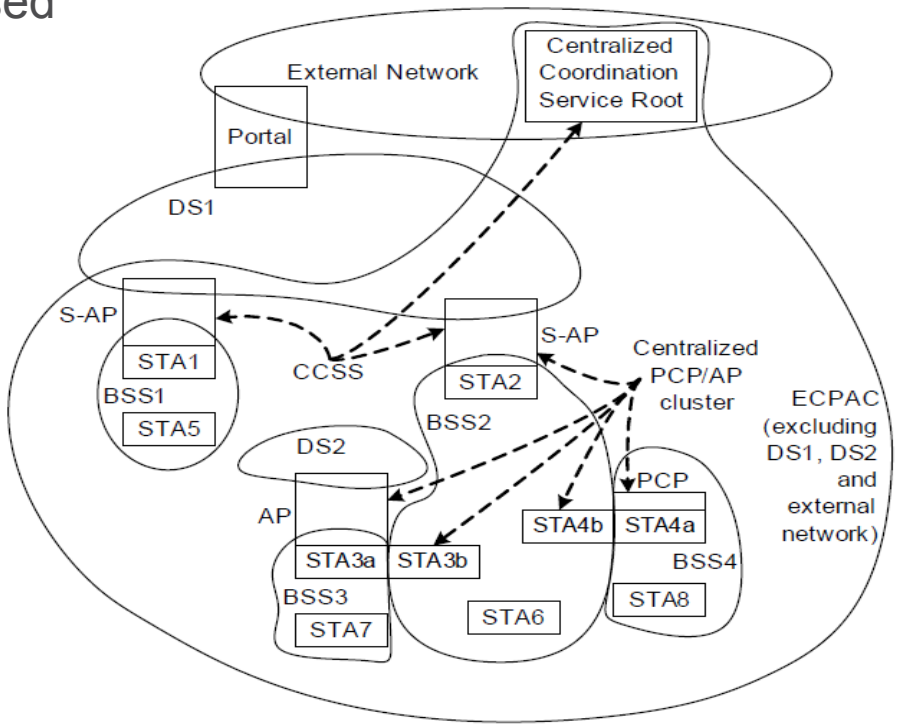
Decentralized clustering

- Decentralized PCP/AP clustering involves a single S-PCP/S-AP in the Basic Service Area (BSA) of the S-PCP/S-AP that transmits a DMG Beacon at least once every aMinBTIPeriod
- By transmitting its DMG Beacon during a empty Beacon SP, Member PCP/AP becomes a member PCP/AP
- Member PCP/AP shall select a beacon interval length that is equal to the beacon interval length of its S-PCP/S-AP



Centralized clustering

- Centralized Coordination Service Set (CCSS) is Centralized Coordination Service Root + S-APs
- Extended Centralized PCP/AP Cluster (ECPAC) is CCSS + Clustered PCP/APs plus all STAs within the BSSs of the S-APs and member PCPs/APs
- Nearby PCPs and APs are advised of free Cluster Time Offset by their S-AP
- Beacon SPs prevent contention during BIHs
- Any STA can use a TXSS CBAP for TXSS (or sending data)

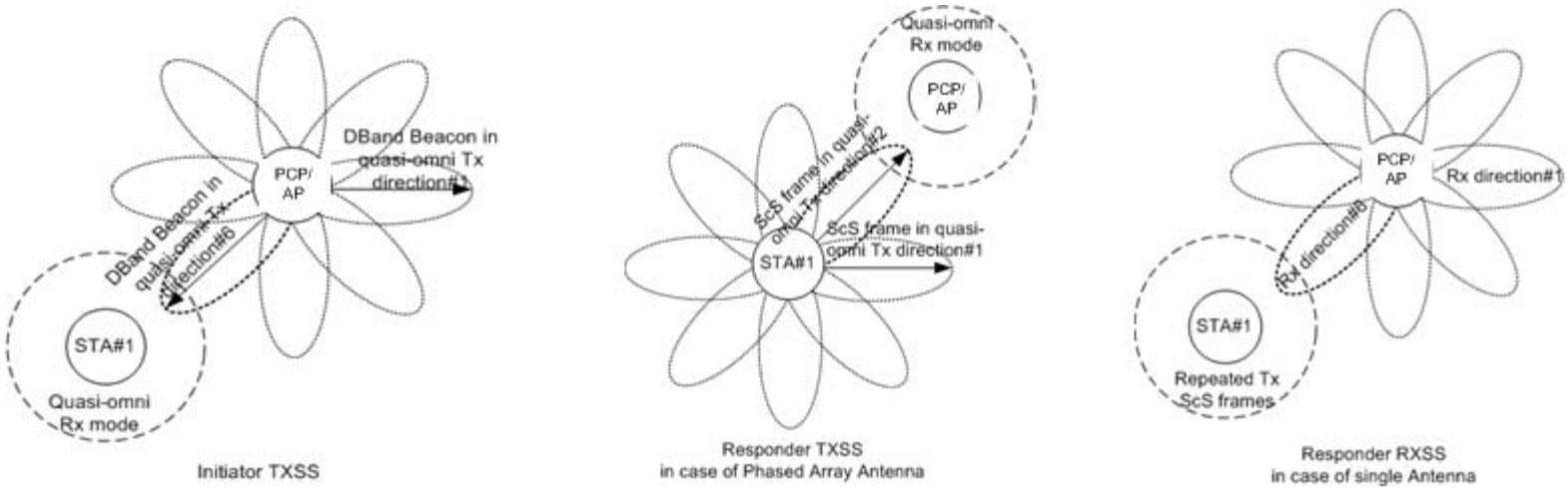


PCP/AP clustering example

- Directional 60 GHz transmissions are suitable for such dense environments. However, beacons and other pre-BF frames can become omni-directional jammers.
- (Optional) Mechanisms defined for supporting Centralized and Decentralized clustering, which allows PCP/AP to coordinate their omni Tx
- Synchronizing PCP/AP form clusters of PCP/AP and schedule Beacon Header Interval (BHI) and other omni transmissions at different timing offsets

- PCP/AP clustering addresses the increasingly common high density usage scenario

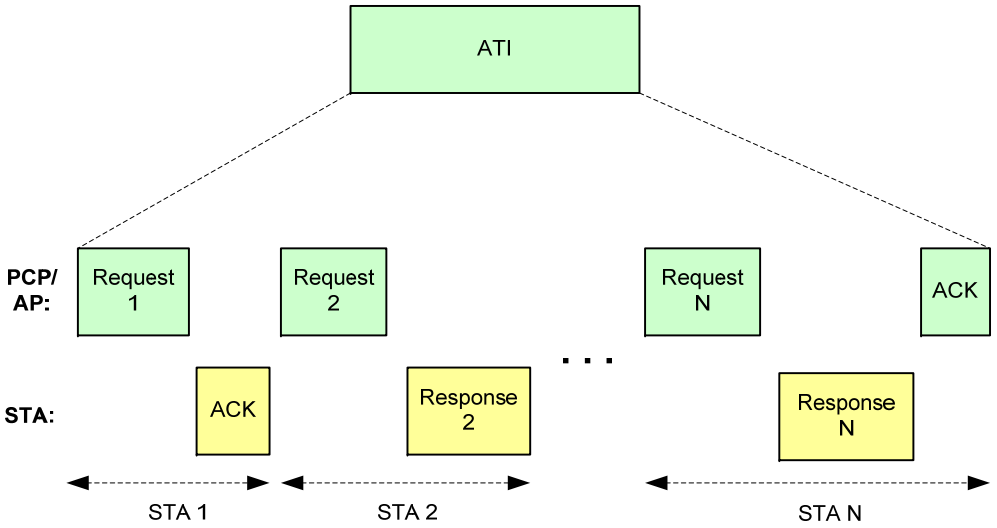
Association Beamforming Training (A-BFT)



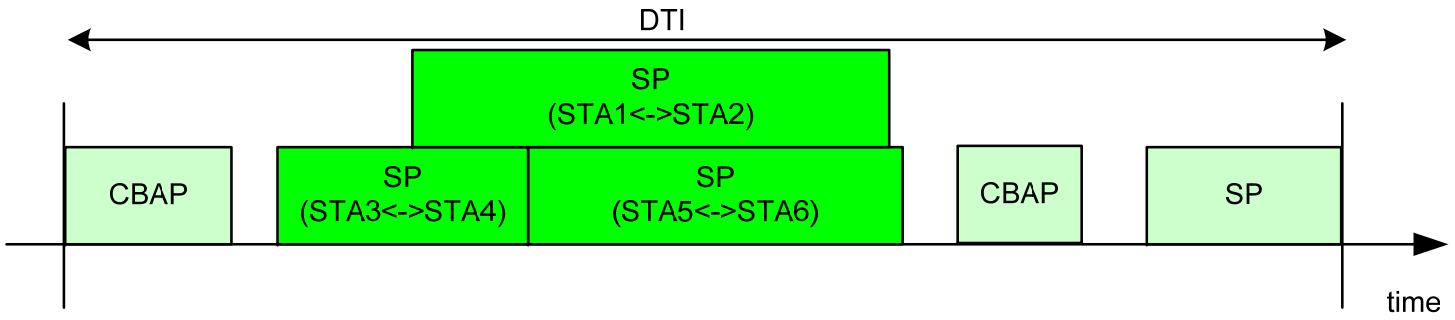
- The purpose of the A-BFT is to allow the PCP/AP to perform BF with other STAs in situations such as BSS joining, BF link re-establishment, etc.
  - Efficient, since it uses the beacon to bootstrap BF
  - More than one STA can perform BF with the PCP/AP within the same A-BFT
- The BTI and the following A-BFT may not be present in every beacon interval or at all

Announcement Transmission Interval (ATI)

- ATI is used to convey control/management between PCP/AP and STA, including scheduling
  - Also allows the PCP/AP to monitor the directional link with the STA
- Very efficient since all transactions can be done in directional, high-rate mode
- After having received a Request frame from the PCP/AP, a STA responds back with an ACK or a response frame



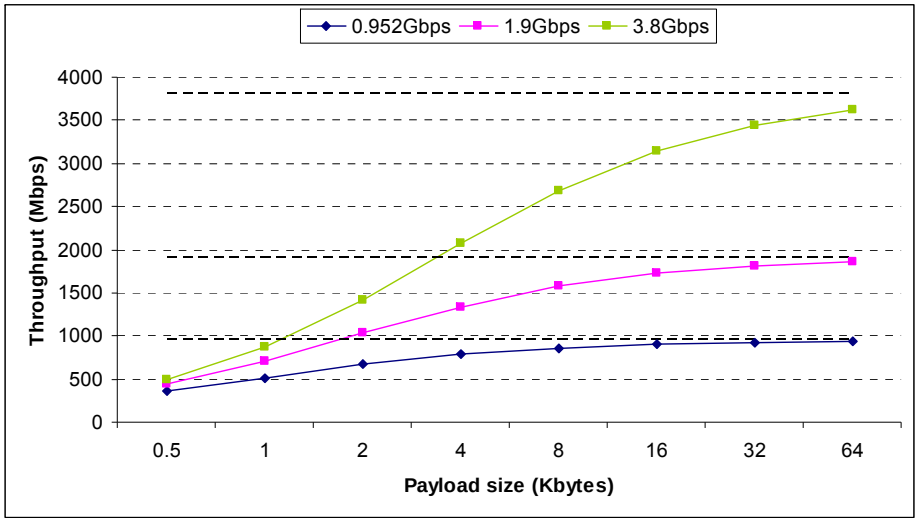
The Data Transfer Interval (DTI)



- The DTI is composed of zero or more Service Period (SP) and Contention-based Access Period (CBAP)
  - Service period: negotiated between AP/PCP and STA or dynamically allocated, wherein only prescribed STAs can access the channel
  - Contention-based Access Period: period of time scheduled by the PCP/AP, wherein any STA can access the channel. Access during the CBAP is based on 802.11 EDCA.
- For links under spatial reuse, their channel allocation during the DTI need not be disjoint in time

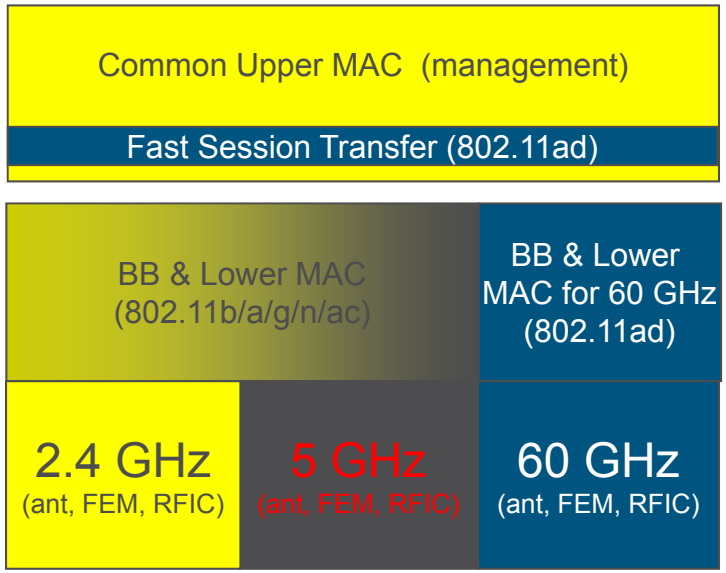
Channel access efficiency

- PCP/AP Scheduling mechanisms (SPCA and Dynamic Allocation by Polling) provides very high efficiency in supporting directionality and power saving
- MAC efficiency is above (or very close to) 90% of the PHY rate for payload sizes larger than 8Kbytes



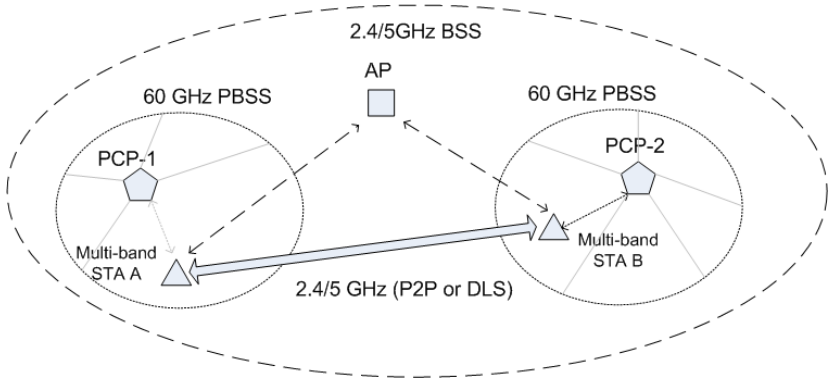
Fast session transfer (FST) for multi-band operation

- Enables seamless integration of 60 GHz with 802.11a/b/g/n/ac
- Allows transition of communication from any band/channel to any other band/channel
- Supports both simultaneous and non-simultaneous operation
- Supports both transparent and non-transparent FST
  - Transparent: the MAC address is the same in both bands/channels
  - Non-transparent: the MAC addresses are different

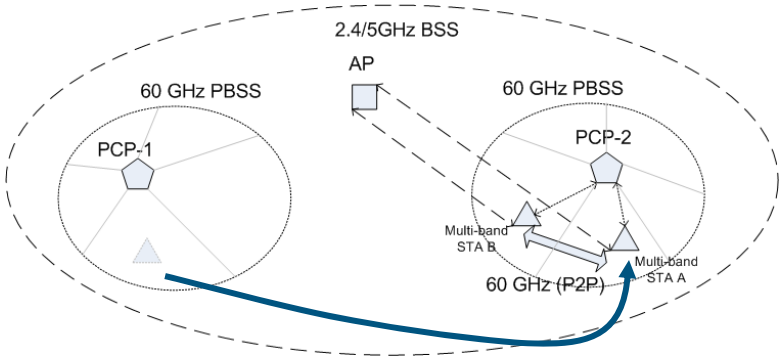


Fast Session Transfer example

STA A and STA B operating in 2.4/5 GHz



After FST, STA A and STA B operating in 60 GHz

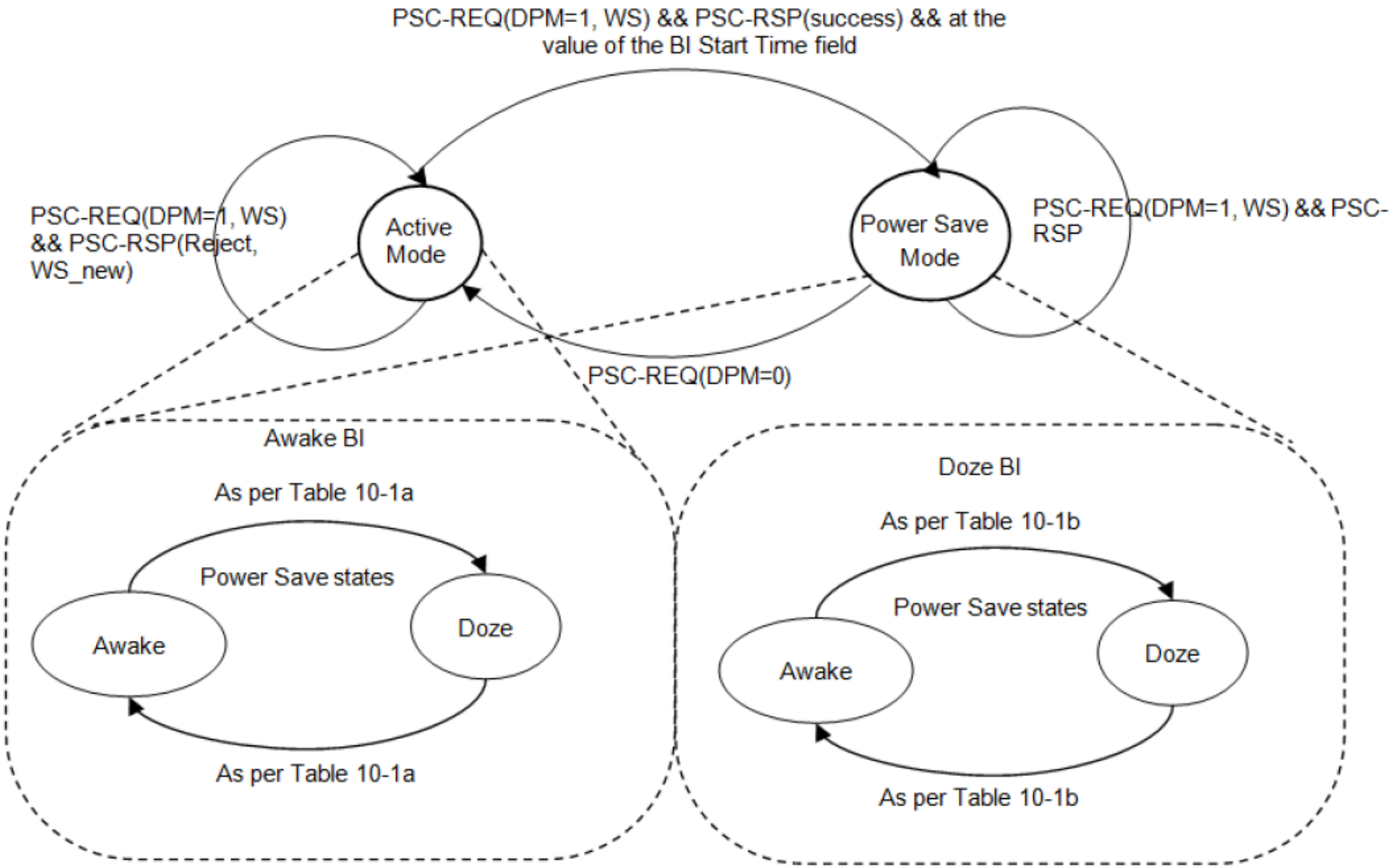


- STA A and STA B are associated with an AP in 2.4/5 GHz and have a Direct Link established (left)
- When STA A moves towards STA B, they move the session (that was transported over DLS in 2.4/5 GHz) to the 60 GHz band

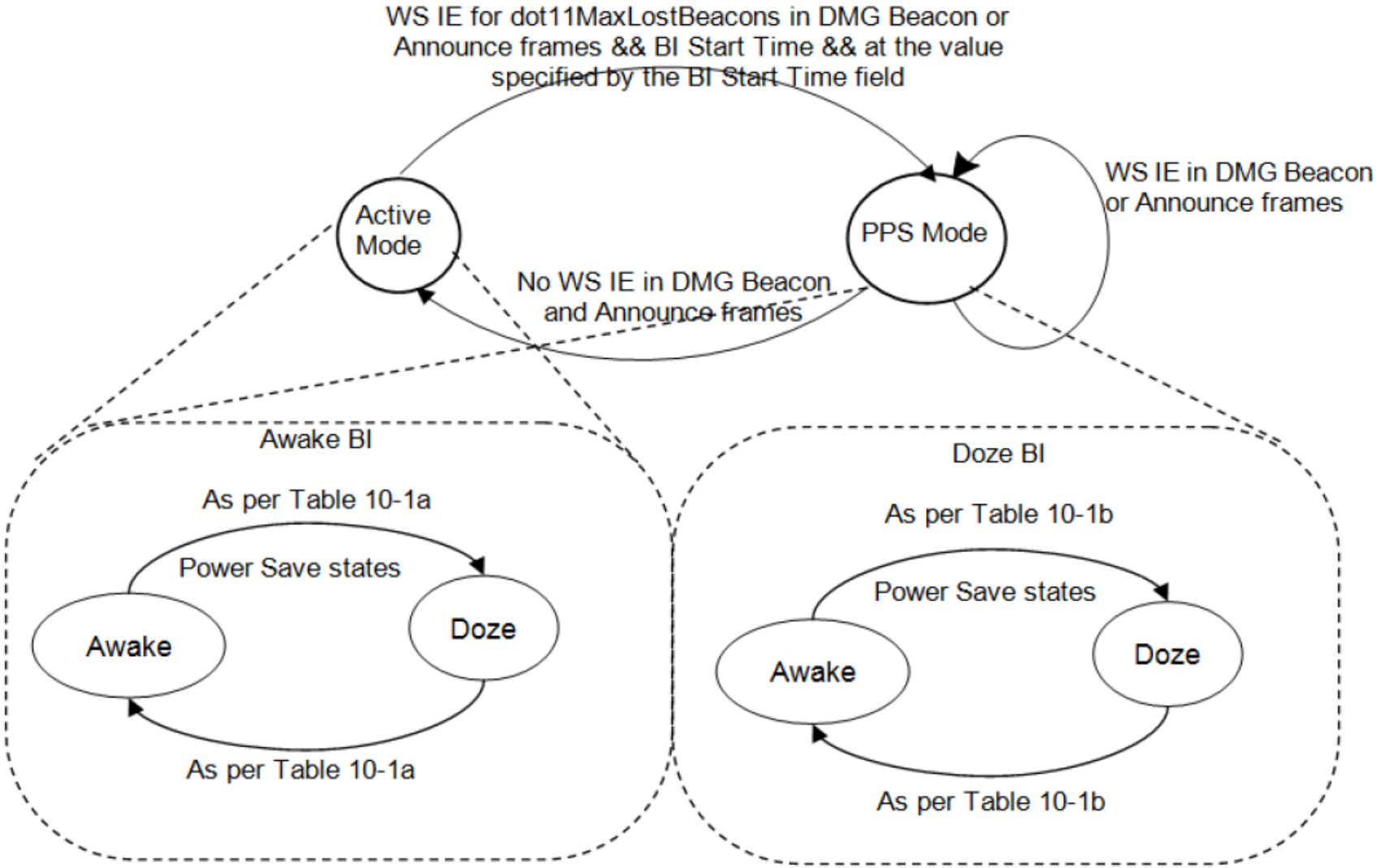
Power management

- A STA may operate in one if two power states
  - Awake: STA is fully powered
  - Doze: STA is not able to transmit or receive and consumes little power
- The manner in which a STA transitions between these two power states is determined by the STA's power management mode:
  - Active mode
  - Power save (PS) mode
- Based on this, two types of power management are defined:
  - Non-PCP/non-AP STA power management: scheduled or non-scheduled
  - PCP power management: scheduled

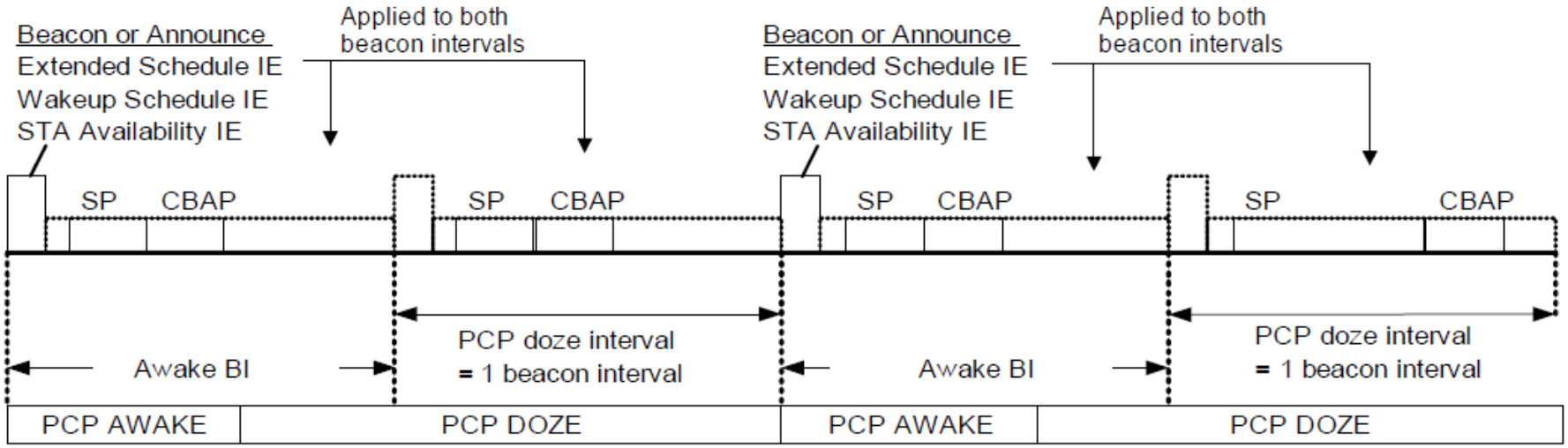
Non-PCP/non-AP STA power management mode



PCP power management mode



Example operation of PPS mode



- A PCP in PPS mode when the PCP sleep interval equals one BI (i.e., PCP sleeps every other BI)
- The first BI and the second BI have the same schedule, but the third BI and the fourth BI have different schedules
- In the first BI, the PCP transmits the Extended Schedule element for the current BI
- Since the schedule of the third BI and the fourth BI are different, the PCP transmits the Extended Schedule element containing the individual allocations for the third BI and fourth BI

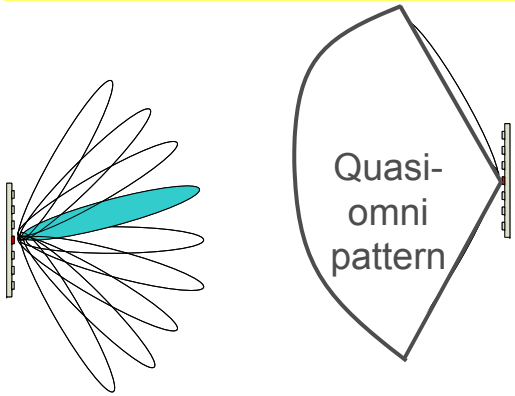
DMG Beamforming (BF)

- Unified and flexible BF protocol is supported that can be tuned to simple, low power devices as well as complex devices
  - Same protocol is used for PCP/AP-to-STA beamforming and STA-to-STA beamforming
- Mechanism used by a pair of STAs to achieve the necessary DMG link budget
- Established by a bidirectional sequence of BF training frames
- A STA does not have to initiate BF, but must support BF of another STA if requested
- BF composed of two independent phases: Sector Level Sweep (SLS) phase and Beam Refinement Protocol (BRP) phase
  - SLS: enables communication at the control PHY rate (MCS0), and typically only provides transmit training
  - BRP: enables receiver training and iterative refinement of the AWV of both transmitter and receiver

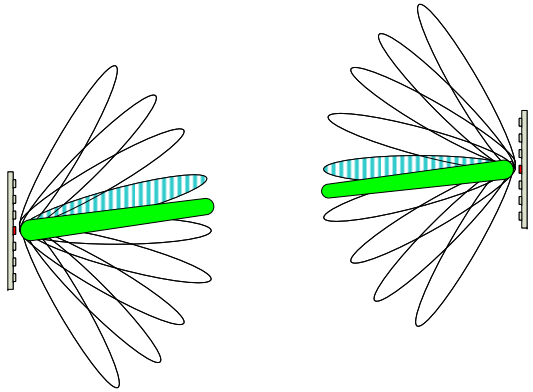
Beamforming protocol overview

- Specification employs:
  - Directional TX / low gain (quasi-omni) RX for acquisition in SLS phase
  - BRP adds RX gain and final adjustment for combined TX and RX
  - Beam Tracking during data transmission to adjust for channel changes

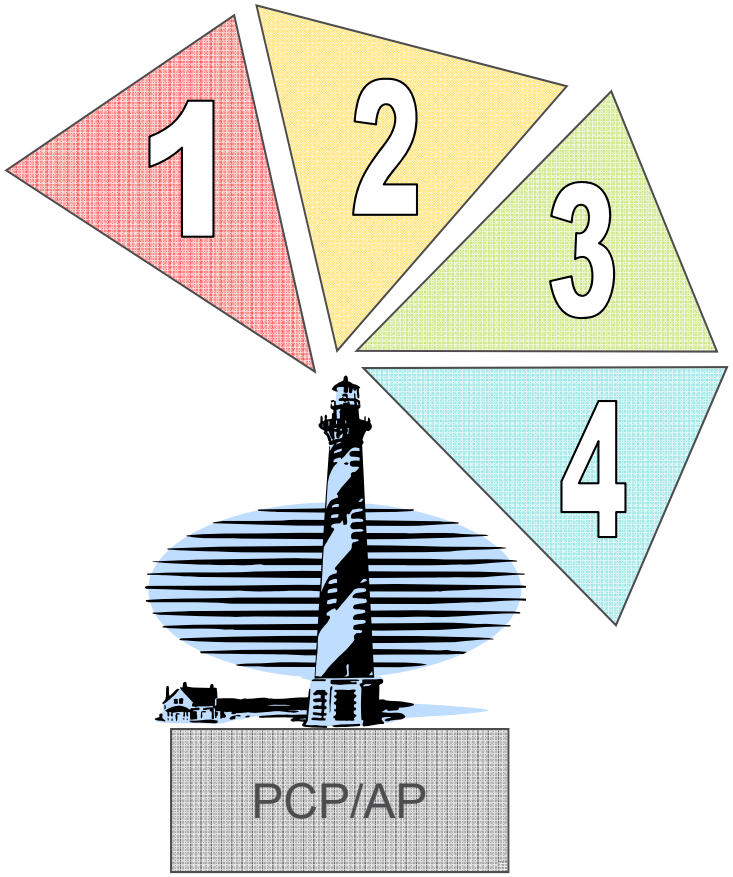
Example of sector level sweep



Example of beam refinement



Transmit (TX) sector sweeps (1 of 3)



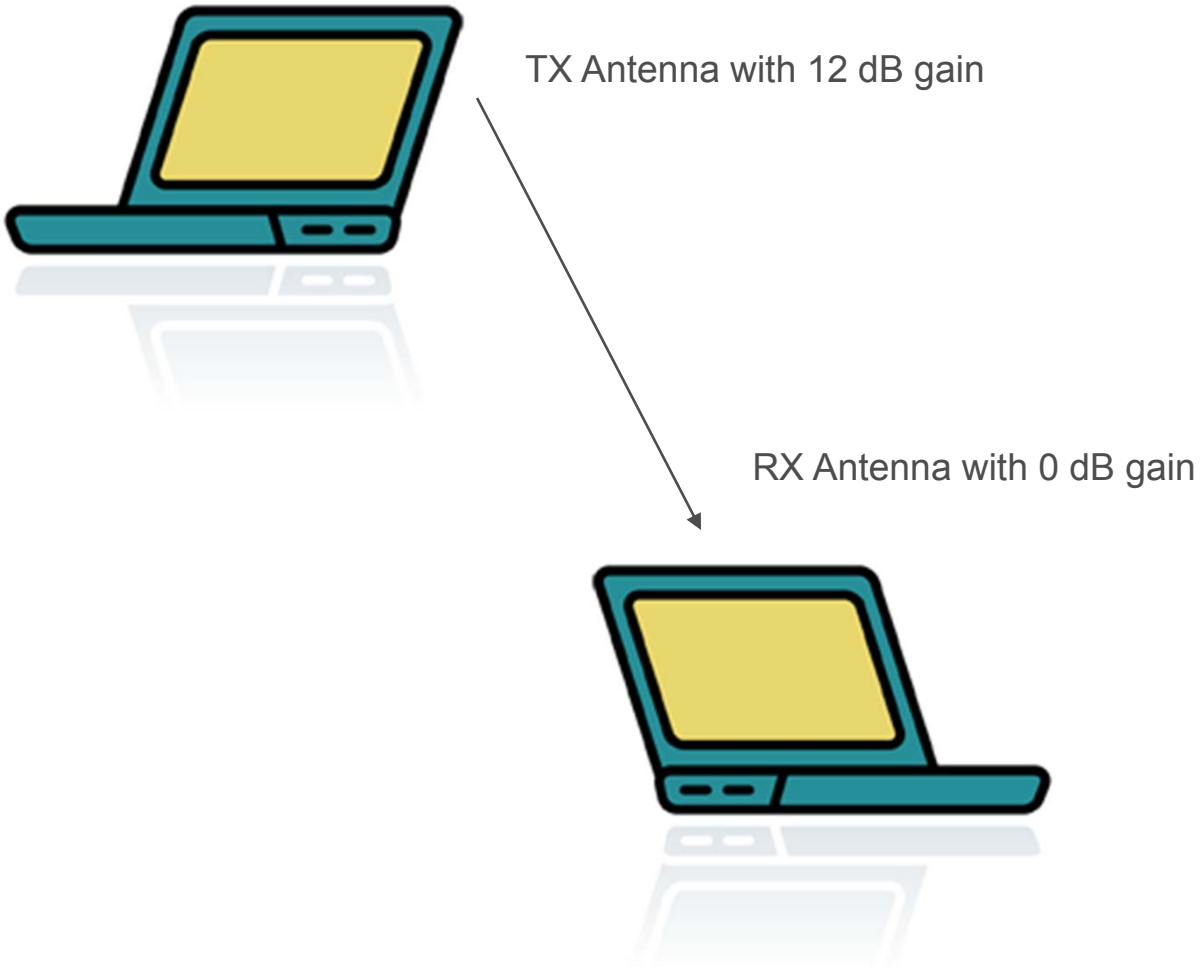
STA

- For the initial connection between two devices (STA and PCP/AP), one will receive with a quasi-omni-directional antenna while the other sends a sequence of frames covering different TX sectors
- For direct connections between two STAs in a BSS

Transmit (TX) sector sweeps (2 of 3)

- After successfully receiving at least one sector sweep frame, the stations reverse roles and the PCP/AP (or initiating STA) sets its antenna to quasi-omni receive and the responding STA starts a TX sector sweep.
- A specific frame format is defined for the TX sector sweep
- A special PHY mode (control PHY) is defined for sector sweeps. This PHY mode operates at a very low SNR (-78 dBm sensitivity) to allow robust communication with antenna gain at only one side

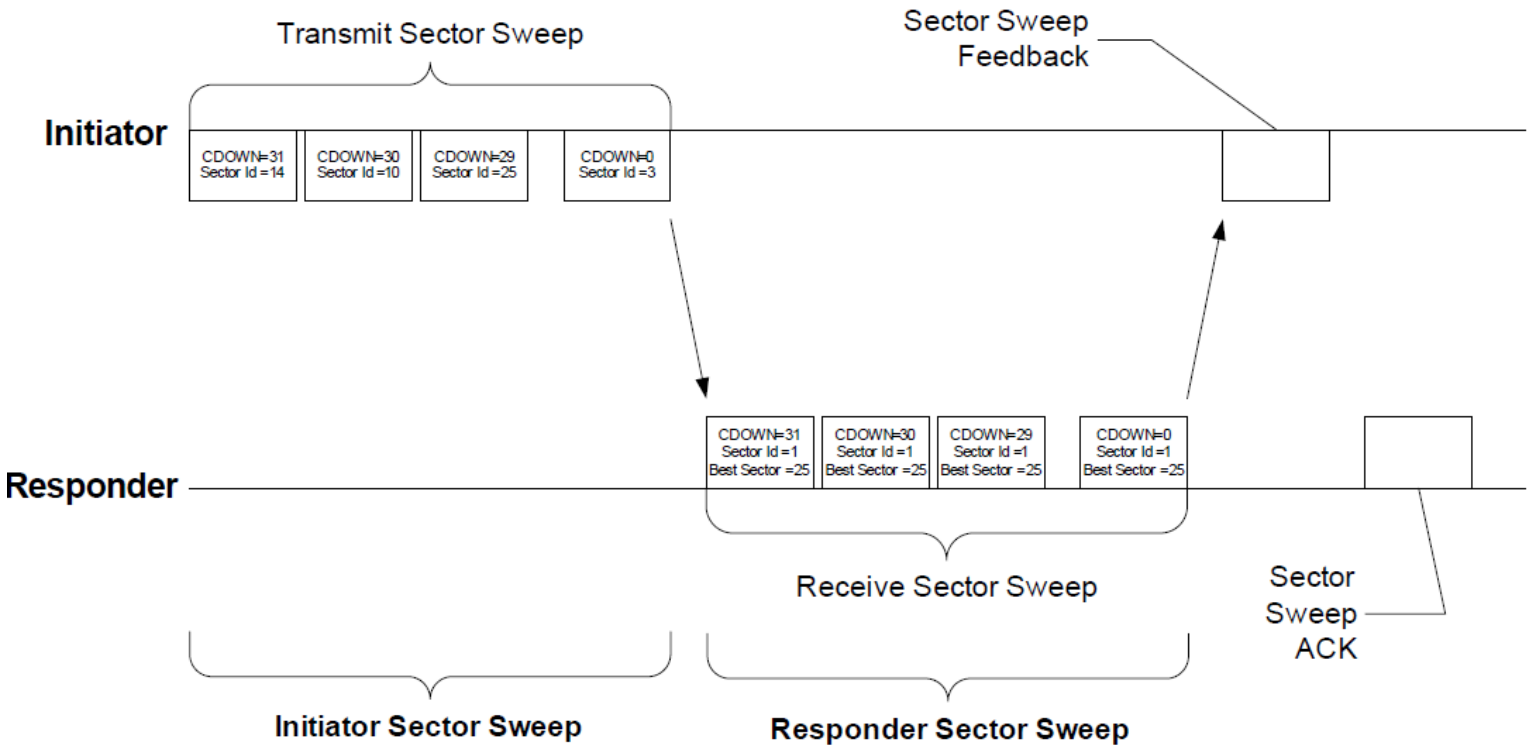
Transmit (TX) sector sweeps (3 of 3)



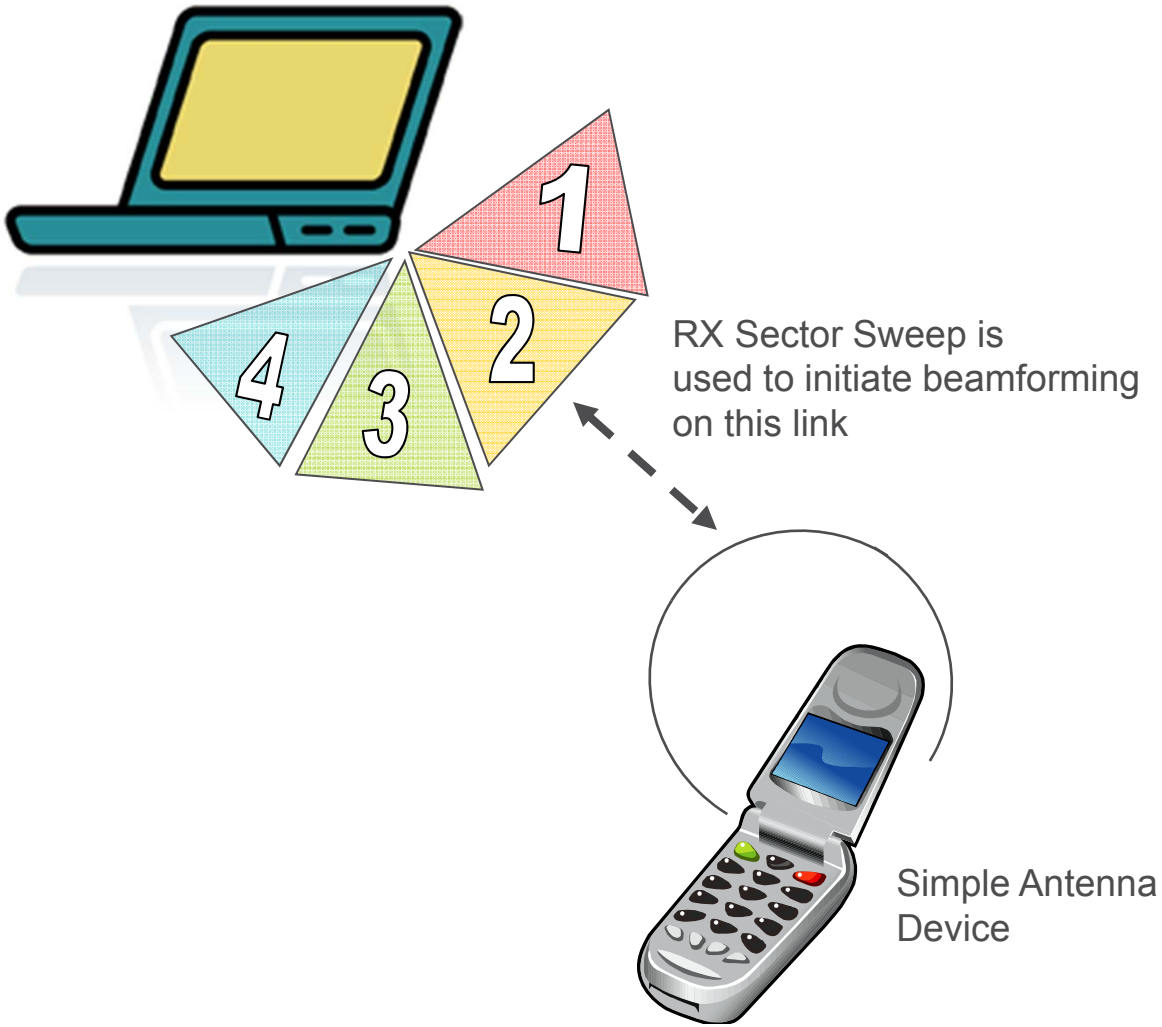
- Example link budget
  - 10 dBm TX power
  - 64 GHz
  - 10 meter range
  - TX gain 12 dB
  - RX gain 0 dB
- Received signal power is -66.6 dBm
- > 11 dB margin

Sector sweep packet sequence

- Each packet in the transmit sector sweep includes countdown indication (CDOWN), a Sector ID, and an Antenna ID
- The best Sector ID and Antenna ID information are fed back with the Sector Sweep Feedback and Sector Sweep ACK packets



Receive (RX) sector sweeps (1 of 2)



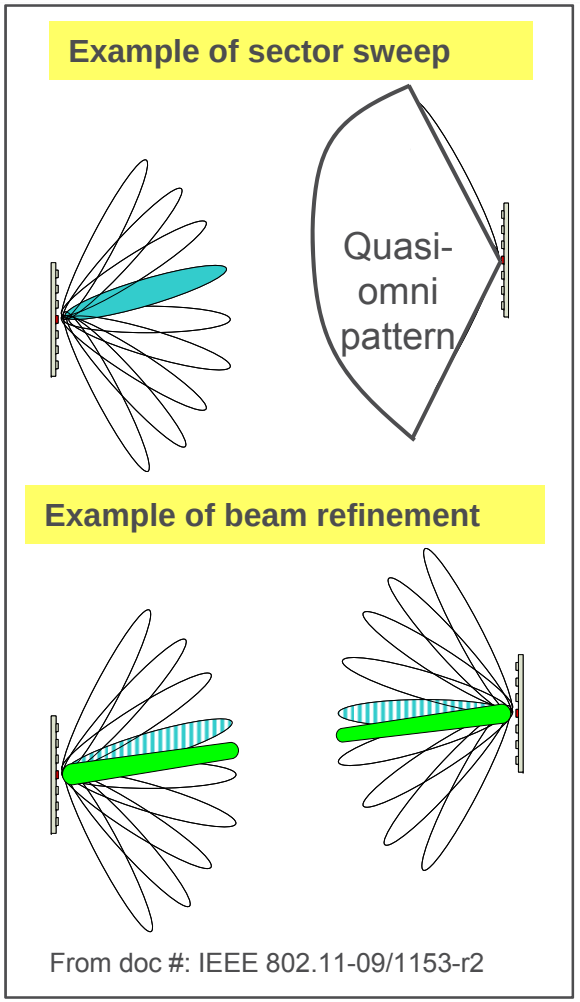
- A device with a simple antenna may not have enough TX gain to reach a distant receiver that is using an omni-directional receiving antenna
- RX Sector Sweep may be employed by the device with the higher performance antenna system
- Allows a simple antenna device, like a handset, to connect at greater range

Receive (RX) sector sweeps (2 of 2)

- For connection to a PCP/AP using RX Sector Sweeps
  - The PCP/AP will transmit beacons using a TX Sector Sweep
    - Beacon indicates the time when the PCP/AP will be listening for responses (A-BFT) and the PCP/AP will be listening with an RX Sector Sweep during the A-BFT
  - The STA listens with its low gain antenna until it hears a beacon
  - The STA responds during the A-BFT with a sequence of frames (Responder RXSS)
  - The PCP/AP listens for the frames and determine the best RX Sector for communication with the STA. This sector will be employed for communication until beam refinement.

Beam Refinement Protocol (BRP) phase

- BRP is a process in which a STA trains its RX and TX antenna array(s) and improves its TX antenna array configuration and RX antenna array configuration using an iterative procedure
  - Fine antenna weight vector adjustment
- BRP may be used regardless of the antenna configuration a STA supports

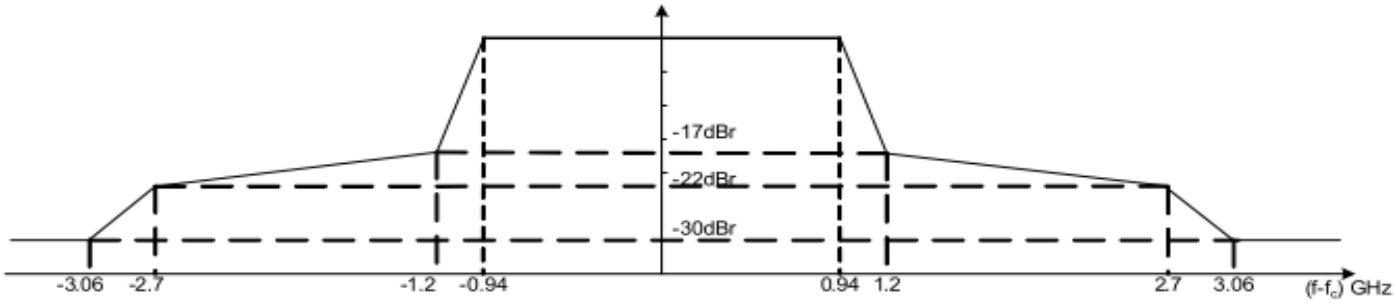


WiGig CERTIFIED™ Program Focus

Physical layer (PHY)

PHY overview

- Three different PHY modes
  - Same preamble structure
  - Control MCS for beacons and beamforming initialization
  - SC and OFDM PHY for directional tx/rx at various data rate and robustness levels
- Channelization
  - Channelization is identical to existing 60 GHz related standards, such as IEEE 802.15.3c.
  - Channel bandwidth is 2160 MHz with the following 4 center frequencies defined: 58.32, 60.48, 62.64, and 64.8 GHz.
- Transmit spectral mask for all PHY modes

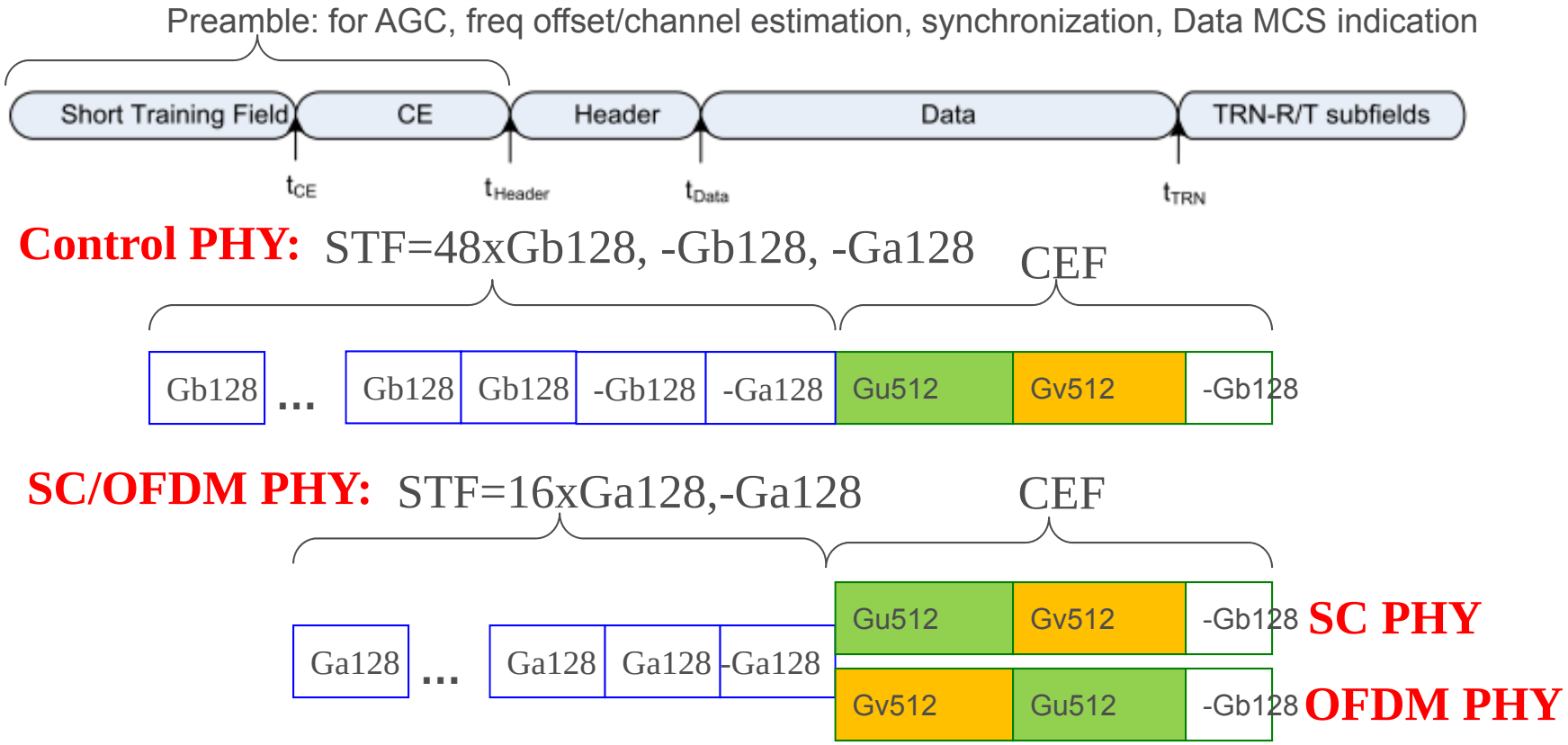


Transmit mask

DMG PHY signaling types

- Single Carrier PHY (some MCS mandatory)
  - Low power & Low complexity & Lower rate with Low Density Parity Coding (LDPC) FEC
  - MCS1 to MCS12, starting at 385 Mbps (MCS1) and up to 4620 Mbps (MCS12) data rate
- Low Power SC PHY (Optional)
  - Additional MCS for lower power using simpler Reed-Solomon error correction coding
  - MCS25 to MCS31
- OFDM PHY (Optional)
  - Higher rate & higher complexity & higher power with LDPC
  - MCS13 to MCS24, starting at 693 Mbps (MCS13) and up to 6756 Mbps (MCS24) data rate
  - Enhanced robustness in frequency selective channels
- Control PHY (Mandatory)
  - Low SNR requirement, suitable for omni-directional Tx (before beamforming)
  - Use SC with spreading to achieve lower, robust rate
  - MCS 0 using DBPSK with 27.5 Mbps data rate
- Coexistence: other than same channelization, the same SC chip rate as that of 802.15.3c CMS (Common Mode Signaling) preamble is adopted

Common preamble structure



- In the STF, complementary sequences are used to differentiate Control PHY MCS: 48 repetitions for Control PHY, 16 repetitions for SC/OFDM PHY
- In the CEF, reuse of sequences and pattern ordering are used to distinguish SC from OFDM PHY while simplifying implementation

LDPC – Low Density Parity Check

- Four codes of common codeword length of 672
- Cyclic shifted identity (CSI) construction
- Submatrix size 42
- Excellent coding gain on realistic channels
- Construction supports high throughput implementation
- Single construction supports code rates of 1/2, 5/8, 3/4, and 13/16

LDPC code set implementation

- Low complexity / low latency encoding
  - Shared terms in systematic product calculation across all codes
  - Back substitution for parity calculation
- High throughput / low power decoding
  - Layer decoding. Each code matrix H has 4 layers with a single set element per column and 4 clock cycles per decoder iteration
- Fully parallel belief propagation decoding
  - Code set super-position matrix has single CSI value per location which minimizes decoder multiplexing and routing
  - 1 clock cycle per decoder iteration

WiGig CERTIFIED™ Program Focus

WiGig CERTIFIED program

Wi-Fi Alliance WiGig CERTIFIED program

- Overall
  - Extend legacy Wi-Fi ecosystem & user experience
  - Span a wide range of Gbps applications.
  - Low power & high efficiency in dense environments
  - Leverage directional property of 60 GHz to compensate for high propagation loss: beamforming
- PHY
  - Different PHY types with shared implementation
  - Beamforming support
  - Coexistence
- MAC
  - More efficient and flexible Channel Access
  - Beamforming support
  - Integration with legacy 802.11: Fast Session Transfer

WiGig CERTIFIED mandatory features

- WPA2™-Personal security for all devices, and WPA2-Enterprise, including GCMP for enterprise devices
  - Use of either secured or OPEN network settings is allowed as a user-selected configuration
- All Non-AP products shall support the roles of both PCP and STA
  - Ensures that all devices are capable of P2P in 60 GHz
- Fast Session Transfer must be enabled if the device is multiband
- Correctly handle received Extended Schedule elements
  - Enhances battery life by sleeping during periods where device is neither a source or a destination
  - Ensures that the QoS characteristics of all the admitted flows in the BSS are guaranteed
- Devices embedded in a Host System supporting IP protocol shall enable IP connectivity
- Devices embedded in a Host System that do not support IP protocol shall enable a function relaying IP traffic to support all Wi-Fi CERTIFIED non-performance related tests

Summary

- The IEEE 802.11ad specification contains unique protocol features for exploiting 60 GHz characteristics and delivering performance
- The WiGig CERTIFIED program is designed to support a range of usage scenarios under varying channel conditions, including support for point-to-point to dense deployments and bursty to streaming traffic
- Supporting industry-wide interoperability, Wi-Fi Alliance expects to launch the WiGig CERTIFIED program in 2014

WiGig CERTIFIED™ Program Focus

Protocol Adaptation Layers (PALs)

Overview of PALs

- PALs support wireless I/O and display
  - Replace cables and ports
  - Transfer data with more efficiency by reducing application and system overhead
- Wi-Fi Alliance has initiated several work streams and there is significant activity in the following areas:
  - WiGig Display Extension
    - Native standard to deliver DisplayPort over WiGig
  - WiGig Bus Extension
    - Wireless instantiation of the PCIe bus
  - WiGig SD Extension
    - Instant file transfer between devices equipped with an SD card

WiGig CERTIFIED™ Program Focus

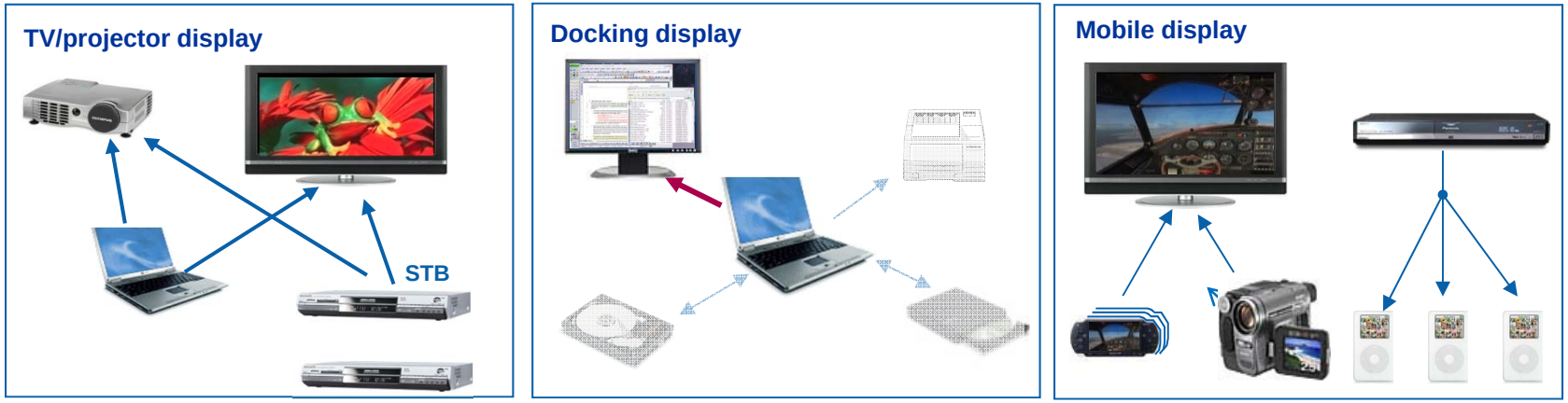
WiGig Display Extension (WDE): Support of HDMI® & DisplayPort® over 60 GHz

Overview

- Introduce the WDE specification and its performance targets for wireless displays
- Present design considerations for WDE to meet performance targets

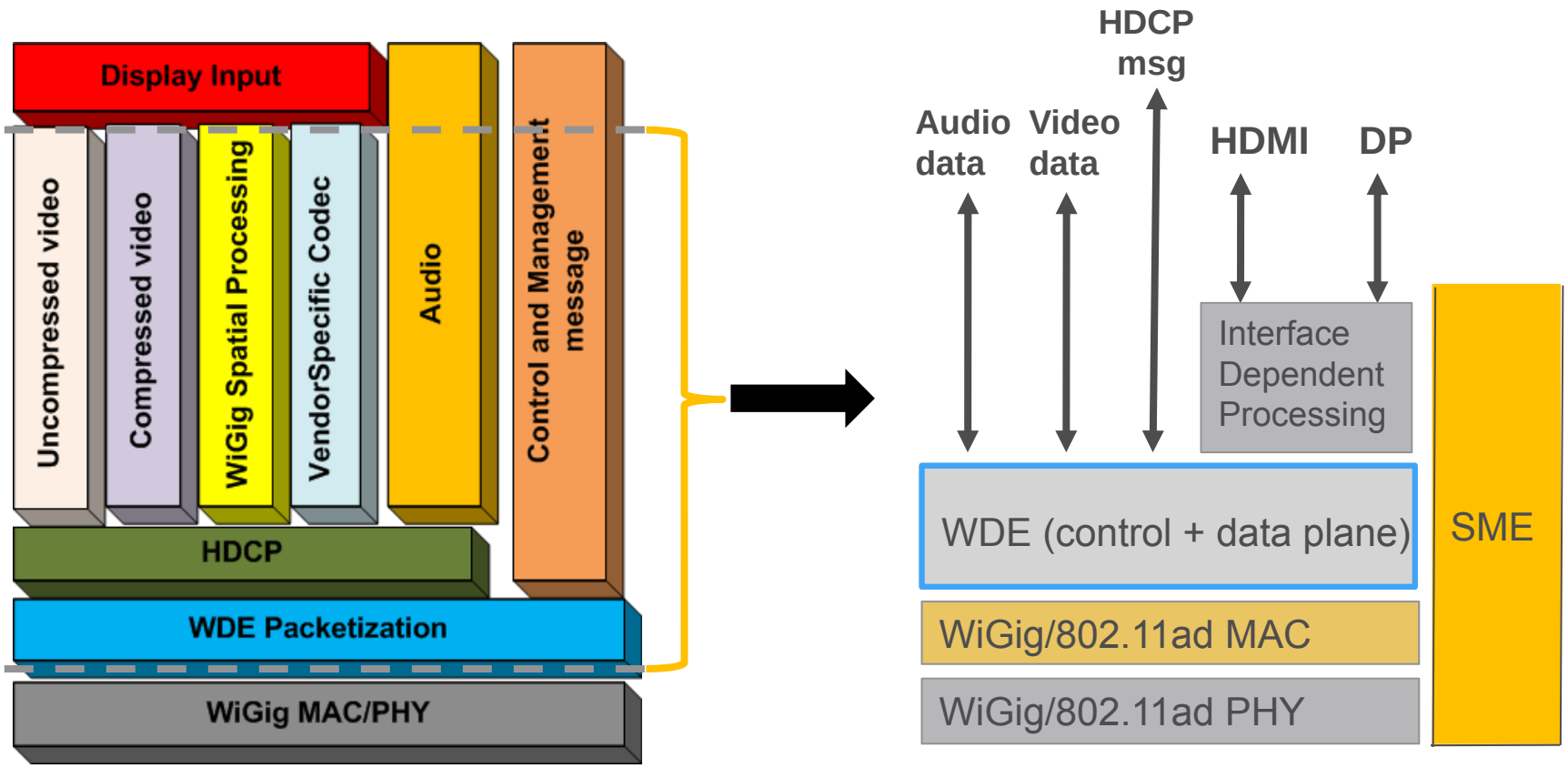
HD wireless display over 60 GHz

- Vision: high quality, robust, multi-purpose wireless display



- Design Target: An Experience Equivalent to Cable
  - Superior quality for all content types, including text
  - Low latency to enable gaming and docking
  - Channel sharing with other traffic types, such as I/O
  - Highly adaptive to temporary link degradation with minimal image quality impact
  - Enable power savings for battery operated devices
  - High protocol efficiency for operation at Gbps speeds

WiGig Display Extension



WDE defines the control and data planes for the wireless display connection to ensure interoperability and targeted performance

Accommodating higher bit rates for video

- Larger screen sizes and higher screen resolutions
  - 1080p is the de-facto minimum resolution
  - 1600p computer displays and 4k televisions are showing up
  - Multiple monitors are used in various scenarios
- For synthetic and computer generated graphics, compressed peak rates that need to be supported can be as high as uncompressed video rates
- Intra only coding might be necessary for various reasons which leads to higher bit rates
  - Complexity of encoders are increasing with the increased encoded bit rate resulting from higher resolution and multiple displays
  - Inter prediction might be costly to do and may introduce latency
  - Intra only coding improves error resilience naturally

Considerations and challenges for wireless display

- As data rates approach 1 Gbps and higher, the ability to meet the following requirements become essential
  - Sub-frame level video adaptation to avoid dropping content during link disruption while maintaining very low latency
  - Tight synchronization to minimize memory requirements for WDE sink and source
  - Minimizing protocol overhead to allow implementation in hardware and/or software
  - Enabling audio and video QoS differentiation at lower layers for desired A/V quality
  - Enabling power saving features

Features that enable a cable equivalent user experience

- Compression: Industry standard codec for display needs is chosen
  - H.264 (AVC) CAVLC 4:4:4 Intra profile – required for lossless rendering of synthetic images and computer graphics
  - CAVLC 444 Intra profile is extended by allowing P-skip macro blocks, i.e. conditional replenishment.
  - WDE also supports low bit-rate use cases.
    - Widely available codecs are geared towards for low-rate A/V transmission.
    - In comparison Wi-Fi Display choice of H.264 lower level profiles enable significant compression to match available throughput with 2.4/5 GHz WLAN – sufficient for video applications.
- QoS differentiation through separate packetization of A/V through the MAC-SAP
- An intelligent jitter handling framework to achieve cable equivalent experience

High Quality and Low Latency are achieved through attention to the architecture as well as compression schemes. Not one of them could achieve the results by itself.

Features that enable low latency

- Fine-granularity rate adaptation in the encoder
  - Shallow data buffer in the decoder is enabled through constraints in the WDE specification
- Tight synchronization between WDE source and sink further reduce required memory
- Smaller accumulated buffers in the data chain yield lower latency

Features to enable high speed processing

- Packetization in WDE is based on MPEG-PS and packets are delivered directly to the MAC without going through RTP/IP stack to minimize protocol overhead
- MPEG-PS allows larger packets and smaller header field overhead compared to MPEG-TS
  - MPEG-TS adds an additional syntax layer outside of the PES packet, while MPEG-PS uses PES packets directly
  - The primary feature of MPEG-TS is support for fine-grained multiplexing of large numbers of programs in one Transport stream, which does not apply to WDE
- Processing of MPEG-TS at high data rates is computationally intensive, adding complexity challenges for any implementation
  - Even with optimized custom hardware, it is difficult to process MPEG-TS at the required data rates using typical clock rates
- MPEG-TS is less efficient compared to MPEG-PS
  - Significant amount of stuffing are required when slices are aligned to PES packets

Features to support display standards

- WDE has a framework to support all HDMI 1.4a and DisplayPort 1.2 usage models, including
  - DP daisy-chaining, stereoscopic 3D content, wide gamut displays, display based audio, premium content, multiple simultaneous display types, DP topology support, AV lipsync
- WDE provides support for downstream displays in a manner that is consistent with OS expectations

Other elements of WDE

- Support of HDCP 2.0
- Spatial domain processing for video rate adaptation
- Vendor-specific codecs are allowed
- Support not transmitting static images in all video modes without adding predictive coding complexity, leading to significant power saving potential for desktop screen applications
- Application of FEC for additional robustness

Summary

- A cable-equivalent experience can only be achieved through careful design of all components in the end to end system
- The WDE specification provides a robust, multi-platform, multi-purpose, multi-user solution with a perceptually uncompromised user experience when compared to its wired counterpart
- WDE 1.0 specification was published in Dec 2011 and supports the full features of HDMI 1.4a and DP1.2

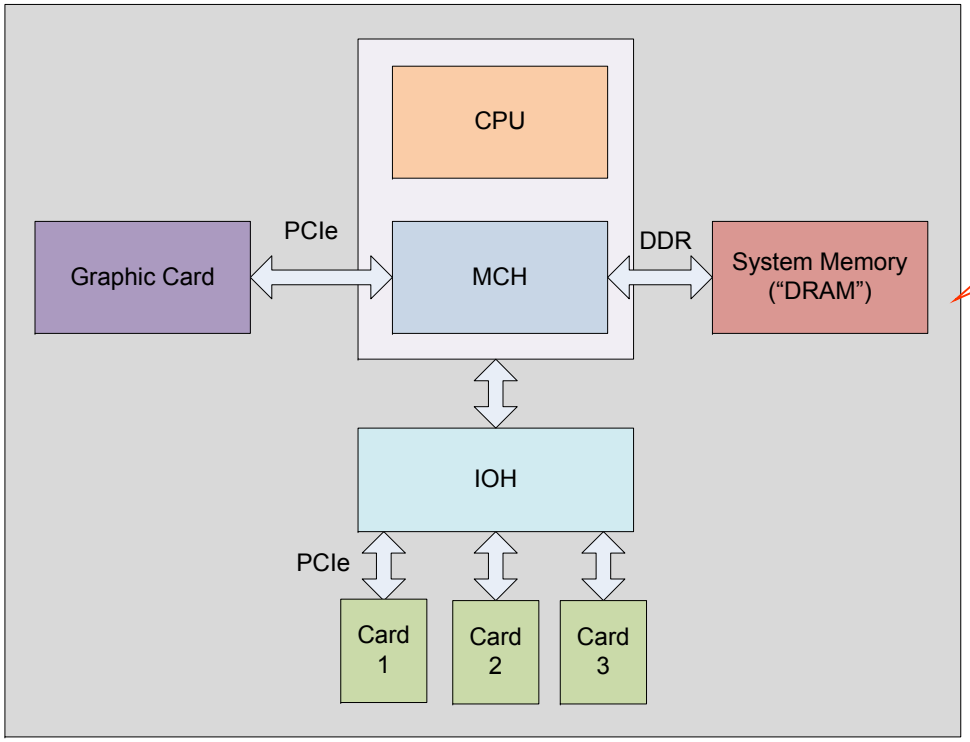
WiGig CERTIFIED™ Program Focus

WiGig Bus Extension (WBE): Support of PCIe over 60 GHz

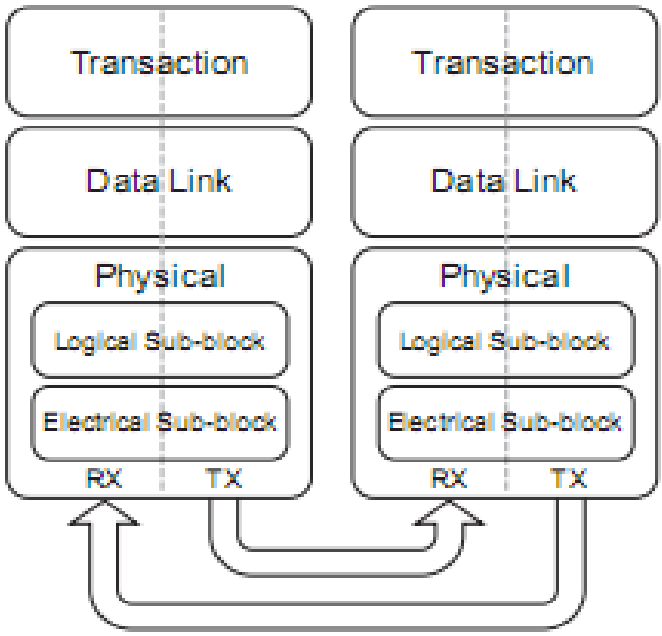
WBE introduction

- The WiGig Bus Extension standard was initiated in WiGig Alliance to define an efficient protocol for PCI Express transactions over the WiGig/802.11ad MAC-PHY
- Through PCIe, *any* I/O interface can be generated
  - USB2/3, Gigabit Ethernet, (e)SATA, Firewire, ONFI, all can be made wireless over WBE
- WBE is all about the Transaction Layer
  - No change to device SW model
  - No change to *any* SW in the OS
  - High bandwidth due to native PCIe devices usage
  - Full re-use of the PCI Express SW-HW existing infrastructure

Re-use of PCIe architecture

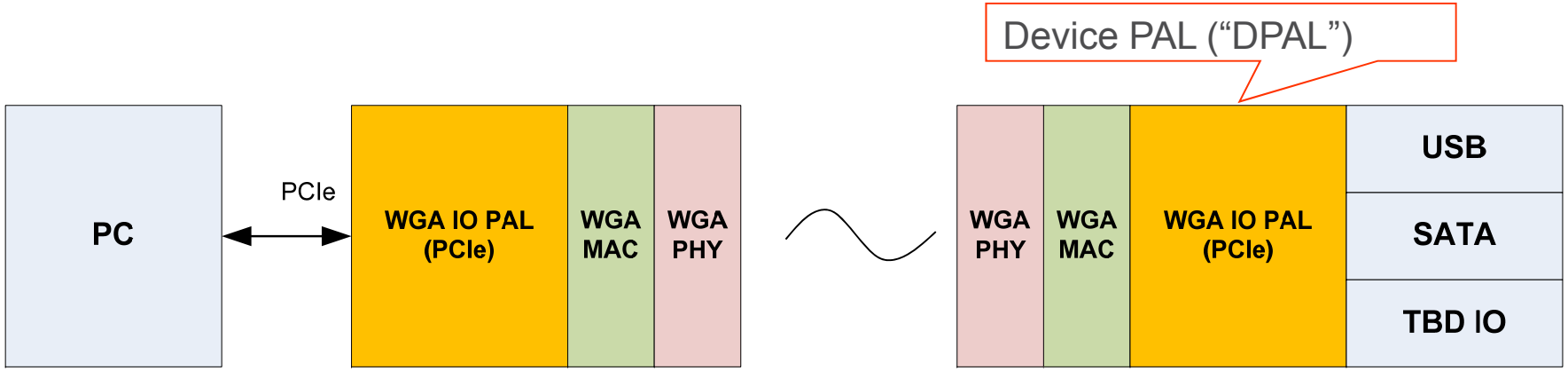


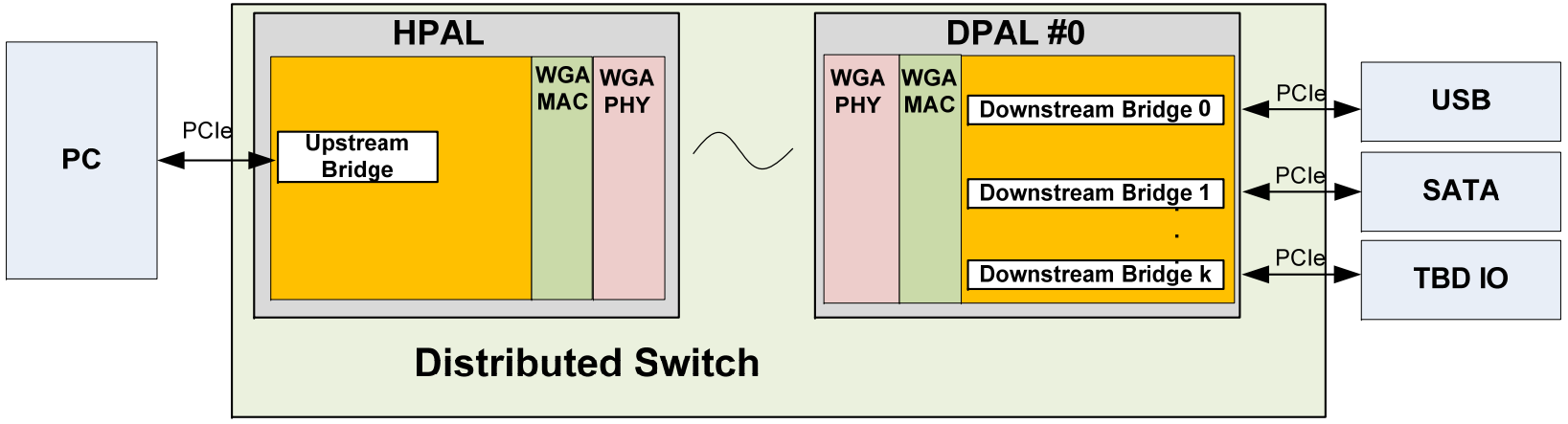
PCIe reuses the logical PCI structure (same SW model)



PCIe Network topology

WBE architecture





Market benefits for WBE

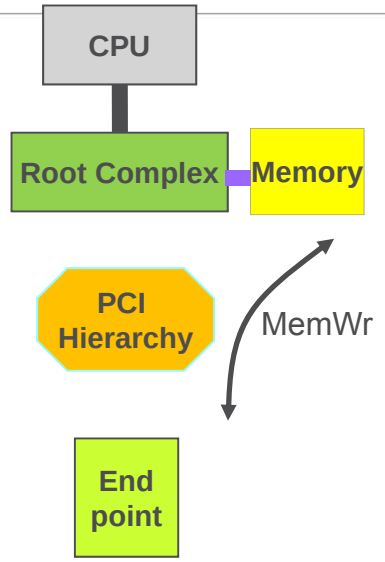
- There are many interfaces needed to fully address the PC and mobile device markets (ex. Ethernet, SATA, PCIe, HDMI, DisplayPort, Firewire, etc.)
- Each of these interfaces is in a constant state of improvement
- PCIe provides maximum flexibility to evolve as the relevant I/O standards evolve

WBE features at glance

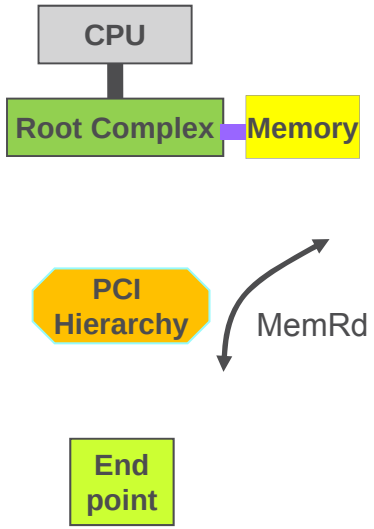
- Support for all wired PCI Express revisions
  - PCIe Gen1-Gen3 devices can be plugged into WBE
- Transaction layer protocol only
  - WBE PAL architecture is not aware to L1-L2 PCIe functionality
  - WBE PAL terminates locally the physical layer and data link layer of PCIe
- Relatively small packetization and MTUs
  - Simple and basic translation from wired protocol
  - Eliminated the need to prioritization
- Ordering rules
  - Full support for ordering rules as defined by the PCIe specification
- Multiple device support
  - Single host PAL (HPAL) can be connected to multiple PAL devices (DPALs)
- MAC interface
  - Using the basic MAC as defined in WiGig/802.11ad specification
  - Requires only single MAC queue
  - Flow control are part of the WBE PAL

Example of WBE Operations

- **Example #1: Re-use of Posted (Memory Write) Operations:**
  - No feedback is required from the system/ End point
  - Back to Back Memory Write operations (all directions) can reside in parallel

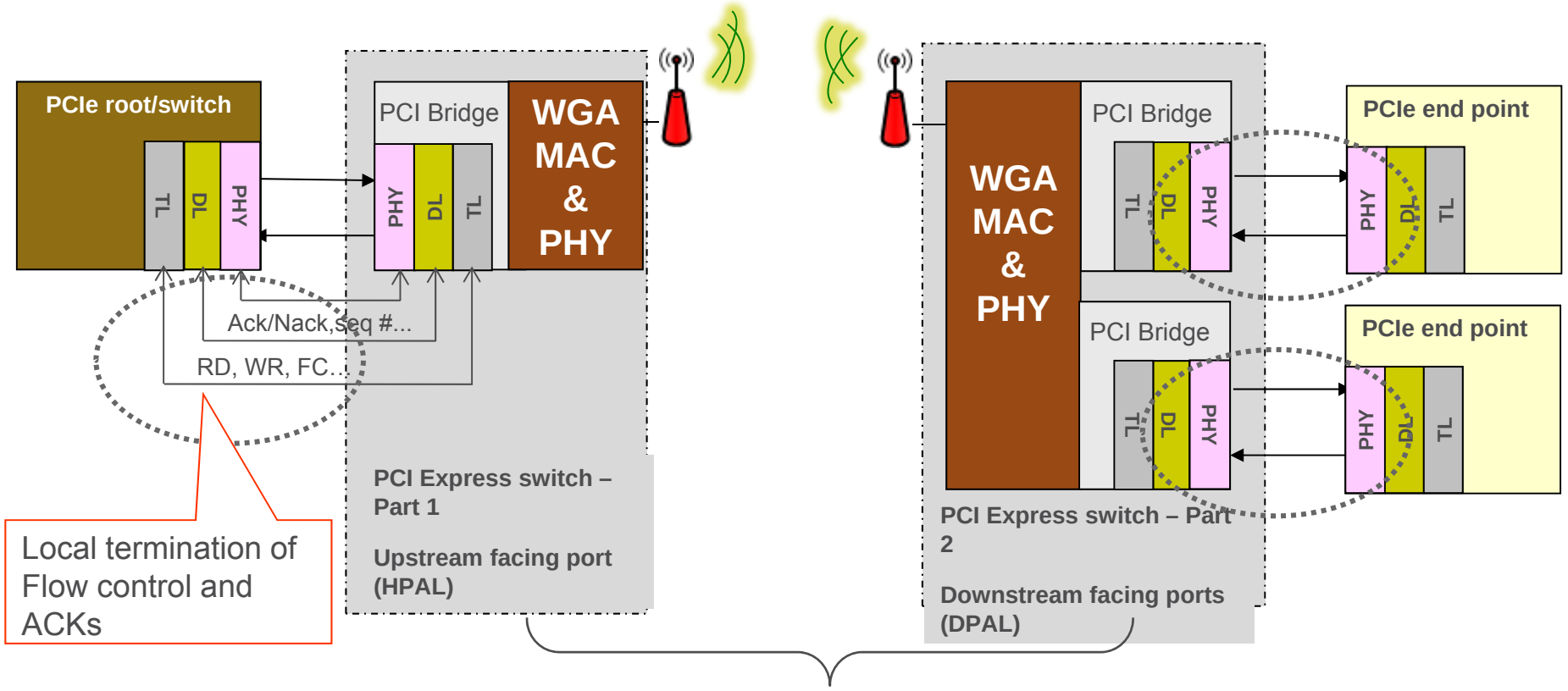


- **Example #2: Re-use of Non Posted (Memory Read) Operations:**
  - Feedback is required from the system/ End point
  - Only limited number of RD requests can reside in the system on the same time



WBE Bridging

Moving PCIe Switch to the Wireless Domain



The PCIe switch is wirelessly distributed (Same functionality as standard switch)

Summary

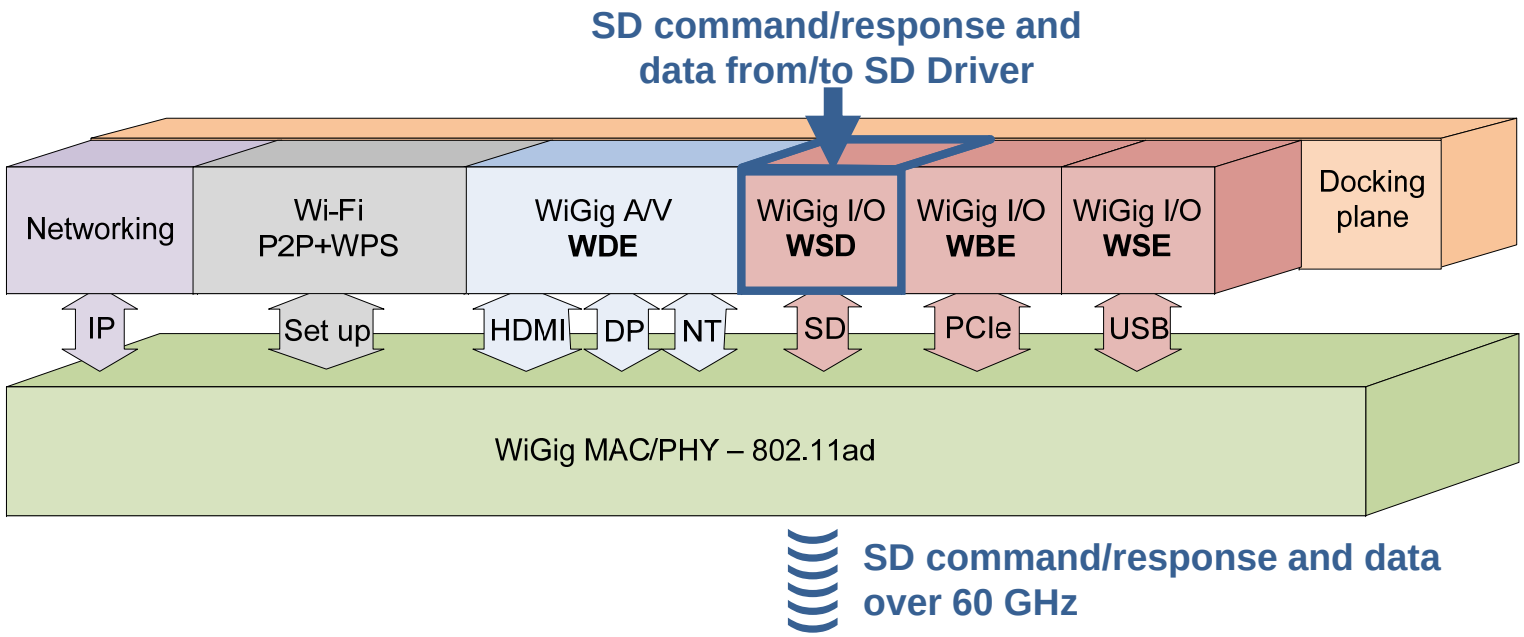
- WBE (Wireless Bus Extension) is a wireless implementation of the PCIe bus
- Enables wireless implementation of any PCIe based interface:
  - SATA
  - USB
  - Gigabit Ethernet
  - Firewire
  - HDMI
  - DisplayPort
  - etc
- WBE allows for wireless PCIe bridging – enabling reuse of controller bus drivers
- PCI SIG + MIPI Alliance have joined forces to enable PCIe over M-PHY for use in low power handsets

WiGig CERTIFIED™ Program Focus

WiGig SD Extension (WSD): Support of SD over 60 GHz

Overview

WiGig SD Extension standard was defined in WiGig Alliance to transport SD Bus protocol over WiGig/802.11ad MAC-PHY in an efficient way

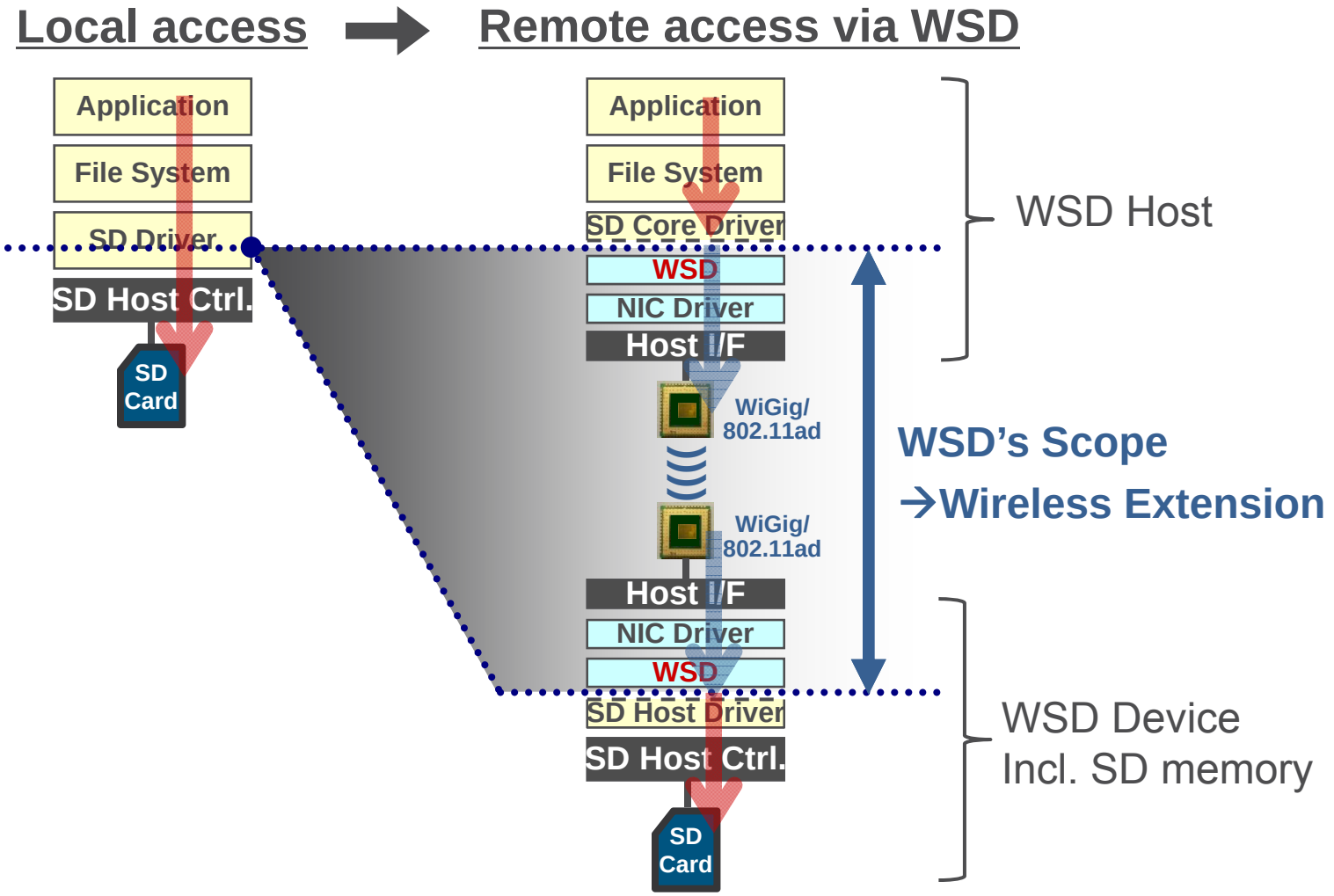


WSD usage

Makes the protocol simpler & more efficient by focusing only on Instant File Transfer between devices equipped with a SD Card

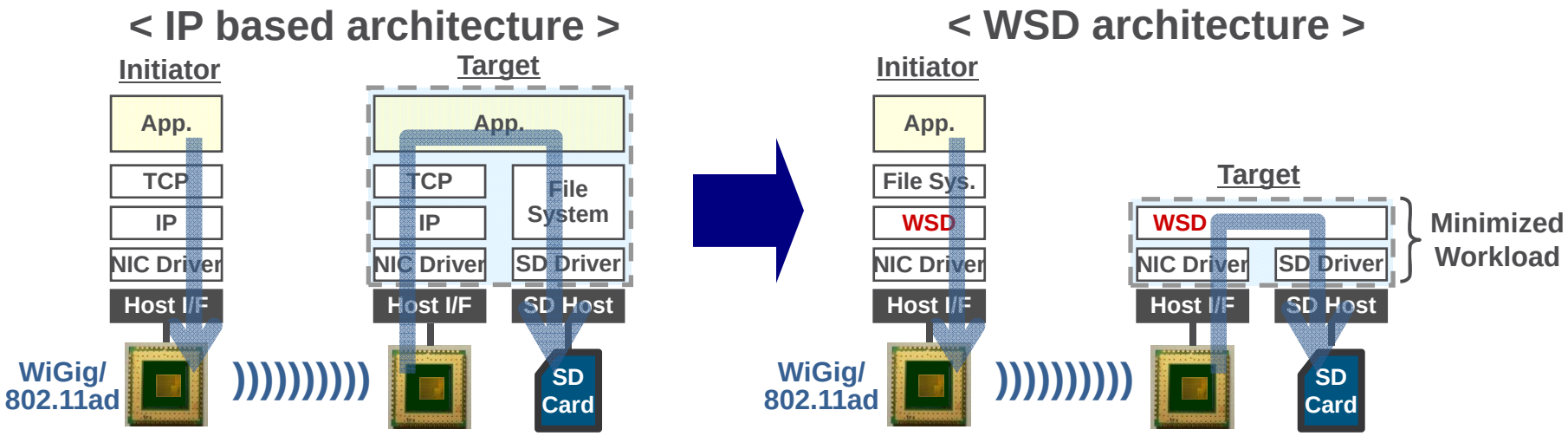
WSD architecture

Designed to hook into the SD Driver layer



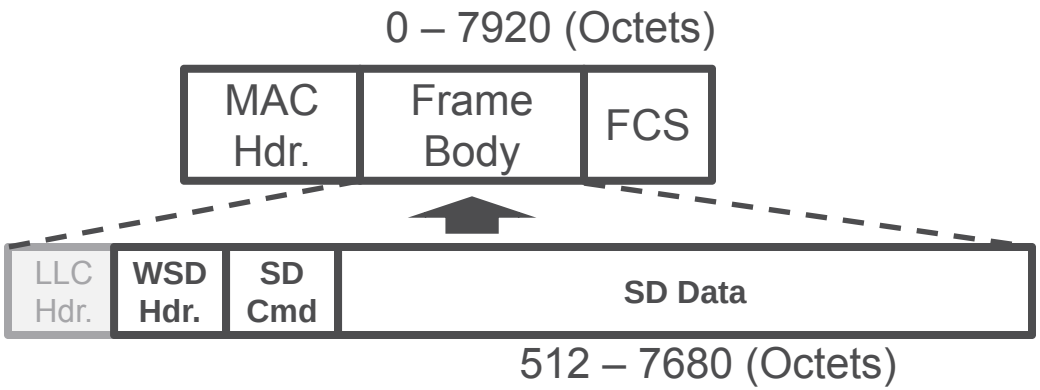
WSD architectural features

- Directly transport an SD command without an IP stack
- Directly mount a remote SD card
  - Reduce the target side workload (e.g., FS) dramatically
  - Estimated -40% workload on 1GHz CPU for 1Gbps file transfer
  - Enable longer battery life and higher throughput, especially for resource-limited handheld products



WSD protocol features

- Simple Transfer Mode
  - SD derived Read, Write transactions (bulk data transfer only)
- Efficient Packet Format
  - Each WSD packet can carry 7.5kB of SD data payload
  - Occupies 97% of Maximum MSDU size



Summary

- WiGig SD Extension
  - Transports SD Bus Protocol over the WiGig/802.11ad MAC-PHY directly
  - Reduces the target side CPU workload dramatically, which is a great fit for resource-limited handheld products
  - Provides simple & efficient protocol
    - SD derived Read / Write (Bulk data transfer only)
    - Densely packetized

Thank you to our contributors

- James C. Yee, Ph.D., MediaTek
  60 GHz MAC/PHY
- Wolfgang Moeseneder, Intel Corporation
  WiGig Display Extension (WDE): Support of HDMI® & DisplayPort® over 60 GHz
- Jorge Myszne, Wilocity
  WiGig Bus Extension (WBE): Support of PCIe over 60 GHz
- Todd Matsumoto, Panasonic Corporation
  WiGig SD Extension (WSD): Support of SD over 60 GHz

Today's agenda

Time	Topic
9:30 – 10:15	Keynote: Wi-Fi Alliance® - Seamless Connectivity
10:15 – 10:30	Sponsoring Lab Presentation
10:30 – 11:00	Wi-Fi Alliance Program Roadmap
11:00 – 11:45	Program Status Updates
11:45 – 12:45	Lunch
12:45 – 14:45	Program Focus: WiGig CERTIFIED™
14:45 – 15:00	**Break**
15:00 – 16:00	Program Focus: Wi-Fi CERTIFIED ac
16:00 – 17:00	Q&A and Wrap-Up

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Wi-Fi CERTIFIED™ ac Program Focus

Focus topics

- Wi-Fi CERTIFIED™ ac technology overview
- 802.11ac PHY Overview
- 802.11ac MAC Overview
- Wi-Fi CERTIFIED ac program

Wi-Fi CERTIFIED™ ac Program Focus

Wi-Fi CERTIFIED™ ac technology overview

802.11 Evolution

- The IEEE 802.11 standard has continued to evolve over the years bringing higher and higher data rates, multiple data streams, and a myriad use cases

	802.11	802.11b	802.11a	802.11g	802.11n	802.11ac	Wi-Fi CERTIFIED ac	802.11ad
Modulation	DSSS	DSSS/ CCK	OFDM	OFDM	OFDM	OFDM	**OFDM**	Single Carrier/OFDM
Access Technology	Single stream	Single stream	Single stream	Single stream	MIMO, multiple streams	DL MU-MIMO, multiple simultaneous streams	**MIMO, multiple streams**	Single stream, Beamforming
Data Rate (Mbps)	1, 2	Up to 11	Up to 54	Up to 54	Up to 600	Up to [1] 6933	**Up to[1] 1.3Gbps**	Up to [2] 6756
Frequency Band (GHz)	2.4	2.4	5	2.4	2.4 and 5	5	**5**	60
Channel b/w(MHz)	22	22	20	22	20 and 40	20, 40, 80, 160	**20,40,80**	2160

- [1] Total aggregated data rate for multiple simultaneous STA's
- [2] Data rate to a single STA

New features and enhancements to IEEE 802.11ac

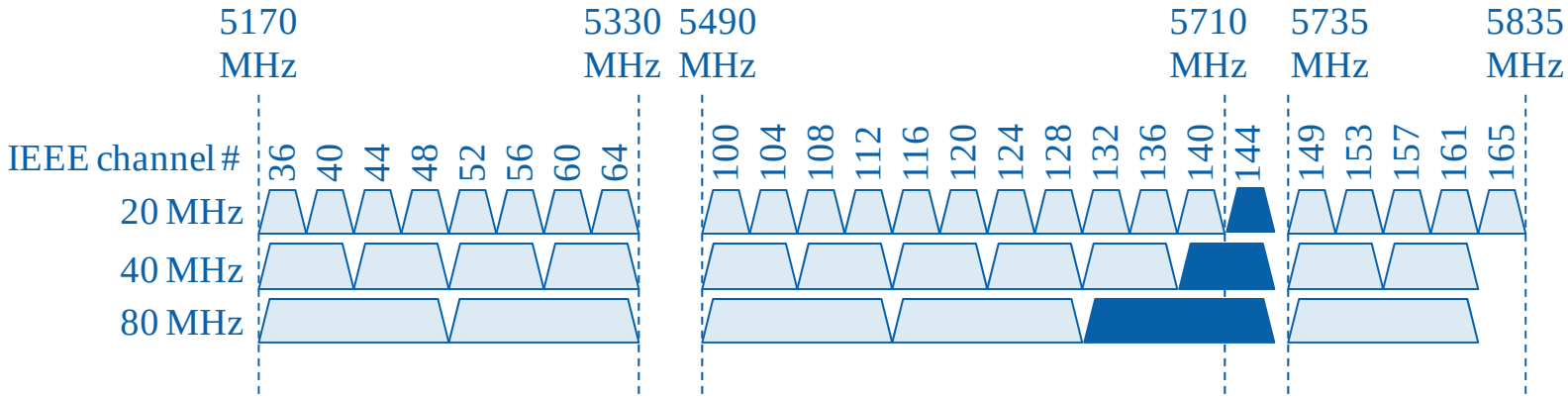
- Wider bandwidth
  - 80 MHz channel width
  - 160 MHz channel width
  - Non-contiguous 160 MHz (80 MHz + 80 MHz)
- Modulation, coding, and spatial streams
  - 256 QAM, rate = ¾
  - 256 QAM, rate = 5/6
  - Up to 8 streams
- Downlink Multi-User MIMO (DL MU-MIMO)
- Increased aggregate size limits
- Enhancement to coexistence mechanisms
- STBC
  - only for 2x1, 4x2, 6x3, 8x4
  - No 3x2 or 4x3 as in 11n
- LDPC
  - Added block-interleaving of constellation symbols per stream, per OFDM symbol
- Transmit Beamforming
  - Only Explicit feedback, no implicit feedback
  - Only Compressed-V feedback, no Uncompressed-V, no CSI
  - Only NDP sounding, no staggered sounding
  - No unequal modulation

Wi-Fi CERTIFIED™ ac Program Focus

802.11ac PHY overview

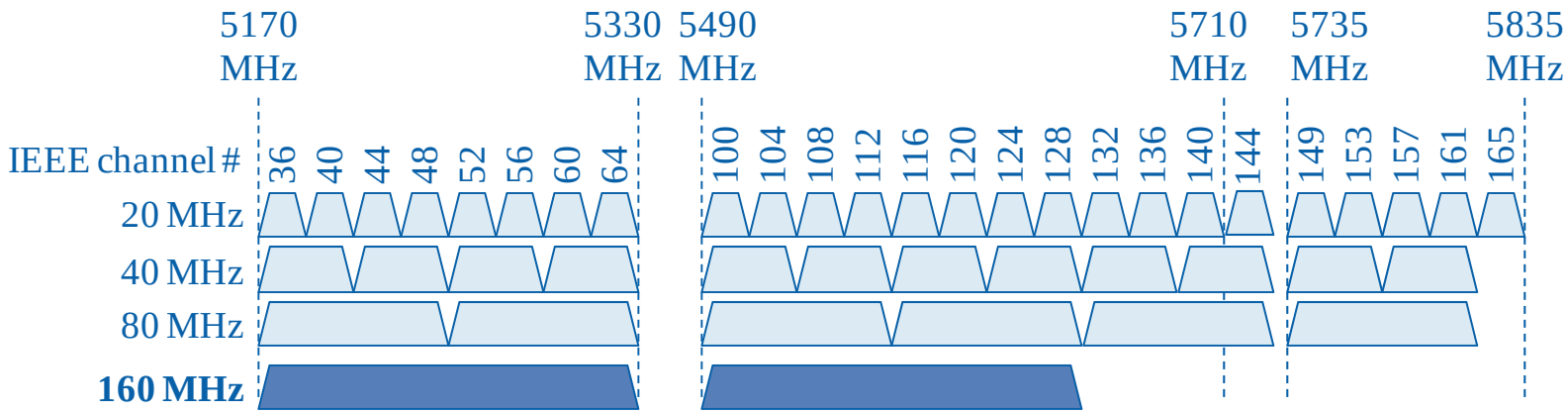
Channelization for 20/40/80 MHz

- 40/80 MHz channelization
  - Consists of two adjacent IEEE 20/40 MHz channels
  - Non-overlapping channelization



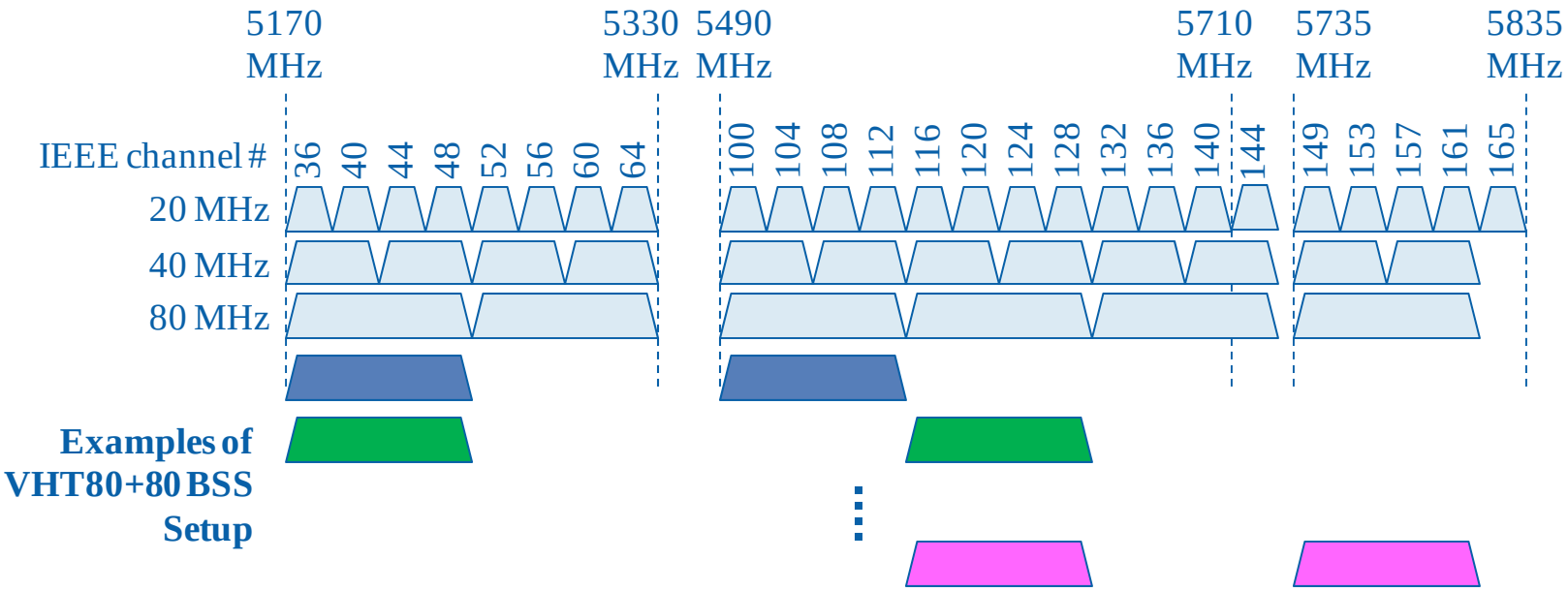
Channelization for contiguous 160 MHz

- Apply the same rule as in 40 and 80 MHz channel construction
  - Consists of two adjacent IEEE 80 MHz channels
  - Non-overlapping channelization
    - Not necessary to come up with coexistence rules for partially overlapping channels



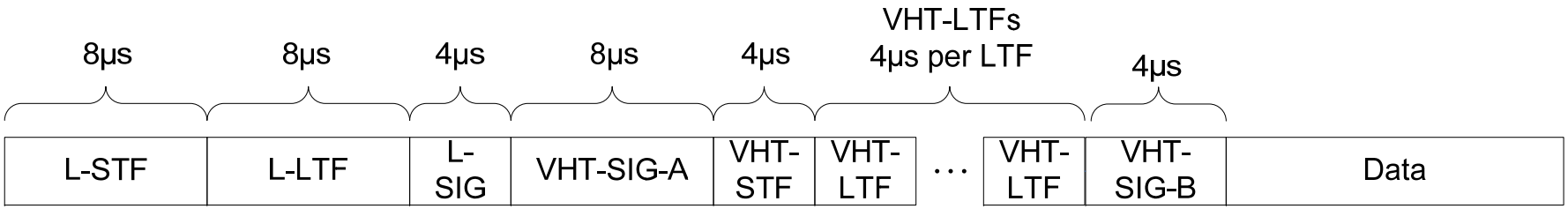
Noncontiguous 160 MHz (VHT80+80) BSS

- Any two nonadjacent 80 MHz channels may be used in setting up a noncontiguous 160 MHz (VHT80+80) BSS
  - Allows VHT80 STA to associate with the VHT80+80 BSS
  - Allows contiguous-only devices to associate with the VHT80+80 BSS as a VHT80 STA

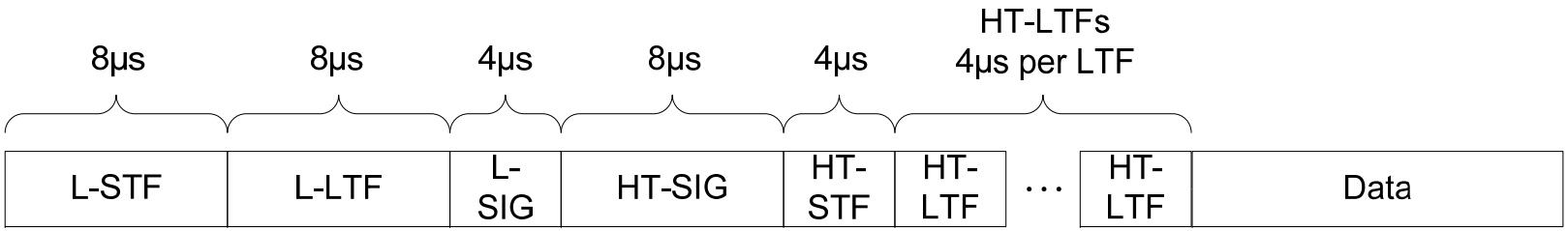


Preamble overview

VHT format PPDU



HT mixed format PPDU



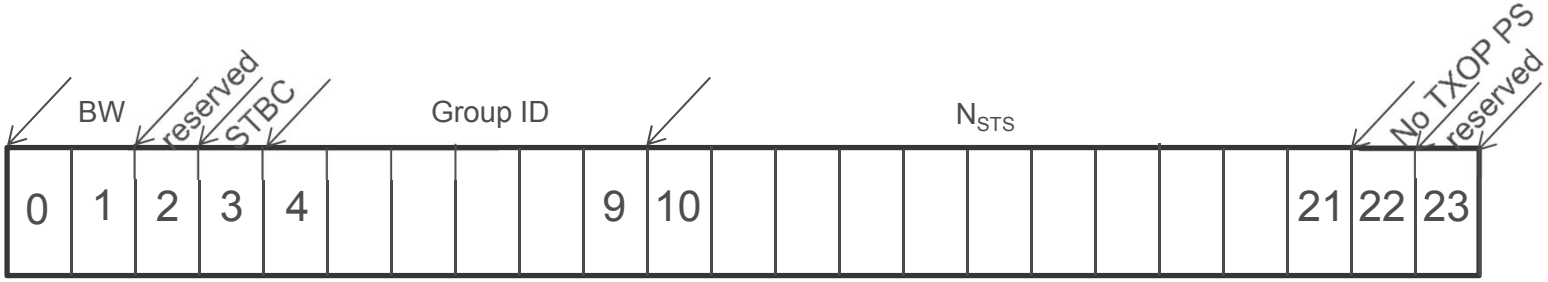
- Legacy format the same as 11a/n
- VHT-SIG-A replaces HT-SIG
- VHT-STF and VHT-LTF similar to HT-STF
- New VHT-SIG-B

VHT-SIG-A Waveform Design

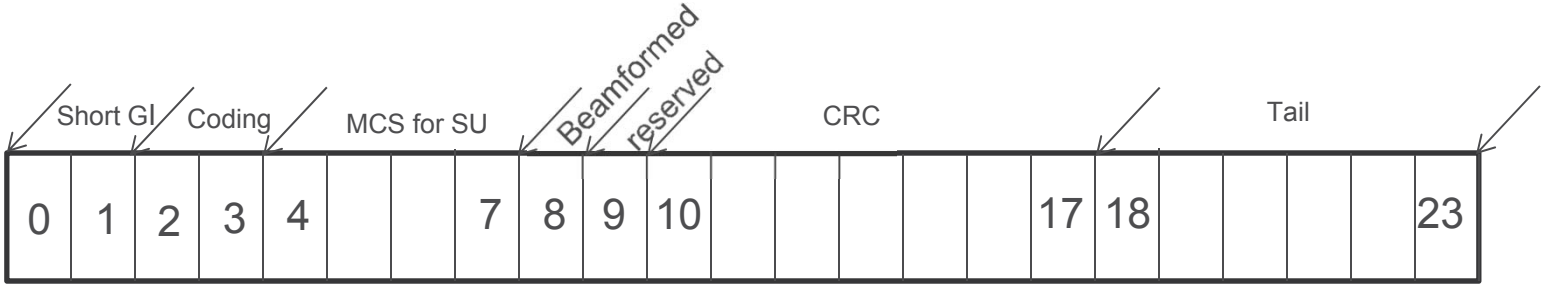
- Two symbols (VHT-SIG-A1 and VHT-SIG-A2)
- Same number of subcarriers (data and pilot) and positions as legacy format
- For 80 MHz and 160 MHz: same number of subcarriers and positions and values as legacy in each 20 MHz subchannel
- CSD and phase rotations same as legacy
- Extend 80 MHz preamble to 160 MHz preamble by simple repetition

VHT-SIG-A Formats

- VHT-SIG-A1



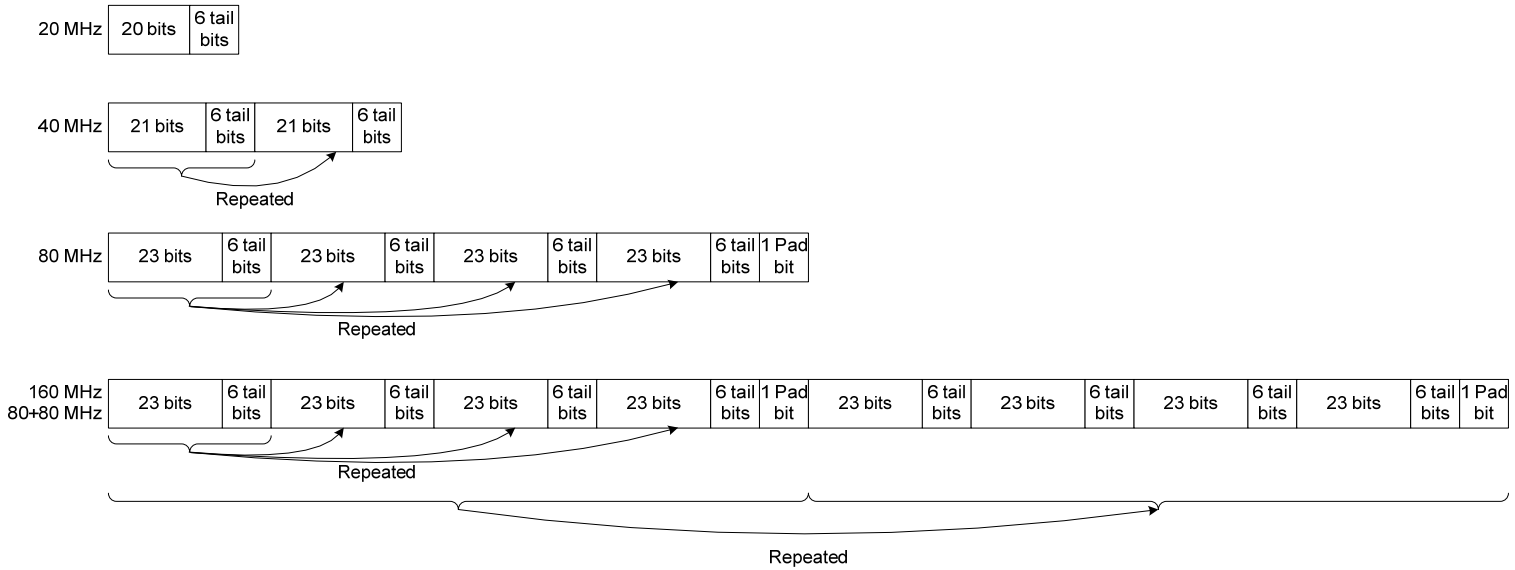
- VHT-SIG-A2



MCS Exclusions

- For the TGac Tx data flow, the number of data bits per OFDM symbol (N_dbps) and number of coded bits per OFDM symbol (N_cbps) must be an integer value for each BCC encoder
  - Also true for 11a and 11n, but this was always the case for all rates and MCSs
- New conditions in TGac lead to fractional N_dbps and N_cbps per encoder:
  - 80 MHz with 234 data subcarriers
  - 256-QAM
  - More than two encoders
- Even thought MSC exclusions do not apply to LDPC, for simplicity same MCSs for LDPC

VHT-SIG-B: Bit encoding



- Single stream Data field OFDM symbol format per user w/ BPSK, R=1/2 modulation
- In 20 MHz mode, 26 bits are available
- For 40/80/160 MHz, repeat bits including tail bits
  - No frequency repetition of 20 MHz sub-channels into other sub-channels
  - Provides easy way for receiver to get processing gain by averaging repeated soft values at the decoder input
- For higher BWs, additional bits are available due to extra tones
  - In 40 MHz, we get 27 bits
  - In 80/160 MHz, we get 29 bits

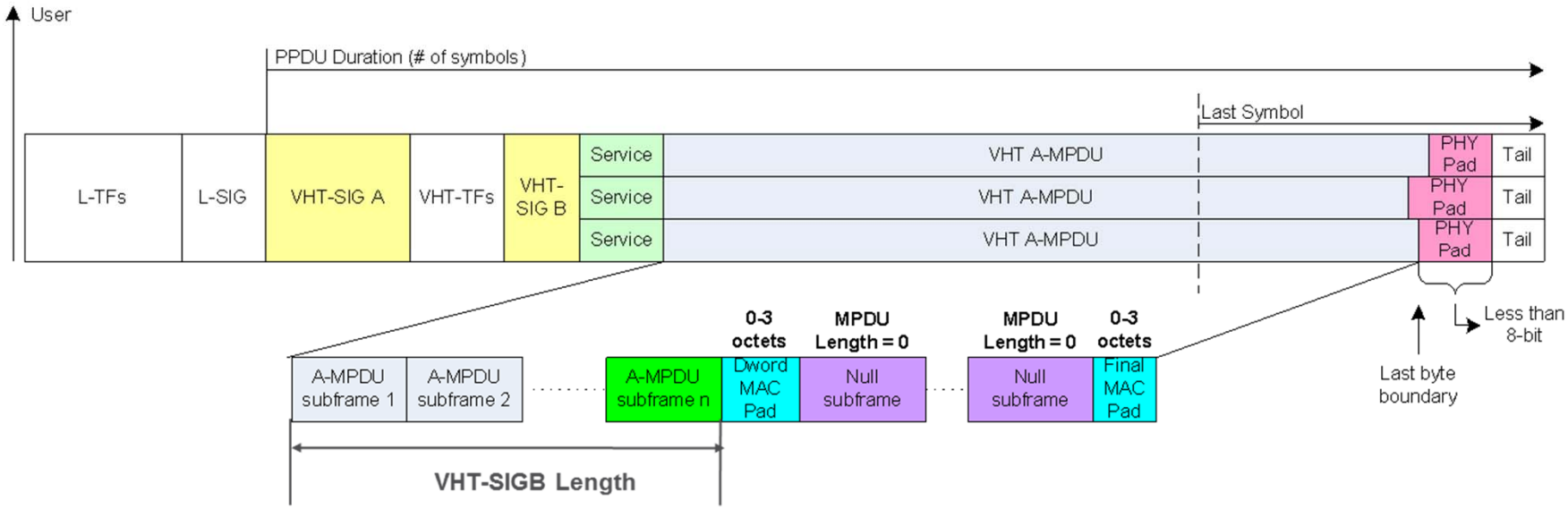
VHT-SIG-B: Bit allocation

- VHT-SIGB Allocation (20/40/80 MHz):

SIGB Fields	MU – Bit allocation			SU – Bit allocation		
	20 MHz	40 MHz	80 MHz	20 MHz	40 MHz	80 MHz
Length (in units of 4 octets)	16	17*	19*	17	19	21
MCS	4	4	4	-	-	-
RSVD	0	0	0	3	2	2
Tail	6	6	6	6	6	6
Total # bits	26	27	29	26	27	29

- * Additional bits to accommodate large packet sizes in 5.46ms (max packet duration in LSIG)
- 160 MHz repeats the 80 MHz VHT-SIG-B twice in frequency

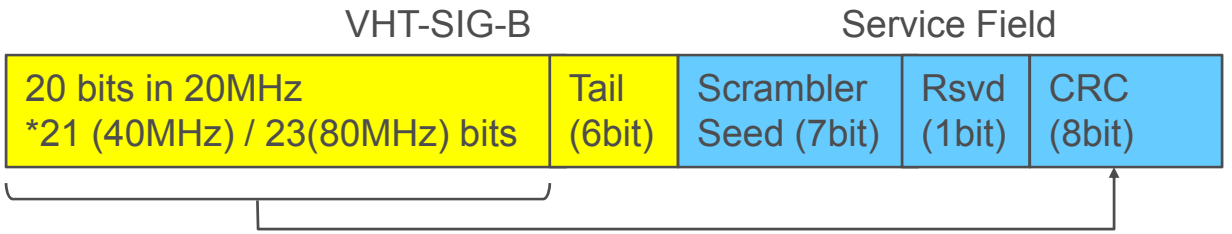
VHT-SIG-B: Length



- Length in VHT-SIG-B is provided to indicate useful data in PSDU, which allows receivers to shut-off PHY processing after receiving useful data thereby saving some power

VHT-SIG-B: CRC in SERVICE field

- Transmitter shall include VHT-SIG-B CRC in SERVICE field
- Transmitter shall compute 8-bit CRC based on SIG B "not including tail" and insert 8-bit CRC in 8 MSBs of the SERVICE field
  - Transmitter will not include scrambler seed in computation of CRC bits
  - CRC defined in 802.11n-2009 section 20.3.9.4.4. C7 of the CRC is mapped to B8 of the SERVICE field, C6 to B7, …, C0 to B15
- The resulting SERVICE field and PSDU shall be scrambled, as in 11n
- CRC achieves protection of the scrambler init field
  - Any error in the scrambler init field will result in a corrupted CRC field after descrambling
  - Check of the CRC field against the contents of SIG-B will then fail

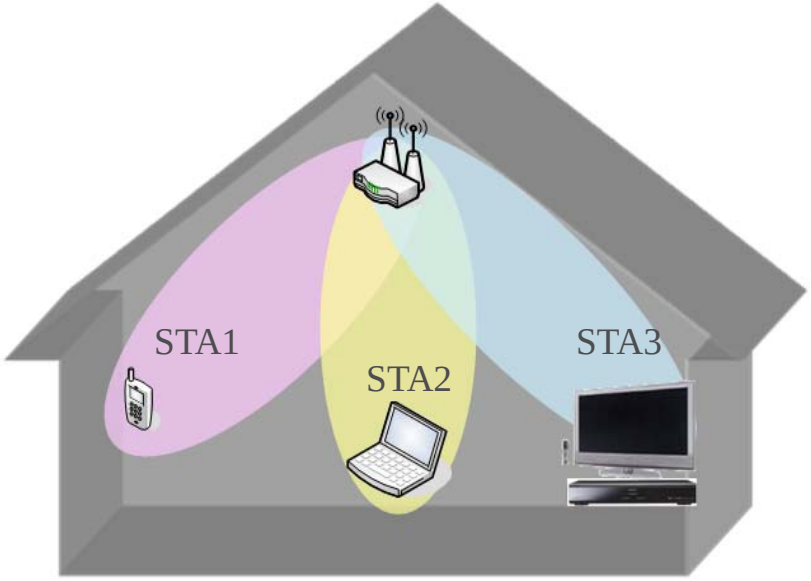


VHT-SIG-B: Requirements for single user

- Tx
  - Required to compute and populate DWORD length, tail, and reserved bits
  - Required to compute and populate VHT-SIG-B CRC in SERVICE field
- Rx
  - Optional to process VHT-SIG-B

Downlink Multi User MIMO (DL MU-MIMO)

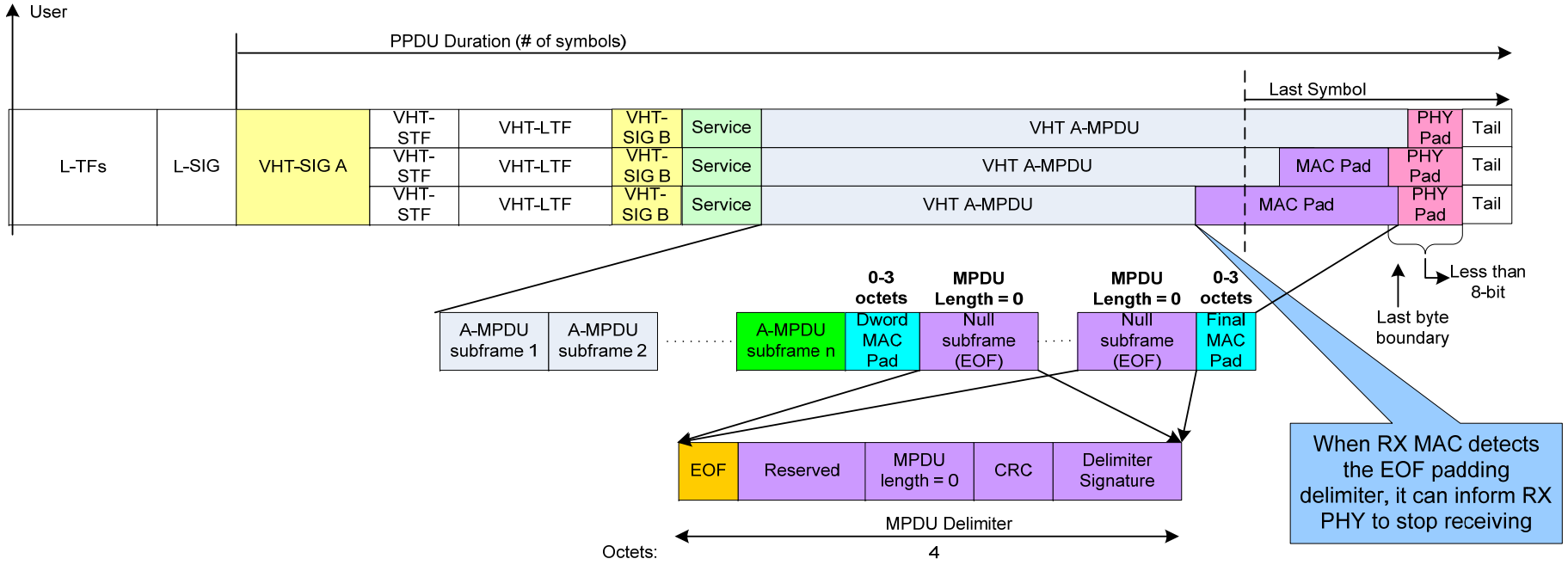
- In 11n MIMO, the access point transmits multiple data streams to a single station at a time
- In 11ac DL MU-MIMO, the access point simultaneously transmits data streams to multiple stations
- Support up to 4 users & 4 streams per user
- Example:
  - Access point with 6 antenna
  - One hand-held client device with one antenna (STA1)
  - One laptop client device (STA2) with two antennas
  - One TV set top box client device with two antennas (STA3)
  - Access point simultaneously transmits one stream to STA1, two streams to STA2, and two streams to STA3



DL MU-MIMO Parameters

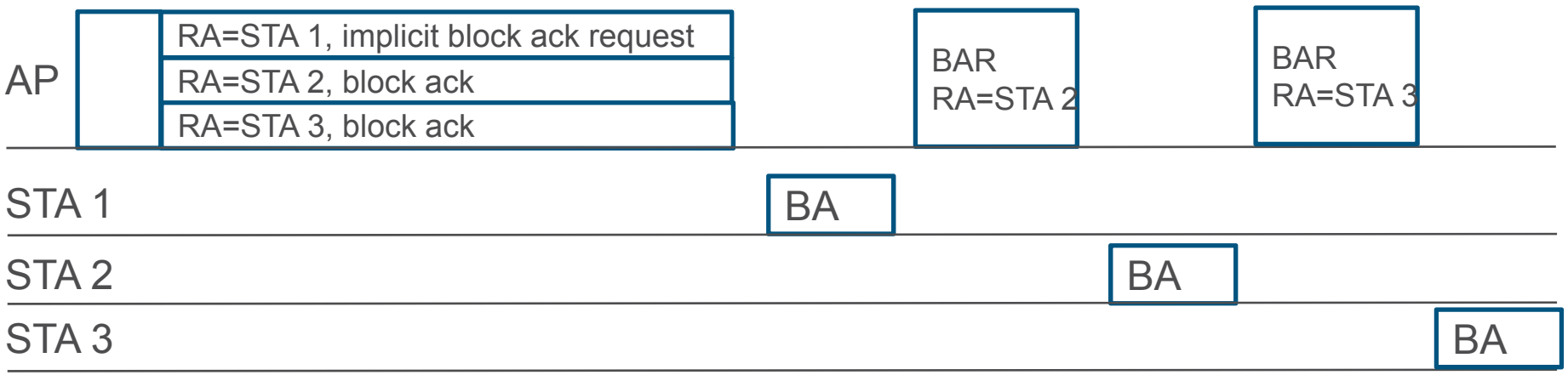
- Maximum number of users in a transmission is 4
- Maximum number of spatial streams per user is 4
- Maximum total number of spatial streams (summed over users) is 8

PPDU overview (MU)



- Illustrating parallel transmissions to multiple users
- Parallel VHT-SIG-B, Service, VHT A-MPDU represents directional transmission to each users
- MAC provides an A-MPDU that fills the frame to the last byte for each user
- Same preamble structure is used for both SU and MU VHT frames
  - Require that A-MPDU always be used with both SU and MU VHT frames
  - “Aggregation” bit in VHT-SIG is then not needed
- Tail: 6 bits per BCC encoder for each user

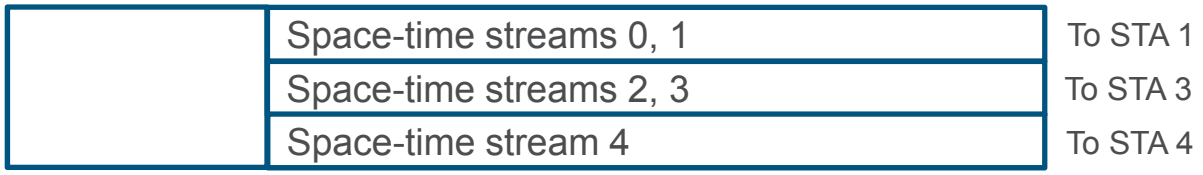
MU Ack Protocol



- Ack protocol is unchanged from 802.11n
- MU PPDU may solicit a response from only one STA
- Remaining STAs are polled for response
- Note: Not to scale; BAR-BA is of much shorter duration that MU PPDU

Group ID concept

- AP transmits MU MIMO PPDU to a group of STAs identified by Group ID
- STAs use Group ID to index local table to identify its Nsts Index



VHT-SIG-A

Group ID	Nsts Table			
2	2	0	2	1

- Nsts Index determines which space-time streams the STA demodulates

STA 1

Group ID	Nsts Index
0	-
1	-
2	0
…	…
63	1

STA 2

Group ID	Nsts Index
0	-
1	0
2	1
…	…
63	2

STA 3

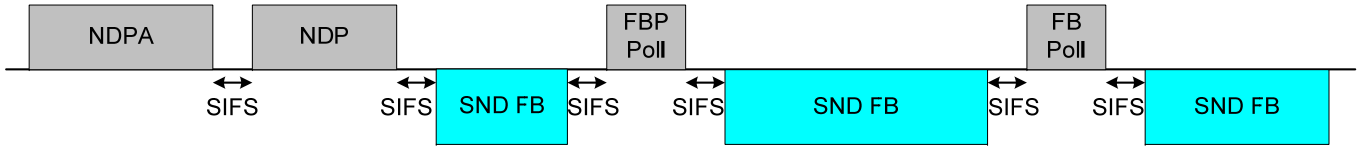
Group ID	Nsts Index
0	0
1	1
2	2
…	…
63	3

STA 4

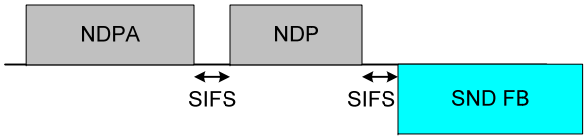
Group ID	Nsts Index
0	1
1	2
2	3
…	…
63	-

Per STA lookup tables

Sounding and Feedback Protocol



1. Sounding feedback sequence starts with AP sending an NDP Announcement (NDPA) frame followed by an NDP
   - NDPA identifies the first responder after the NDP and may identify other STAs which will be polled subsequently
2. STA identified as first by the NDPA sends Sounding Feedback frame (SND FB) SIFS time after the NDP
3. AP polls all remaining STAs

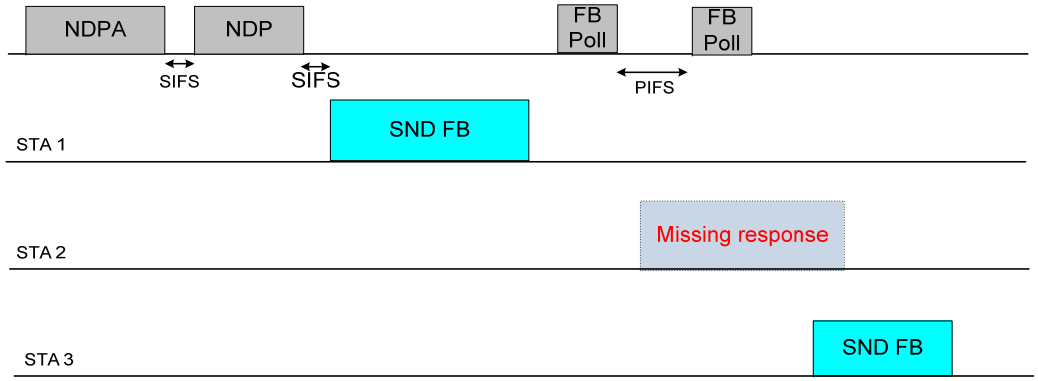


- Note that in the SU case, the sequence is simply NDPA-NDP-SND FB

Recovery mechanism

- In case first STA does not send SND FB SIFS time after NDP
  - If NDPA frame exchange is the first frame exchange of a TXOP
    - AP terminates transmissions of the current TXOP and proceed to exponential backoff to re-send the NDPA
  - If NDPA frame exchange is not the first frame exchange of a TXOP and TXOP started with a frame that received a valid response
    - AP is allowed to access the medium PIFS after NDP and send a FB Poll frame (or any other frame)
- In case STAi does not send SND FB SIFS time after a FB Poll and TXOP started with a frame that received a valid response
  - AP is allowed to access the medium PIFS after current FB poll and send a FB poll to retrieve SND feedback from same or next STA

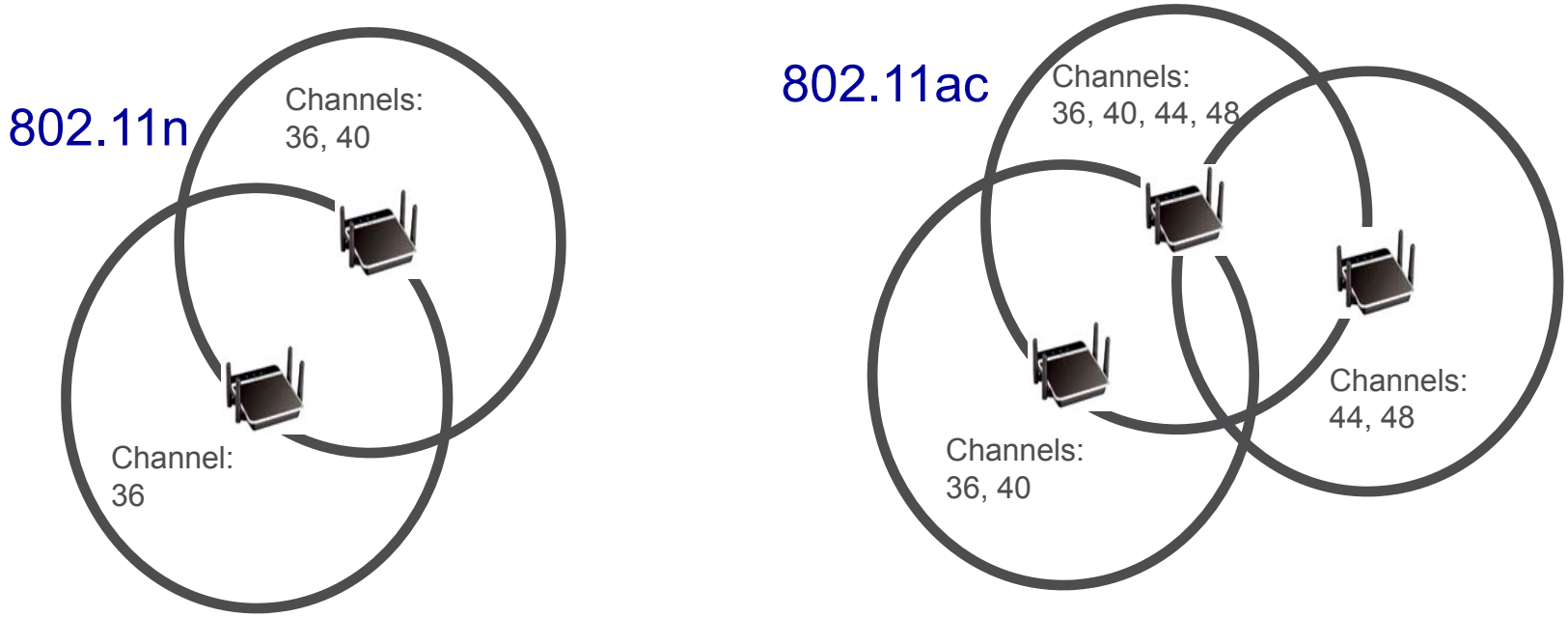
Example of recovery for the case where multiple STAs are sounded and one STA does not send a response to a Poll



Wi-Fi CERTIFIED™ ac Program Focus

802.11ac MAC overview

Coexistence in wider channels

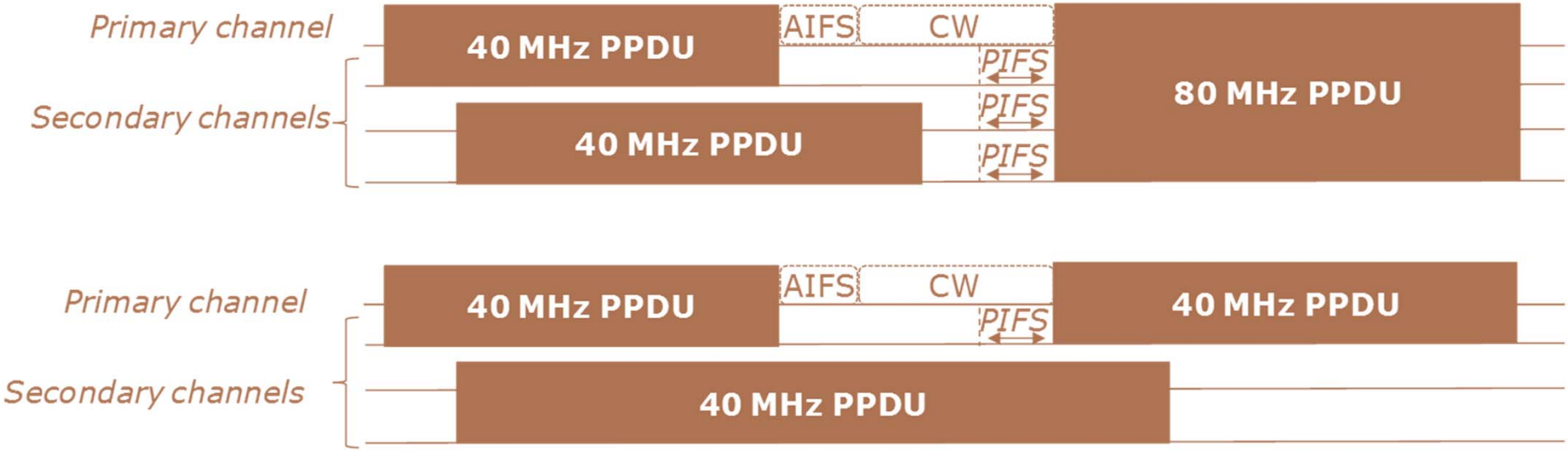


- With 11n it is relatively easy to handle overlapping networks:
  - Easy to avoid overlap by choosing different channel
  - Choose primary channel that matches neighbor if overlap unavoidable
- With 11ac it becomes much harder
  - More channels used means greater probability of co-channel operation
  - Harder to chose primary channel common to all overlapping networks

Enhancements to coexistence mechanisms

- 802.11ac extends the medium access protocol developed in 11n to wider channels
- 802.11ac improves co-channel operation with the following:
  - Enhanced secondary channel CCA
  - Improved dynamic channel width operation
  - Notify operating mode frame

Medium access in wider bandwidth



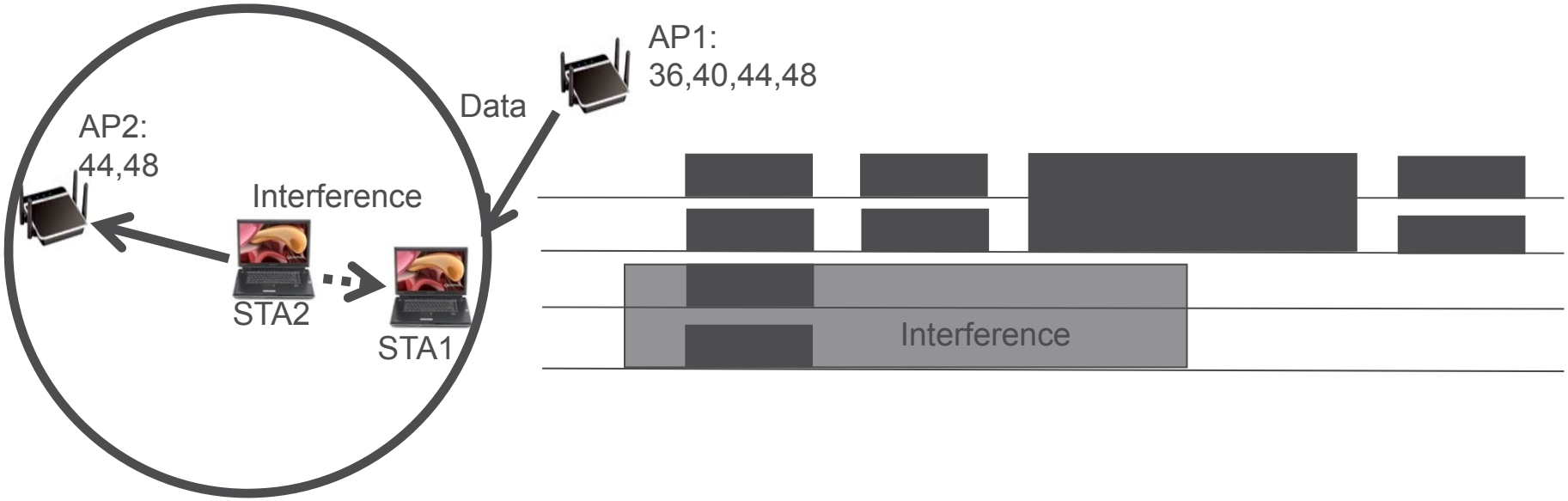
- Basic 11n channel access mechanism is extended to wider bandwidth
- Random backoff (AIFS+CW) is based on primary channel activity
- Secondary channels must be sensed idle PIFS before transmission
- If some of the subchannels are busy, a narrower transmission is permitted
  - A transmission always includes primary channel
- Note that mid-packet signal detect is needed on secondary channel since packet may start while primary channel transmission is in progress

Enhanced CCA

	802.11n	802.11ac
Primary channel	Valid signal: -82 dBm Energy detect: -62 dBm	Valid signal: -82 dBm Energy detect: -62 dBm
Secondary channel	Energy detect only: -62 dBm	Valid signal: -72dBm Energy detect: -62 dBm

- Detecting a valid signal in secondary channel is harder than in primary channel
- Because the STA always transmits in the primary channel, it only needs to detect start of packet in primary channel
- Because a secondary transmission may begin while a primary channel transmission is in progress, a STA must be able to detect signal in middle of a packet on secondary channel

Improved Dynamic Channel Width Operation



E.g. STA1 receives interference from STA2, but transmission is not detected by AP1

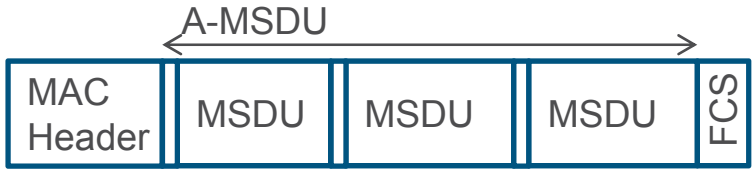
- BW signaling is added to RTS and CTS frames
- AP1 sends RTS with BW of intended transmission
- STA1 sends CTS response with BW of clear channels
- AP1 only sends data on clear channels

Notify Operating Mode Frame

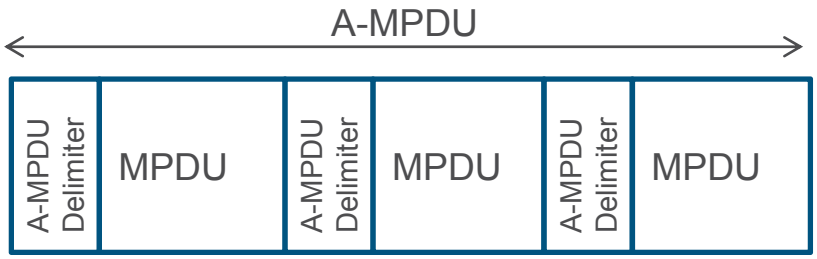
- If the interference in the previous example is strong or frequent, then STA1 can send a Notify Operating Mode frame
- Notify Operating Mode frame tells AP that the STA is changing the BW on which it operates
  - E.g. 80 MHz → 40 MHz
- AP will then only send data frames occupying the reduced BW

Aggregation in 11n

- 802.11n added two forms of aggregation:
- A-MSDU
  - Performed at the top of the MAC
  - Easily done in software
  - Limited by max A-MSDU size (approx 8kB)

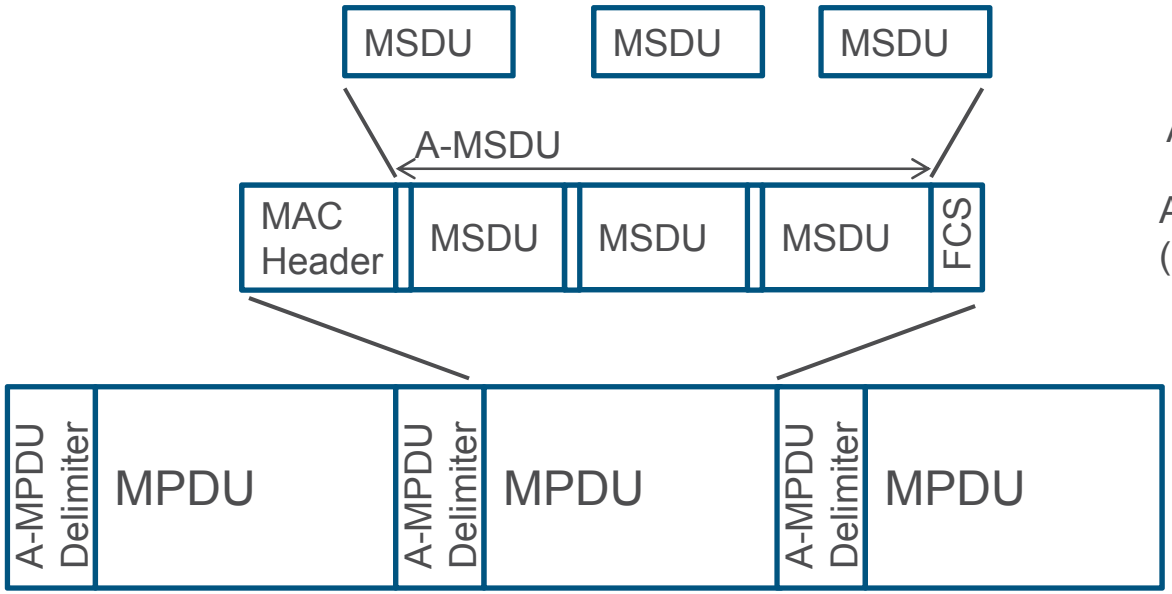


- A-MPDU
  - Performed at the bottom of the MAC
  - Done in hardware
  - Limited by PPDU length field of 64kB



- Most 11n implementations only did A-MPDU
  - Doing both A-MSDU and A-MPDU, while permitted, had little benefit

Aggregation in 11ac



MSDUs typically ≤1500B in size

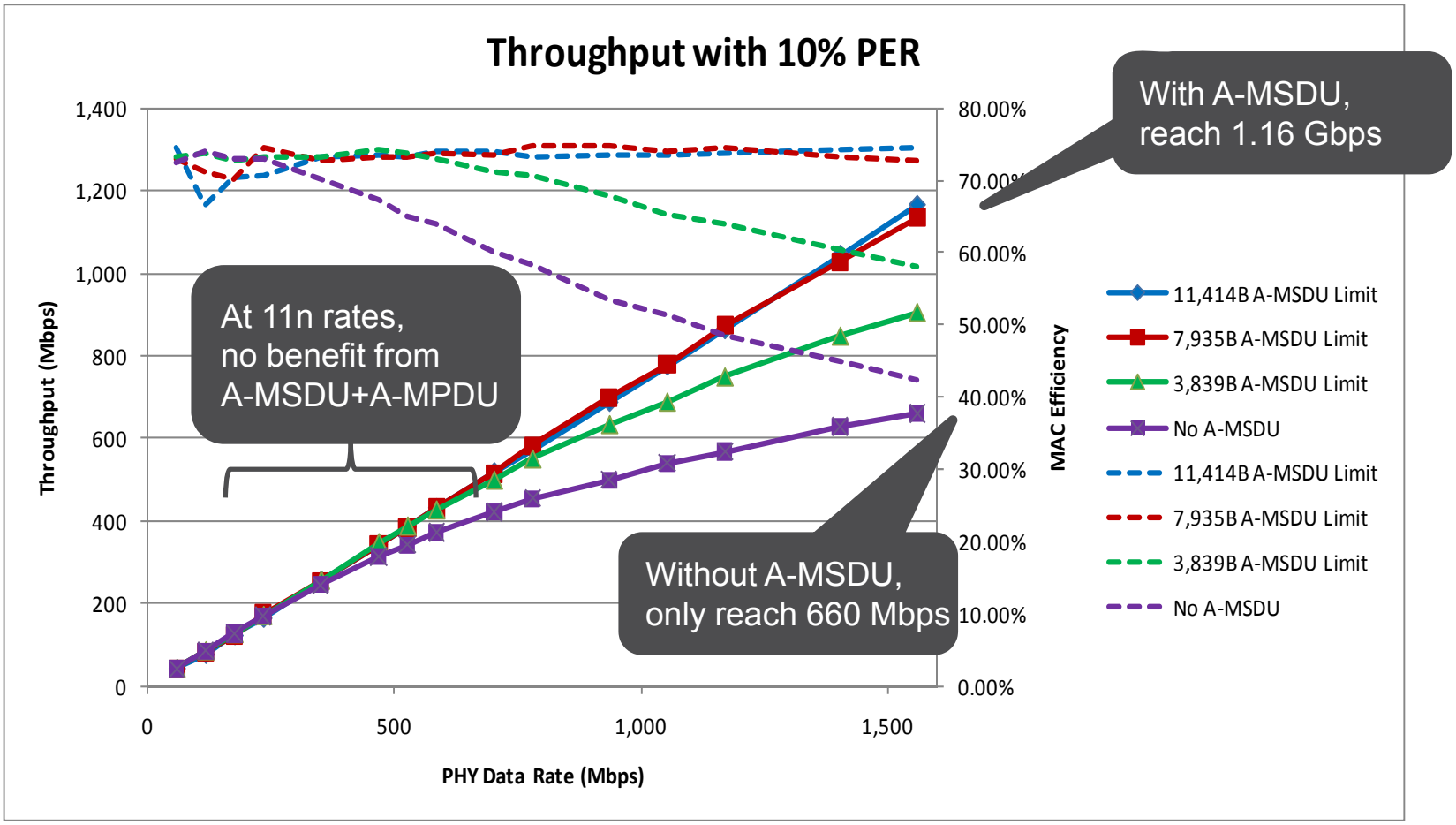
Aggregated to form A-MSDU

A-MSDU encapsulated in MPDU
(length limit increased to 11,454B)

MPDUs aggregated to form A-MPDU
(length limit increased to 1MB,
BA window limit of 64 remains
unchanged)

- With 11ac, both A-MSDU and A-MPDU aggregation are required to achieve good efficiency at higher data rates
- Also, in 11ac all packets required to be A-MPDU
  - PHY no longer conveys the number of octets in the packet, just number of OFDM symbols
  - MPDU only contains duration, not length
  - Delimiter in A-MPDU contains MPDU length

Aggregation in 11ac A-MPDU only vs A-MSDU+A-MPDU



Throughput simulation, 1 and 2 spatial streams, 160 MHz

Wi-Fi CERTIFIED™ ac Program Focus

Wi-Fi CERTIFIED ac program

Wi-Fi CERTIFIED ac mandatory features

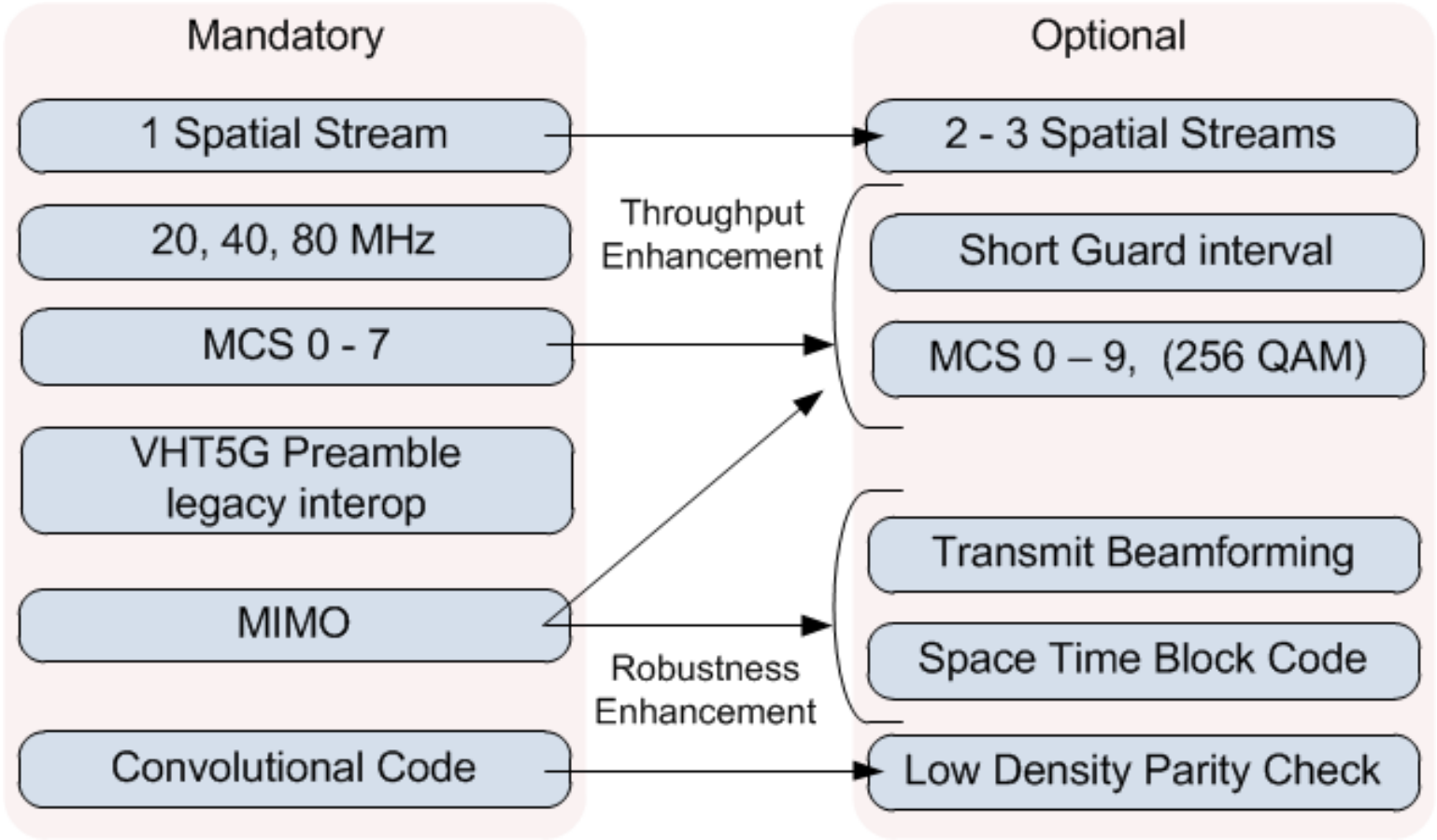
- 5 GHz Operation
- 20, 40, and 80 MHz channels
- Spatial Streams supported
  - Non-Mobile AP (connected to AC power) supports two spatial streams (2 * SS)
  - Mobile AP (battery operated) supports one spatial stream (1 * SS)
- MCS 0-7 (BPSK, r=1/2 through 64-QAM, r=5/6)
- VHT A-MPDU delimiter for RX and TX for single MPDU
- RX A-MPDU
- TX- AMPDU
- Clear Channel Assessment (CCA) on Secondary
- CTS with BW signaling in response to RTS with BW signaling

Wi-Fi CERTIFIED ac optional but tested features

If these features are implement they will be tested during certification:

- 2-3 SS (TX and RX) client
- 2 SS (TX and RX) AP (for Mobile Access Point)
- 3 SS (TX and RX) AP
- MCS 8 (256-QAM, r=3/4)
- MCS 8-9 (256-QAM, r=3/4 and r=5/6)
- Short Guard Interval (GI)
- AP STBC TX 2x1
- STA STBC RX 2x1
- RX A-MPDU of A-MSDU
- Transmit beamforming (TxBF)
- Low Density Parity Check (LDPC) coding

Wi-Fi CERTIFIED ac mandatory and optional PHY features



Wi-Fi CERTIFIED ac bandwidth improvements

- 5 GHz operation only
  - Backward compatibility with legacy 802.11 in 5 GHz
- Increased aggregate size limits
  - MPDU size of (2^20)-1
- Enhancement to coexistence mechanisms
- Wider channel bandwidth
  - +2x Greater throughput
  - 80 MHz channel widths (vs. 40 MHz max in 802.11n and 20 MHz in 802.11a)

Wi-Fi CERTIFIED ac data rate and robustness improvements

- Unified Beamforming
  - Greatly helping link reliability and smoothing out dead spots
  - First Wi-Fi Alliance program to test/certify this technique
  - Only explicit feedback, no implicit feedback
  - Only Compressed-V feedback, no Uncompressed-V, no CSI
  - Only NDP sounding, no staggered sounding
- No unequal modulation
- Modulation
  - 33% data rate increase
  - 256-QAM, rate 3/4 and 5/6, added as optional modes (vs. 64-QAM, rate 5/6 maximum in 802.11n)

Wi-Fi CERTIFIED ac MAC improvements

- STBC
  - only for 2x1
- LDPC
  - Added block-interleaving of constellation symbols per stream, per OFDM symbol
- Other elements/features
  - MAC modifications (mostly to support above changes)
  - Coexistence mechanisms for 20/40/80/160 MHz channels, 11ac and 11a/n devices
    - 160 MHz channels are not part of Wi-Fi CERTIFIED ac scope

Summary

- Based on IEEE 802.11ac technology, the Wi-Fi CERTIFIED ac interoperability program launched June 2013
- Wi-Fi CERTIFIED ac devices are ideal for streaming high-quality multimedia and rapidly syncing large amounts of data, using the 5 GHz frequency band and wider channels to deliver gigabit speeds
- As with all Wi-Fi CERTIFIED devices, Wi-Fi CERTIFIED ac products interoperate with legacy Wi-Fi CERTIFIED products

Today's agenda

Time	Topic
9:30 – 10:15	Keynote: Wi-Fi Alliance® - Seamless Connectivity
10:15 – 10:30	Sponsoring Lab Presentation
10:30 – 11:00	Wi-Fi Alliance Program Roadmap
11:00 – 11:45	Program Status Updates
11:45 – 12:45	Lunch
12:45 – 14:45	Program Focus: WiGig CERTIFIED™
14:45 – 15:00	Break
15:00 – 16:00	Program Focus: Wi-Fi CERTIFIED ac
16:00 – 17:00	**Q&A and Wrap-Up**

Join the Wi-Fi Alliance: Membership ROI

- Regular (& Affiliate) Wi-Fi Alliance membership brings…
  - Product certification (better products that users want)
  - Marketing resources, access to top brands
  - Regulatory influence
  - Opportunities to network

    ... and has great Return on Investment at $15,000/year
  - Insights into the future of the Wi-Fi industry
- Adopter membership
  - For companies that want the insight, networking and marketing opportunities, but don't have a need to certify products or participate in industry-shaping task groups… only $5,000/year
- See http://www.wi-fi.org/become_a_member_overview.php

Members: Please get involved!

- Marketing task groups: define & document market requirements
- Technical task groups: develop test plans according to the market requirements documents
- Regulatory task groups: work with regulatory and policy bodies to address needs
- **Please get involved and contribute your knowledge and experience!**