AN214845

CYW43XX: Wi-Fi Direct Concurrency

Associated Part Family: CYW43XX

This application note describes the Wi-Fi® Direct concurrent multi-channel use cases and limitations in real-world scenarios when implemented using a single radio. This document focuses on application implementation considerations on CYW43XX products, though most of the information is not limited to such.

1 Introduction

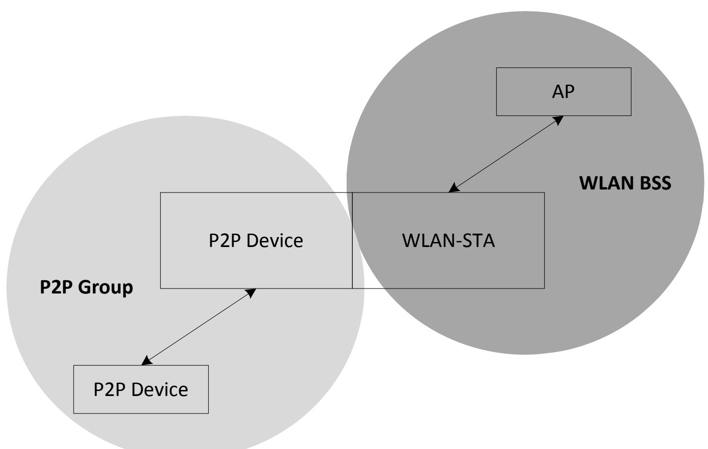
The Wi-Fi® Direct concurrent multi-channel use cases and limitations in real-world scenarios when implemented using a single radio. This document focuses on application implementation considerations on CYW43XX products, though most of the information is not limited to such.

This document does not provide an exhaustive account of all the scenarios that can be encountered in providing an acceptable user experience for every use case.

Some basic knowledge of Wi-Fi Direct is assumed.

Figure 1 describes the basic definition of concurrence, as defined in the Wi-Fi Direct specification (see IOT Resources [2] on page 2.

Figure 1. Basic Concurrence Definition



Basic concurrence, as described in Figure 1, can be further split into three cases:

1. Same channel concurrency—In this case, the P2P group and WLAN basic service set (BSS) exist on the same channel regardless of the band. The two networks share the bandwidth of the channel.
2. Multichannel concurrency—In this case, the P2P group and WLAN BSS operate on different channels. The channels could be on different bands (for example, group on 2.4 GHz and WLAN BSS on 5 GHz) for a dual-band device, or on same band (for example, group on channel 6 and WLAN BSS on channel 11).
3. Multiple groups operating concurrently with each other and/or WLAN BSS.

1.1 Cypress Part Numbering Scheme

Cypress is converting the acquired IoT part numbers from Broadcom to the Cypress part numbering scheme. Due to this conversion, there is no change in form, fit, or function as a result of offering the device with Cypress part number marking. The table provides Cypress ordering part number that matches an existing IoT part number

Table 1. Mapping Table for Part Number between Broadcom and Cypress

Broadcom Part Number	Cypress Part Number
BCM43XX	CYW43XX

2 IoT Resources

Cypress provides a wealth of data at http://www.cypress.com/internet-things-iot to help you to select the right IoT device for your design, and quickly and effectively integrate the device into your design. Cypress provides customer access to a wide range of information, including technical documentation, schematic diagrams, product bill of materials, PCB layout information, and software updates. Customers can acquire technical documentation and software from the Cypress Support Community website (http://community.cypress.com/).

For technical documentation and software through its Customer Support Portal (CSP) and Downloads & Support site (see Technical Support).

Document (or Item) Name	Source
Wi-Fi Direct Specification, Revision 1.15	Wi-Fi Alliance
IEEE Std 802.11-2007	IEEE

3 Scope

This application note discusses use cases 1 and 2 described above; use case 3 is not covered. This document does not address “Managed P2P Device operations”, as described in section 3.4 of the Wi-Fi Direct specification. Also, the Cypress implementation with 5.100.98.33 has the following stipulations:

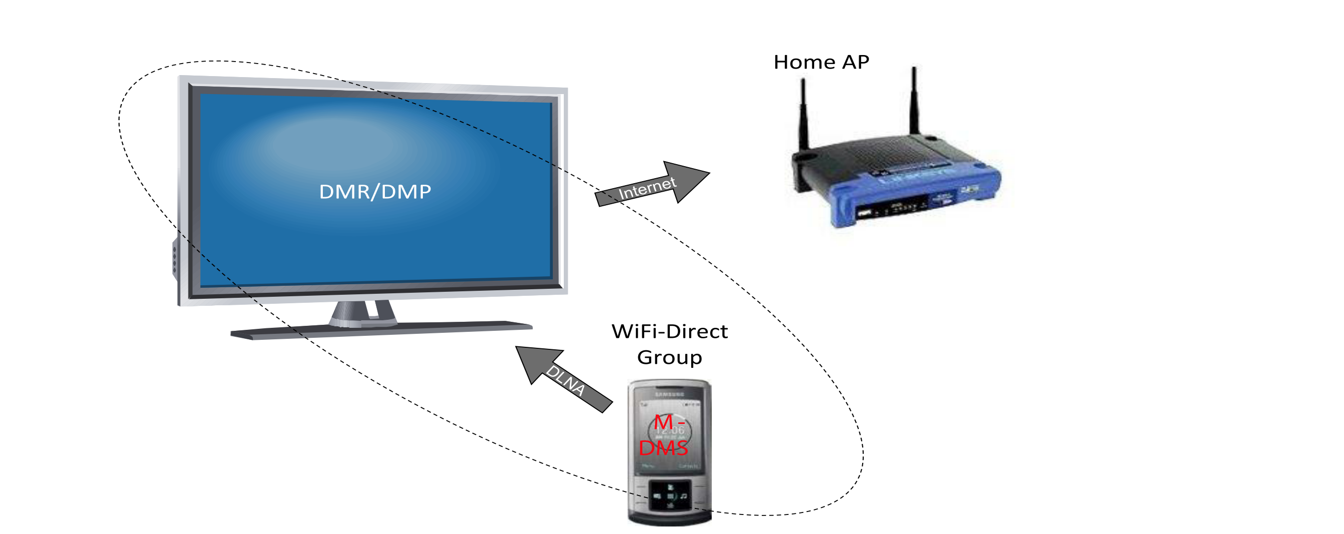
- Only one P2P group and one infrastructure station (STA) are supported.
- Only P2P Group Owner (STA or Group Client)-STA combinations are supported. It does not support Group Owner-SoftAP concurrency.
- Although P2P discovery is supported with concurrent connections, dismantling existing groups and creating a new group with a new device that was discovered is up to the application.

3.1 Use Cases

The following use cases are used as representatives to describe Wi-Fi Direct Concurrency. There are many more use cases that can benefit from this feature that are beyond the scope of this document.

3.1.1 Use Case #1: Smart TV to the Internet

Figure 2. Concurrency Use Case #1—Smart TV



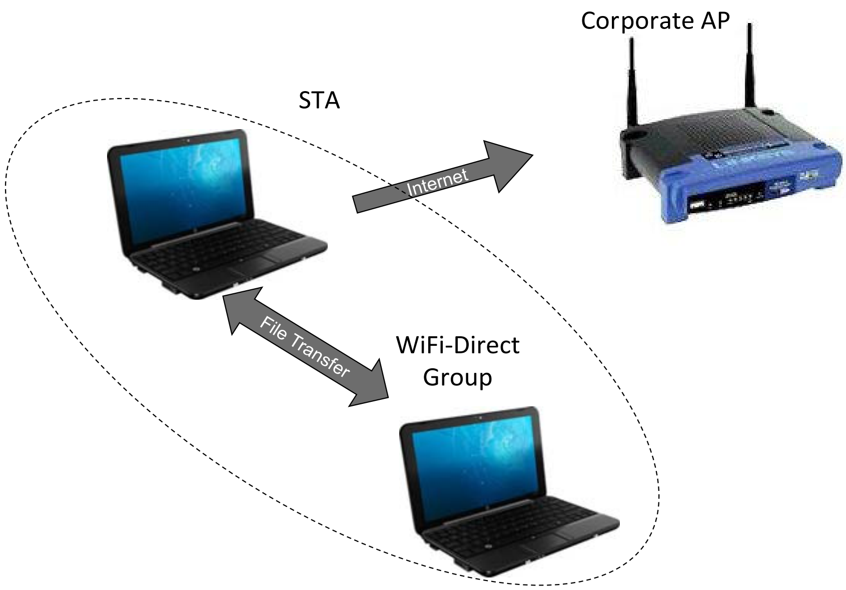
John has a SmartTV with Wi-Fi Direct and DLNA that is connected to his home network and is watching Netflix®. Jane comes home and wants to show John the videos she shot from her Wi-Fi Direct and DLNA-enabled phone on the TV. John will have to use the following process:

4. Disconnect from the home network.
5. Connect to the camera using Wi-Fi Direct.
6. After watching the videos, disconnect from the P2P group.
7. Reconnect to the home network to continue watching Netflix.

This is an undesirable user experience for John to have to disconnect and reconnect to the home network, as it disrupts his existing connection.

3.1.2 Use Case #2: File Transfer over Laptop

Figure 3. Concurrency Use Case #2—File Transfer



Ian has a laptop connected to corporate Wi-Fi for Internet and email access. His business partner Joan, who is a visitor in Ian's company and does not have access to the corporate network, wants to send her presentation slides to Ian so he can share them with other meeting attendees. However, Ian needs his laptop to remain connected to the corporate network.

In this case, most likely:

1. Joan and Ian will search for a USB memory stick.
2. Provided they find one, Joan manually copies the presentation to the USB memory, then give the USB to Ian.
3. Ian inserts the USB in his laptop. If this is the first time he is using this USB memory stick, he must wait for the driver to install.
4. After the driver installs, Ian can copy the file on his machine to send by email.

In this case, if there was no USB memory stick (or a similar media, such as an SD card), it would not have been possible for Joan to transfer the file and conduct the meeting effectively.

4 Wi-Fi Direct Concurrency

In the use cases described above, the ability to form a Wi-Fi Direct group while remaining connected to the other BSS enhances user experience, while retaining other advantages of Wi-Fi Direct, such as fast, easy, and secure temporary data connections. However, there are some practical considerations for OEMs when considering a concurrency implementation.

4.1 General Concurrency Considerations

Concurrency implies co-existence of two networks, which inherently uses more system resources to support data connections over two networks. This also means, in addition to the network contention, they share the bandwidth through traffic load-balancing (if on the same channel) or time sharing (if over different channels).

Also, depending on the use case, the system requires a DHCP server (to implement Group Owner functionality for Wi-Fi Direct, not just concurrency) and routing service/network address translation (NAT) if there is an expectation that data from the P2P group is routed via the infrastructure connection.

One example of such a use case is “Internet Sharing”, where such a system may extend the Internet connection from the Infrastructure BSS to the P2P group. (In an Enterprise environment, such an implementation is expected to adhere to the Managed AP feature.)

4.2 Same Channel Concurrency

The use cases described above could be fulfilled by creating a P2P group on the same operating channel as the infrastructure network. To enhance the possibility of selecting the same operating channel for the P2P group, the application could do the following:

1. Set the Group Owner (GO) intent to be 15 and set the operating channel attribute to be same as the operating channel as the infrastructure network.
2. In addition, it could set the acceptable channel list to contain only one channel: the infrastructure network channel. This ensures that if the other end becomes the GO, it only picks this operating channel, provided it does not have any restrictions.

Note: Depending on the situation (as noted in the limitations below), this may not guarantee the right operating channel, and the group creation may fail.

In such cases, it may be advantageous for the concurrent P2P interface to take the GO role, so that if the concurrent STA “roams” to another AP on a different channel, the GO could switch the group operating channel to the new channel using CSA.

Note: Switching the Group Owner’s operating channel should take into account the client’s capabilities. If the client does not support the new operating channel, then the P2P group will need to be disbanded.

4.2.1 Advantages

The advantages of same channel concurrency include the following:

- Simple to implement. It is a logical extension of the AP-STA concurrency model that Cypress has supported for years.
- Minimum disruption to existing connection.
- As a Group Owner, it may be possible for the GO to follow the infrastructure network as the STA roams on a mobile device.

4.2.2 Limitations

The limitations of same channel concurrency include the following:

- Both devices must have at least some supported channels in common. For example, in use case 1, if the infrastructure network is on the 5G band and the Wi-Fi in the DTV is a dual-band device, but the P2P client (the mobile device) is only 2.4G, then the group cannot be formed. Also, depending on the regulatory environment and support, even if both devices are dual-band, they may not have a common operating channel.
- If the infrastructure STA roams to a channel that is no longer a common channel, it disrupts the P2P group.
- If both devices are connected to infrastructure networks on different channels, and both support only same channel concurrency, then the group cannot be created. For example, in use case 2, if Joan’s laptop is also

connected to a network (could be a guest network) that is on different channel, then either Ian or Joan must disconnect for the connection to be possible.

- Some of these limitations can be overcome if the Wi-Fi adapter supports multichannel concurrency.

4.3 Multichannel Concurrency

Multichannel concurrency occurs when the Wi-Fi adapter is able to connect to the infrastructure network on one channel and create a P2P group on a different operating channel. This solves some of the problems described in 4.2.2 Limitations, above:

- The devices can advertise their true capabilities in the “supported channels” list based on the full spectrum with the preferred operating channel as the same as the infrastructure channel. This makes group creation more likely to succeed, because the two sides are more likely arrive at a common channel with an expanded set.
  - For use case 1, if the mobile device is only 2.4G capable, the DTV can form the group on a 2.4G channel while remaining connected to the Internet.
  - For use case 2, selecting the operating channel becomes easier with either side supporting a multichannel implementation.
- If the infrastructure network is on a DFS channel, then the group owner must become a DFS master to exist on that channel. This adds to testing, implementation, and certification costs.

4.3.1 Multichannel Concurrency in a Single Radio World

Multichannel concurrency requires two Wi-Fi interfaces to be present on two different radio channels at the same time. The easiest way to achieve the best user experience is to have two radios that can independently tune to different channels without interfering with each other’s traffic. This is impractical in most cases, because of the very high system costs associated with replicating Wi-Fi design, not considering just antenna placement issues. Also, as the Wi-Fi Direct group use cases described above cater to ad-hoc connections that are temporary in nature, it may be excessive to have a redundant Wi-Fi module.

Therefore, using the same Wi-Fi module with a single radio can support connections on two channels at the same time. This is achieved by using a time division multiplexing (TDM) scheme. In this type of scheme, each BSS gets some time to send/receive traffic on its own channel before the driver switches the channel.

Note: Before Wi-Fi Direct, multichannel operation between an AP and STA was not possible, as the AP could never go off-channel. The Wi-Fi Direct Notice Of Absence (NOA) implementation makes it possible for a Group Owner to go off-channel to cater to other BSS traffic. The infrastructure STA and the P2P group clients continue to use the IEEE 802.11 PS method (PM bit) to go off-channel.

4.3.1.1 Driver Responsibility

Cypress is one of the few Wi-Fi vendors with implementations that can handle multichannel operations through the driver. The driver must do the following:

- Buffer traffic for the BSS that is off-channel.
- Let traffic for the current BSS flow through.
- Implement a switching policy that is practical and fair (see Appendix A: Channel Switching Considerations on page 9), within constraints.
- As a Group Owner, publish an NOA schedule that matches the switching policy.
- When each BSS time is up, stop the traffic for that BSS, and open the gate for the other one.

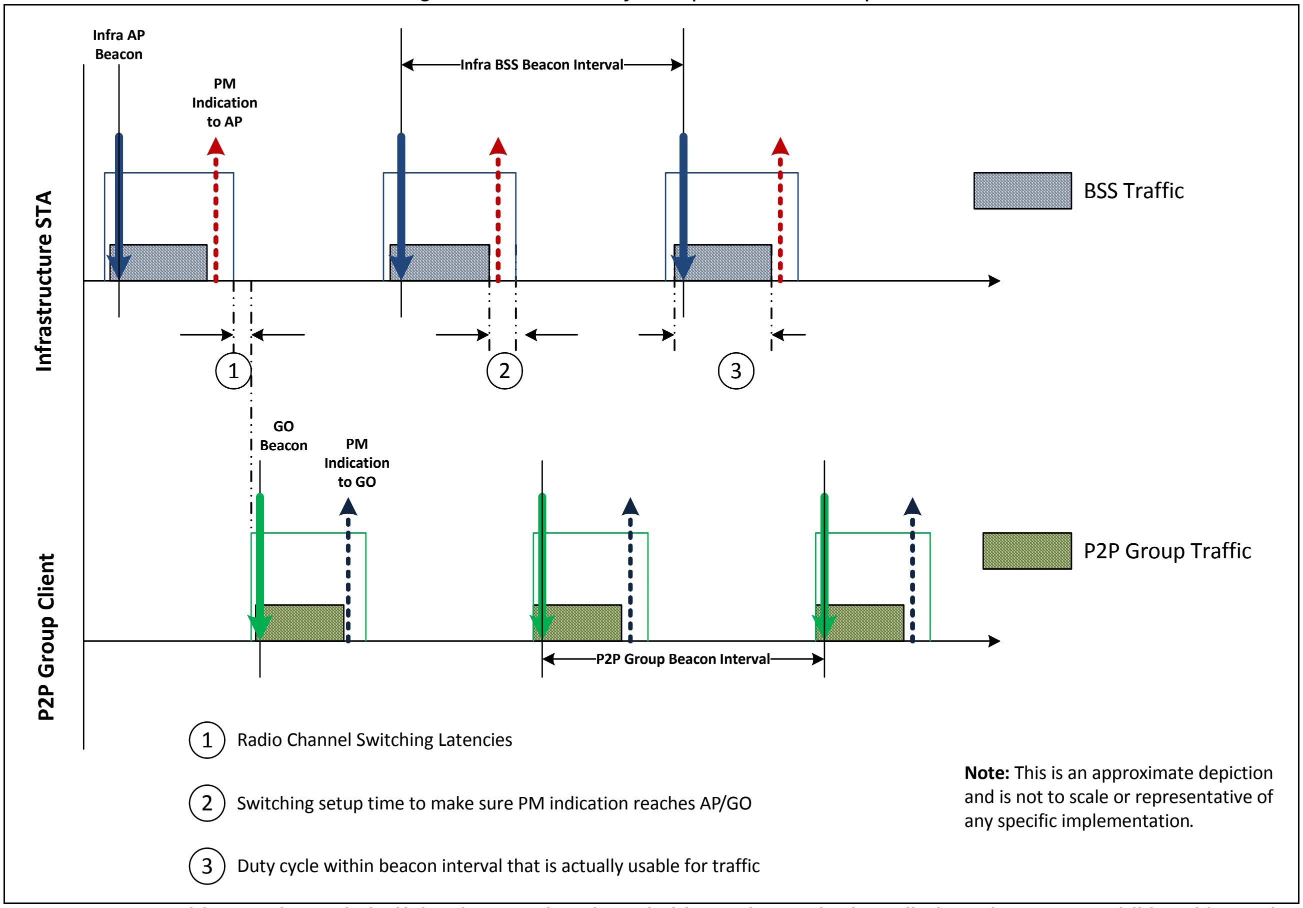
4.3.1.2 Practical Considerations

The following practical considerations should be addressed:

Latencies

The traffic encounters various latencies in such an implementation (see Figure 4).

Figure 4. Concurrency Setup STA with Group Client



Besides getting only half the time on the air, switching using a single radio introduces two additional latencies:

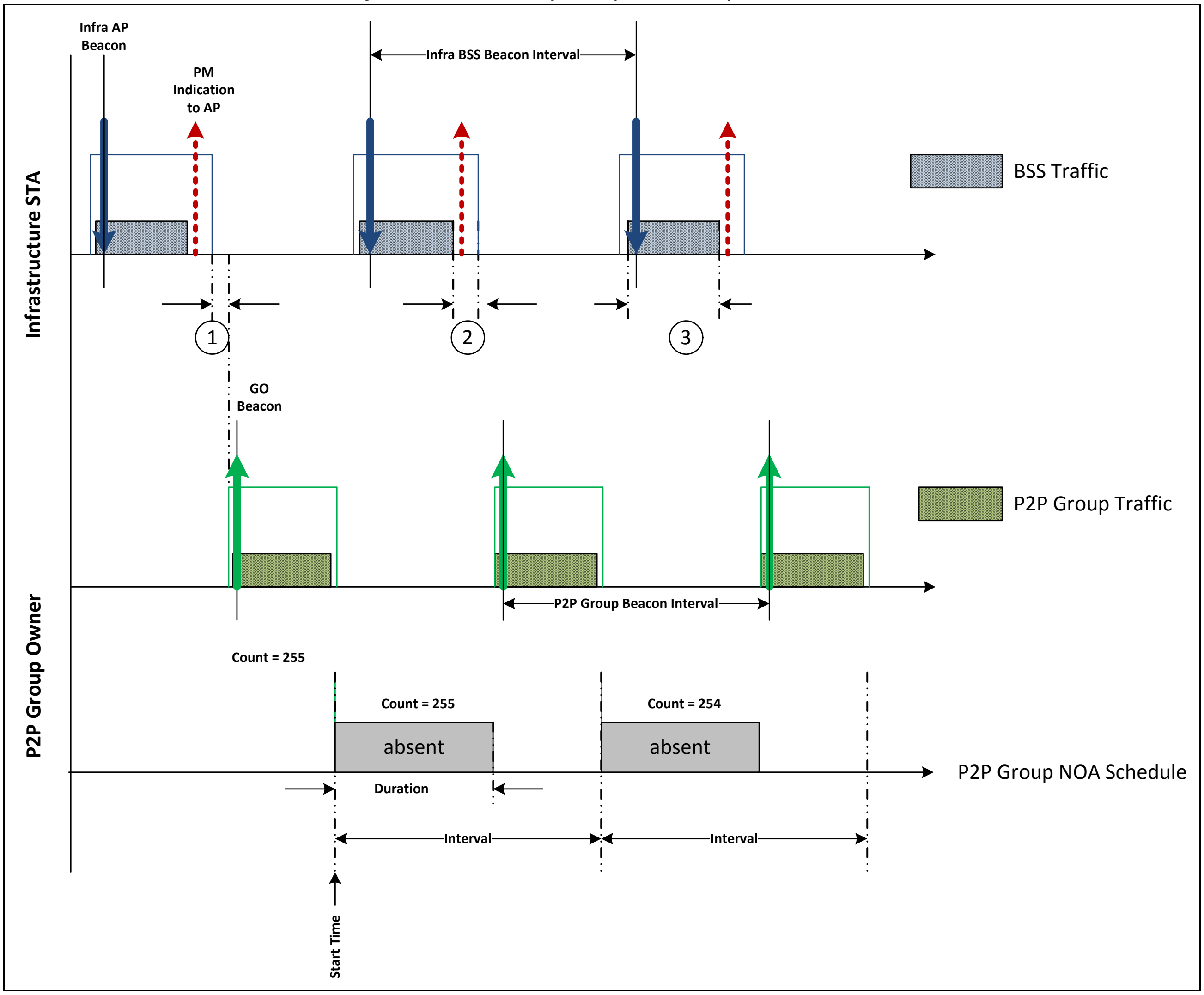
- Channel switching latencies—The mount of time required for the radio to switch channels and tune to a new channel.
- Switching setup time—There is non-zero time required for the driver to send the PM indication frame to the AP or the Group Owner to make sure that AP/GO will ACK and buffer the traffic destined for the STA/Group client. This must be done with anticipation of the impending switch.

The actual usable traffic time for a BSS (or P2P group) becomes:

> Usable traffic time = Beacon interval – Duty cycle for the BSS – Channel switching latency – Switching setup time

In the case of concurrency for a Group Owner and infrastructure STA, the GO may get fractionally more time for traffic, as it does not have to notify anyone about buffering traffic because its NOA schedule takes care of it (see Figure 5).

Figure 5. Concurrency Setup with Group Owner and STA



Bursty Traffic
Traffic is buffered for the duration of its off channel, so when the channel switches to that BSS, traffic is transmitted immediately, making it inherently bursty. This also means the receiver should be able to absorb such a burst.

Power Savings
In this implementation, not much power can be practically saved, as the radio is always tuned to one or the other active channel. A little bit of savings can be realized for the infrastructure STA if there is no traffic to send, as the radio could go in power save mode for its allotted duration.

Memory Requirement
Buffering traffic during off-channel operation requires the memory to hold the packets destined for the BSS. Store this traffic on the host side if it needs to be seamless to the applications above.

Usable Traffic Window
As seen above, when TDM switching is applied in a beacon interval (assuming 100 TU beacon interval for both BSS), the amount of idle time on the air is approximately equal to twice that of: [Channel switching latencies + Switching setup time]. This is because the BSS must switch once to change the channel, then switch back to its home channel. Even with zero channel switching latencies (with hardware assistance, if available), switching setup time is still impacted. Switching setup time could be environment-dependent, as in a crowded environment it takes longer for STA to deliver PM indications to the AP.

Timing and CPU Utilization

Because switching windows are tight, other things that affect the performance include interrupt handling latency and CPU capability to handle the traffic for multiple interfaces.

5 Summary

Although multichannel P2P (and, in the future, TDLS) may enable more use cases by removing restrictions posed by single-channel concurrency, it also poses various system design challenges that arise due to the TDM nature of such an implementation. The applications on such systems must be designed to withstand the latencies and bursty traffic introduced by such a scheme. Because of that, it may not be suitable for applications that are delay sensitive (for example, the upcoming Wi-Fi-Display), being one of them without substantial mitigation. The user expectations would need to be managed as well.

Single-channel concurrency is not without its own problems, as traffic on a particular BSS is still going to encounter higher latencies because it is intermixed with traffic from the other BSS. In addition, some device capability issues restrict its usage. However, system implementers should strive to balance between addressing every use case and scenario versus providing an acceptable user experience.

6 FAQ

Which Cypress products support single channel and multichannel concurrency?

Because of different memory requirements, different host capabilities, and different driver architectures, contact your Cypress Product Line Manager for more information about product support.

Can I have an arbitrary duty cycle for multichannel concurrency?

As explained in Appendix A: Channel Switching Considerations on page 9, the scheduling and duty cycles must be under the driver's control because of latencies, differing switching times, and target beacon transmission time (TBTT) management.

7 Appendix A: Channel Switching Considerations

This section describes some of the considerations for channel switching policies.

7.1 STA-Group Client

An infrastructure station (or a group client) can be in IEEE 802.11 PS for most cases (see Reference [2] on page 6). However, the STA/Group clients in PS also expected to wake up to receive the Delivery Traffic Indication Message (DTIM) beacon and the broadcast traffic that follows. It is also expected to look at the TIM bit and retrieve the buffered traffic. In such a case:

- TBTTs for infrastructure BSS and P2P group are well spaced.
- In this case, the TBTT is well spaced enough to allow a switching schedule where the STA/client receives the DTIM beacon (or every beacon). That is, referring to Figure 4: "Concurrency Setup STA with Group Client ," on page 7, this means that spacing is larger than [Channel switching latencies + Switching setup time].
- In such a case, the BSS switching can be at the predetermined offset from TBTT, which is at least [Channel switching latencies + Switching setup time]. After switching, the BSS can spend approximately half of its beacon interval.
- TBTTs that overlap for the STA and P2P group client.
- In this case, the TBTTs are close, such that the spacing is smaller than [Channel switching latencies + Switching setup time].
- In such a case, one of the BSS must sacrifice receiving its beacon interval and the subsequent broadcast traffic.

7.2 STA-Group Owner

In this case, the group owner may have liberty of setting its TBTT far enough apart from that of the Infrastructure AP. The driver must switch to the channel of the Group Owner sufficiently early, [Channel switching latencies + Switching setup time], to allow the GO to transmit its beacon. Also, there is no switching setup time for the GO to switch back.

The following issues exist in this case:

- This scheme depends on the order of connection: The Group Owner must know the TBTT of the infrastructure connection before establishing the group.
- Even with right order, the STA can roam to a new AP whose TBTT overlaps with that of the GO.
- The group client's desired schedule is not taken into account. With such a schedule, it is possible that the client, which itself might be concurrent with an infrastructure network, may never find a suitable traffic window to communicate with the group owner. In such a situation, the group cannot function and must be disbanded.

8 Acronyms and Abbreviations

In most cases, acronyms and abbreviations are defined on first use.

Acronym	Definition
BSS	Basic Service Set
CSA	Channel Switch Announcement
DFS	Dynamic Frequency Selection
DMP	DLNA Media Player
DMR	DLNA Media Renderer
DTV	Digital TV
M-DMS	Mobile DLNA Media Server
OEM	Original Equipment Manufacturer
P2P	Peer-to-Peer
TBTT	Target Beacon Transmission Time
TIM	Traffic Indication Map
TU	Time Unit

Document History Page

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*B	5834576	BENV	07/27/2017	Updated logo and copyright

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