*Technical White Paper*

# *Advantages and Challenges of Multi-Role Multi-Channel versus Single-Channel*

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**ABSTRACT**

Modern Wireless (Wi-Fi™ and Bluetooth®) connectivity networks is composed of several heterogeneous devices such as internet of things (IoT) sensors, HD (high definition) streaming devices, or low latency gaming consoles. It is common practice to functionally separate high-end devices network and low-end devices network, by using multiple radios to reduce collisions between those network; which would be costly for an overall system implementation.

This white paper describes how Wi-Fi multi-role capability within a single radio can enable functional networks separation. More specifically it shows how a multi-role multi-channel solution provides an affordable way to also achieve collision domains separation which dramatically increases system bandwidth utilization, especially in comparison to multi-role single channel solution.

This is demonstrated by measurements done on the TI WiLink™ Wi-Fi™ and Bluetooth® combo transceivers (WL18xx), which shows up to 118% throughput improvement in a typical separated network deployment.

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# Acronyms

| | |
|---|---|
| ACK | Acknowledgment |
| AP | Access Point |
| BT | Bluetooth |
| BW | Bandwidth |
| CH | Channel |
| CL | Client |
| DUT | Device Under Test |
| DTIM | Delivery Traffic Indication Message |
| GO | Group Owner |
| MIMO | Multiple Input Multiple Output |
| MRSC | Multi Role Single Channel |
| MRMC | Multi Role Multi Channel |
| P2P | Peer to Peer |
| PS | Power Save |
| SISO | Single Input Single Output |
| STA | Station |
| SP | Service Period |
| WLAN | Wireless Local Area Network |

# 1 Introduction

Legacy WLAN implementations assume a single WLAN role operation (station, access point or any other WLAN role). Multi Role means that several WLAN roles (two or more) are operating concurrently, on the same or even different channels and/or bands.

A typical example for Multi Role can be a gateway device where one role is a WLAN station connected to home access point which provides the access to the internet, and the other role is a WLAN access point connected to one or more sensors scattered around the house. In such a system a user can access the gateway device to easily monitor and control each one of the sensors instead of accessing one by one.

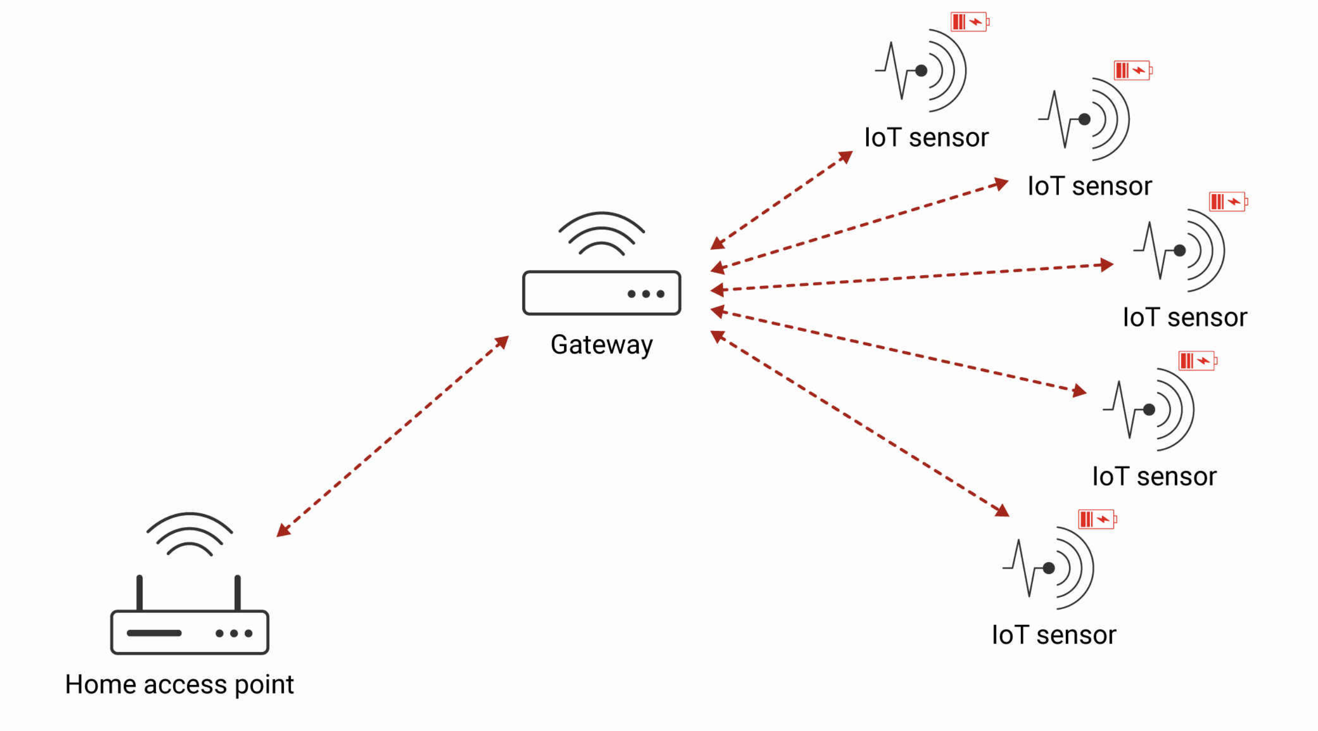


**Figure 1-1. Multi Role Example**

One approach is to implement concurrency using two or more completely separate radio systems (for example, one per each role). This fits the high-end, highest-performance, and most expensive solution.

On the other hand, for more cost-effective solutions – a single radio system (for example, radio and SW controller) manages transitions between multiple roles. With the single radio approach, the concurrency can be implemented using time-division sharing of system resources and thus achieve a more cost-effective solution. In such single radio solutions, the Multi Role implementation can be limited to operate all roles on the same physical channel (“Single-Channel” Multi Role) or allow the different roles to operate on different channels (“Multi-Channel” Multi Role).

This paper presents the multi-channel approach advantages over a single-channel approach of such multi-role solutions from an overall system performance point-of-view. This paper also discusses the challenges of achieving a cost-effective multi-role multi-channel solution with a single radio, and describes the different solutions that ensure a stable, high performing and reliable system as implemented in TI WL18xx™.

## 2 Single-Channel Versus Multi-Channel

As mentioned, a Multi Role solution implements several WLAN roles operating concurrently. There are different multi role types and each one has different properties: The single channel type limiting the WLAN roles to operate on same band and channel (for example AP and STA operating on channel 1 on the 2.4-GHz band). The multi-channel type, on the other hand, can avoid this by allowing the WLAN roles to operate on different channels and even bands.

Another aspect is the amount of radios used for the multi-role solution. The multiple radios solution can achieve full concurrency where each WLAN role gets its own resources and full radio access. The single radio solution can achieve similar system efficiency and performance by dividing the radio access and resources in a managed way and overcome some of the challenges.

### 2.1 MRSC Single Radio Network Topology

The following example will demonstrate the Multi-Role Single-Channel use case and how system efficiency is significantly impacted when roles are operating on same channel (and band): As can be seen in the Figure 2-1 below the traffic between the IoT STAs connected to the Multi-Role device Access Point overlaps and collides with the traffic running from the Remote Station to the Remote Access Point running on the same channel. Thus, overall system throughput is degraded. In addition, the system’s overall power consumption is higher as the amount of re-transmissions required from all the devices is higher.

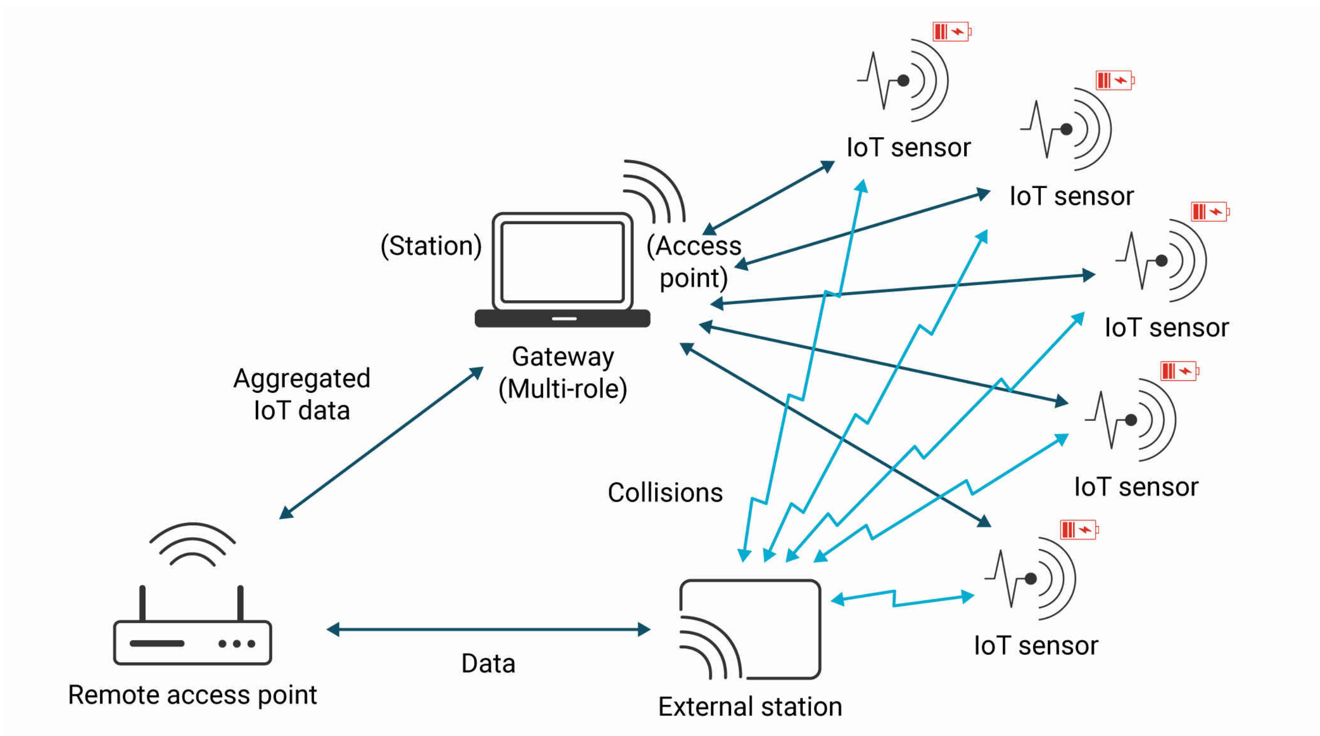


**Figure 2-1. Multi-Role Single-Channel Network Topology**

### 2.2 MRMC Single Radio Network Topology

The following example will demonstrate the Multi-Role Multi-Channel use case and how system efficiency is significantly improved when roles are operating on different channels or bands. As can be seen in the Figure 2-2 below, the traffic does not overlap and no collisions between the IoT STAs connected to the Multi-Role device Access Point (“Red network”) and the Remote Station connected to the Remote Access Point (“Blue network”). Thus, overall system throughput is higher (very important for heavy data consumers). In addition, the system’s overall power consumption is lower as the amount of re-transmissions required from all the devices is lower compared to a single channel (very important for IoT nodes).

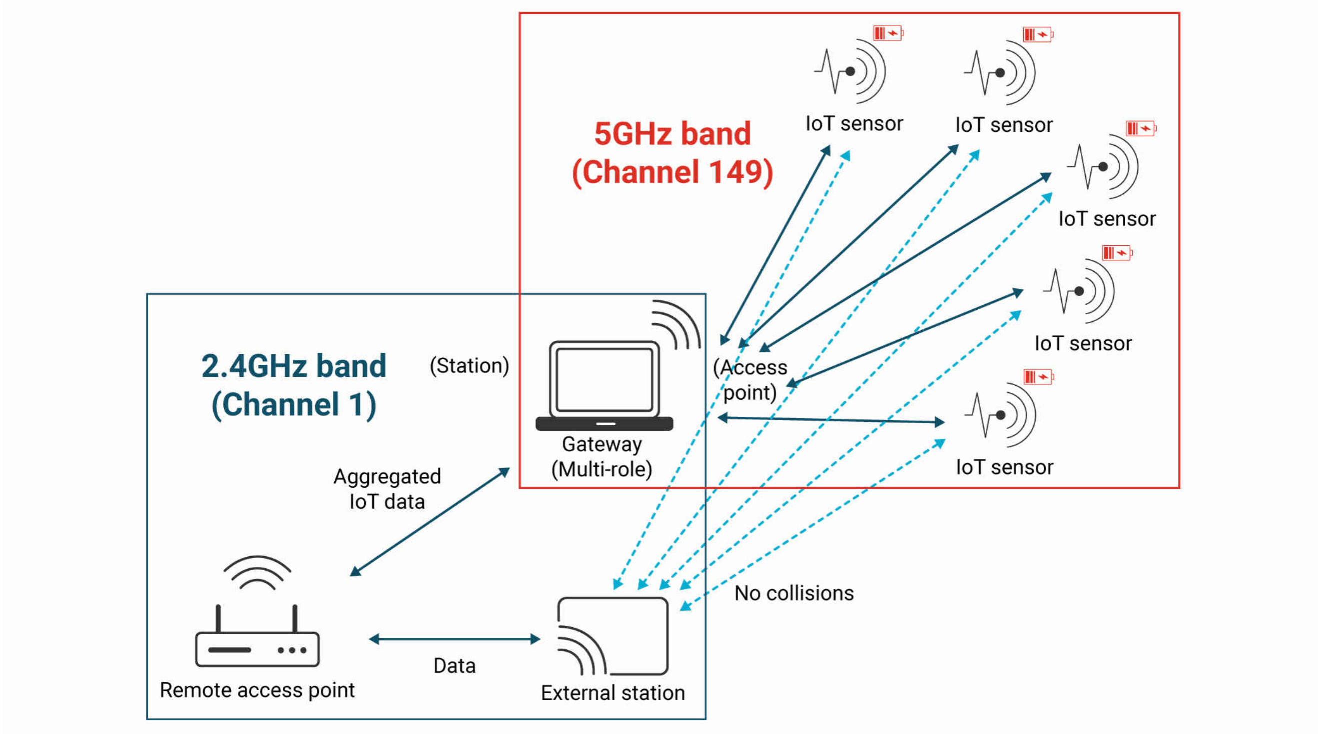


**Figure 2-2. Multi-Role Multi-Channel Network Topology**

## 2.3 Experiment and Results

The test below compares the overall system efficiency (throughput) of a multi-role single-channel solution where both of STA and AP roles are running on the same channel as the external AP network versus a multi-role multi-channel solution where the AP role is running on a different band than the STA role and the external AP network. Please refer to the Appendix for the test setup details. See Figure 2-3 for a diagram of the test setup.

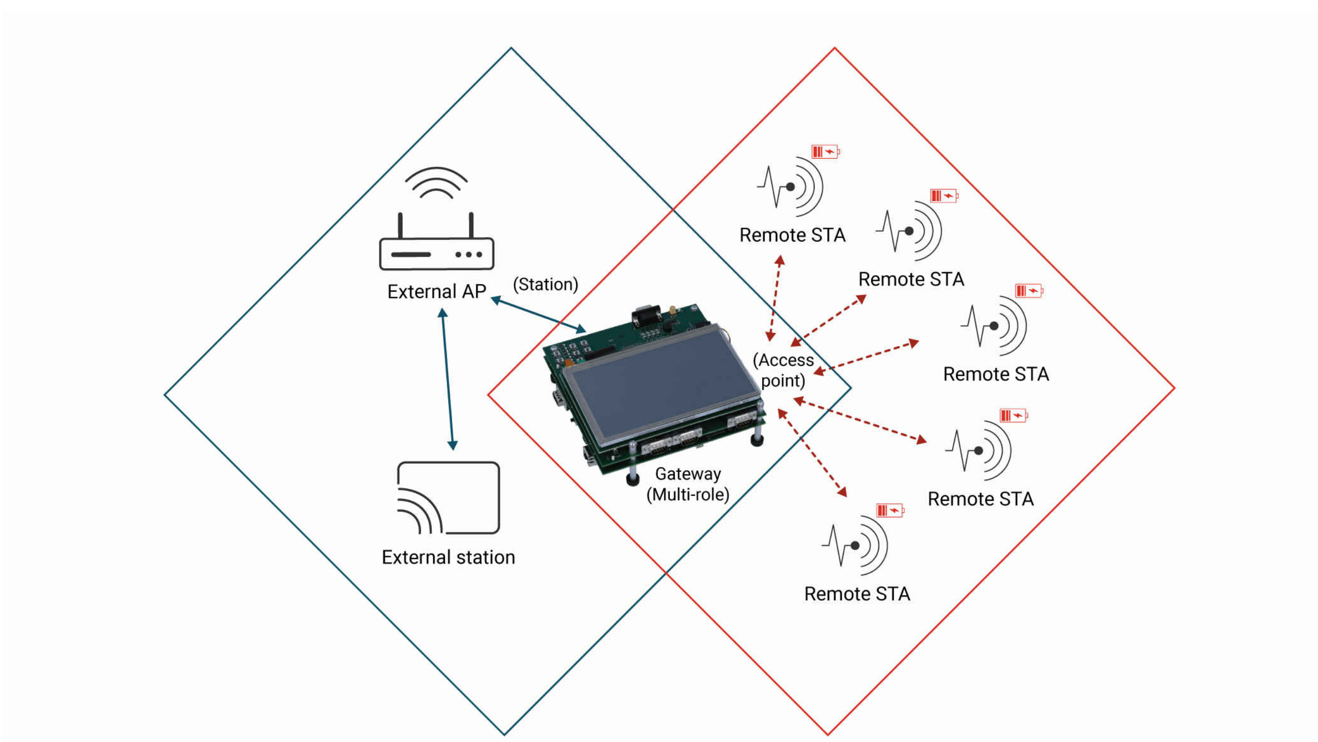


**Figure 2-3. Test Setup Diagram**

In the multi-role single-channel case the traffic running in the Multi-Role as an AP network (red network) impacts the traffic running in the External AP network where the External STA is also connected (blue network) and vice versa.

In the multi-role multi-channel case, the Multi-Role as an AP is operating on a different channel (and band) compared to the External AP. This actually creates a full separation between the two networks. It means that the traffic running in the Multi-Role as an AP network (red network) does not impacts the traffic running in the External AP network (blue network) and vice versa.

The test was repeated with increasing number of remote STAs from 1 to 5. The external STA was configured to send UDP of 50 Mbps while each Remote STA was configured to send UDP of 1 Mbps. For multi-channel versus single-channel results, refer to Table 2-1

The throughput results of this comparison are summarized in Table 2-2 and Figure 2-4.

**Table 2-1. Multi-Channel Versus Single-Channel Results**

| Configuration | | | | | | Blue Network | | Red Network | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test Case | Multi-Role AP (Red Network) | | External AP (Blue Network) | | Bandwidth | External STA | Multi-Role STA | Remote STA#1 | Remote STA#2 | Remote STA#3 | Remote STA#4 | Remote STA#5 |
| | Band | CH | Band | CH | | | | | | | | |
| MRSC | 2.4 GHz | 11 | 2.4 GHz | 11 | SISO20 | 27.6 Mbps | 1 Mbps | 1.0 Mbps | | | | |
| MRMC | 5 GHz | 36 | 2.4 GHz | 11 | SISO20 | 27.8 Mbps | 1 Mbps | 1.0 Mbps | | | | |
| MRSC | 2.4 GHz | 11 | 2.4 GHz | 11 | SISO20 | 24.8 Mbps | 2 Mbps | 1.0 Mbps | 1.0 Mbps | | | |
| MRMC | 5 GHz | 36 | 2.4 GHz | 11 | SISO20 | 27.9 Mbps | 2 Mbps | 1.0 Mbps | 1.0 Mbps | | | |
| MRSC | 2.4 GHz | 11 | 2.4 GHz | 11 | SISO20 | 22.2 Mbps | 3 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps | | |
| MRMC | 5 GHz | 36 | 2.4 GHz | 11 | SISO20 | 27.5 Mbps | 3 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps | | |
| MRSC | 2.4 GHz | 11 | 2.4 GHz | 11 | SISO20 | 18.6 Mbps | 4 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps | |
| MRMC | 5 GHz | 36 | 2.4 GHz | 11 | SISO20 | 26.0 Mbps | 4 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps | |
| MRSC | 2.4 GHz | 11 | 2.4 GHz | 11 | SISO20 | 11.3 Mbps | 4.6 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps | 0.6 Mbps | 1.0 Mbps |
| MRMC | 5 GHz | 36 | 2.4 GHz | 11 | SISO20 | 24.7 Mbps | 5 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps | 1.0 Mbps |

**Table 2-2. Multi-Channel Throughput Improvement**

| Number of remote STAs | External STA throughput in Single-Channel | External STA throughput Multi-Channel | Improvement |
|---|---|---|---|
| 1 | 27.6 Mbps | 27.8 Mbps | 0.7% |
| 2 | 24.8 Mbps | 27.9 Mbps | 12.5% |
| 3 | 22.2 Mbps | 27.5 Mbps | 23.87% |
| 4 | 18.6 Mbps | 26.0 Mbps | 39.78% |
| 5 | 11.3 Mbps | 24.7 Mbps | 118.58% |

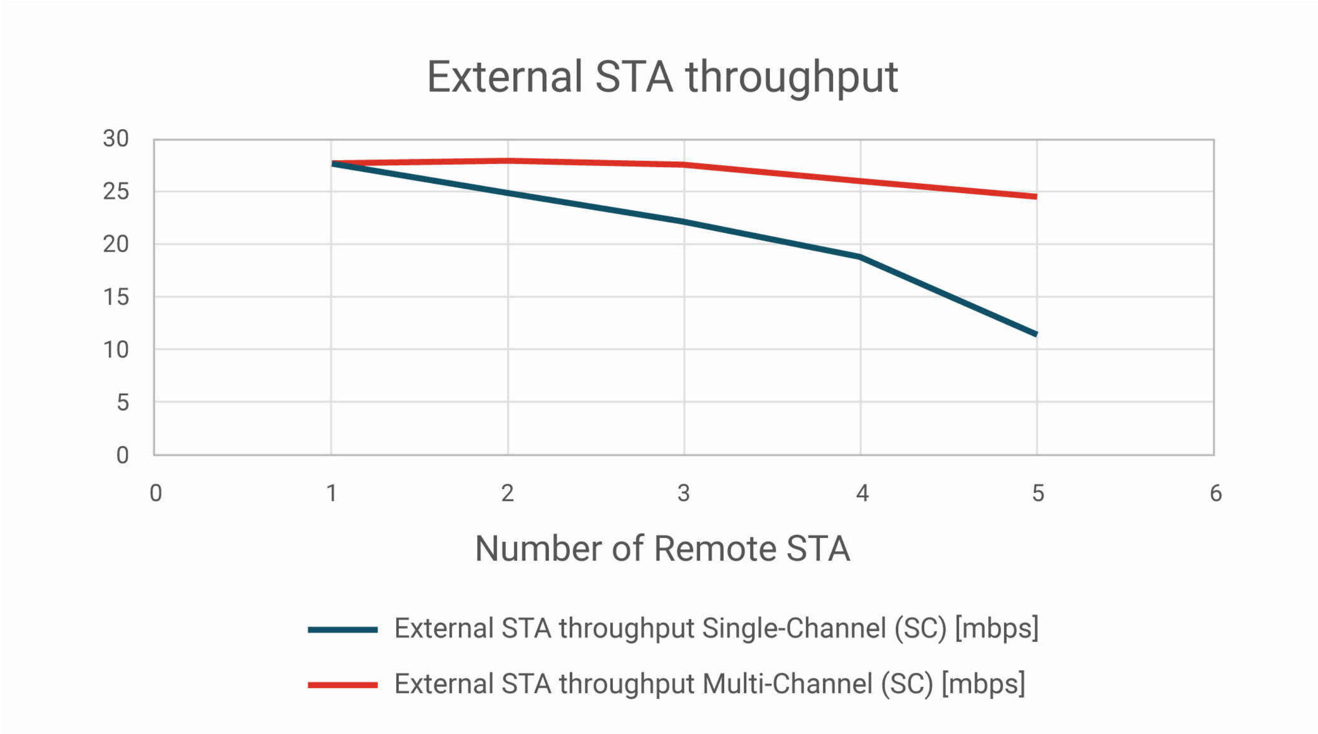


**Figure 2-4. Multi-Channel Throughput Improvement**

As can be seen from the results, when each network was operating on a different channel and band (multi-channel) the overall throughput of the external STA was better for any number of remote STAs used. The throughput improvement is significantly higher when number of remote STAs in increased and can get to more than 100% with 5 remote STAs. This is directly related to the networks separation between bands which helped to avoid the interference between the Remote STAs and the External STA even though they were not connected to the same access point.

# 3 Multi-Channel Challenges and Requirements

Implementing a cost-effective single radio multi-role multi-channel system has many challenges and should meet some mandatory requirements in order to overcome those challenges. This chapter will first describe basic concepts of a multi-role system like what is role switch protection and what are the tools provided by the IEEE 802.11 specification to enable it. Then it will elaborate on how those tools are used and related to the multi-role multi-channel challenges and requirements.

## 3.1 802.11 Spec Enablers for Role Switch Protections

The MRMC solution is based on time division between the roles. When these roles operate on different channels, it means that for each role there are portions of time in which it is absent (not transmitting and unable to receive) on its operating channel. The typical WLAN operation (and in the original spirit of the 802.11 specification) the rest of the network will normally assume a device (especially an AP) is present on the channel at all time. Therefore, these absences from the channel need to be protected, in terms of their timing and the procedures taken in order to leave the channel.

The IEEE 802.11 WLAN specification provides several tools which can be utilized as protection mechanisms for seamlessly switching between the active roles:

- CTS-To-Self – no transmissions on channel for a period of time defined by transmitter on this CTS frame (hold peers TX allowing AP role to leave the channel)
- Power Save Mode – an AP will buffer packets for a STA during PS (hold RX by others to allow STA role to leave the channel)

## 3.2 Role Switch Protection Implementations

### 3.2.1 AP Based Roles

- A CTS frame destined to our own MAC-Address is sent without an RTS frame preceding it (CTS-to-Self)
- Other wireless devices in the network will refrain from accessing the medium for the duration mentioned in the CTS frame and wait to access the medium, while in fact the AP based role is leaving the channel as illustrated by Figure 3-1 below:

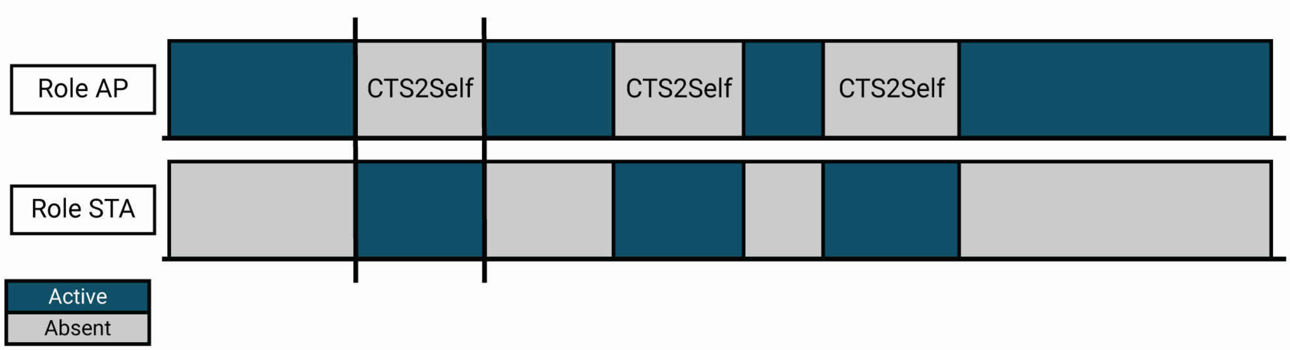


**Figure 3-1. Role Switch Protection - Role AP**

### 3.2.2 STA Based Roles

- Entering power save indicates to the remote AP to start buffering packets destined to role STA. Because of this, a STA can be absent from the channel for a period of time, knowing that it is not missing any packets that it is supposed to receive, and once it returns the AP will send all buffered packets.
- Role STA remains active (based on hangover learning algorithm) to handle the case where AP continue to send packets to avoid possible rate drops or disconnection. As shown in Figure 3-2 below:

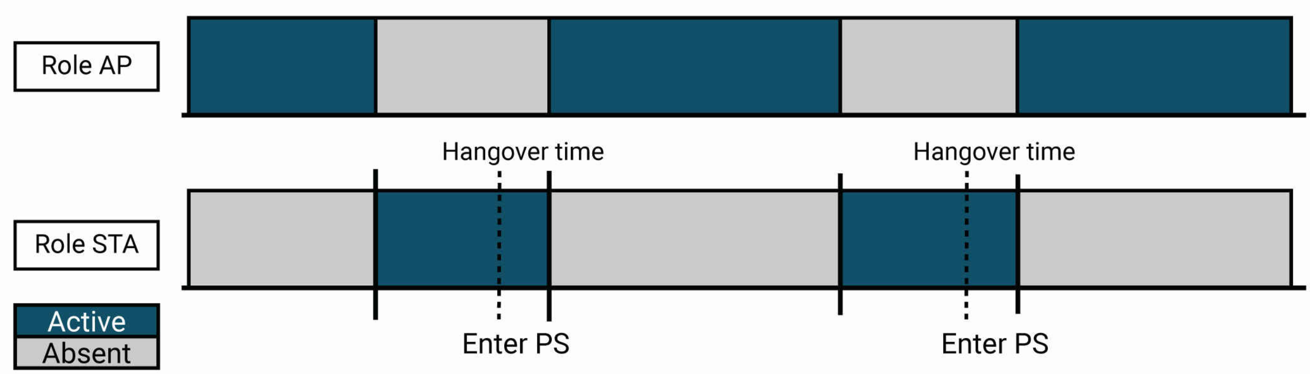


**Figure 3-2. Role Switch Protection - Role STA**

## 3.3 Single Radio Multi-Channel Challenges

The MRMC uses a time division solution between the roles and therefore it is required to manage each of the role's absences from their channel in order to protect it. An unmanaged concurrent operation of multiple WALN role on a single radio chip can result in an unstable and unreliable system and even expose the system to disconnections, low performance and bad user experience. For example, the implications of unmanaged AP absence from its operating channel will cause the connected STAs to have many data transmission retries or poll for data without receiving the ACK or data back from the AP. The system can then suffer from rate drops or even disconnections. Similarly, new STAs might fail to connect. Another example for a challenge in MRMC single radio is handling unmanaged STA absence from the channel. In this case, the connected AP may send data and receive no ACK which might lead to rate drop, disconnections and lost beacons, DTIMs and multicast data. Table 3-1 summarizes the challenges:

**Table 3-1. Multi-Role Multi-Channel Single-Radio Implication of Unmanaged Role Absence**

| Implication / WLAN Role | Unmanaged AP absence | Unmanaged STA absence |
|---|---|---|
| Rate drops | Connected STAs try to send or poll for data and receive no ACK/data results in rate drop | Connected AP try to send data and receive no ACK results in rate drop |
| Disconnections | Connected STAs lost too many beacons and disconnect from the AP | Connected AP try to send data and receive no ACK results in disconnection |
| Network Integrity | New STAs fail to complete the connection process | STA might lose channel switch indication |
| Low Performance | Bi-directional traffic is lower due to multiple retries and low data rate | |

### 3.4 Single Radio Multi-Channel Key Requirements

The above mention challenges make any MRMC single radio system a complex one to implement, and as such there are some requirements which it is expected to meet in order to ensure a reliable and a stable solution. This section elaborates the key requirements expected from any solution to consider when coming to implement a MRMC single radio system.

First is the role's availability. Each one of the active roles' availability must be handled carefully and its absence from the operating channel must be taken in account. As will be further elaborate in Section 3, there are some actions that can be taken by the system (some are defined by the 802.11 specification) which allows the active role to indicate its peers he is about to leave the operating channel and avoid any of the implication described earlier.

Second is the role's activities timing. Each one of the active roles has its own unique timing and priority requirements for each of its activities (for example, activity starting point, its duration, minimum time required, expiry time). The solution is required to handle multiple of those hard-timing activities and requests coming from each one of the roles simultaneously and asynchronously. To do that the solution might include some kind of scheduling mechanism that is able to suspend and resume each role activities on time and thus minimize user experience impact and keep system efficiency high.

Failing to handle the above requirements properly can cause unstable system behavior, periodic disconnections and very low unbalanced throughput.

# 4 WL18xx™ Multi-Channel Implementations

The Texas Instruments WL18xx™™ has implementations that can address the previously mentioned challenges and provide great performance, robustness, and stability. Some of them are mentioned in the IEEE 802.11 specification and used as is or with some modifications. Other implementations are unique.

## 4.1 Arranging the Role Activity Requests by Priority

One of the key methods that allows meeting the hard-timing activity requests coming from each one of the roles is prioritization. Each activity request can be submitted at any point in time representing the rough requirements of their activity. The priority can then be dynamically changed to increase the system reliability (for example due to new higher priority requests). This activity prioritization is the baseline for the scheduling decision for each role.

## 4.2 Scheduling the Role Activities

Based on the up-to-date activity requests status a plan is generated (and re-generated with every new request or based on timeout). The plan is always open for changes and the scheduler manages suspension and resumption of those activities to utilize the system as much as possible. For this, the current activity can be pre-empted by another higher priority activity and as a consequence when it resumed it might be compensated.

To suspend or resume role's activities is not immediate and takes some time. When a new activity starts, the time needed to complete it is computed in advance. This allows to estimate the point in time to be ready to start suspending the current activity and be ready to resume the next one just in time. A high-level multi-role activity scheduling scheme is presented in Figure 4-1.

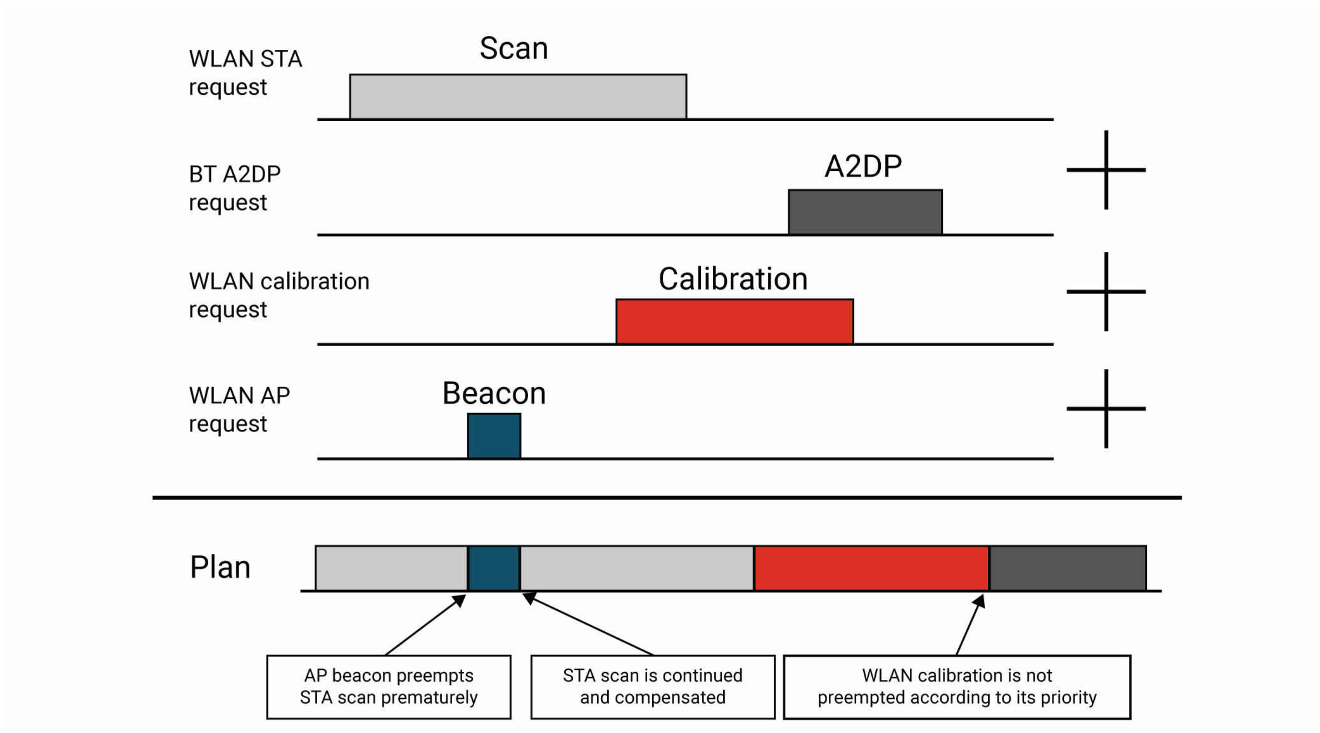


**Figure 4-1. High Level Scheduler Generated Plan Guidelines**

## 4.3 Leveraging MRMC to Improve WLAN-BT Coexistence

Bluetooth is another wireless technology commonly used with WLAN. Bluetooth shares the same radio band (2.4 GHz) with the WLAN roles and can co-exist with them making the scheduling even more complex. From a scheduling perspective, Bluetooth's role is considered equivalent to WLAN, which needs to be scheduled and protected as well. The same principles mentioned before can applied, with some hard-timing Bluetooth activities getting priority and bypassing the scheduler to avoid a bad user experience.

This is further illustrated in Figure 4-2 below.

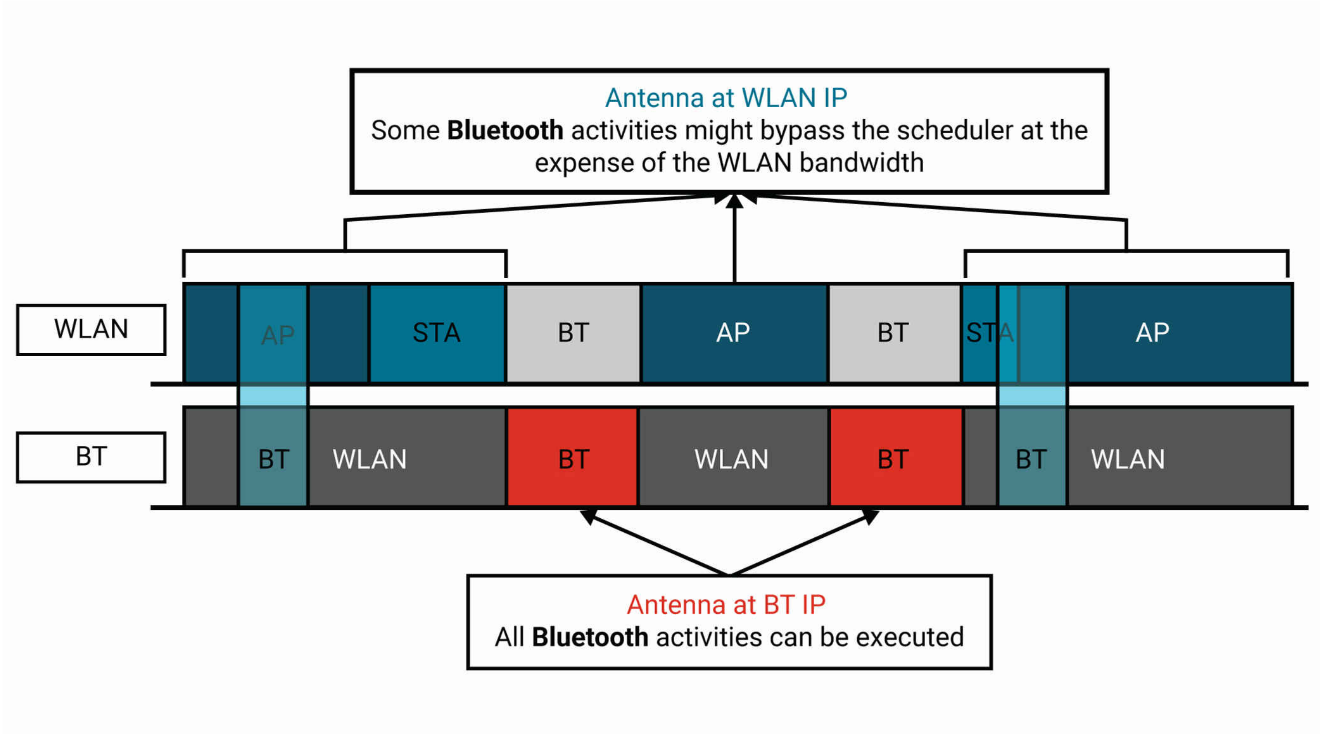


**Figure 4-2. Scheduling with WLAN-Bluetooth Coexistence**

# 5 Conclusions

Multi-role solutions which allows the concurrent operation of one or more WLAN or Bluetooth® roles are becoming more and more commonly used in many products. The multi-channel multi-role is clearly more complex and challenging to implement than the single-channel one, however it has significant advantages over it like higher throughput and lower power consumption.

WL18xx™ is a great implementation of multi-role multi-channel that meets all challenges and provide great system performance. The results suggest that using the cost-effective WL18xx™ multi-role multi-channel solution with a single radio has several advantages over the multi-role single-channel: Improved throughput for the stations connected to the access point and improved power consumption for the entire system (not covered in the results section)

For more information on the WL18xx™ products, TI's Wi-Fi and Bluetooth Low Energy combo transceivers, visit www.ti.com/wifi.

# Appendix

The setup described in Section 2.3 was placed in an anechoic clean room with the following devices:

- Multirole device is Sitara AM335x™ with WL18xx™ running R8.8 release and configured as a bridge between the roles.
- Remote STAs are Sitara AM335x™ with WL18xx™ running R8.8 release limited to 1Mbps.
- External AP is Sitara AM335x™ with WL18xx™ running R8.8 release.
- External STA is Linksys AE1000 dongle.

The two different network topologies are as follows:

- The blue network includes the External AP, External STA and WL18xx™ STA role.
- The red network includes WL18xx™ AP role and 5 WL18xx™ STAs.

Throughput was measured using iPerf tool running UDP for 5 minutes.