IEEE P802.11  
Wireless LANs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Text Contributions to the FD-TIG Technical Report regarding  Full Duplex for 802.11 | | | | |
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|  |  |  |  |  |

Abstract

This document contains text contributions to be considered for inclusion in the FD-TIG Technical Report.

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# Introduction

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# FD use cases

# Full Duplex(FD) functional requirements

## Support for legacy 802.11 devices

Any IEEE 802.11 device (e.g. STA or AP) that supports full duplex functionality shall be able to operate in a heterogeneous 802.11 network populated with a variety of 802.11 devices defined in the IEEE Std 802.11 2016 (e.g. .11n(HT), .11ac(VHT), …) and the IEEE P802.11ax/D3.0 (i.e. HEW WLAN).

## IEEE 802.11 Channels and bandwidths of FD operations

### 2.4 GHz

Full Duplex capability shall be operational in these existing IEEE 802.11 2.4 GHz channels and bandwidths:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **11b DSSS** | | |  |  |  | **11 g/n OFDM** | | |  |  |  | **11n OFDM** | | |  |
| **Ch. Idx** | **Min (MHz)** | **Fc (MHZ)** | **Max (MHz)** | **BW (MHz)** |  | **Ch. Idx** | **Min (MHz)** | **Fc (MHZ)** | **Max (MHz)** | **BW (MHz)** |  | **Ch. Idx** | **Min (MHz)** | **Fc (MHZ)** | **Max (MHz)** | **BW (MHz)** |
|  |  | 2401 |  |  |  |  |  | 2402 |  |  |  |  |  | 2402 |  |  |
| 0 |  | 2407 |  |  |  | 0 |  | 2407 |  |  |  | 0 |  | 2407 |  |  |
| **1** | **2401** | **2412** | **2423** | **22** |  | **1** | **2402** | **2412** | **2422** | **20** |  | 1 |  | 2412 |  |  |
| 2 |  | 2417 |  |  |  | 2 |  | 2417 |  |  |  | 2 |  | 2417 |  |  |
| 3 |  | 2422 |  |  |  | 3 |  | 2422 |  |  |  | **3** | **2402** | **2422** | **2442** | **40** |
| 4 |  | 2427 |  |  |  | 4 |  | 2427 |  |  |  | 4 |  | 2427 |  |  |
| 5 |  | 2432 |  |  |  | **5** | **2422** | **2432** | **2442** | **20** |  | 5 |  | 2432 |  |  |
| **6** | **2426** | **2437** | **2448** | **22** |  | 6 |  | 2437 |  |  |  | 6 |  | 2437 |  |  |
| 7 |  | 2442 |  |  |  | 7 |  | 2442 |  |  |  | 7 |  | 2442 |  |  |
| 8 |  | 2447 |  |  |  | 8 |  | 2447 |  |  |  | 8 |  | 2447 |  |  |
| 9 |  | 2452 |  |  |  | **9** | **2442** | **2452** | **2462** | **20** |  | 9 |  | 2452 |  |  |
| 10 |  | 2457 |  |  |  | 10 |  | 2457 |  |  |  | 10 |  | 2457 |  |  |
| **11** | **2451** | **2462** | **2473** | **22** |  | 11 |  | 2462 |  |  |  | **11** | **2442** | **2462** | **2482** | **40** |
| 12 |  | 2467 |  |  |  | 12 |  | 2467 |  |  |  | 12 |  | 2467 |  |  |
| 13 |  | 2472 |  |  |  | **13** | **2462** | **2472** | **2482** | **20** |  | 13 |  | 2472 |  |  |
|  |  |  |  |  |  |  |  | 2482 |  |  |  |  |  | 2482 |  |  |

### 3.2.2 5 GHz

Full Duplex capability shall be operational in these existing IEEE 802.11 5 GHz channels and bandwidths:

| **Ch. Idx** | **Min (MHz)** | **Fc (MHZ)** | **Max (MHz)** | **BW (MHz)** |  | **Ch. Idx** | **Min (MHz)** | **Fc (MHZ)** | **Max (MHz)** | **BW (MHz)** |  | **Ch. Idx** | **Min (MHz)** | **Fc (MHZ)** | **Max (MHz)** | **BW (MHz)** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | 5170 |  |  |  |  |  | 5170 |  |  |  |  |  | 5170 |  |  |
| **36** | **5170** | **5180** | **5190** | **20** |  | 36 |  | 5180 |  |  |  | 36 |  | 5180 |  |  |
| 38 |  | 5190 |  |  |  | **38** | **5170** | **5190** | **5210** | **40** |  | 38 |  | 5190 |  |  |
| **40** | **5190** | **5200** | **5210** | **20** |  | 40 |  | 5200 |  |  |  | 40 |  | 5200 |  |  |
| 42 |  | 5210 |  |  |  | 42 |  | 5210 |  |  |  | **42** | **5170** | **5210** | **5250** | **80** |
| **44** | **5210** | **5220** | **5230** | **20** |  | 44 |  | 5220 |  |  |  | 44 |  | 5220 |  |  |
| 46 |  | 5230 |  |  |  | **46** | **5210** | **5230** | **5250** | **40** |  | 46 |  | 5230 |  |  |
| **48** | **5230** | **5240** | **5250** | **20** |  | 48 |  | 5240 |  |  |  | 48 |  | 5240 |  |  |
| 50 |  | 5250 |  |  |  | 50 |  | 5250 |  |  |  | 50 |  | 5250 |  |  |
| **52** | **5250** | **5260** | **5270** | **20** |  | 52 |  | 5260 |  |  |  | 52 |  | 5260 |  |  |
| 54 |  | 5270 |  |  |  | **54** | **5250** | **5270** | **5290** | **40** |  | 54 |  | 5270 |  |  |
| **56** | **5270** | **5280** | **5290** | **20** |  | 56 |  | 5280 |  |  |  | 56 |  | 5280 |  |  |
| 58 |  | 5290 |  |  |  | 58 |  | 5290 |  |  |  | **58** | **5250** | **5290** | **5330** | **80** |
| **60** | **5290** | **5300** | **5310** | **20** |  | 60 |  | 5300 |  |  |  | 60 |  | 5300 |  |  |
| 62 |  | 5310 |  |  |  | **62** | **5290** | **5310** | **5330** | **40** |  | 62 |  | 5310 |  |  |
| **64** | **5310** | **5320** | **5330** | **20** |  | 64 |  | 5320 |  |  |  | 64 |  | 5320 |  |  |
| 66 |  | 5330 |  |  |  |  |  | 5330 |  |  |  | 66 |  | 5330 |  |  |
| 98 |  | 5490 |  |  |  | 98 |  | 5490 |  |  |  | 98 |  | 5490 |  |  |
| 100 | **5490** | **5500** | **5510** | **20** |  | 100 |  | 5500 |  |  |  | 100 |  | 5500 |  |  |
| 102 |  | 5510 |  |  |  | **102** | **5490** | 5510 | **5530** | **40** |  | 102 |  | 5510 |  |  |
| **104** | **5510** | **5520** | **5530** | **20** |  | 104 |  | 5520 |  |  |  | 104 |  | 5520 |  |  |
| 106 |  | 5530 |  |  |  | 106 |  | 5530 |  |  |  | **106** | **5490** | **5530** | **5570** | **80** |
| **108** | **5530** | **5540** | **5550** | **20** |  | 108 |  | 5540 |  |  |  | 108 |  | 5540 |  |  |
| 110 |  | 5550 |  |  |  | **110** | **5530** | **5550** | **5570** | **40** |  | 110 |  | 5550 |  |  |
| **112** | **5550** | **5560** | **5570** | **20** |  | 112 |  | 5560 |  |  |  | 112 |  | 5560 |  |  |
| 114 |  | 5570 |  |  |  | 114 |  | 5570 |  |  |  | 114 |  | 5570 |  |  |
| **116** | **5570** | **5580** | **5590** | **20** |  | 116 |  | 5580 |  |  |  | 116 |  | 5580 |  |  |
| 118 |  | 5590 |  |  |  | **118** | **5570** | **5590** | **5610** | **40** |  | 118 |  | 5590 |  |  |
| **120** | **5590** | **5600** | **5610** | **20** |  | 120 |  | 5600 |  |  |  | 120 |  | 5600 |  |  |
| 122 |  | 5610 |  |  |  | 122 |  | 5610 |  |  |  | **122** | **5570** | **5610** | **5650** | **80** |
| **124** | **5610** | **5620** | **5630** | **20** |  | 124 |  | 5620 |  |  |  | 124 |  | 5620 |  |  |
| 126 |  | 5630 |  |  |  | **126** | **5610** | **5630** | **5650** | **40** |  | 126 |  | 5630 |  |  |
| **128** | **5630** | **5640** | **5650** | **20** |  | 128 |  | 5640 |  |  |  | 128 |  | 5640 |  |  |
| 130 |  | 5650 |  |  |  | 130 |  | 5650 |  |  |  | 130 |  | 5650 |  |  |
| **132** | **5650** | **5660** | **5670** | **20** |  | 132 |  | 5660 |  |  |  | 132 |  | 5660 |  |  |
| 134 |  | 5670 |  |  |  | **134** | **5650** | **5670** | **5690** | **40** |  | 134 |  | 5670 |  |  |
| **136** | **5670** | **5680** | **5690** | **20** |  | 136 |  | 5680 |  |  |  | 136 |  | 5680 |  |  |
| 138 |  | 5690 |  |  |  | 138 |  | 5690 |  |  |  | **138** | **5650** | **5690** | **5730** | **80** |
| **140** | **5690** | **5700** | **5710** | **20** |  | 140 |  | 5700 |  |  |  | 140 |  | 5700 |  |  |
| 142 |  | 5710 |  |  |  | **142** | **5690** | **5710** | **5730** | **40** |  | 142 |  | 5710 |  |  |
| **144** | **5710** | **5720** | **5730** | **20** |  | 144 |  | 5720 |  |  |  | 144 |  | 5720 |  |  |
|  |  | 5730 |  |  |  |  |  | 5730 |  |  |  | 146 |  | 5730 |  |  |
| 147 |  | 5735 |  |  |  | 147 |  | 5735 |  |  |  | 147 |  | 5735 |  |  |
| **149** | **5735** | **5745** | **5755** | **20** |  | 149 |  | 5745 |  |  |  | 149 |  | 5745 |  |  |
| 151 |  | 5755 |  |  |  | **151** | **5735** | **5755** | **5775** | **40** |  | 151 |  | 5755 |  |  |
| **153** | **5755** | **5765** | **5775** | **20** |  | 153 |  | 5765 |  |  |  | 153 |  | 5765 |  |  |
| 155 |  | 5775 |  |  |  | 155 |  | 5775 |  |  |  | **155** | **5735** | **5775** | **5815** | **80** |
| **157** | **5775** | **5785** | **5795** | **20** |  | 157 |  | 5785 |  |  |  | 157 |  | 5785 |  |  |
| 159 |  | 5795 |  |  |  | **159** | **5775** | **5795** | **5815** | **40** |  | 159 |  | 5795 |  |  |
| **161** | **5795** | **5805** | **5815** | **20** |  | 161 |  | 5805 |  |  |  | 161 |  | 5805 |  |  |
| 163 |  | 5815 |  |  |  | 163 |  | 5815 |  |  |  | 163 |  | 5815 |  |  |
| **165** | **5815** | **5825** | **5835** | **20** |  | 165 |  | 5825 |  |  |  | 165 |  | 5825 |  |  |
|  |  | 5835 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

| **Ch. Idx** | **Min (MHz)** | **Fc (MHZ)** | **Max (MHz)** | **BW (MHz)** |
| --- | --- | --- | --- | --- |
|  |  | 5170 |  |  |
| 36 |  | 5180 |  |  |
| 38 |  | 5190 |  |  |
| 40 |  | 5200 |  |  |
| 42 |  | 5210 |  |  |
| 44 |  | 5220 |  |  |
| 46 |  | 5230 |  |  |
| 48 |  | 5240 |  |  |
| **50** | **5170** | **5250** | **5330** | **160** |
| 52 |  | 5260 |  |  |
| 54 |  | 5270 |  |  |
| 56 |  | 5280 |  |  |
| 58 |  | 5290 |  |  |
| 60 |  | 5300 |  |  |
| 62 |  | 5310 |  |  |
| 64 |  | 5320 |  |  |
| 66 |  | 5330 |  |  |
| 98 |  | 5490 |  |  |
| 100 |  | 5500 |  |  |
| 102 |  | 5510 |  |  |
| 104 |  | 5520 |  |  |
| 106 |  | 5530 |  |  |
| 108 |  | 5540 |  |  |
| 110 |  | 5550 |  |  |
| 112 |  | 5560 |  |  |
| **114** | **5490** | **5570** | **5650** | **160** |
| 116 |  | 5580 |  |  |
| 118 |  | 5590 |  |  |
| 120 |  | 5600 |  |  |
| 122 |  | 5610 |  |  |
| 124 |  | 5620 |  |  |
| 126 |  | 5630 |  |  |
| 128 |  | 5640 |  |  |
| 130 |  | 5650 |  |  |
| 132 |  | 5660 |  |  |
| 134 |  | 5670 |  |  |
| 136 |  | 5680 |  |  |
| 138 |  | 5690 |  |  |
| 140 |  | 5700 |  |  |
| 142 |  | 5710 |  |  |
| 144 |  | 5720 |  |  |
| 146 | 5650 | 5730 | 5810 | 160 |
| 147 |  | 5735 |  |  |
| 149 |  | 5745 |  |  |
| 151 |  | 5755 |  |  |
| 153 |  | 5765 |  |  |
| 155 |  | 5775 |  |  |
| 157 |  | 5785 |  |  |
| 159 |  | 5795 |  |  |
| 161 |  | 5805 |  |  |
| 163 |  | 5815 |  |  |
| 165 |  | 5825 |  |  |
|  |  |  |  |  |

## System Performance

### Maximum Effective Throughput rate per BSS

{Editor Note: Need simulation results comparing the Effective Throughput rates per unit area of WLANs without and with Full Duplex capability.

### Reduction in Latency between FD enabled STAs and AP

{Editor Note: Need empirical or simulation data to define the latency that two or more FD capable 802.11 devices can support relative to IEEE 802.11 devices that are not FD capable.}

### Hidden node mitigation

{Editor Note: Need text describing the overall improvement in performance of a BSS populated with devices that are hidden from each other.}

## Receiver Requirements

### Reflection/Echo Cancellation

In a well designed full duplex communicaions system, it is possible to enable simultaneous transmission and reception of data and control packets using the same frequency carrier. Some of the design challenges that need to be addressed in such a system are:

* The cancellation of reflected Tx signals, which may be greater in magnitude than the desired received signal. Figure 1 illustrates one such example of self interference due to a reflected impulse = .



|  |
| --- |
|  |

Figure 1: Self Interference due to backscatter

### Self-interference cancellation

Figure 2 illustrates the locations of various parasitic self-interference mechanisms present in a full duplex transceiver that need to be mitigated:

|  |
| --- |
| BB Tx  BB Rx  PA  LNA  **Antenna Interface**  DAC  ADC  Full Duplex Transceiver  Parasitic Self-Interferers |

Figure 2: Self Interference Mechanisms in a Full Duplex Transceiver

Figure 3 illustrates one potential architecture in which an analog self interference cancellation (SIC) Filter and a Digital SIC Filter have been added to a full duplex transceiver to mitigate the effects of the internal and external parasitic self-interferers that are present in any RF system.

|  |
| --- |
| BB Tx  BB Rx  PA  LNA  **Antenna Interface**  DAC  ADC  Full Duplex Transceiver  Parasitic Self-Interferers  **Digital SIC Filter**  **Analog SIC Filter** |

Figure 3: Analog and Digital SIC Filtering

An example use case, in which two Full-dulplex capable transceivers are simultaneously transmitting to and receiving from each other, is illustrated in Figure 4. Also illustrated are the magnitudes of the Transmit and Receive signals in relationship to the interference signals measured after the Analog and Digital SIC filters in each Full-duplex transceiver. {EditorNote: Need additional text here re: magnitudes of PTx1  ,PTx2  , PRx1 , PRx2  and the magnitudes of the interference signals after each stage of filtering.}

|  |  |
| --- | --- |
| Tx1  Rx1  Tx2  Rx2 | |
| **Prsi2**  **Psi2**  **PRx2**  **PTx2**  **Prsi1**  **PTx1**  **Psi1**  **PRx1**  ~35-55 dB  ~40-50 dB | |
| **PTxi =** | Transmit signal power level from each transceiver “i” |
| **PRxi =** | Received signal power level at each transceiver “i” |
| **Psii =** | Self-interference(SI) power level within each transceiver “i” |
| **Prsii =** | Residual SI level within each transceiver “i” after analog and digital BB cancellations |

Figure 4: Relative Signal Strengths as measured in two Full-duplex transceivers with SIC Filtering.

# 4.0 Technical Feasibility

## 4.1 Current instantiations of Full Duplex PHY functionality

Table 1 lists six approaches, their affiliation and their attributes for enabling full duplex PHY behavior in a wireless networking system.

Table 1: Comparison of Full Duplex PHY Approaches

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Approach 1** | **Approach 2** | **Approach 3** | **Approach 4** | **Approach 5** | **Approach 6** |
|  | Antenna Separation | Meta-materials based circulator | Antenna Polarization | Delay and Subtract | Photonics | Hybrid RF/ Photonic/ Digital Baseband |
| Bandwidth | 5MHz | 1MHz | 20MHz | 20/40MHz | 10MHz | 800MHz |
| Drift  Tolerance | Low | High | Low | Moderate | Moderate | High |
| Scatter Tolerance | No | No | No | No | No | Yes |
| Environ-ment Fluctuation | Intolerant | Intolerant | Intolerant | Intolerant | Intolerant | Tolerant |
| MIMO  capability | Limited | Limited | Yes | Yes | Limited | Yes |
| Form Factor | Antenna spacing | Small | Small | Small | Small | Chip-scale |

## 4.2 Current simulations of Full Duplex MAC functionality

A review of the current technical literature regarding MAC protocols that support the Full Duplex (FD) exchange of packets in an IEEE 802.11 network revealed an extensive bibliography of papers. Out of this extensive list, these, at the moment, three FD capable MAC protocols were selected as indications of the evolving maturity of full duplex. The criteria used to select these three protocols are listed in the first column labelled Attributes. A key attribute that is currently missing from this list of attributes is the “Performance Gain” in the presence and absence of Half-Duplex (HD) nodes in a wireless network with FD nodes present. This attribute will be added later since the performance gains reported in the papers describing each of the three FD MACs here need to be normalized so as to make fair comparisons among the three. Also note that there will probably be additional candidate FD MAC protocols added to this list as new papers are published or made known to the FD-TIG.

Table 2: FD MAC Comparisons

| **Attributes** | **S-CW Full Duplex** | **SRB-MAC** | **STR-MAC** |
| --- | --- | --- | --- |
|  | Sabanaci U. | Rice U. | Toshiba Research |
| Modifications of existing Frame Formats | 2 bits in existing MAC Hdr ctrl field; 10 bit *next\_bo* field at head of payload | Adds a 13 bit FD Hdr between the MAC Hdr and the Payload | FD Capability Info Field; 1-bit mod of reserved bits in CTS (CTS\_FD) |
| New MAC Mechanisms |  | Shared random backoff; virtual backoff; header snooping | Adaptive Tx & ACK TO |
| Supports Heterogeneous FD/HD WLANS | Yes | If HD Nodes support snooping, then Yes, else No | Yes |
| Supports Homogeneous FD WLAN | Yes | Yes | Yes |
| BiDirectional FD | Yes | Yes | Yes |
| UniDirectional FD | Yes | Yes | Yes |
| Hidden Node Mitigation | Yes via FD & FDmaster bits in MAC Hdr ctrl fld. | Via Snooping | Via RTS/CTS |
| Backwards Compatible w/ HD WiFi | Yes | If HD Nodes support snooping, then Yes, else No | Yes |
|  |  |  |  |

## 4.3 Real world Implementations of Full Duplex operations

### 4.3.1 Full Duplex DOCSIS 3.1-FDX

DOCSIS 3.1 R-PHY and DOCSIS 3.1-FDX provide yet another example of a wired protocol that borrows heavily from the wireless communications domain (e.g.11n-OFDM and 11ax OFDMA). Both DOCSIS 3.1 documents define the use of a full duplex protocol between cable modems (CM) and cable modem termination systems (CMTS) in a hybrid fiber/coax (HFC) network as illustrated in Figure 5.



Figure 5: Example Cable Network based upon DOCSIS 3.1-FDX

The goals of this specification are to:

* Increase the capacity (i.e. total available bandwidth) of the current HFC network infrastructure without replacing existing coax to-the-home/buisness with fiber-to-the-home/business
* Provide backwards compatibility for CMTSs and CMSs based upon earlier versions of DOCSIS specifications (e.g. CMTSs: 3.0, 2.0, and 1.1; CMSs:3.1, 3.0). For instance, continued support for the 16-QAM, 64-QAM, 128-QAM and 256-QAM downstream modulation schemes and the QPSK, 8-QAM, 16-QAM, 32-QAM and 64-QAM upstream modulation schemes in DOCSIS 3.0 are mandatory and required.
* Improve the scalability of hybrid-fiber-coax (HFC) network infrastructure via
  + higher modulation schemes in both the downstream and upstream data flows as defined in DOCSIS 3.1 R-PHY: For example, the addition of 512-QAM, 1024-QAM, 2048-QAM, and 4096-QAM are new, mandatory modulation schemes that are unique to DOCSIS 3.1 R-PHY and are not present in earlier versions of DOCSIS. In addition, DOCSIS 3.1 R-PHY defines these two new optional modulations 8192-QAM and 16384-QAM
  + new spectrum usage options that increase the amount of available bandwidth, while at the same time maintaining backwards compatibility with earlier versions of DOCSIS.
  + Improved energy efficiency.
* Increase bi-directional peak speeds by enabling symmetrical multi-gigabit per second data rates between the CMTS and CMs in both the downstream and upstream data flows (see Table 2). Key enabling technologies in support of this goal are ***robust echo cancellation, co-channel interference, adjacent channel interference and self-interference mitigation techniques***.

Table 3: The Evolution of DOCSIS Downstream and Upstream Data rates

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **DOCSIS 1.0** | **DOCSIS 1.1** | **DOCSIS 2.0** | **DOCSIS 3.0** | **DOCSIS 3.1** | **Full Duplex DOCSIS 3.1** |
| Highlights | Initial cable broadband technology | Added VoIP | Increased upstream data rate | Increased capacity & data rates | Continued increases in capacity and data rates | Symmetrical data flows w/ increased upstream data rates |
| Downstream Capacity | 40 Mbps | 40 Mbps | 40 Mbps | 1 Gbps | 10 Gbps | 10 Gbps |
| UpStream Capacity | 10 Mbps | 10 Mbps | 30 Mbps | 100 Mbps | 1-2 Gbps | 10 Gbps |
| Production Date | 1997 | 2001 | 2002 | 2006 | 2013 | 2017 |

A major Multi-system Operator (MSO) is currently field testing a hybrid RF/Photonic analog frontend based upon the requirements specified in the DOCSIS 3.1-R-PHY and DOCSIS 3.1-FDX specifications. Key test items of this field test system, as illustrated in Figure 5, are support for:

* Independentlly configurable downstream OFDM channels in which each channel may occupy a spectrum of up to 192 MHz with either 7680, 25 kHz subcarriers or 3840, 50 kHz subcarriers encompassing the frequency range between 108MHz and 684MHz (e.g. three 192 MHz OFDM channels);
* Independently configurable upstream OFDMA channels in which each channel may occupy a spectrum of up to 95 MHz with either 3800, 25 kHz subcarriers or 1920, 50 kHz subcarriers encompassing the frequency range between 108 MHz and 684 MHz (e.g. six 95 MHz OFDMA channels).
* Full duplex functionality between the CMs and CMTS, which is dependent upon the implementation of effective echo cancellation techniques to mitigate
  + Adjacent Leakage-interference (ALI)
  + Adjacent Channel Interference (ACI)
  + Co-Channel Interference (CCI)
* Backwards compatibility with CMs and CMTSs based upon earlier versions of DOCSIS.

Preliminary results from this field test are indicating that the Hybrid RF/Photonics analog frontend is meeting/exceeding the DOCSIS 3.1-R-PHY requirements for

* Echo cancellation at each CM of at least 35 dBm, which is effectively mitigating the effects of
  + Adjacent Leakage-interference (ALI)
  + Adjacent Channel Interference (ACI)
  + Co-Channel Interference (CCI)

# 8.0 Economic Feasibility

Over the past two-plus decades, each IEEE Wi-Fi group that proposed an addition to the IEEE 802 LMSC standard provided evidence for the economic feasibility of their proposal. Evidence such as: balanced costs, known cost factors, installation costs, operational costs and estimated market size. In keeping with that tradition, the FD-TIG provides its perspective for each of these items:

1. Balanced costs (infrastructure versus attached stations)

While there will be an initial small cost increment for each Full Duplex enabled access point, infrastructure utilization will be increased significantly by the addition of Full Duplex, which will enable each access point to handle more client STAs and thereby either reducing or removing the need to add and install more access points. This savings far outweighs the added cost to purchase and install new access points. For user devices, there will similarly be a small cost increment that will be no different than that encountered during a typical upgrade cycle with performance enhancements such as from 802.11n to 802.11ac or 802.11ac to 802.11ax. Depending upon the implementation, there can also be some component savings (e.g. removal of some filters/diplexers), thus offsetting the total cost when adding full duplex capability.

1. Known cost factors

Support of the proposed standard will likely require a manufacturer to develop a modified radio, modem and firmware. This is similar in principle to the transition between IEEE 802.11n and IEEE 802.11ac as well as in previous iterations of IEEE 802.11 enhancements. By utilizing existing high-volume IC wafer, packaging, and testing facilities, devices that implement Full Duplex capable PHYs are expected to be of similar cost to current front end/ filter solutions.

1. Consideration of installation costs

Since Full Duplex AP\_s and STA\_s are required to be backwards compatible with earlier versions of installed dot\_11 devices, the installation of Full Duplex enabled AP\_s and STA\_s will follow a ramp function instead of a step function thereby minimizing the cost of installation.

1. Consideration of operational costs (e.g. energy consumption)

Devices that implement Full Duplex are expected to require similar physical and electrical connections to existing front end and standard RFIC devices. Power consumption and thermal requirements are also expected to be similar to standard RFIC / filter solutions.

1. Market size:

The market size for Full Duplex enabled Wi-Fi chipsets is expected to be 500M units in 2021 and 800M units in 2022, which equates to 20% of the combined 802.11ac and 802.11ax market in 2021 and 30% of the combined market in 2022. These market projections are derived from a WFA sponsored ABI forecast for the volume of Wi-Fi chipsets to be delivered as illustrated in Figure 6. In addition, it is assumed that pre-standard Infrastructure solutions could be available before completion of the standard to help drive market learning, uptake and cost reduction.

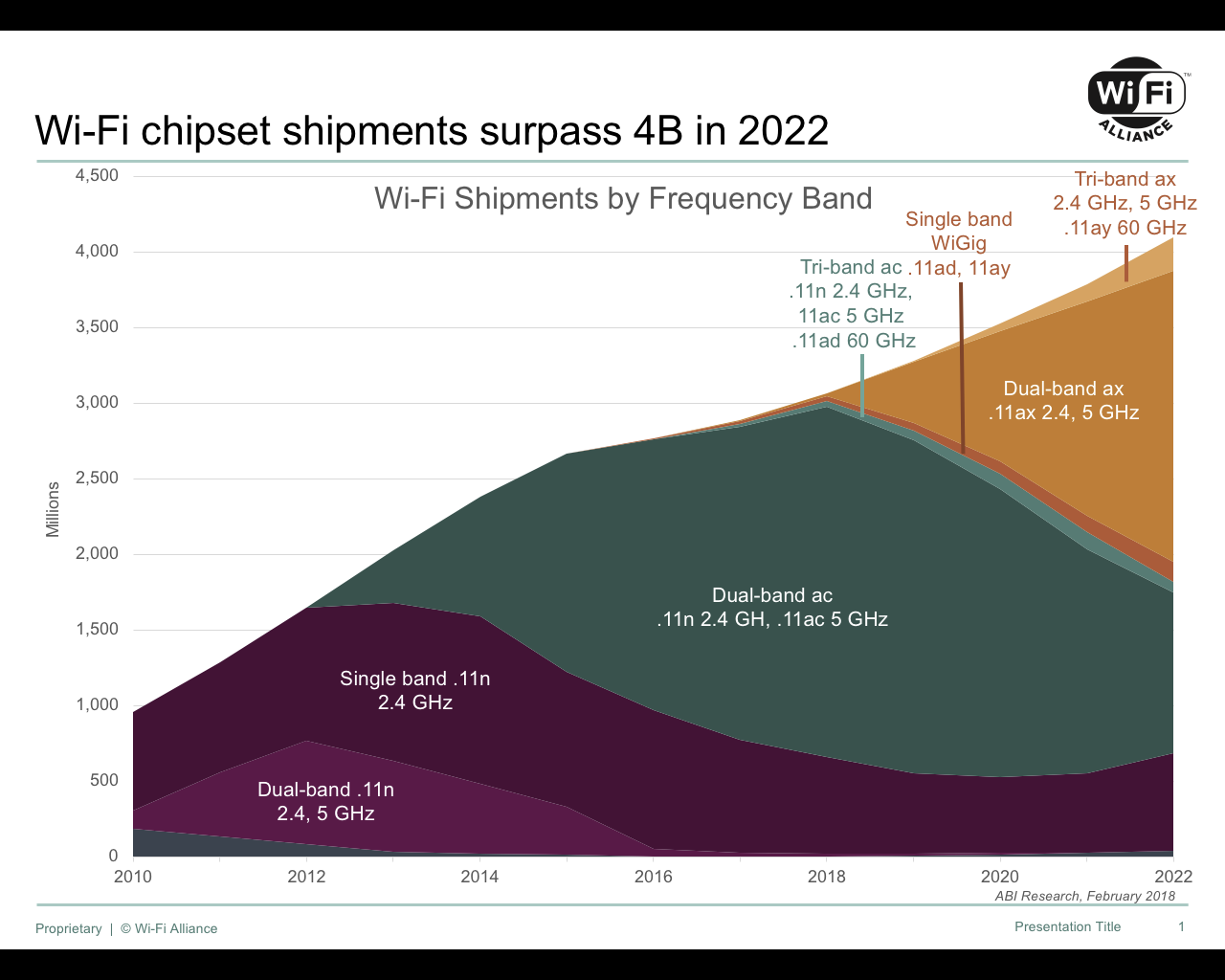


Figure 6: Projected Wi-Fi chipset shipments

# 9.0 Recommendation(s)

EditorNote: need text here.}

## References:

[1] Ref 1

[2] Ref 2

[3] Ref 3