BSS Coloring

How to Reduce CCI in Dense Environments

CWNE Candidate Paper

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Introduction

Wi-Fi uses an unbounded environment, a CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) protocol used to minimize collisions and to keep the channel clear for only one sender or transmitter at a time. It also provides extra time to acknowledge packets received. This process is performed rather than reducing channel bandwidth because of excess collisions, which result in undelivered information that must be retransmitted. High retransmission rates due to collisions would result in significantly reduced throughput and increased latency in the channel.

In all IEEE 802.11 standards, the technique of allowing one talker (sending packets) and maintaining others silent within the channel is essential. The silenced stations (STAs) are watching their backoff timers to have the opportunity to talk (send packets) and listening for channel activity. This listen-before-you-talk mechanism is a key function in the success of the Wi-Fi technology.

In this paper, I will discuss the new mechanism of BSS coloring and how it manages excess delays due to multiple BSSs existing in the same channel, or CCI (Co-Channel Interference), and how a station and access point can differentiate between users connected to other access points on the same channel as opposed to those connected to the same AP on the channel.

Managing Wireless 802.11 Channel Access

In Wi-Fi we can’t send and receive data at the same time. It is a half-duplex environment so when a transmission happened the ACK (acknowledgement) frame must be received to inform the transmitter it was received well on the other side, that’s because transmitters can’t detect a collision in the RF environment, so avoiding it is more efficient.

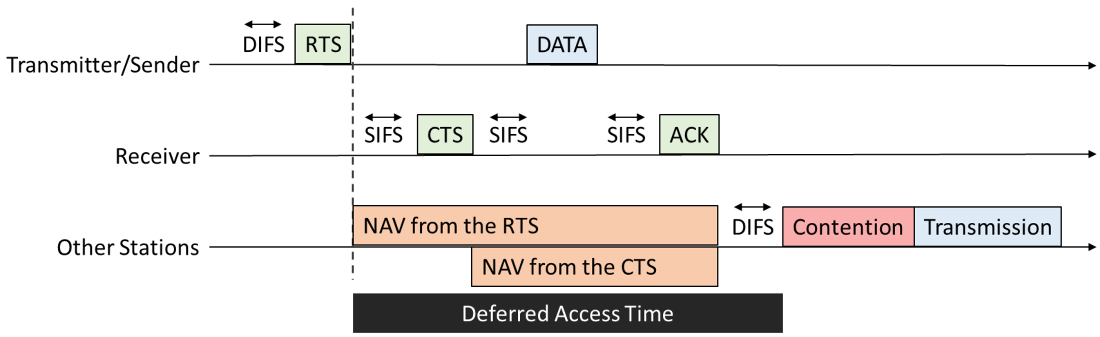
In IEEE802.11, the fundamental access method is DCF (Distributed Coordination Function), many other enhanced methods were introduced in later amendments, I am not going to discuss here, and my aim is to show how the access method basic work is.

A carrier sense mechanism is used to make clear channel assessment and then the winner of the medium can transmit, and this can happen with what is called CCA (clear Channel Assessment).

CCA uses two types of assessments:

- Energy Detect (CCA-ED)
  Stations detect RF energy in the AIR, and by the IEEE 802.11 standard, the threshold for the detected energy should be 20 dB above the signal detect CCA-SD threshold. Unfortunately, those measurements can be different depending on the electronic sensitivity of the receiver.

- Signal Detect (CCA-SD)
  Sometimes called Preamble Detect (PD) and here stations listen to any 802.11 frames. Then, from the duration field (the station must demodulate received signals to decode the duration field) it can know how much time it must wait until this transmission ends, including delays and frames after the current frame. The detected signal should typically be 4 dB above noise floor.

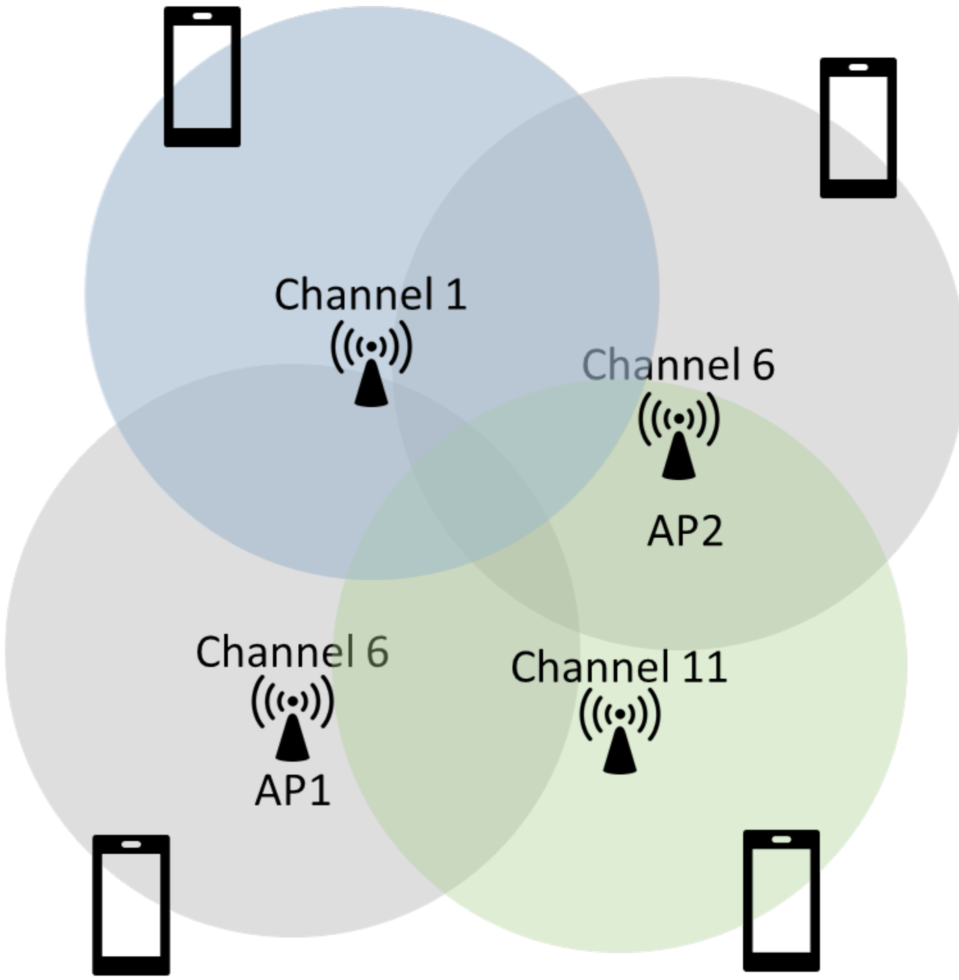


Backoff and NAV timers used in the contention process are pictured above.

After any of the previously mentioned signal detection methods detected a signal or RF energy, the station will backoff for an arbitrary period and use the NAV (Network Allocation Vector). The NAV is a timer based on the duration of the ongoing transmission period plus the interframe spacing and the ACK frame or Block ACK frame based on the duration field value. If an ACK frame is not heard in the medium then a collision has occurred and backoff timers will increase for all station to rearrange the medium.

In the RTS/CTS controlled medium a SIFS interframe spacing is used between data and Ack frames to manage and control the process and maintain no collisions or fewer collisions.

All of this happens in one channel. So if we ask ourselves what will happen if two access points close to each other are transmitting on the same channel, then the whole environment on this channel must contend on the same medium. This reality means that all stations, with the addition of to two access points, will have to be silent when a station is transmitting or talking.



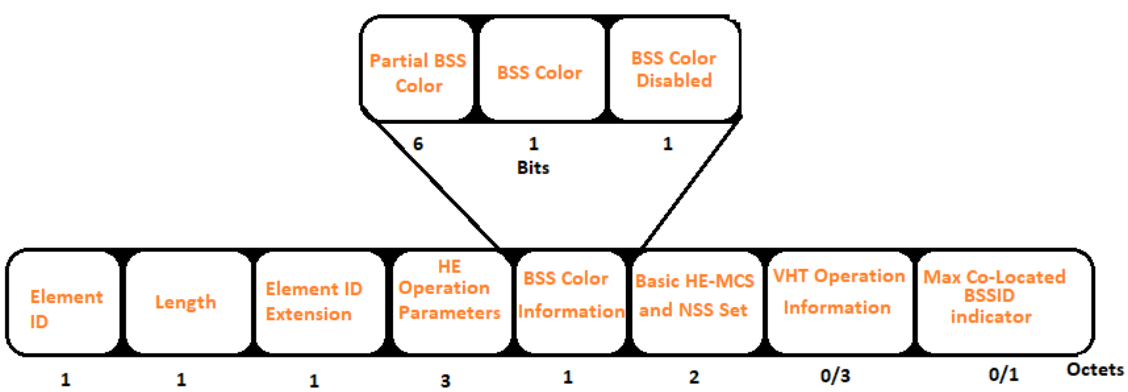
To explain the image above, access point 1 (AP1) and AP2 are transmitting on channel 6 on 2.4 GHz (2437 GHz), and they can hear each other. So, in this case they will contend on the same medium or channel, and if each access point has four connected stations, then each access point will see four locally-connected stations plus up to five stations for the other access point (here, the access point will be considered as a station for the other access point) and its locally-connected stations. Note that AP-1 may not see all the stations associated with AP-2 if those stations are out of range for AP-1.5 This configuration will reduce the performance of the devices participating in the channel because of that which is called "contention overhead" and more collisions may occur as well. More collisions are likely because AP-1 may not hear all of AP-2's associated stations and vice-versa. The result is that a station may be transmitting to AP-2, but AP-1 cannot hear it, so it transmits to one of its associated stations. Given that AP-2 can hear AP-1, the transmission from AP-1 results in a collision between AP-2's associated station transmission and the transmission from AP-1. The collision actually occurs at AP-2 in this case.

The new IEEE 802.11ax standard has introduced a new technique to diminish these kinds of issues and it is called BSS-Coloring. I will explain BSS Coloring more in the coming sections.

BSS Coloring

BSS Color was first introduced in standard IEEE802.11ah-2016 amendment (which primarily introduced Sub-1 GHz Wi-Fi, also called Wi-Fi HaLoW) and it is a technique used to identify overlapped BSSs (Basic Service Sets) in a channel and abbreviated as OBSS.

This technique also used in the new standard of Wi-Fi 6 IEEE802.11ax for all bands 2.4 GHz, 5 GHz, and 6 GHz. The image below shows how the HE Operation Element header is structured for BSS Color:



And by looking to the frame bits of the BSS Color Information you can find that it is an identifier for a number between 1 to 63, and this can identify for 63 Basic Service Sets.

Each identifier number can discriminate one BSS radio from another radio on the same channel by the color number (1-63), but if the color number is identical to another BSS here, we call it an intra-BSS frame, and for the different BSS color then stations will consider in an inter-BSS frame.

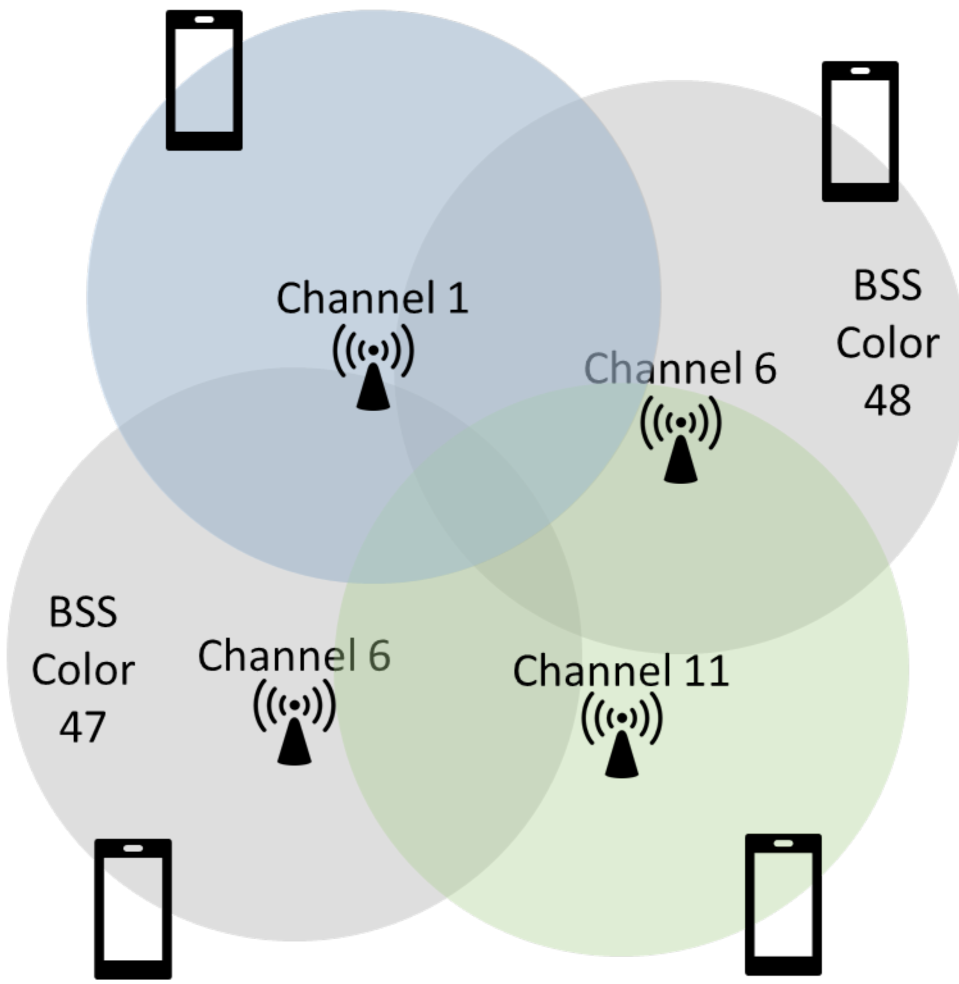
BSS color uses both PHY and MAC sublayer, and from here you can find the BSS Color identifier in the preamble, which contain 6-bits for this field. Therefore, the BSS Color can be identified as long as the PHY header can be demodulated, which is transmitted at a very low data rate for easier demodulation.

CCA Clear Channel Assessments may vary based on RF receiver electronics sensitivity and thus may influence the decisions of hearing activity in the AIR and then transmitting and causing collisions in some cases, but the introduction of BSS Coloring reduces that and makes the CCA more adaptive to the environment measurements. This technique, which may be used in the newer IEEE 802.11ax devices, where the values of signal detection thresholds become more tolerant when inter-BSS frames are heart and result in increased BW available and more efficiency in many cases.

How BSS Coloring Reduces Wi-Fi CCI

As in my basic explanation of the contention operation before, and when a station needs to transmit, it listens to the medium first and then it will transmit based on CCA (Clear Channel Assessment), and you can imagine how much this will impact the station transmissions and access to the medium based on how many other stations are in the access point BSS coverage area. In additional, traditional access methods required deferring to OBSS transmissions as well, regardless of their signal strength (assuming it was over that of the PHY threshold for signal detect).

With the introduction of BSS Coloring, the stations can now differentiate between their BSS and other overlapping BSSs that have a different color value, so the station in BSS Color 47 will not be silent when station in BSS Color 48 is accessing the medium and the signal is seen with a stronger power level than would be allowed for an intra-BSS frame. This will decrease the impact of Co-Channel interference and provide more data bandwidth for more stations, theoretically. We have not seen much of it "in the wild" at this point, but the theory indicates its value.



In high-density environments, such stadiums, auditoriums, and large venues, the use of such techniques may have a helpful impact and make the deployment of wireless services (Wi-Fi) much more efficient with the reuse of frequency at closer distances than one could implement previously.

When a station is listening to the medium, it reads the preamble (PHY level) of the frame and finds the BSS Color different than the one to which it is connected; it will ignore the transmission, if it is below the strength threshold for inter-BSS frames, and suppose the medium is clear to send. It will typically send an RTS then follow with data after an ACK from the access point.

This method allows the stations to transmit in the presence of signals from another OBSS wherein it could not in the past. The potential for increased efficiency is obvious as is the potential for new problems, such as collisions with devices at the edge of the OBSS cell. Careful design can prevent or minimize such collisions.

But what if the station listened and found a transmission for the identical BSS Color from a far access point, what is the action then? Well, in this case the station will report a BSS Color collision for the access point, then the access point will report to the controller or cloud which is responsible for managing the RF environment; this leads to the access point changing its BSS Color ID. In this case, which is rare for the relatively large number of BSS Color IDs - up to 63 Color IDs - but in some cases or deployments it may happen, particularly in very high-density areas.

Conclusions

IEEE 802.11ax has many functions and techniques that enhance and increase the utilization of RF medium, and this leads to higher real user throughput available for use.

At this point of in the evolution of 802.11, we are taking another important step. If we look back to the early amendments of IEEE 802.11, we see how much change in RF medium access were made and more can be done in the future.

BSS Color is one of those changes and has the potential to significantly impact our networks. Given that a station can transmit, even in the presence of signals from distant BSSs, the efficiency of the network can be increased. However, it is important to note that one must design the network well to ensure that the BSS Color-based transmissions to not cause significantly increased collision rates that would counter any efficiencies gained. This can be achieved through careful inter-BSS threshold configuration and thoughtful RF design within the space.