**Before the**
**FEDERAL COMMUNICATIONS COMMISSION**
**Washington, D.C. 20554**

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|---|---|---|
| In the Matter of | ) | |
| | ) | |
| Use of the 5.850-5.925 GHz Band | ) | ET Docket No. 19-138 |
| | ) | |
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**FORD MOTOR COMPANY REPLY COMMENTS ON THE USE OF THE 5.850-5.925 GHZ BAND**


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Ford Motor Company (Ford), the largest producer and exporter of motor vehicles in the United States, with offices at One American Road, Dearborn, Michigan 48126-2798, replies to comments submitted in response to the Notice for Proposed Rulemaking ET Docket No. 19-138, FCC 19-129 (rel. Dec. 17, 2019) ("*NPRM*"). In addition, Ford participated in the development of the reply comments submitted by 5G Automotive Association (5GAA), Intelligent Transportation Systems of America (ITSA), Alliance for Automotive Innovation and thereby, incorporates by reference those comments in our reply comments.

## I. EXECUTIVE SUMMARY

Ford once again commends the Commission for recognizing C-V2X as the ITS technology of the future and proposing the upper 20-30 MHz of the 5.9 GHz Band for C-V2X operations. The initial comments that were filed from several automotive OEM's and telecommunication companies in this proceeding clearly demonstrate support for the inclusion of C-V2X in the band. Industry associations such as the Alliance of Automotive Innovators, the Intelligent Transportation Society of America, and the Highway Users Association also suggest that C-V2X should be allowed to operate within the band. Ford has announced its intention to begin deploying C-V2X in its U.S. vehicles beginning in 2022. Given the lead time that is required in order for us to meet this commitment it is imperative that C-V2X be granted access to the upper 20 MHz of the band either through an expeditious completion of this NPRM that would conclude by this summer, or by granting a waiver for access until the NPRM is concluded.

While securing the upper 20 MHz for C-V2X is critical, in order for that portion of the band to be usable it must be free from interference. Hence, the rulemaking must provide adequate protection for ITS applications. We agree with many of the comments that were filed that the proposed NPRM rules for protection of the ITS portion of the 5.9GHz band may not be sufficient. We recommend changes to these rules to effectively minimize interference in the upper portion of the band. Moreover, we believe that expedited testing must be conducted to validate any proposals for unlicensed use of the 5.9GHz band.

Ford analyzed both the Wi-Fi Alliance and 5GAA proposals for Out-of-Band Emissions (OOBE). Test results show that the Wi-Fi Alliance proposal fails to protect C-V2X in the entire upper 30 MHz of the 5.9 GHz band. In contrast, the 5GAA proposal provides protection in the upper 20 MHz of the band but only if devices remain indoors. Neither proposal can protect the

lower 10 MHz of the proposed ITS band. Moreover, we demonstrate that some popular applications that utilize Radio Local Area Network (RLAN)-will have a high probability of collision with Basic Safety Messages (BSM)s even if their duty cycles are low.

There appears to be overwhelming support to preserve all 75 MHz of the 5.9 GHz band for ITS. In our opinion, this should include not only provisioning the upper 20 MHz for C-V2X, but also providing an additional 40 MHz for advanced C-V2X applications. We believe that retaining the entire 5.9 GHz for ITS applications is needed to ensure our country's global competitiveness and leadership in this space, but also to preserve global harmonization given that most regions utilize the 5.9 GHz band for ITS (US, EU, and China).

We are encouraged with the FCC's recent approval of 1200 MHz of spectrum for unlicensed use in the 6 GHz band. It appears that this would negate the need for a mere 45 MHz in 5.9 GHz band and creates a unique opportunity to meet the needs of unlicensed without sacrificing the benefits of ITS for the greater good of society.

Ford is aware of the recent announcement by the Alliance of Automotive Innovators to commit to 5 million units of ITS radios in operation within 5 years if all 75 MHz of the 5.9 GHz band is maintained for ITS. Given the magnitude of Ford's C-V2X deployment and the benefits of ITS network effects, Ford believes this industry commitment will encourage other automotive OEM's, as well as road operators, to declare their own C-V2X deployments, thus creating a broader network of connected vehicles and infrastructure.

Finally, Ford believes that the greater connectivity enabled by leading ITS technologies like C-V2X will help us to realize the promise of a truly interconnected and automated mobility eco-system. Moving people, goods, and facilitating commerce in a safe, efficient, and timely manner will be critical as our urban centers become denser and we seek ways to improve

carrying capacity beyond building more roads. The societal benefits go beyond possible accident mitigation and improved orchestration of movement and will likely include reduced carbon emissions as well. We believe C-V2X is critical to realizing this future, and as such, encourage the Commission to quickly approve the use of C-V2X in the 5.9 GHz band and ensure there is available spectrum in the future for its transition to 5G and advanced use cases like autonomous vehicles.

## II. CONSENSUS SUPPORT FOR C-V2X AND PRESERVATION OF THE ENTIRE 5.9 GHZ SPECTRUM FOR ITS

### A. Ford believes the FCC should move immediately to allow C-V2X in the upper 20 MHz of the 5.9 GHz band.

The record now shows there is broad support by automotive OEM's to allocate the upper 20 MHz of the 5.9 GHz band for C-V2X. This can be done either through an expeditious NPRM or by granting the previously filed 5GAA waiver request that was supported by several automotive OEM's which included Ford, GM, FCA, BMW, and Audi. There has also been broad support from numerous telecommunications companies and industry associations who stand ready to support C-V2X deployment. Allowing C-V2X in the band will provide the certainty the private sector is seeking for automotive OEM's and technology companies to both announce and continue planned deployments. It will also provide clarity for federal and state DOT's to plan future infrastructure investments.

We believe that C-V2X is ready for deployment now and is the only technology that has a pathway to 5G. We have done extensive testing on C-V2X and are convinced of its merits and superiority relative to other ITS technologies. This is what led us to commit to begin deployment of the technology in our vehicles starting in 2022. Any delays to allowing C-V2X in the 5.9 band beyond the NPRM process itself will only further put off deployment of a potential safety technology.

### B. Ford and a majority of key industry stakeholders support preserving all 75 MHz of the 5.9 GHz band for ITS applications.

We believe that an overwhelming majority of the 75 MHz in the 5.9 GHz band will ultimately be needed for C-V2X. While we believe we have made a case for C-V2X in the upper 20 MHz of the band, there is an additional need for 40 MHz of spectrum for advanced C-V2X

applications. This would include facilitating transition of C-V2X's direct communication capability to 5G and support use cases beyond vehicles themselves which would include vulnerable road users such as pedestrians, scooters and bikers, as well as advanced infrastructure to support an autonomous future. This 60 MHz of spectrum would be utilized to bring about a fully connected mobility eco-system in the future.

In addition, the Commission's recently passed 6 GHz NPRM has allocated 1200 MHz of spectrum for unlicensed use. This development should be able to meet any unlicensed Wi-Fi needs for the foreseeable future while preserving the additional 40 MHz for advanced C-V2X applications. This will also allow the 75 MHz band to operate free of any harmful interference.

Furthermore, the 5.9 GHz band is internationally recognized as an ITS band. As ACEA/CLEPA commented, "many countries have already designated the same or a similar amount of spectrum in the 5.9 GHz band for V2X communications, including Canada (75 MHz), Mexico (75 MHz), Australia (70 MHz), South Korea (70 MHz), Singapore (50 MHz), CEPT member states (70 MHz), Europe (70 MHz), and Russia (70 MHz)." It is therefore important that technologies like C-V2X and its advanced forms be kept within that band to assure global harmonization for deployments. Aligning both technology and deployment schedules with major trading partners is important to the transportation industry. This will ensure OEM's can leverage economies of scale across their supply chains, while also maximizing the ability to manufacture vehicles domestically and being able to export them to as many markets as possible.

## III. THE 5GAA PROPOSED OUT-OF-BAND-EMISSION LIMITS FOR INDOOR-ONLY UNLICENSED DEVICES PROTECT C-V2X OPERATIONS IN THE UPPER 20 MHZ

The 5.9 GHz NPRM [1] solicited comments on out-of-band emission (OOBE) limits (masks) for devices operating in the proposed U-NII-4 band, which would be directly adjacent to the new ITS allocations. The Wi-Fi Alliance and the 5G Automotive Association (5GAA), both submitted comments with proposed OOBE limits in the ITS band to protect the ability of vehicles to receive Basic Safety Messages (BSMs) [9], [13]. We have analyzed the OOBE limits proposed by the 5G Automotive Association (5GAA) and the Wi-Fi Alliance by conducting our own laboratory testing and through joint testing with a consortium of automotive OEMs and Qualcomm, Inc. at CAMP LLC [14]. Our analysis identifies the minimum isolation needed between C-V2X receivers and U-NII-4 devices operating under the proposed rules to protect ITS applications. The results show that outdoor Wi-Fi usage under the proposed OOBE limits will create harmful interference to C-V2X operations and must not be allowed as sufficient isolation cannot be provided. Results also show that of the two proposals, the one made by 5GAA which restricts Wi-Fi operations to indoor use only, provides acceptable protection for C-V2X operation in the upper 20 MHz of the band. In addition, our measurements demonstrate that C-V2X operation in the lower 10 MHz of the proposed allocation is severely affected by both proposals. Adopting either the 5GAA or Wi-Fi Alliance proposed OOBE limits leaves only 20 MHz of spectrum free from interference available for ITS.

We therefore provide evidence to these claims as follows:

- We first introduced OOBE proposals that were put forward during the NPRM comment period.

- We then presented results of the laboratory testing performed by Ford followed by results from testing performed by the CAMP LLC C-V2X project [14]. We used these results to evaluate the proposed out-of-band emission limits for unlicensed devices.

In Figure III-1 we show three OOBE limit proposals analyzed in this section. The Wi-Fi Alliance has proposed separate OOBE limits for indoor and outdoor devices, while the 5G Automotive Association has proposed a single mask with the additional requirement that U-NII-4 devices operate indoor only [9], [13]. The Wi-Fi Alliance proposed indoor limits are 20 dB higher than their proposed outdoor limits, with the justification that building entry loss (BEL) of at least 20 dB which will effectively result in similar outdoor emissions.

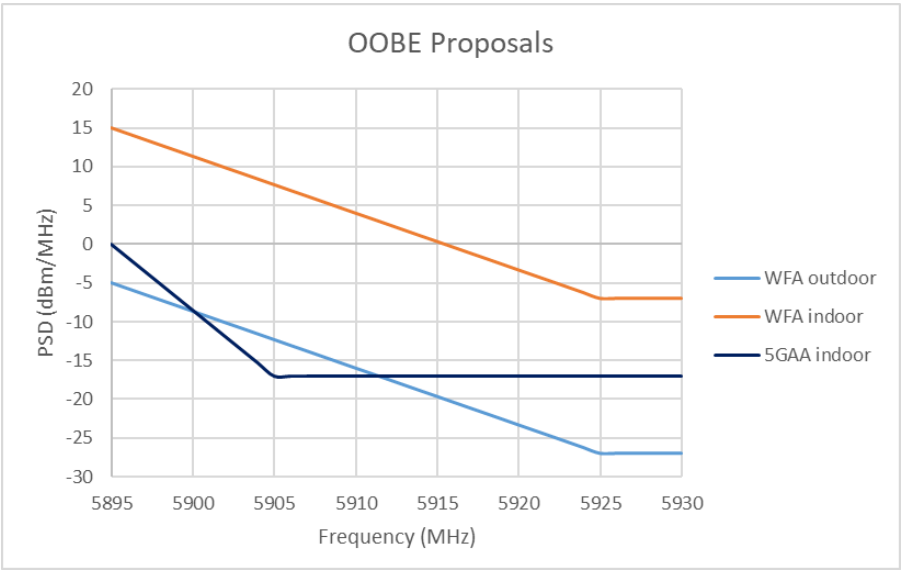


Figure III-1. Peak OOBE limit proposals from the Wi-Fi Alliance and the 5GAA. The 5GAA proposes indoor usage only.

The above proposals are specified as maximum unwanted emissions, which are measured using a peak detector, as per FCC KDB 789033 [11]. The 5GAA further specified a 10 dB lower

OOBE limit for average levels measured using an RMS detector [13]. If we assume that the OOBE peak-power limits in Figure III-1 are 10 dB above the corresponding RMS values, then the average OOBE power emitted in each of the two V2X channels is shown in Figure III-2.

| OOBE proposal | OOBE levels (dBm) | |
|---|---|---|
| | CH180 | CH183 |
| WFA indoor | 11.8 | 5.2 |
| WFA outdoor | -8.2 | -14.8 |
| 5GAA indoor | -6.0 | -14.0 |

Figure III-2. Total adjacent/non-adjacent channel power levels at the Wi-Fi transmitter in channels 180 and 183 assuming each signal's OOBE follows the mask exactly.

As shown in Figure III-1, the proposal from the Wi-Fi Alliance [9] contains the following OOBE limits for devices operating outdoors:

- All emissions at or above 5.925 GHz shall not exceed an EIRP of −27 dBm/MHz increasing linearly to -5 dBm/MHz at 5.895 GHz.

These proposals were tested using the approach described in Ford's NPRM comments [8]. In this a Wi-Fi interference source, C-V2X transmitter and C-V2X receiver are connected through cables, and variable attenuators are used to vary the path loss between the interference source and receiver, and between the C-V2X transmitter and receiver. A similar test was conducted by CAMP LLC and is detailed in [14]. Figure III-3 depicts the power spectral density (PSD) of the generated Wi-Fi signals in CH171 (80 MHz) that was part of the laboratory test. This was measured as per FCC KDB 789033 Procedure II.G.5 [11] to determine compliance with the proposal. The orange line represents the Wi-Fi Alliance proposed OOBE limits, which also comply with the FCC proposed limit of -27 dBm/MHz at and above 5925 MHz[1].

[1] *We ran the test with the Wi-Fi interferer transmit power at 4.7 dBm and consequently measured 20 dB lower adjacent/non-adjacent channel power levels compared to the values in*

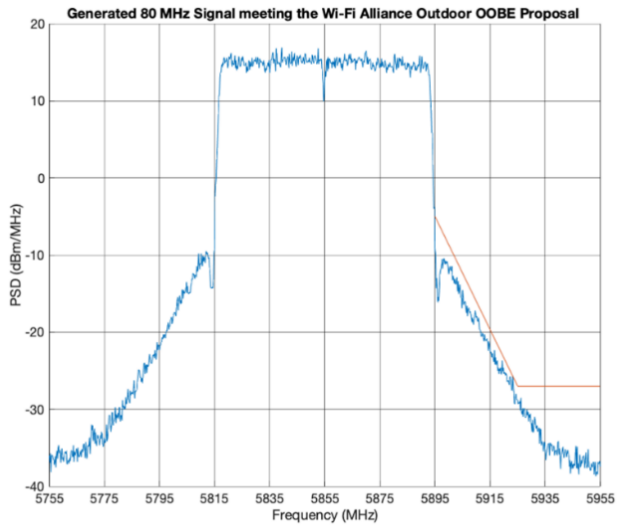


Figure III-3: Peak power spectral density of the Wi-Fi signal in 80 MHz channel 171 (blue), shown with the proposed Wi-Fi Alliance outdoor emission limits (Orange)

Figure III-4 shows measured average channel power levels in the lower 10 MHz, (CH180, 5895-5905 MHz) and upper 20 MHz (CH183, 5905-5925 MHz) of the proposed allocation for the signal in Figure III-3. The average power in each channel is slightly smaller than predicted by mask-based computation in Figure III-2 because there is a small gap between the out-of-band emissions of the Wi-Fi signal and the Wi-Fi Alliance outdoor OOBE limits.

| Power levels (dBm) | | |
|---|---|---|
| CH171 inband | CH180 adjacent | CH183 non-adjacent |
| 24.7 | -12.0 | -16.9 |

Figure III-4. Adjacent/Non-Adjacent channel interference power levels in CH180 and CH183 from 80 MHz Wi-Fi signal in channel 171, complying with the Wi-Fi Alliance-proposed outdoor OOBE mask.

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*Figure III-4. Since our goal is to show impact close to the OOBE limits, we assume 24.7 dBm transmit power and compensate for this by introducing a fixed offset of 20 dB to the path loss value between the Wi-Fi interferer and the C-V2X receiver in Figure III-5. From the receiver viewpoint, this is equivalent since the interference level is the same (20 dB higher transmit power and 20 dB higher path loss).*

The signal shown in Figure III-3 was used as an interference source in the bench test to determine the impact on C-V2X communication in CH183 when devices operate under the Wi-Fi Alliance proposed OOBE limits for outdoor devices. The results of this test are depicted in Figure III-5, which shows the impact of Wi-Fi interference on receive Packet Error Rate (PER) of C-V2X communications at varying levels of path loss (isolation between the Wi-Fi interference source and the C-V2X receiver. From the figure, it can be concluded that a Wi-Fi transmitter must have a path loss (isolation) of at least 78 dB to the C-V2X receiver to ensure no harmful interference to C-V2X reception[2]. Figure III-6 shows a plot of the results of the test for all three proposed limits conducted by CAMP LLC in CH183 and can be used to reach a similar conclusion for the Wi-Fi Alliance outdoor proposal.

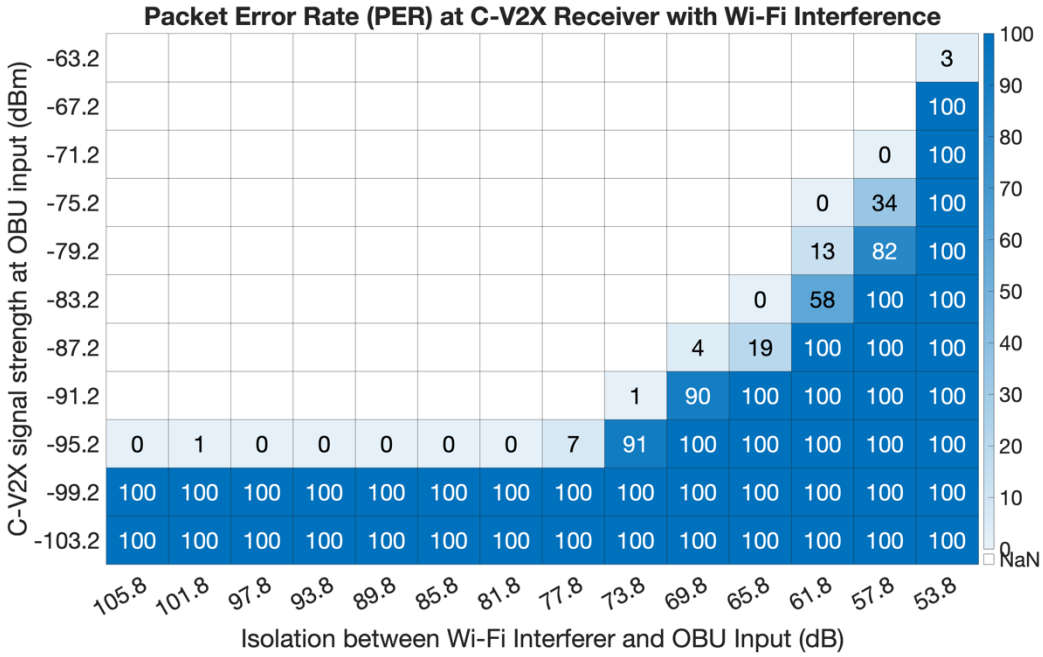


Figure III-5: Impact of out-of-band-emissions from Wi-Fi in 80 MHz channel 171, complying with the Wi-Fi Alliance-proposed outdoor limits, on C-V2X in Channel 183.

[2] Using this path loss and the CH183 OOBE level of -16.9 dBm in Figure III-4, we obtain –94.9 dBm as the interference level at the C-V2X receiver, which translates to -107.9 dBm/MHz as the maximum tolerable receive interference level matching our results in [8].

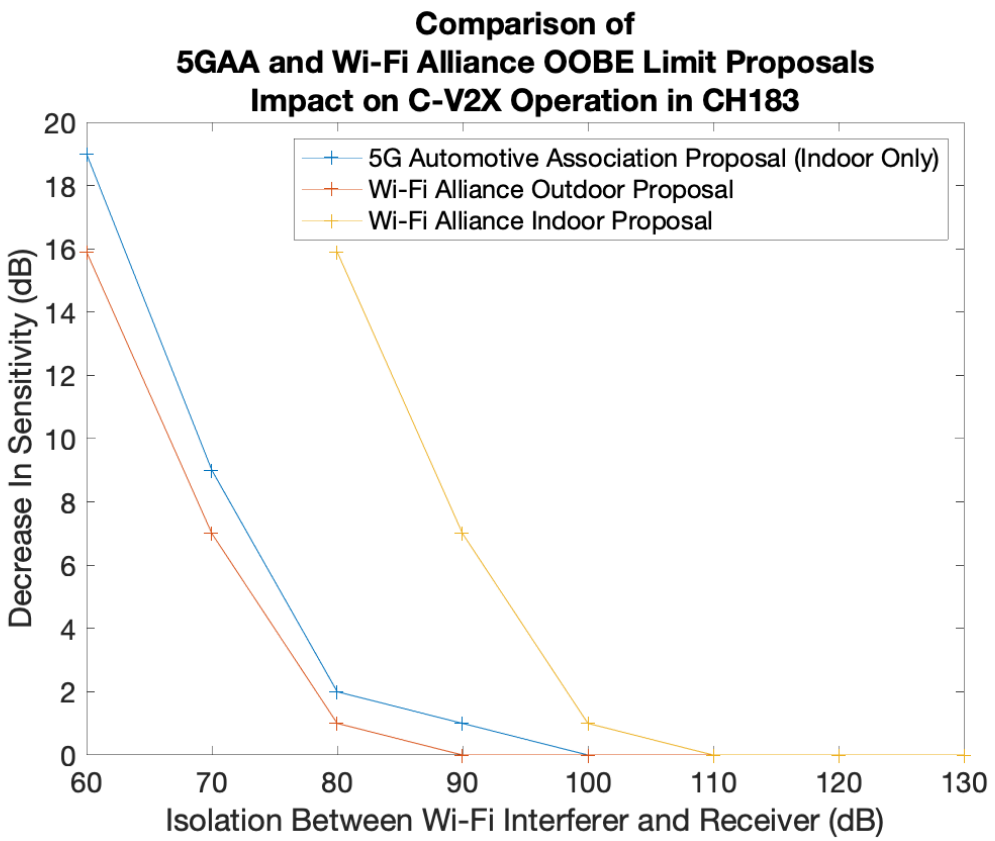


Figure III-6: CAMP LLC results for impact of the 5GAA and Wi-Fi Alliance OOBE limit proposals on C-V2X receiver sensitivity in CH183

The path loss needed to avoid harmful interference shown by the results of the tests is much higher than can be guaranteed between unlicensed devices operating outdoors and vehicular C-V2X stations. In Ford's previous field test, which included an in-vehicle interference source, only 60 dB path loss was measured from the interference source to C-V2X antennas on the roof of the vehicle. Depending on the placement of the C-V2X antennas and an unlicensed device operating in the vehicle, this path loss could be as low as 34 dB [12, 13]. Even assuming a path loss of 60 dB, the harmful interference to a receiver's ability to receive Basic Safety Messages would be significant. CAMP LLC results in Figure III-6 show that with the Wi-Fi

Alliance outdoor limit and a path loss of 60 dB, receiver sensitivity is degraded by 16 dB. This is supported by the Ford results shown in Figure III-5.

A degradation in receiver sensitivity of 16 dB would severely reduce C-V2X communications range, which in realistic non-line-of-sight situations would impair safety applications. An example of this is Ford's intersection test described in its initial comments in this proceeding [8]. As a result, it can be concluded that Wi-Fi Alliance proposed outdoor OOBE limits would not protect ITS applications.

The Wi-Fi Alliance proposed indoor emission limit is 20 dB higher than the Alliance's proposed outdoor limits. Even when the 20 dB building entry loss assumed by their proposal is taken into account, sufficient isolation will not exist to prevent harmful interference to C-V2X operations. Assuming a 20 dB building entry loss, 80 dB further isolation to C-V2X receivers from unlicensed devices operating under the proposal must exist to avoid harmful interference. For this to be provided by free space path loss, the indoor devices must be separated from C-V2X users on the road by a distance of at least 40 m. As it is impossible to guarantee this amount of separation, the adoption of this proposal would lead to situations in which C-V2X users would be exposed to harmful interference from devices operating indoors. Further analysis of this proposal is shown in Section V where we consider aggregation effects.

Additional tests were conducted by CAMP LLC to evaluate the impact of the 5GAA OOBE limit proposal which assumes indoor operation of unlicensed devices [14]. Figure III-6 contains a plot of the test results for the impact of the 5GAA proposal on C-V2X operation in CH183 and shows that there is not significant impact on C-V2X operation if there is more than 80 dB of isolation. Because operation of unlicensed devices under this proposal is stipulated as being indoor only, building entry loss will reduce impact. If building entry loss is 20 dB, then 60

dB free space path loss is needed, which is provided by a separation of four meters. Unlicensed devices operating indoors will generally exceed this separation, and as a result will be unlikely to cause harmful interference.

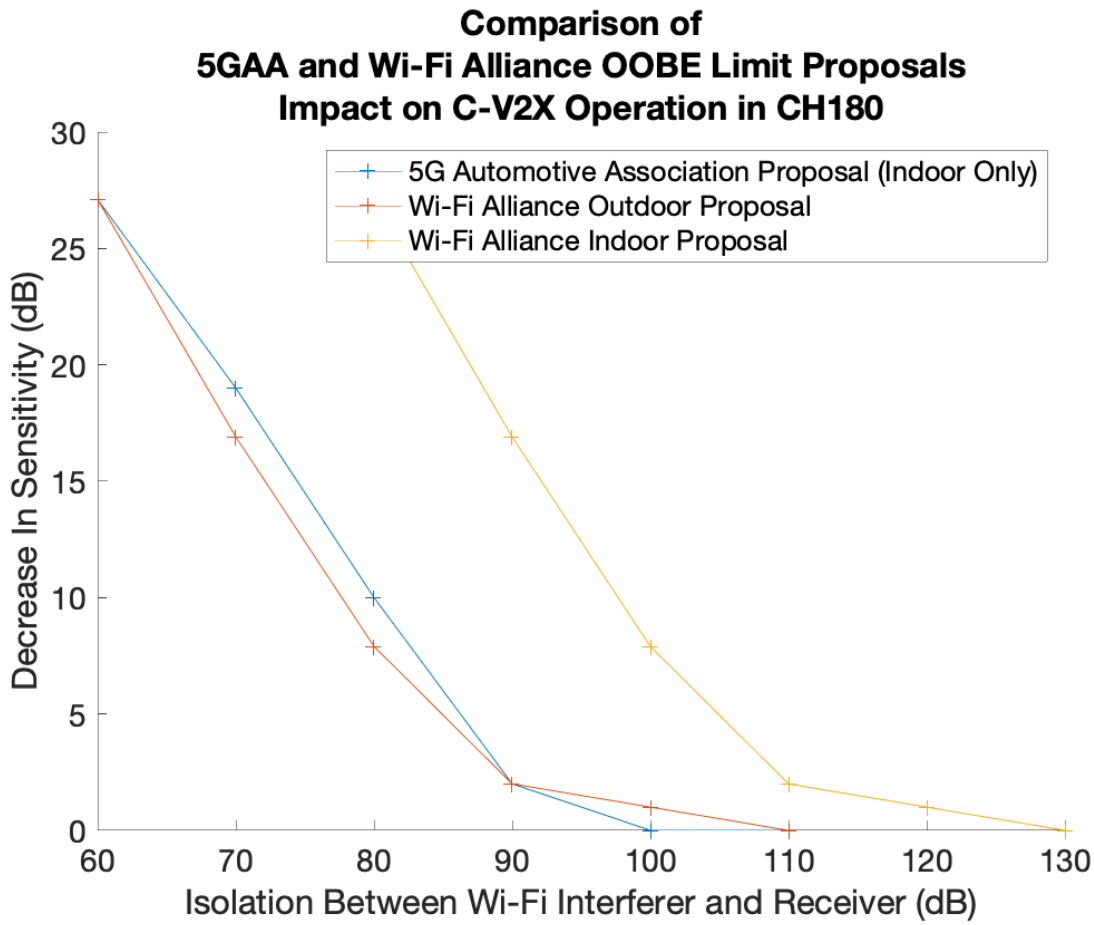


Figure III-7: CAMP LLC results for impact of 5GAA and Wi-Fi Alliance OOBE limit proposals on C-V2X receiver sensitivity in CH 180.

Figure III-7 shows a plot of the CAMP test results for the impact of the proposals on operation in the lower 10 MHz of the proposed ITS allocation, CH180. The figure shows that 10 dB more isolation is needed to prevent harmful interference in CH180 than CH183. Because the Wi-Fi Alliance Proposal was already shown to have a significant negative impact on CH183, it can be concluded that operation in CH180 will be subject to even more interference, preventing

reception of BSMs in more circumstances. For devices operating under the 5GAA proposal the figure shows that at least 90 dB isolation from C-V2X users is required to avoid significant impact on receiver sensitivity. If 20 dB building entry loss is assumed because unlicensed devices operating under the proposal are stipulated as being indoors, an additional 70 dB of isolation is needed to avoid harmful interference. To achieve this level of isolation with free space path loss, 13 m separation is required. In situations in which buildings are located close to roads, such as in cities, unlicensed access points placed indoors can easily be within 13 m of roads. As a result, C-V2X operations in CH180 would be subject to interference from unlicensed devices operating indoors under the 5GAA proposal.

**In summary, of the two proposals, only the 5GAA out-of-band-emission limits for unlicensed devices operating indoors are adequate to prevent harmful interference in the upper 20 MHz of the proposed ITS allocation**. Outdoor operation and indoor operation under the limits proposed by the Wi-Fi Alliance were shown to not be low enough to prevent harmful interference. Analysis of the 5GAA proposal showed that limits under this proposal are not sufficient to prevent harmful interference to the lower 10 MHz of the proposed ITS allocation. Effectively this means that only 20 MHz would be left useable for safety applications, rather than 30 MHz as proposed in this proceeding.

## IV. POPULAR WI-FI APPLICATIONS CAN CREATE PERSISTENT INTERFERENCE CONDITIONS

Proponents of relaxed or no OOBE limits in the upper portion of the 5.9 GHz band, most notably Broadcom and Facebook, have argued that RLAN devices typically operate with a low duty cycle of less than 1% and as a result will have low probability of collision with BSMs [7]. This argument relies on false assumptions about the relationship between the duty cycle and probability of collision between Wi-Fi and C-V2X signals, as shown in this section.

The example that Broadcom and Facebook use to argue for low duty cycle is HD video streaming, which does not have a high data rate relative to the 1 Gbps throughput afforded by the 160 MHz channel referenced in the example, and as a result the duty cycle is claimed to be low. While this may be true for this example, we demonstrate with test results that other popular applications do have high data rates relative to maximum throughput, and as a result will operate with higher duty cycles which will create persistent interference conditions for BSMs.

More importantly, duty cycle alone is insufficient to determine the probability of a BSM colliding with Wi-Fi transmissions. It is possible for even a low duty cycle Wi-Fi transmission to have a high likelihood of overlap with a BSM. For example, if a Wi-Fi transmitter sends packets with duration 200 µs every 1 ms, the duty cycle will be 20%. However, because the interframe gap (IFG) is only 800 µs, less than the length of C-V2X BSMs that last 1 ms, there is a 100% chance of collision between the Wi-Fi transmissions and BSMs. We show that some popular low duty cycle applications with short interframe gaps will have a high probability of collision with BSMs.

### Collision Probability Considerations

The probability of collision was derived from its complement, the probability that a BSM sent at a random time would not collide with a Wi-Fi packet. This was determined by calculating

the percentage of the time during which a BSM could start transmitting without any overlap with Wi-Fi transmissions in an interval consisting of Wi-Fi transmissions and interframe gaps. For each Wi-Fi interframe gap of length $T_{IFG}$, there exists an opportunity time, $T_{OT}$ for a BSM to transmit without colliding. This is shown by the blue double-arrow in Figure IV-1. This is defined as the length of time over which a BSM transmission can start, without any part overlapping with a Wi-Fi packet. If $T_{IFG}$ is shorter than the duration of a BSM, $T_{BSM}$ then the opportunity time is zero because a packet sent at any time in the IFG is guaranteed to collide with a Wi-Fi transmission. For IFGs longer than $T_{BSM}$, the opportunity time is $T_{OT} = T_{IFG} - T_{BSM}$, because a BSM sent less than $T_{BSM}$ before the end of the IFG will collide. This reduction in opportunity time is shown by the red arrow in Figure IV-1. The probability of a BSM not colliding is calculated by summing the durations of the opportunity times for all the Wi-Fi IFGs in the interval of interest and dividing by the length of the interval over which this is calculated. The probability of collision is the complement of this.

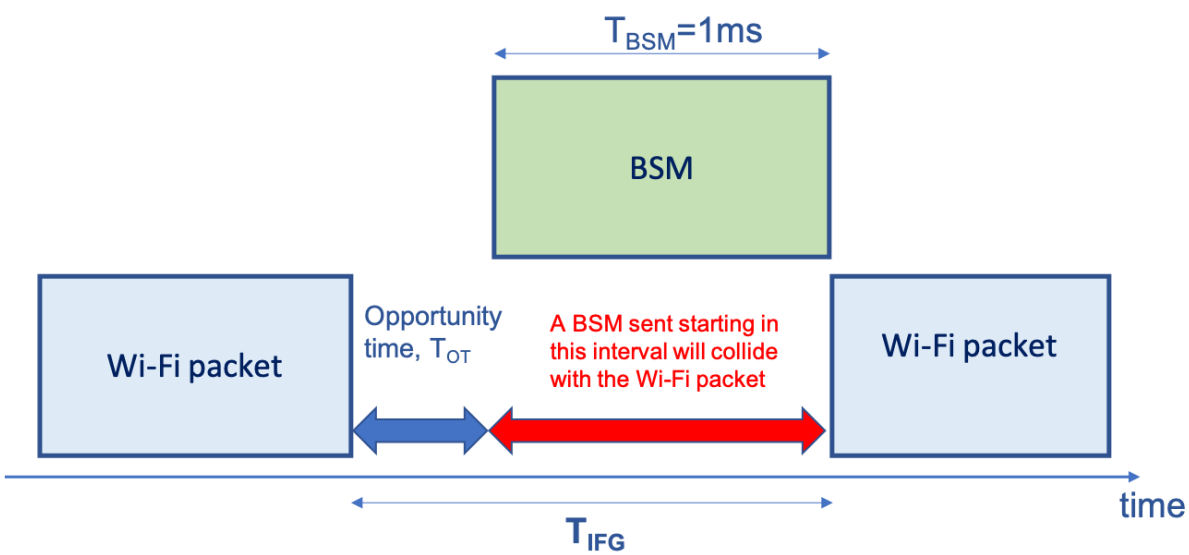


Figure IV-1: Method of computing probability of collision by calculating opportunity times in each interframe gap.

### Duty Cycle Considerations

An application that can utilize the high throughput afforded by wide channels is device-to-device file transfer using Wi-Fi Direct. Because of the high data rate that this application is capable of utilizing, duty cycle is high. It is conceivable that this application could be used by passengers in a vehicle. A passenger with a large video or other file could use Wi-Fi direct to transfer the file to another passenger without using cellular data.

To demonstrate the impact of this example, a test was conducted where a device-to-device data transfer between two portable Android devices was conducted and the Wi-Fi channel was sniffed. The file transferred was 200 MB in size, the transfer lasted for seven seconds, and was sent over an 80 MHz wide Wi-Fi channel. In order to measure the transmission times and interframe gaps during the transfer, Wireshark was used to extract transmit timestamps and durations for the captured packets that originated at the MAC addresses of the devices used in the test. Duty cycle, probability of collision, and average data rate were calculated over 100 ms intervals, the time between successive BSMs. Figure IV-2 shows a plot of these statistics along with the interframe gap between successive Wi-Fi packets over a period of five seconds. The average duty cycle was 74%, the average data rate was 259 Mbps, and the average probability of collision with BSMs was 98% over this period.

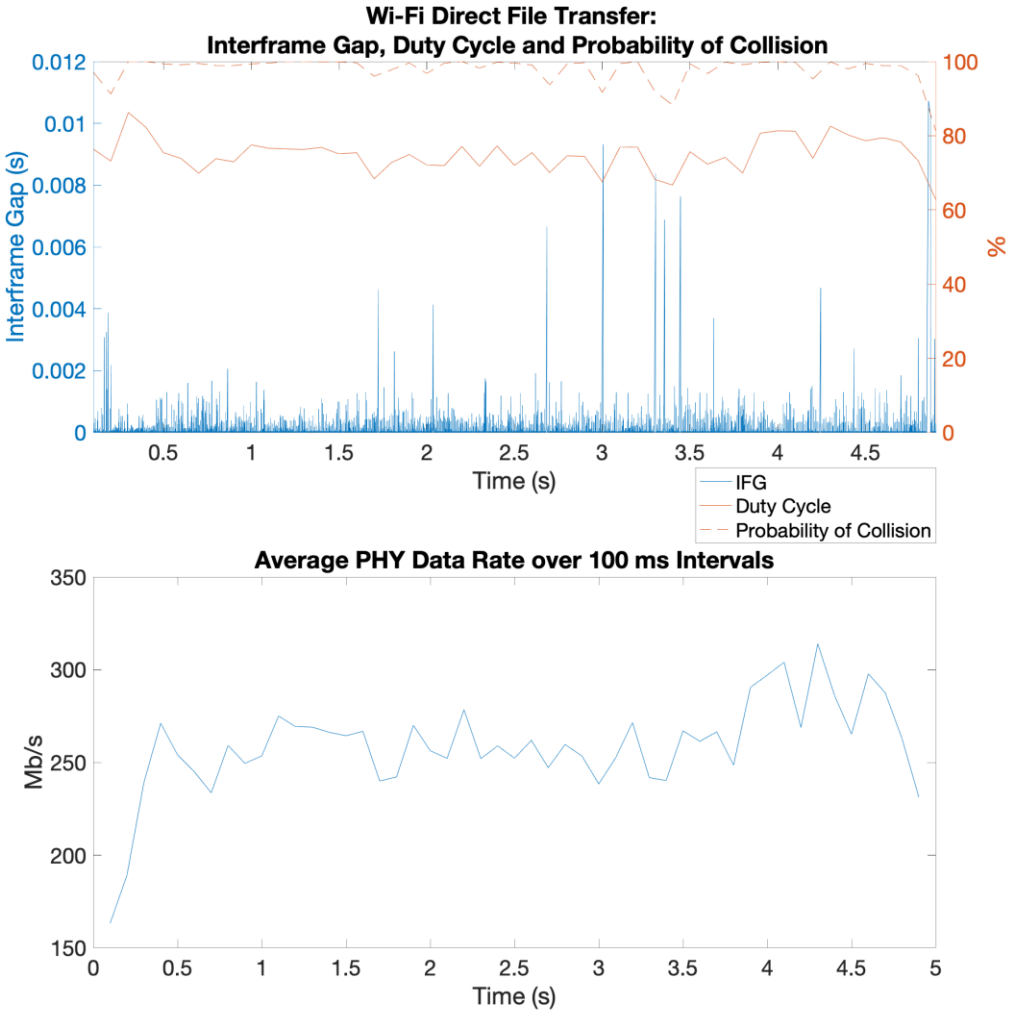


Figure IV-2: Test results for Wi-Fi direct data transfer between two devices.

To examine the potential impact of other applications, another test was conducted to determine the duty cycle and probability of collision with BSMs for video streaming. In this test an 802.11ac Wi-Fi access point was configured to operate on a 20 MHz channel in the 5.8 GHz band. A single computer attached to the access point and 2160p, 60 fps video was streamed from YouTube. The Wi-Fi packets sent on the channel used were sniffed by a client device in monitor mode. The test was repeated with the access point set to use an 80 MHz channel. Figure IV-3

shows the results for the test using the 20 MHz channel, and Figure IV-4 shows the results for the test using the 80 MHz channel.

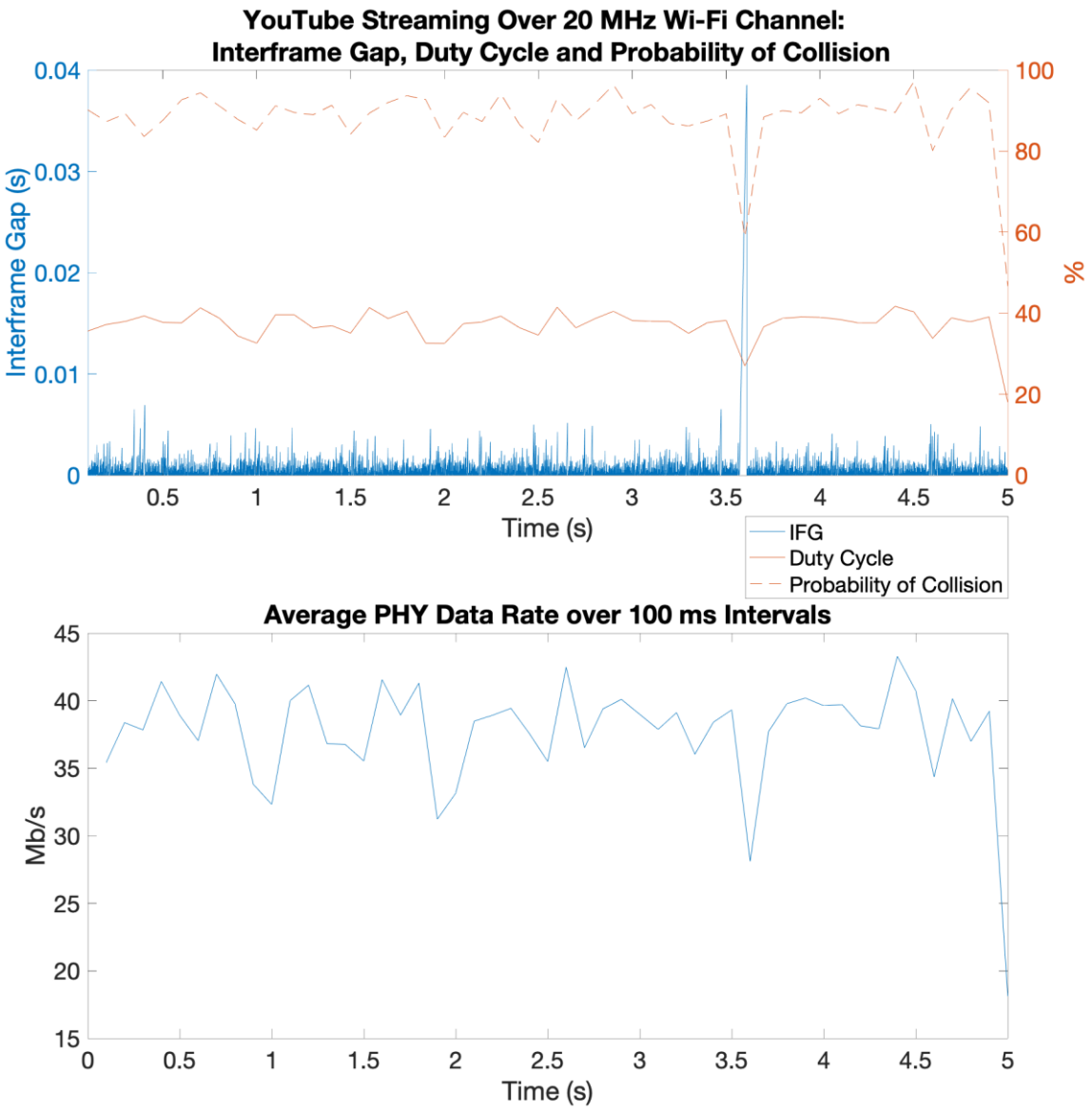


Figure IV-3: Test results for 20 MHz YouTube streaming

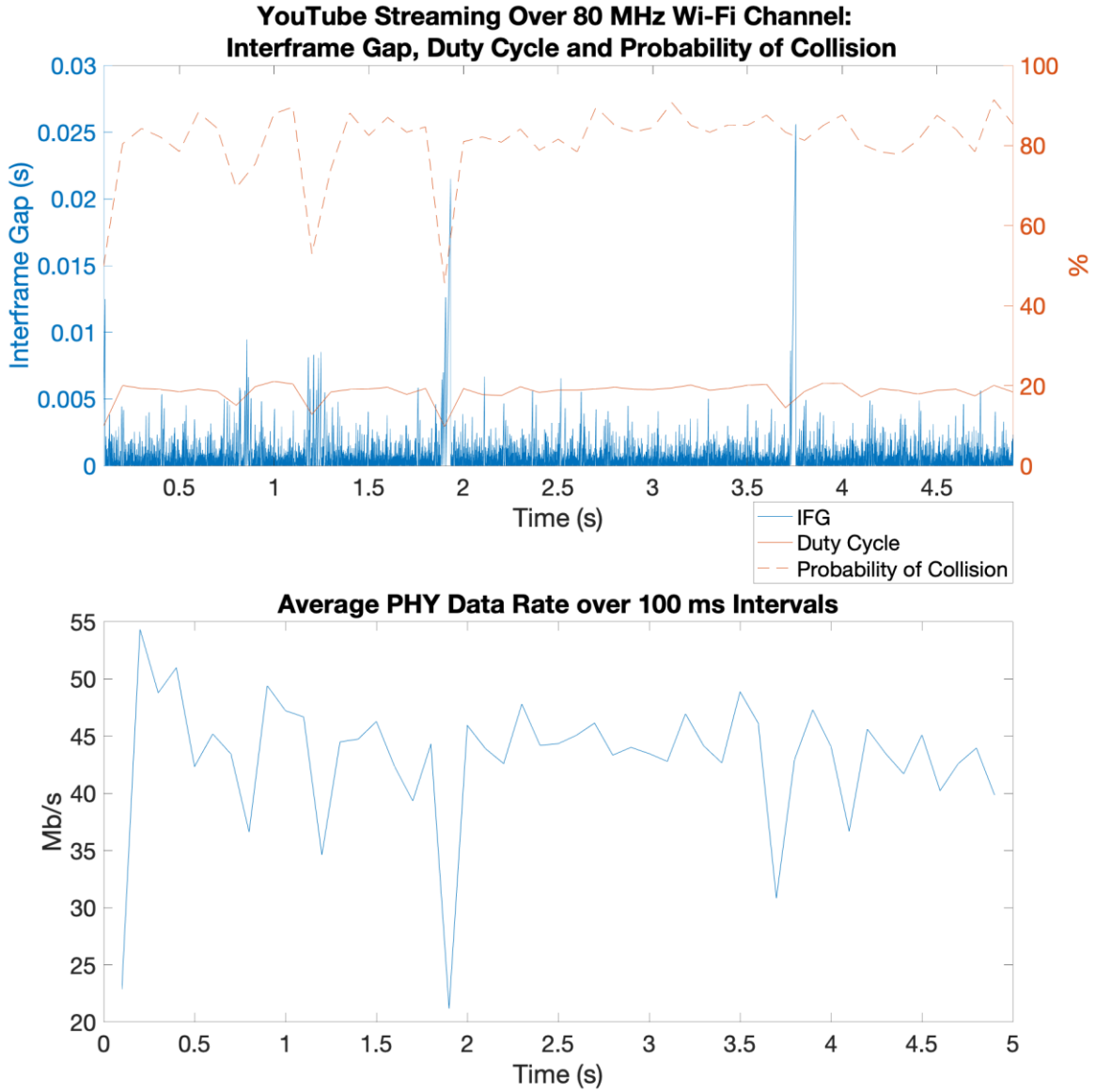


Figure IV-4: Test results for 80 MHz YouTube streaming

Compared to the Wi-Fi Direct peer to peer application, the YouTube results show lower duty cycle, but still have a high probability of collision with BSMs. When the video was streamed using a 20 MHz channel, the average duty cycle was 38%, and the average probability of collision was 90%. Moving to an 80 MHz channel reduced the duty cycle to 18%, a 47% decrease, but reduced the probability of collision only by 12%, down to 79%. While

counterintuitive, a high probability of collision can exist even with a low duty cycle, if the durations of interframe gaps are short relative to the durations of BSMs.

**In summary, this demonstrates that frequently used Wi-Fi applications would pose a significant interference risk to ITS applications if out-of-band emissions of Wi-Fi devices are not limited in the vicinity of vehicles**. The Wi-Fi direct file transfer test showed a sustained high duty cycle of 74% for several seconds. This application could be used by passengers in a vehicle and would create a similar interference pattern to that generated for our previous test [8]. In that test Wi-Fi packets were sent with a duty cycle of 70%, lower than that demonstrated by Wi-Fi direct, and the Wi-Fi transmissions prevented reception of BSMs which would prevent safety applications from working. We have also shown that lower duty cycle applications such as video streaming have a high probability of collision with BSMs. Harmful interference from these applications cannot be ruled out based on duty cycle alone.

## V. WI-FI USAGE AT SCALE PRESENTS ADDITIONAL CHALLENGES THAT MUST BE ADDRESSED TO AVOID HARMFUL INTERFERENCE

Laboratory tests presented in Section III demonstrate significant interference impact of a single Wi-Fi transmitter. As Wi-Fi usage is widespread, simultaneous operation of multiple Wi-Fi transmitters could accumulatively affect C-V2X reception especially in dense urban scenarios. In this section, we complement the lab analysis presented earlier with a study that examines the impact of Wi-Fi operation at scale in U-NII-4 band. Through simulations run for a real-world intersection with crash history, we illustrate that the aggregate interference levels will be unacceptably high if the OOBE mask does not provide sufficient protection to ITS operation. Specifically, we show that the Wi-Fi Alliance proposal does not provide protection to ITS operation, whereas, the 5GAA proposal can sufficiently limit interference on C-V2X in channel 183 if U-NII-4 mobile devices remain strictly indoor. However, we also demonstrate that when such devices venture outside, in the setting of outdoor cafes, open garages and home lawns, that protection will be rendered ineffective. The proximity of such devices to public roads with line-of-sight to victim C-V2X receivers with little to no building entry loss may lead to harmful levels of OOBE interference despite ostensibly indoor operation.

### The Model

Our analysis seeks to determine the level of aggregate interference at a typical crash-prone urban intersection with Access Points (APs) and mobile devices operating in the U-NII-4 band. This analysis is based on a model of Liberty St. and S. Main St. in Ann Arbor, Michigan shown in Figure V-1(left). This location has several cafes with outdoor seating areas as well as a history of crashes. In one such crash, illustrated in Figure V-1 (right), a vehicle moving northwards on S. Main St. with a green signal at the intersection was hit by a vehicle moving

westwards on E. Liberty St [10]. Aggregate interference from the U-NII-4 Wi-Fi devices must not exceed -108 dBm/MHz at C-V2X receivers to avoid degradation of vehicle safety applications as shown in Section III and our previous laboratory results [8].

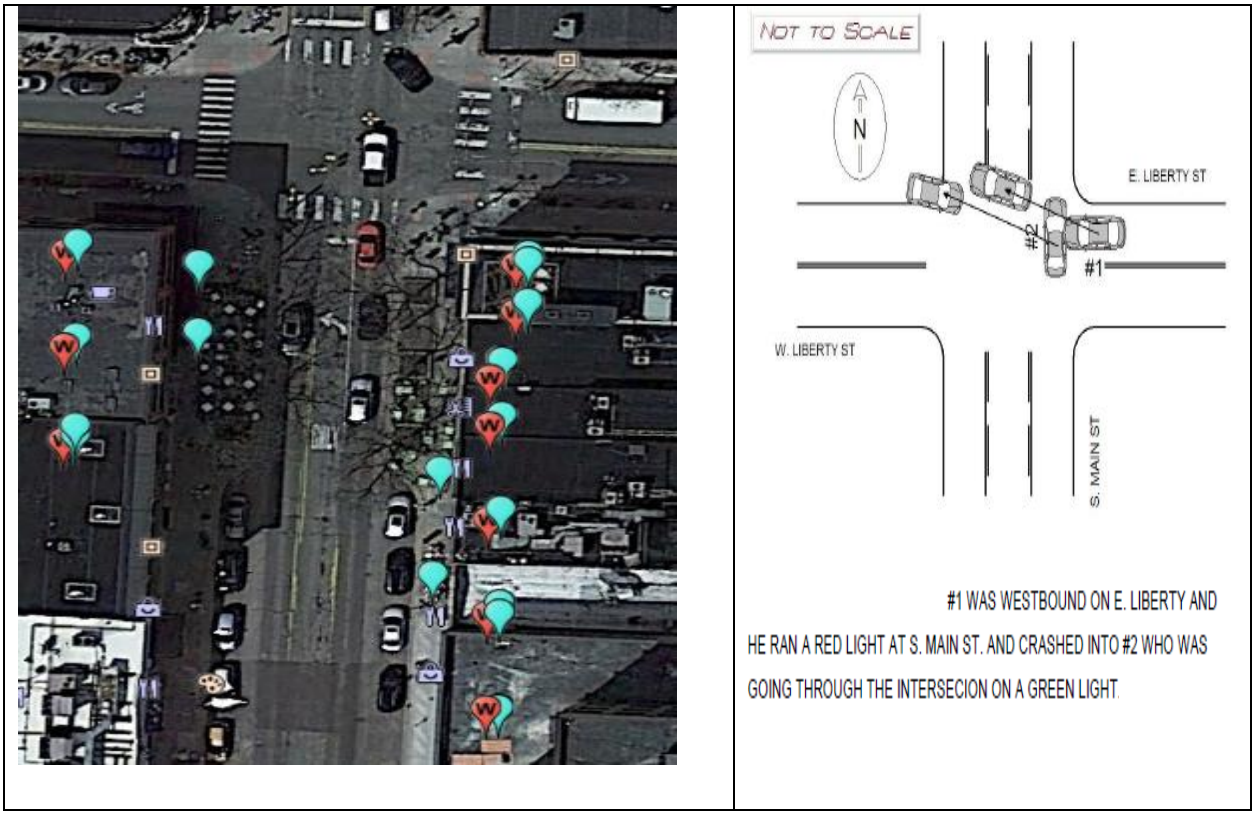


Figure V-1. (Left) Map illustrates the simulated location of Wi-Fi devices in an Ann Arbor intersection. (Right) A police crash report for the chosen intersection.

In the model, we assume ten APs, each represented by a red pin labelled 'W', per cafe along S. Main St. as shown in Figure V-1(left). Each AP has two attached mobile devices operating indoors as part of a Basic Service Set (BSS) which are shown as cyan pins. We consider two scenarios:

1) All indoor operation

   In this arrangement, all twenty mobile devices are positioned indoors emulating customers in the shop.

2) Mixed indoor/outdoor operation

In this arrangement, sixteen mobile devices are positioned indoors and four are positioned outdoors on the sidewalk emulating customers sitting outside.

The locations of the mobile devices were varied randomly with their average position shown for the mixed indoor/outdoor setting in Figure V-1(left). Additional model parameters used in the Monte Carlo simulation are shown in Figure V-2).

| **Simulation Parameter** | **Value/Model** |
|---|---|
| Number of U-NII-4 BSS (AP + mobile device) sets | 10 |
| Number of mobile devices (clients) per AP | 2 |
| CSMA/CA Scheduling principle | 1. Multiple devices transmit simultaneously if pairwise mutual received power (i.e. Wi-Fi transmit power minus path and building entry loss) below detection threshold<br>2. Within a BSS, only one transmitter at a time. |
| Wi-Fi transmit power | 20 dBm |
| OOBE | RMS mask[3] |
| CSMA/CA detection threshold | -85 dBm |
| Channel model | Free space path loss |
| Indoor-to-outdoor building entry loss | 20 dB[4] |
| Device location distribution within shown position | Uniform 4 m range |
| OOBE emission levels | See Figure III-2 |

[3] The 5GAA mask specifies RMS limits, while the Wi-Fi Alliance masks only specify peak limits. For the Wi-Fi Alliance proposal, we assume RMS levels 10 dB lower than peak limits.

[4] Numerous studies [2-6] show that the building entry or penetration loss from indoor to outdoor environments is less than 16 dB. In order to maintain consistency with the work described in previous sections, we adopted the loss assumed by the Wi-Fi Alliance.

| | |
|---|---|
| Activity factor (%)[5]: Uniform distribution that indicates the likelihood that each BSS is independently active | {20%, 100%}[6] |
| Downlink factor: Uniform distribution that indicates the fraction of traffic generated by AP within a BSS | 80% |
| CDF plot generated for the set of 50 x 2000 = 100000 interference samples | 2000 trials for each meter between 0m to 50 m from intersection middle of right-most S. Main St. |

Figure V-2. Model parameters and assumptions.

**Results**

In Figure V-3, we plot the cumulative density function (CDF) for the aggregate interference received at a victim C-V2X vehicle as it moves towards the intersection over a span of 50 m. In Figure V-3 (top right and top left), the acceptable limit is defined by the dashed line. From this we can see that for channel 183 in the all-indoor scenario, the Wi-Fi Alliance indoor proposal results in unacceptable levels of interference at the receiver even for low activity factor (20%). For the 5GAA proposed limits, the interference level is always below the limit even for high activity factor (100%). Note that even at high activity factor, due to the CSMA/CA-based scheduling, only a fraction of BSS can simultaneously transmit. With low activity factor, in 10% of the trials, there is no interference because no BSS is active.

[5] The activity factor represents the probability that in a time interval an individual BSS (either AP or mobile device) will have Wi-Fi traffic to transmit, with the actual transmission conditional as per the CSMA/CA principle.

[6] The effective duty cycle per transmitter is correspondingly 6.5% and 26.7%, respectively.

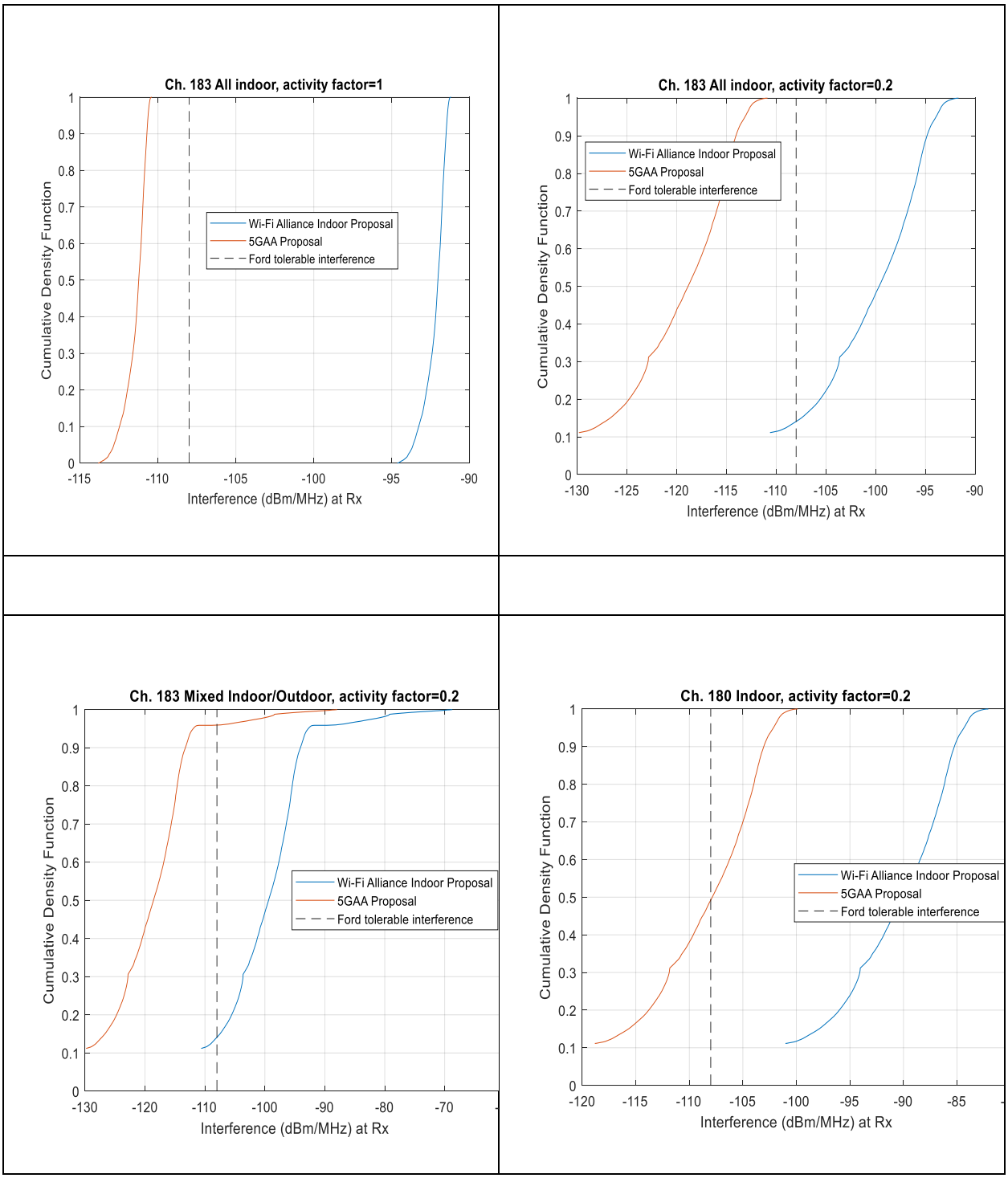


Figure V-3. The probability that interference at a receiver is below a certain level is shown for various scenarios.

However, as shown in Figure V-3 (bottom left), when few devices are stationed outdoors while using indoor APs (emulating café hotspots), the level of interference can rise significantly even for channel 183. Even with a low activity factor of 20%, the 5GAA proposed mask will occasionally result in higher than acceptable interference. This is due to the combination of low path loss and no building entry loss for OOBE from an outdoor mobile device.

In Figure V-3 (bottom right), we plot the results for all-indoor U-NII-4 operation for channel 180. We can observe that interference is high for both Wi-Fi Alliance and 5GAA masks despite a low activity factor. This is consistent with the laboratory results and conclusions in Section III. Additional factors such as fading, or antenna patterns will increase the variance in the interference from each BSS. None of these variations will alter the key conclusions of the analysis.

Note that while these results are based on 20 dB building entry loss, with lower building entry losses likely at many locations, the impact could be worse. In order to address this, the following mechanisms might be considered to prevent harmful interference from APs that have insufficient isolation to areas where C-V2X devices operate:

- Detection of C-V2X signals by unlicensed devices, in which case the unlicensed device would stop using the frequency which is causing the interference.
- Unlicensed devices with unique IDs check to determine whether they appear in a database of prohibited unlicensed devices known to have caused interference.
- Geolocation by unlicensed devices to determine whether they are sufficiently separated from areas of C-V2X operation.

## VI. SUMMARY AND RECOMMENDATIONS OF RULES FOR UNLICENSED DEVICES OPERATING IN THE U-NII-4 BAND

The analysis of the interference impact of Wi-Fi using lab tests and simulations leads to the following conclusions:

- Operation of unlicensed devices with out-of-band-emission levels meeting the Wi-Fi Alliance limits for indoor and outdoor operation would lead to harmful interference to C-V2X users.
- The 5GAA mask would protect ITS operations in channel 183 provided operation of unlicensed devices is kept indoors, and 20 dB building entry loss can be ensured.
- Neither proposal would protect ITS operation in channel 180.
- Neither proposal would protect ITS operations when users of mobile devices venture outside while utilizing indoor access points. This necessitates a mechanism to detect and prevent outdoor mobile devices from communicating with indoor APs.

We support the full use of the 75 MHz ITS band. However, if the lower 45 MHz are allocated for unlicensed operation and the 5GAA proposal is adopted, ITS operation in channel 180 will be sacrificed due to adverse levels of adjacent channel interference. To protect operation in the upper 20 MHz proposed for C-V2X the following steps should be strongly considered.

- All unlicensed devices (APs and mobile) in U-NII-4 must operate indoors and must comply with OOBE limits that meet the ones proposed by the 5GAA.
- Mobile devices must not be allowed to form peer-to-peer connections in U-NII-4 or operate in ad-hoc modes. This is needed to prevent operation onboard vehicles.

- Mobile devices operating under the proposal must not be allowed to act as an AP. This measure is needed to prevent such devices from creating harmful interference when operated outdoors.
- Mobile devices that act as clients must detect if they are outdoors and stop using U-NII-4 channels when that happens. This measure would ensure that there is always indoor building entry loss to reduce impact outdoors.
- Adherence to the rules governing unlicensed devices that utilize U-NII-4 band should be enforceable to avoid causing harmful interference.

## VII. CONCLUSION

Ford respectively submits these reply comments in hopes that the Commission will grant the upper 20 MHz for C-V2X and do so in an expeditious manner. We have also provided substantial reasoning for the eventual, near-term need for an additional 40 MHz of spectrum for advanced C-V2X capabilities. As such, we and the majority of others in the transportation field believe that all 75 MHz of the 5.9 GHz band should be retained for ITS. This capacity will be needed as the technology transitions to 5G and is put to use in Automated Vehicles. Not only is there widespread support for preservation of the band, but as noted, it is uniquely internationally harmonized allowing for more efficient deployment scenarios globally.

In order for Ford to meet its C-V2X deployment commitment in 2022, certainty of spectrum allocation must exist. This will also ensure that others – both public and private sector participants – also commit to deploying C-V2X. These deployments must be protected from harmful interference in order to ensure consistent and reliable interpretation of safety messages. The evidence we provide through test results support some of the necessary steps that need to be taken to ensure that any harmful interference is mitigated.

Ford envisions a transportation future that is increasingly connected and autonomous. We believe that C-V2X is the cornerstone to enabling that future and that it will provide tremendous economic and social benefits through both a safer and more efficient mobility eco-system. Again, we thank the Commission for the opportunity to reply to this proceeding and we look forward to its timely and successful conclusion.

Respectfully submitted,
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