DSRC-Unlicensed Device Test plan

To characterize the existing radio frequency signal environment and identify the impacts to DSRC operations of unlicensed devices operating in the 5850-5925 MHz band and adjacent bands

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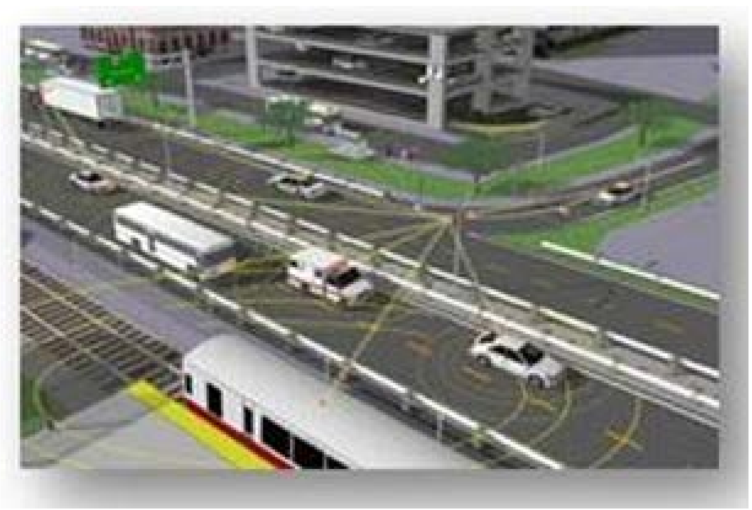

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

***SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)**

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List of Abbreviations

Abbreviation	Term
AP	Access Point
BER	Bit Error Rate
BSM	Basic Safety Message – Messages from OBUs containing vehicle data including GPS location coordinates
C/I	Carrier-to-Interference ratio
CCA	Clear Channel Assessment – mechanism by which radios listen and don't try to transmit until the channel is clear of transmissions from other radios.
CCH	Control Channel (Channel 178 in the DSRC band)
CCTV	Closed Circuit Television
CFR	Code of Federal Regulations
Client	Device that uses a wireless link to connect to an AP to reach a network
dB	Decibel
dBi	Decibel (referenced to isotropic, that is an antenna radiating equally in all directions)
dBm	Decibel referenced to 1 milliwatt
DSRC	Dedicated Short Range Communication
EDCA	Enhanced Distributed Channel Access – a way to prioritize messages that try to access the channel at the same time. See Appendix B.
EIRP	Equivalent Isotropic Radiated Power
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FLETC	Federal Law Enforcement Training Center
FSS	Fixed Satellite Service
GHz	Giga-Hertz (1 billion cycles per second) – unit of frequency
GPS	Global Positioning System
Handheld DSRC	Portable DSRC – DSRC radio in a handheld device like Smartphone or Tablet
IEEE	Institute of Electrical and Electronic Engineers
ISM	Industrial, Scientific & Medical – devices radiating non-communication RF energy
ITS	Intelligent Transportation Systems
kHz	Kilohertz (1000 cycles per second) – unit of frequency
km	Kilometer (1000 meters) – unit of distance
LAN	Local Area Network
LTE	Long Term Evolution – 4^{th} generation cellphone technology standard
m	Meter – unit of distance
MHz	Mega-Hertz (1 million cycles per second) – unit of frequency
mph	Miles per hour
mW	Milliwatt (1 millionth of a Watt) – unit of power
NRPM	Notice of Proposed Rule Making
NTIA	National Telecommunications & Information Administration

Abbreviation	Term
NTIA/ITS	National Telecommunications And Information Administration/Institute for Telecommunication Sciences
OBE	On-board Equipment – Electronic equipment in a vehicle that includes an OBU
OBU	Onboard Unit – DSRC radio mounted in a vehicle
Octet	8 bit byte
OFDM	Orthogonal Frequency Division Multiplexing
PAN	Personal Area Network
PER	Packet Error Rate
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
Rec	Receive
RF	Radio Frequency
RSE	Roadside Equipment – Traffic equipment near a road, may contain an RSU
RSSI	Receive Signal Strength Indicator
RSU	Roadside Unit – DSRC radio mounted to fixed or moveable but not mobile infrastructure
RTK	Real Time Kinematic
S/N	Signal-to-Noise ratio
SAE	Society of Automotive Engineers
SPaT	Signal Phase and Timing – Data from a traffic signal controller giving signal status and the timing of upcoming state changes in all directions.
TFHRC	Turner Fairbank Highway Research Center
Tx	Transmit
U-NII	Unlicensed National Information Infrastructure
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VSG	Vector Signal Generator
V-TTSS	Vehicle Technology Test Support System
W	Watt – unit measure of power
WAN	Wide Area Network
Wi-Fi	Wireless Fidelity

1. Introduction

The FCC allocated 75 MHz of spectrum for use by Dedicated Short Range Communications (DSRC) to support Intelligent Transportation Systems (ITS) in 1999.[1] This spectrum, 5850-5925 MHz is referred to as the DSRC band or ITS band interchangeably. The allocation for DSRC is a co-primary allocation shared with the Fixed Satellite Service (FSS) as the other non-government primary allocation. Federal use on a primary basis is for radiolocation (i.e. radar) operation. Testing and analysis conducted in the mid to late 1990's demonstrated compatible operation between an early implementation of DSRC, FSS, and government radars.[2, 3, 4, 5]

Note that there are no sharing mechanisms. The incumbents are to work out interference issues amongst themselves if they arise. Too close to radar or FSS and DSRC transmissions may suffer interference. They may also suffer interference from users of the adjacent bands below 5850 MHz and above 5925. Figure 1-1 illustrates the DSRC band.

In addition, there is also a secondary Amateur allocation for the entire band, and unlicensed as well as Industrial, Scientific, and Medical (ISM) operations are permitted in the 5850-5875 MHz portion of the band.

[1] FCC Report and Order "Amendment of Parts 2 and 90 of the Commission's Rules to Allocate the 5.850-5.925 GHz Band to the Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Services," FCC 99-305, released October 22, 1999.

[2] Measured Occupancy of 5850-5925 MHz and Adjacent 5-GHz Spectrum in the United States, NTIA Technical Report TR-00-373, December 1999, http://www.its.bldrdoc.gov/publications/2404.aspx, Accessed 5/4/2015

[3] Electromagnetic compatibility testing of a dedicated short-range communication system, NTIA Technical Report TR-98-352, July 1998. Not available electronically.

[4] Electromagnetic compatibility testing of a dedicated short-range communication system that conforms to the Japanese standard, NTIA Technical Report TR-99-359, November 1998. http://www.its.bldrdoc.gov/publications/2390.aspx. Accessed 5/7/2015

[5] To avoid interference from co-channel radars, DSRC frequency assignments need to be coordinated with local radar assignments to avoid co-channel operations at short separation distances.

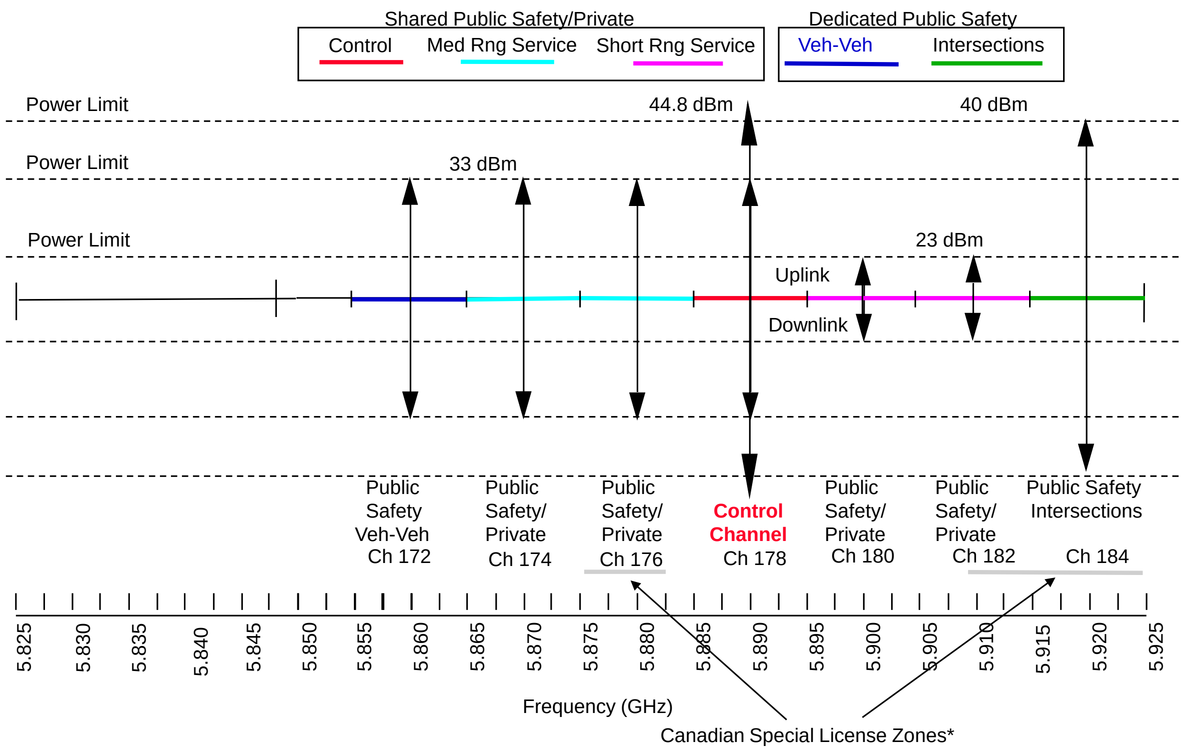

Figure 1-1 DSRC Channel Plan in the ITS Band[6] [7]

In a more recent notice the FCC solicited input for a proposed rule to open up more bandwidth for unlicensed Wi-Fi devices based on the 802.11ac standard (Figure 1-2).[8] (DSRC devices are based on the 802.11p standard.) The proposed new U-NII-4 band overlaps the DSRC band (purple in Figure 1-2). That means DSRC devices would share the band with an uncontrolled number of unlicensed 802.11ac devices if an adequate sharing method can be found. Such a sharing mechanism would have to give deference to the DSRC devices since they are primary users of the band and unlicensed devices are not allowed to interfere with primary users.[9] Figure 1-3 gives a close up view of the proposed sharing in the DSRC band.

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[6] DSRC Tutorial, Rockwell Collins, 2003.

[7] Note that the DSRC Channel plan allows for two 20 MHz channels to be formed as well. Channels 174 and 176 can be combined to form 20 MHz channel 175 and Channels 180 and 182 can be combined to form 20 MHz channel 181. Tests will be conducted in both the 10 MHz and 20 MHz DSRC channels.

[8] FCC Notice of Proposed Rulemaking (NPRM) 13-22, (Docket 13-49), February 20, 2013, proposes revising Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, to operate within the majority of the 5.850 to 5.925 GHz frequency band, designated as the U-NII-4 band.

[9] CFR 47, §2.1 and Part 15, §15.5.

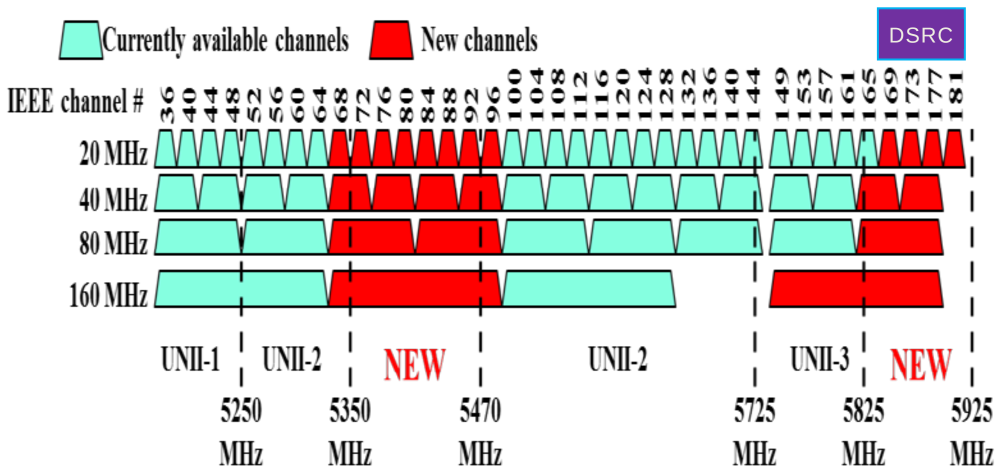


Figure 1-2 Proposed new U-NII-4 band

Though the impetus for creating the U-NII-4 band comes from desire to provide more bandwidth for 802.11ac Wi-Fi devices, a rule considered by the FCC would permit sharing by any unlicensed device in the band that complied with FCC part 15 rules for the band. One example is License Assisted Access (LAA) also known as LTE-U (for unlicensed) which looks to offload LTE data traffic unto the unlicensed bands. Others include UAV downlinks, other forms of video streaming, wireless backhaul concepts, and any new application that might be devised in the future.

This plan tests 802.11ac as the first, but not only, unlicensed device that may be tested. We start with 802.11ac because commercial devices are available for the U-NII-3 band that can be adjusted in frequency to act as surrogates for potential U-NII-4 devices well enough to investigate interference, (but not mitigation). We will incorporate other unlicensed devices, including potential U-NII-4 devices, into our testing as soon as we have access to devices to test. By potential U-NII-4 devices we mean devices designed and programmed to share the band with DSRC.

Terminology to describe unlicensed devices in this test plan	
Term	Definition
U-NII-3	Off-the-shelf devices operating in 5 GHz bands, particularly 5.8 GHz, that are programmed for the U-NII-3 rules set by the FCC. Tested to see how much energy they leak into the DSRC band seen by DSRC devices as out of band interference.
U-NII-4	Placeholder for rules to allow unlicensed devices into additional bands, including the DSRC band. There are several proposals but these rules have not been written. We can only test proposed ideas.
Surrogate U-NII-4	U-NII-3 devices modified to operate at the higher frequencies of the DSRC band but using the U-NII-3 rules.
Potential U-NII-4	Devices built for the purpose of operating unlicensed in the DSRC band. We test the devices operating by rules the designer proposes that the FCC adopt if they write a U-NII-4 rule. Their proposed rules must mitigate interference with DSRC.
Unlicensed device	Any device operating under FCC Part 15. Includes but is not limited to U-NII devices.

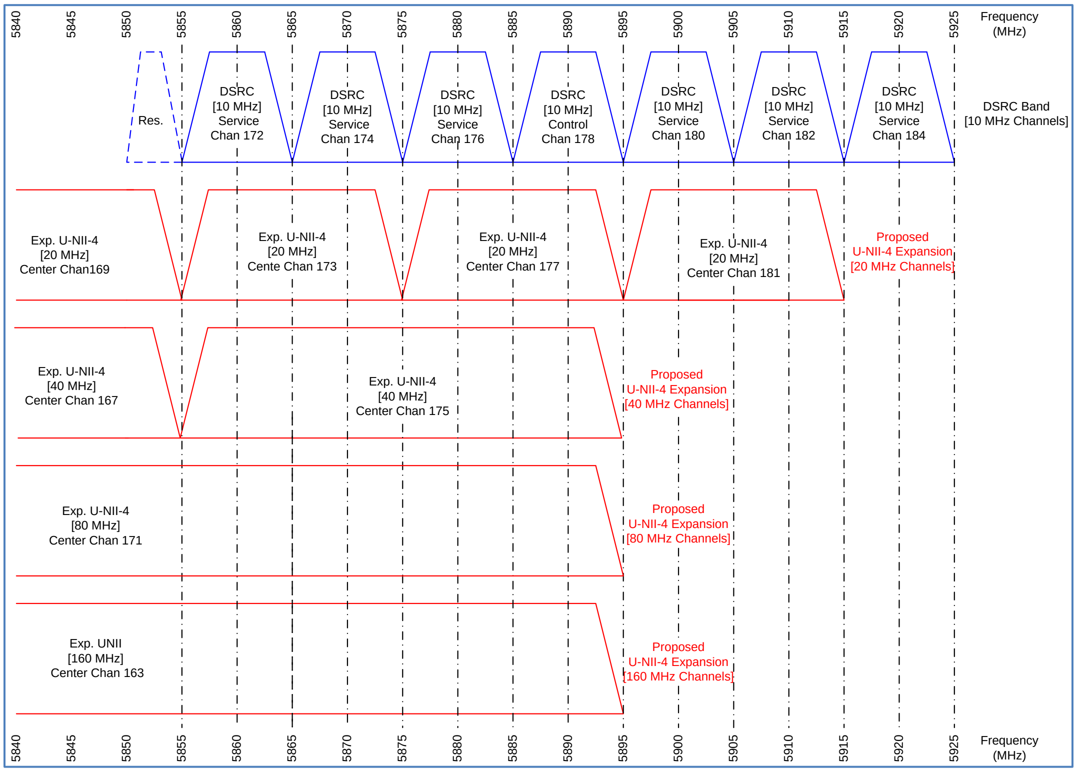


Figure 1-3 U-NII-4 overlap with the DSRC band[10]

The USDOT concern is focused on anything that disrupts DSRC communications. By this definition then, Radio Interference can take three forms:

- First, is the increase in ambient noise level due to unlicensed devices transmitting in or near the DSRC band.
- Second, is when two or more packets from different sources enter a receiver at the same time. In that case, the receiver may accurately interpret only one, or likely none, of the incoming message packets. Those messages are transmitted but lost.
- Third, is when the Clear Channel Assessment (CCA) mechanism causes a radio to suppress and not send its message because it hears another source already transmitting on the channel. A secondary or unlicensed user preventing a primary user from transmitting in this way is considered to be interfering with the primary user's ability to communicate by the USDOT. Messages are not received because they are prevented from being sent.

The USDSOT needs to understand the impacts of unlicensed devices operating in the DSRC band in order to provide recommendations through NTIA to the FCC. The FCC may use these inputs to make decisions that will avoid interference with and ensure reliable operation of DSRC as well as ensure highly available access to the DSRC band. The USDOT will undertake the bench and lab testing[11], field testing, simulation and

[10] Source: Rockwell Collins

[11] Bench test is defined here as component tests most often for checking out that devices work properly. Lab test is indoors performance and interference testing.

analysis[12] described in this test plan. The following sections first provide the goals and objectives, then an overview of the plan by phases, followed by sections that detail the planned measurements.

2. Goals and Objectives

2.1 USDOT GOALS

The overarching goal that permeates this process is assuring safe, reliable, and on demand access to the 5850-5925 MHz spectrum for DSRC operation. Without the spectrum access, DSRC will not be viable supporting safety applications that require fast response times in order to reduce automobile crashes, injuries, and save lives. To achieve that, the USDOT seeks to attain the following specific goals:

1. Understand the impacts of unlicensed devices operating in the DSRC band.
2. Develop the capability to evaluate proposed band sharing mechanisms.
3. Define requirements necessary for sharing mechanisms to prevent interference.
4. Collaborate with the NTIA and FCC to provide Congress with results on impacts to DSRC operations from proposed sharing mechanisms.

2.2 Test Plan Objectives

The USDOT should be able to achieve those goals by accomplishing the following test plan objectives:

1. Develop the capability to do accurate and relevant experimental evaluations of band sharing and interference between unlicensed devices and DSRC devices.
2. Characterize the existing radio frequency (RF) signal environment in and near the DSRC band.
3. Measure the effect of unlicensed devices on the background noise level.
4. Measure the impact unlicensed device transmissions have on receiving DSRC messages.
5. Measure DSRC suppression caused by Clear Channel Assessment (CCA) of DSRC devices in the presence of unlicensed device transmissions.
6. Measure other impacts on DSRC channel quality of unlicensed device transmissions (e.g., S/N, PER, etc.).

[12] Existing interference models have not been applied to the DSRC environment. Our test data is needed in order to adapt and verify those models for use in this band.

7. Determine the minimum received power levels at which DSRC and unlicensed devices can sense the other.

8. Investigate how interference and detection (determined in the previous objectives) varies if the bandwidth of the overlapping unlicensed device transmission changes.

9. Measure the impact of DSRC operations on unlicensed device performance recognizing that the two radios may form an interactive system.

10. Investigate mitigation possibilities once potential U-NII-4 devices designed and programmed to share the band with DSRC are available.

Each of these objectives is described in further detail below.

2.2.1 Develop the capability to do accurate and relevant experimental evaluations of band sharing and interference between unlicensed devices and DSRC devices

The USDOT needs to acquire equipment, set up test facilities, and train personnel to make the measurements and perform the experiments needed to explore possible interference.

2.2.2 Characterize existing RF signal environment in the DSRC band

The USDOT must measure existing background noise levels and interference from existing transmitters to set the baseline values in order to see what changes when DSRC devices and unlicensed transmitters operate in or near the band. This includes out-of-band as well as in-band transmitters since energy can leak between channels.

2.2.3 Measure the effect of unlicensed devices on the background noise level

Background noise level limits the range that DSRC safety applications can function. The higher the noise level, the shorter the range, until it is too short for the applications to warn the driver. The first step in considering possible sharing is to measure how much the noise level increases due to unlicensed devices transmitting in and near the band. The NTIA/ITS will input these measurements into models to examine noise level in full deployment scenarios of DSRC and unlicensed devices. That means aggregating the energy leaked into the band by many unlicensed devices including those out of range and in adjacent channels. The effect on noise level will be much higher with hundreds or thousands of transmitters out of range but still adding energy to the noise floor compared to the number of devices that will be tested under this plan. Because signal-to- noise ratio (S/N) limits the range at which connected vehicle safety apps can work, higher noise level means, smaller S/N hence less range. With NTIA/ITS models we can estimate the effect on safety range both in our test scenarios and at deployment scales.

2.2.4 Measure the impact of unlicensed transmissions on the receipt of DSRC messages that are transmitted

This objective measures signals from different transmitters that collide in the DSRC receiver and its impact on performance. This would be the case of unlicensed devices that don’t function with the same channel access protocol as the 802.11p DSRC devices. They could cause interference while operating in the same or an adjacent channel to the DSRC device. This also measures the kind of interference that occurs in hidden node scenarios, which is when one device that is transmitting drives into range of another device that is also transmitting at the same time. This interference can occur even with a mutual channel sharing protocol. This objective looks at how many Basic Safety Messages (BSMs) are transmitted and not correctly interpreted by the receiver. These BSMs would not be available to safety applications in the receiving vehicle.

2.2.5 Measure DSRC suppression caused by Clear Channel Assessment (CCA) of DSRC devices in the presence of unlicensed device transmissions

This objective measures packet suppression. This occurs when use of a channel by an unlicensed device causes the CCA mechanism of the DSRC device to prevent transmission of BSMs because it hears that the channel is busy. These BSMs are then not available for safety applications in all of the receiving vehicles in range.

2.2.6 Measure other impacts on DSRC channel quality of unlicensed transmissions (e.g., S/N, PER, etc.)

Other measurements are commonly used in wireless communications to determine channel quality as well. These can provide insight as to the nature of interference, other ways it might affect channel capacity and possible mitigations. Possible measures include signal-to-noise ratio (S/N), packet error rate (PER), Packet Reception Rate (PRR), channel busy percentage, inter-packet gap, average channel energy, channel availability and more. The objective is to identify and use other channel quality measures that add insight to potential interference.

2.2.7 Determine the energy levels at which DSRC and U-NII-4 devices can sense the other

DSRC receivers are highly sensitive and can receive signals in the range of -95 to -105 dBm. If unlicensed devices do not have similar or better sensitivity, they will not hear DSRC devices that hear them. The result is the unlicensed devices will think the channel is clear when it is not. The DSRC devices will hear the unlicensed devices and suppress their own transmissions. By preventing the DSRC transmissions the unlicensed devices would be directly interfering. Comparing receiver sensitivities with range will indicate the potential for this kind of interference.

2.2.8 Investigate how interference and detection (determined in the previous objectives) varies if the bandwidth of the overlapping unlicensed transmission changes

As shown in Figure 1-2 the U-NII-4 band can overlap the 10 MHz DSRC channels with 20, 40, 80 and 160 MHz U-NII-4 channels. When the same energy is spread over a wider channel, the amount of energy available to interfere in the 10 MHz channel is less. Therefore it is possible that if the narrower U-NII-4 channels interfere in the DSRC channels, the wider U-NII-4 channels might not. This objective is to determine if such conditional sharing might be possible.

2.2.9 Measure the impact of DSRC operations on unlicensed device performance recognizing that the two radios may form an interactive system

Processors and logic are central to modern radios. Therefore, two radios that can affect decisions made by the other form an interactive system. That is especially true when they follow the same rule set, 802.11 in this case. Studying a single component does not surface the deleterious modes that can occur when two components interact even when both follow their component oriented rules correctly. It is well known that component-based analysis fails to capture important system behaviors.

In addition, measuring the effect of DSRC devices on the operation of unlicensed devices will allow the USDOT to evaluate the credibility of claims made for unlicensed device operation. It will allow the USDOT to evaluate the feasibility of proposed deployment scenarios. This knowledge would better position the USDOT for its collaboration with the FCC and reporting to Congress. Such understanding may also allow the USDOT to develop a sharing mechanism that is more likely to be complied with by unlicensed users.

2.2.10 Investigate mitigation possibilities once potential U-NII-4 devices designed and programmed to share the band with DSRC are available

When devices are available with potential U-NII-4 sharing mechanisms from industry our objective is to test and evaluate the impact on DSRC communications and potential sharing in the 5850-5925 MHz band. The USDOT will also vary parameters within interference tests to explore other possible mitigation concepts as well.

The following sections describe the preparation, tests and other activities to accomplish these objectives.

3. Test Plan Overview

At the highest level, testing first requires a preparatory phase. In this phase the planners agree on the purpose of the tests, what tests are needed, requirements for equipment, facilities and tools. Then they procure them and make them operational. The testing phase then focuses on the objectives described in the previous section beginning with collecting baseline data. The final phase of the work is to analyze the measurements made and report the results and conclusions.

3.1 Test Plan Roadmap

The following road map summarizes key aspects of all test activities to make sure that all activities support at least one test objective and to make sure all objectives will be achieved. Test activities that don't map to an objective are a sign of an unnecessary activity or a missing objective. Objectives not associated with a test activity would indicate gaps in the plan.

Table 3-1 Test plan roadmap

Tasks & Tests	Requirements	Results	Objectives Served[13]
PREPARATORY PHASE			
Determine or validate scenarios to test		◆ Conditions to create ◆ Use cases to test	All
Determine or validate measurement requirements	Metrics to measure and equipment needs.	◆ Acquisition plan ◆ Measurement plan	All
Measure baseline background and existing RF signals	Mobile equipment for passive data collection	◆ Background noise levels ◆ Interference levels	2. Existing interference secondarily 1, 3, 6 & 7
TEST PHASE			
Measure background noise level with operation of various devices	DSRC and U-NII devices ISM Video links UAVs Others	Effect on in-band ambient noise level of DSRC and U-NII in-band and out-of-band transmitters	3. Background noise levels
Measure baseline performance of DSRC and unlicensed devices with no interference.	<u>DSRC baseline</u>: ◆ OBE to OBE ◆ OBE to RSE ◆ RSE to OBE (vary range, power, bandwidth, modulation	Device performance and channel quality benchmarks to compare with interference tests	4-9

[13] Defined in Section 2.2.

Tasks & Tests	Requirements	Results	Objectives Served[13]
	and packet size)		
	<u>Surrogate U-NII-4 baseline</u>: ◆ Outside fixed to/from mobile ◆ Indoors fixed to/from mobile ◆ Mobile to mobile (vary range, power, bandwidth, modulation, packet size, and car windows up/down)	Device performance and channel quality benchmarks to compare with interference tests	4-9
Determine detection and S/N levels	◆ DSRC sensing surrogate U-NII-4 ◆ surrogate U-NII-4 sensing DSRC (vary range, power, bandwidth and *modulation?*	◆Minimum sensitivities ◆ Bounding cases for CCA detection ◆ Potential interference and energy detection ◆ Same bandwidth signal recognition (20 MHz)	7. Detection levels
Interference tests	<u>Fixed surrogate U-NII-4 Outdoors</u> ◆ RSE to/from OBE ◆ OBE to OBE (vary range, power, bandwidth, modulation and packet size)	Effect of handheld and and external U-NII-4 Access Points on V2V, I2V and portable DSRC	4. BSM interference, 5. BSM suppression, 6. Channel quality, 8. U-NII-4 channel width 9. U-NII-4 performance
	<u>Fixed surrogate U-NII-4 Indoors</u> ◆ RSE to/from OBE ◆ OBE to OBE (vary range, power, bandwidth, modulation, packet size and wall composition and number)	Effect of indoors U-NII-4 Access Points with multiple clients on V2V, I2V and portable DSRC	4. BSM interference, 5. BSM suppression, 6. Channel quality, 8. U-NII-4 channel width 9. U-NII-4 performance
	<u>surrogate U-NII-4 in vehicle w/OBE</u> ◆ RSE to/from OBE ◆ OBE to OBE (vary range, power, bandwidth, modulation and packet size)	Effect of single and multiple mobile U-NII-4 devices inside a connected vehicle on V2V, I2V and portable DSRC	4. BSM interference, 5. BSM suppression, 6. Channel quality, 8. U-NII-4 channel width 9. U-NII-4 performance

Tasks & Tests	**Requirements**	**Results**	**Objectives Served**[13]
Co-existence tests[14]	*Same as interference tests above but with potential U-NII-4 devices*[15]	*Impact of mitigation mechanisms on DSRC*	*10. Potential mitigation*
ANALYSIS PHASE			
Analyze interference test results		Report on impact of U-NII-4 operation on DSRC device performance and channel quality for all use case scenarios	4. BSM interference, 5. BSM suppression, 6. Channel quality,
		Report on effect of U-NII-4 energy density reduction with wider channels on the interference to DSRC device performance and channel quality for all use case scenarios	8. U-NII-4 channel width
		Report on impact of DSRC operations on U-NII-4 device performance and channel quality for all use case scenarios	9. U-NII-4 performance
		Report on ability of DSRC and U-NII-4 devices to detect each other in all bands and to recognize each other if both operating in the same 20 MHz band	7. Detection levels
		Report on ability of DSRC and U-NII-4 devices to co-exist in all bands with various sharing mechanisms	*10. Potential mitigation*

[14] Depends on external entities providing potential U-NII-4 devices, or being successfully developed for the USDOT.
[15] Unlike surrogate devices using U-NII-3 rules, potential U-NII-4 devices will test actual sharing mechanisms proposed for this band.

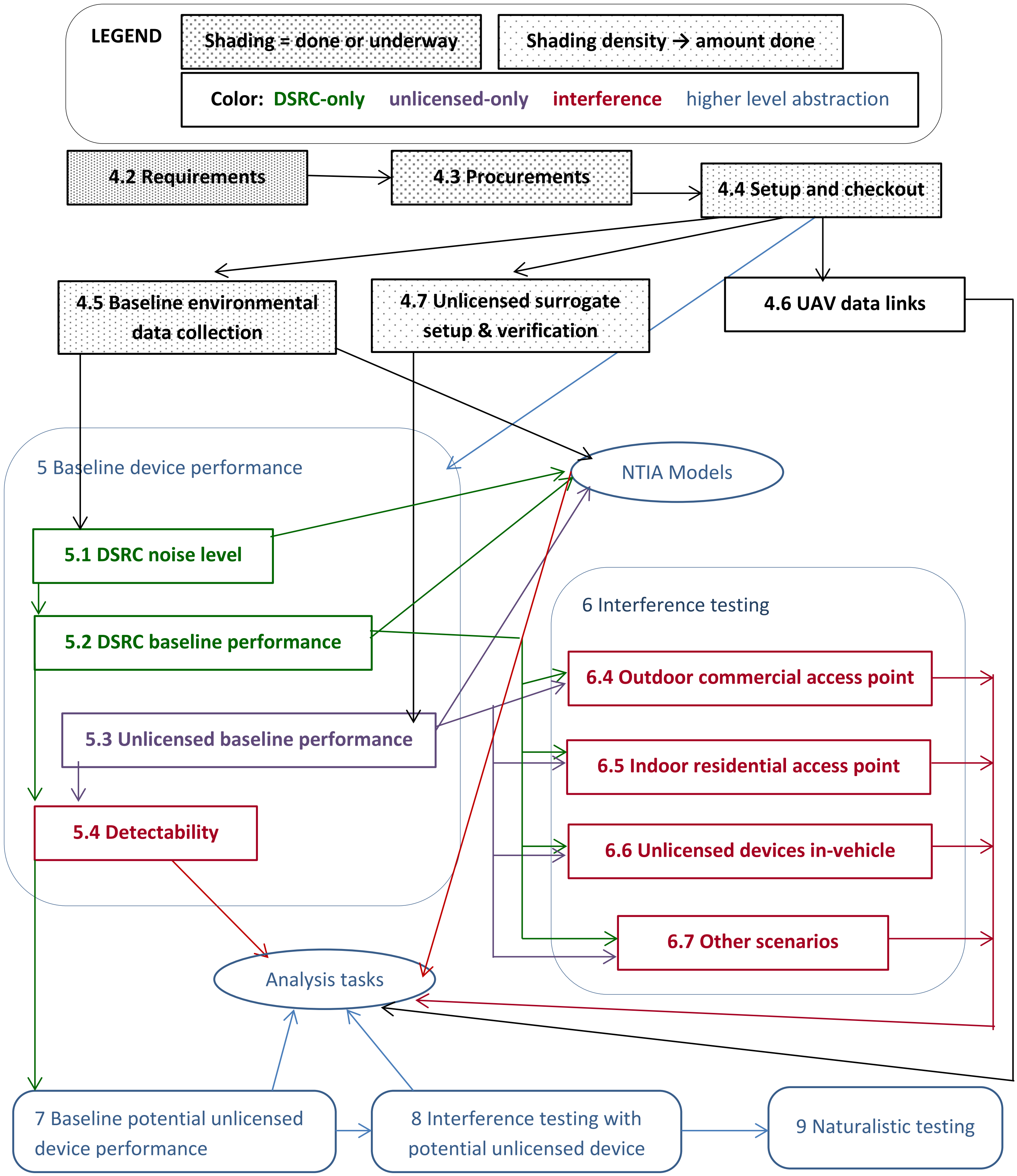
Tasks & Tests	Requirements	Results	Objectives Served[13]
		provided or developed[16]	
Document and analyze the test process and experience.		◆ Lessons learned ◆ Recommendations for conducting future tests ◆ Recommendations for additional testing	1. Learning curve
Input to NTIA models		Device performance input to determine simulated interference at deployment scale scenarios.	3. Background noise levels 4. BSM interference, 5. BSM suppression, 6. Channel quality, 8. U-NII-4 channel width 9. U-NII-4 performance *10. Potential mitigation*

3.2 Dependencies

Some activities require input from others and must be done in series while other tasks do not and may be done in parallel given adequate resources and personnel. Figure 3-1 on the following page depicts the relationship between the activities described in this test plan.

[16] Depends on external entities providing potential U-NII-4 devices, or being successfully developed for the USDOT.

Figure 3-1 Test activity dependencies



3.3 Timeline

TBD. The technical teams will provide an estimate after a sample of actual test runs so that the time to set up and conduct runs is better known. Variables that need to be addresses to develop an accurate timeline include:

1. the time to set up and tear down specific test configurations,
2. the time to make a single data collection run,
3. the time required to analyze a data collection run to ensure the data collected is of high quality and
4. The number of data collection runs that are needed to ensure the data is statistically significant.

4. Preparatory Phase Activities

The initial activities were to recognize the USDOT Goals and identify the Test Objectives needed to achieve those goals. From that we derived the tests that need to be conducted and the requirements that must be met to be able to conduct those tests. The following sections summarize the test scenarios, requirements for equipment, facilities and tools (hardware and software), that were procured for the testing and the baseline data collection.

4.1 Test Scenarios

The initial tests will be to characterize the DSRC and U-NII-4 devices and create baseline performance benchmarks with no interference. We will also characterize existing signals in the band. Both of these activities are straightforward. We will test other unlicensed devices similarly if they become available.

Potential interference depends on the many variables of actual operation for both types of devices. Since it is not possible to test all cases we will test specific cases that represent the most common scenarios in which these devices would be likely to interact and have potential for interference. The initial set of potential interference scenarios we will test are the following:

1. The effect of an 802.11ac Access Point externally mounted on a commercial building near an intersection on RSE-to-OBE and OBE-to-OBE communications.
2. The effect of an 802.11ac Access Point inside a house in a residential area near an intersection on RSE-to-OBE and OBE-to-OBE communications.
3. The effect of an 802.11ac Access Point and portable devices inside a vehicle on RSE-to-OBE and OBE-to-OBE communications.
4. The effect of an 802.11ac Access point on the OBE-to-OBE communications of two vehicles approaching at high speed.
5. The effect of multiple 802.11ac Access points and client devices along a corridor on RSE-to-OBE and OBE-to-OBE communications.

Scenario 1 above is likely for applications like linking wireless CCTV cameras to building security.

Scenario 2 would be common where a home access point links computers, printers, TV, appliances and any object in the future Internet of Things (IoT).

Scenario 3 is the case of handheld devices like tablet or phone that includes 802.11ac Wi-Fi. The vehicle could even have an 802.11ac Access Point as automakers are starting to include Wi-Fi connectivity in their vehicles.

Scenario 4 is a typical case of two vehicles on a rural road, where traffic and radio densities will be low compared to urban and suburban scenarios. This case would be more sensitive to interference because they approach at such a high combined speed the loss of a single BSM could be a greater threat to safety than in the other urban scenarios.

Scenario 5 increases the scale from a couple of devices to a couple dozen to simulate possible conditions at deployment if unlicensed devices are allowed into the 5.850 to 5.925 GHz band.

USDOT will test possible mitigation methods in the above scenarios when devices capable of sharing are available.

Learning from testing these scenarios could point to other scenarios that need to be included as well. Moreover, other types of unlicensed devices may require different scenarios because they have different use cases or don’t recognize 802.11 channel sharing mechanisms. Hence, this test plan is likely to be updated during the course of the testing.

4.2 Requirements

4.2.1 Equipment

The following table lists the equipment requirements.
(As

#	Equipment Requirements	Need met
L-1	5-7 GHz spectral range	Measure RF energy in the DSRC band and adjacent bands on either side: 5.830-5.850 GHz and 5.925-6.425 GHz (CFR 47 Part 2).
L-2	Frequency Resolution	Sufficient to identify 802.11-2012 channels, other unlicensed device, and radar pulses.
L-3	Precision – Frequency and Power	Frequency is a function of span and Resolution bandwidth. Power accuracy shall be better than 1 dB
L-4	Data Collection and Storage	Ability to collect and record RF, position and timing data
L-5	Data Collection and Storage	Ability to collect the data from a mobile platform
L-6	Time - 100 nanoseconds	Precise timestamping provided through GPS time source

4.2.2 Facilities

The following table captures the test facility requirements that are needed to accomplish the test objectives.
Lab Test Facility:

#	Lab Test Facility Requirements	Need met
L-1	Sufficient secured space	Protect equipment and testing from physical disruption
L-2	110AC building power	Electrical power for equipment
L-3	HVAC	Controlled environmental conditions
L-4	Shielding	Minimize electrical and radio frequency interference
L-5	Data network	Collect and store data and send control signals
L-6	Computer (PC or laptop)	Collect and store data and send control signals
L-7	Hard drive	Secure data storage
L-8	Sufficient rack and bench space	Mount radio devices and equipment

Field Test Facility:
The following table lists the requirements for the field test site.

#	Field Test Facility Requirements	Need met
F-1	1000 m or more clear line of site	Test best case DSRC communications for class D RSUs and high power mobile public safety communications
F-2	Flat level surface for vehicles to	Repeatable signal over distance measurements. Cannot

#	**Field Test Facility Requirements**	**Need met**
	drive on for at least 300m	have vehicle tilting while moving, which would move the peak gain of the antenna pattern up and down confounding the relationship of signal power with range.
F-3	Absence of manmade RF reflectors for at least 300m of the test lane. Reflectors to avoid include: buildings, signs, fence posts, power lines, parked vehicles. Shielding by foliage would be next best thing.	Need measurements to be as repeatable as possible and independent of the environment as possible. Eliminate or minimize multipath that would be unique to the test environment.
F-4	Infrastructure for mounting at least one antenna up to 15 m high	To be able to test the maximum RSU horizon permitted. FCC R&O permits RSU antennas up to 15 m but no higher.
F-5	Drivable surface	For making variable range measurements and testing communication with vehicle mounted OBEs.
F-6	Building	Test Wi-Fi Access points mounting internally and externally.
F-7	On site power or portable generator. Also inverter in vehicles.	Electrical power
F-8	DGPS, RTK or other infrastructure that improves on GPS	Accurate range measurement between transmitter and receiver, to 5 cm or better accuracy.

4.2.3 Tools

4.2.3.1 Software

#	Software Requirements	Need met
S-	Off-the-shelf control software supplied with the SDKs	Control the UNII SDK
S-2	Center Frequencies proscribed by FCC proposed UNII-4 Band Plan (see Figure 1-3).	Provided by SDK Control Software
S-3	Bandwidth (see figure 1-3)	Provided by SDK Control Software
S-4	Power Output Control	Provided by SDK Control Software

4.2.3.2 Hardware

#	Hardware Requirements	Need met
H-1	External rugged hard drives	Store collected data for offline analysis
H-2	Test vehicles to mount with OBUs	Make the OBUs mobile

4.3 Procurements and Arrangements

4.3.1 Equipment

The key measurement and test components procured for DSRC interference measurements are the following:

- PXI vector signal generator platform;
- Display for generator waveform;
- Broadband signal analyzer;
- Remote Laptop;
- Ethernet switch.
- Host computers
- Antennae suite with cables and mounts;
- Power equipment
- Surrogate U-NII-4 devices
- DSRC devices (RSU & OBU)
- GPS-RTK precision positioning instrumentation

Detailed lists of equipment for the laboratory and the mobile data collection follow.

4.3.1.1 Lab Equipment

Equipment	Specifications	Notes
Antennas		
Omni-directional	50, 5-6 GHz 6 dBi, vertical polarization, 360° azimuth angle, 25° elevation angle, Mobile Mark, ECO6-5500-WHT	To make 30 dBm EIRP UNII3 access point
Omni-directional	2, 5-6 GHz 9 dBi, vertical polarization, 360° azimuth angle, 12° elevation angle, Mobile Mark, ECO9-5500-WHT with lightning protection	For the VSG but also to make 33 dBm EIRP UNII3 access point
Omni-directional	2, 5.9-6.0 GHz 12 dBi, vertical polarization, 360° azimuth angle, 7° elevation angle, Mobile Mark, ECO12-5900-WHT	For the VSG but also to make 36 dBm EIRP UNII3 access point
Omni-directional	2, 6 dBi, vertical polarization, 360° azimuth angle, 25° elevation angle, Mobile Mark EC06-5500RN-WHT	To be able to operate the DSRC RSU with MIMO since it can run with as well as without diversity
Omni-directional	2 Mobile Mark MGWG-303-3HM3HM2HC-WHT-79 Magnetic Mount Antenna	Magnet roof mount antenna for the DSRC OBUs, it integrates 2 Wi-Fi MIMO antennas modified

Equipment	Specifications	Notes
		for DSRC band and a GPS antenna
Omni-directional	5" White GPS Antenna	GPS antenna for the DSRC RSU
Precision directional	4.9-6.1GHz, 7 degree beamwidth Dual Polarization Antenna Mars MA-WA55-27B	High gain to compensate for the limited receiver sensitivity of the VSA
Antenna cables	3 dB loss cables, 6' LMR400 Jumper NM plus RFI TRFC-11806-12 1 foot N Female to MMCX Male	Jumpers to connect the UNII devices to the external antennas listed above.
Vector Signal Generator/Analyzer	2 Aeroflex 3070A	Generating UNII test waveforms and measuring received signals
Portable Broadband Signal Analyzer	Aeroflex CS9000SM System	Monitor spectrum to detect external signals that may interfere with measurements
UNII-3 Wi-Fi development kit	25 Compex, MMJ344HV6A06AFCEBRV527-B, programmed for U-NII-4 band, with integrated PoE (Power over Ethernet), 27 dBm	Surrogate UNII 3/4device for testing adjacent band and in-band interference
Fixed DSRC radio	23 dBm, Cohda Wireless MK5 RSU (with integrated antennas)	DSRC RSU
Mobile DSRC radio - external antenna	2 23 dBm, Cohda Wireless MK5 OBU, MK5 OBU CWP-OBU-MK05-WW00102	DSRC OBU to simulate OEM devices built into the vehicle
Mobile DSRC radio – integral antenna	TBD	DSRC OBU to simulate aftermarket devices
CCTV	Infrared Sony EFFIO ULTRA High Resolution CCTV camera 5.8 GHz Wireless Transmitter Kit - WIRC5800VT 5.8 GHz Wireless Receiver Kit - WIRC5800VR	To test adjacent band interference from common CCTV surveillance equipment
UAV transmitters	TBD	To test adjacent band interference from UAV control and video stream downlinks
Laptop		For data collection and analysis
8 Port Power over Ethernet Ethernet Switch	Transition Networks 1-1000520 8-port 10/100BASE-TX w/POE and 2-port 10/100/1000Base-T or 100/1000Base-X-SFP Combo ports, Industrial Managed Switch	ethernet data switch to transfer data or provide power to components in the Ethernet chain: switches, cameras, DSRC devices, UNII devices (but not

Equipment	Specifications	Notes
		the laptop)
Power supply	Transition Networks 25080 power supply for industrial converters, 48VDC @ 2.5A / AC 120V	Power source for the Power over Ethernet switch
Embedded Processor Computer (EPC)	Quad-Core 900 MHz 1GB RAM New Raspberry Pi 2 with 8 GB MicroSD Card	To generate data traffic for the surrogate UNII4 devices to transmit
External Hard drive	Silicon Power 2TB Rugged Armor A80 2.5-Inch USB 3.0 Military Grade Portable	Data storage
Cable, connection and mounting hardware	Various, not described here.	Document with data collection.

4.3.1.2 Equipment in mobile data collection platform:

Equipment	Specifications	Notes
Antennas		
Omni-directional	2-6 GHz magnetic mount Wi-Fi antenna, Mobile Mark ECOM6-5500-3C-BLK-120	Receive any signals in the environment
Handheld directional	680MHz to 8GHz Log Periodic Antenna, Kaltman Creations HyperLOG 6080	Rough identification of signal source for aiming directional antennas
Directional	4.9-6.5GHz, 20 degree beamwidth Single Polarization Antenna, Mars MA-WA57-3HG1B	Narrow down signal source location
Precision directional	4.9-6.1GHz, 10 degree beamwidth Dual Polarization Antenna Mars MA-WA56-DP23B	To identify signal source
Precision directional	4.9-6.1GHz, 7 degree beamwidth Dual Polarization Antenna Mars MA-WA55-27B, small form factor	To identify signal source
High gain horn	4.9 - 7.05 GHz, 20 dB Gain Pasternack WR-159 Standard Gain Horn Antenna	Highly sensitive measurement of signals
Pan/Tilt/Zoom mount	FLIR D48 E-series, D48E-SS-SS-000-SS	For aiming directional antennas
DC Power supply	Converts 110-240VAC, 47-63Hz to 30VDC, FLIR PTU-APS-30V-NA	Power for PTZ mount
Power inverter	2 kilowatt Xantrex PROWatt 2000 Inverter, Model# 806-1220	Convert 12VDC vehicle power to 110VAC for the instruments

Equipment	Specifications	Notes
Magnetic base	Master Magnetics #07217 2.04"d Round Base Magnet	Moveable base for PTZ mount
Controller	Wireless Gamepad Controller with Vibration Feedback, Logitech pn F710	Control PTZ mount movement
Antenna switch	USB/Ethernet controlled RF Switch Matrix, 4:1 RF ports, Mini Circuits RC-1SP4T-A18	Switch antenna input to the signal analyzer
Portable Broadband Signal Analyzer	Aeroflex CS9000SM System	Spectrum analysis
Laptop		For data collection and analysis
8 Port Gigabit Ethernet Switch	Netgear GS608NA	
External Hard drive	Silicon Power 2TB Rugged Armor A80 2.5-Inch USB 3.0 Military Grade Portable	Data storage
Cable, connection and mounting hardware	Various, not described here.	Document with data collection.

4.3.1.3 Equipment at Turner Fairbanks Highway Research Center

The Turner Fairbanks Highway Research Center (TFHRC) was established as a Telecommunications test facility in 2013. Capabilities and equipment are documented in the Communications and Positioning Test Bed Final Report[17].

4.3.1.4 Equipment at Federal Law Enforcement Training Center

The Federal Law Enforcement Training Center (FLETC) will have similar capabilities to TFHRC but since this facility will not be a permanent installation, any equipment installation will need to be removable.

4.3.2 Facilities

The geographic and environmental conditions of a test site may influence test results. It is useful to perform similar tests under varying conditions and normalize the results. The USDOT Spectrum team has received permission and obtained research licenses for a set of sites that offer a range of environmental factors such as line-of-sight, controlled roadways, real-world roadway operations, laboratories, etc. This section describes the facilities and highlights the key equipment associated with them.

4.3.2.1 Laboratory 1 – Rockwell Collins/ARINC

[17] To be published.

This laboratory is a shielded room with electrical power, Ethernet and environmental control. It is 10’ x 20’.

Laboratory 2 – Turner Fairbanks Highway Research Center (TFHRC) – Indoor Facility

This laboratory offers access to an indoor bench testing and laboratory capability to ensure devices are operating to specifications upon receipt and for controlled laboratory testing. It is configured as illustrated below:

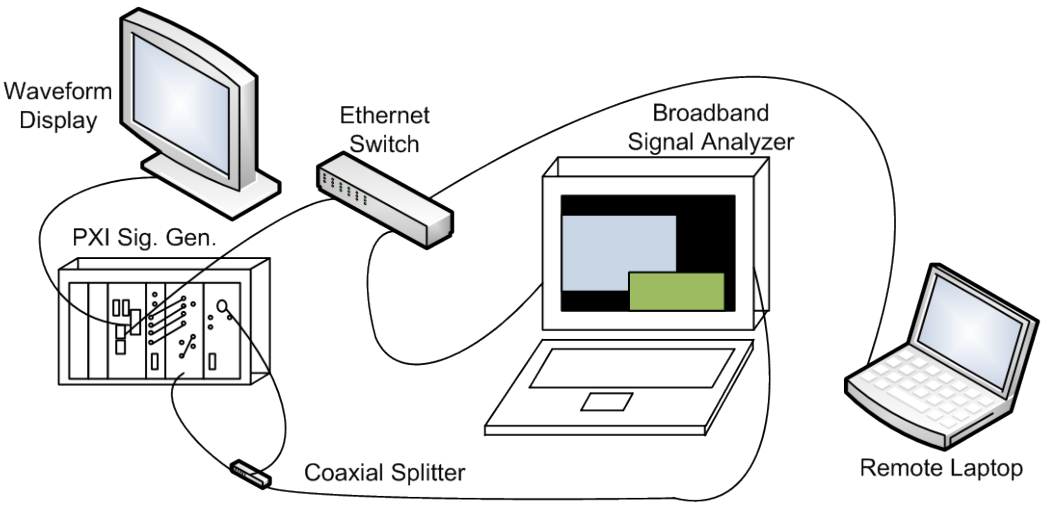


Figure 4-1 RF Signal Measurement Lab Configuration

Field sites:

4.3.2.2 Field Site 1 - ARINC Parking lot

This is paved level ground with 200 yards maximum clear line of sight distance that can be closed for test purposes. There is lighting but no power onsite. Rockwell Collins security monitors the site with video surveillance. The clear line of sight and flat ground is important for minimizing multipath and minimizing variation in multipath. This facility can be used for equipment checkout, power calibration measurements and short range tests that can be compared with short range tests at other ranges.

4.3.2.3 Field Site 2 – Turner Fairbank Highway Research Center – Cooperative Vehicle-Highway Testbed (CVHT) – Outdoor Test Facility

The Cooperative Vehicle-Highway Testbed (CVHT) is one of the three test beds that form the Turner-Fairbank Highway Research Center’s (TFHRC) Saxton Transportation Operations Laboratory (STOL).

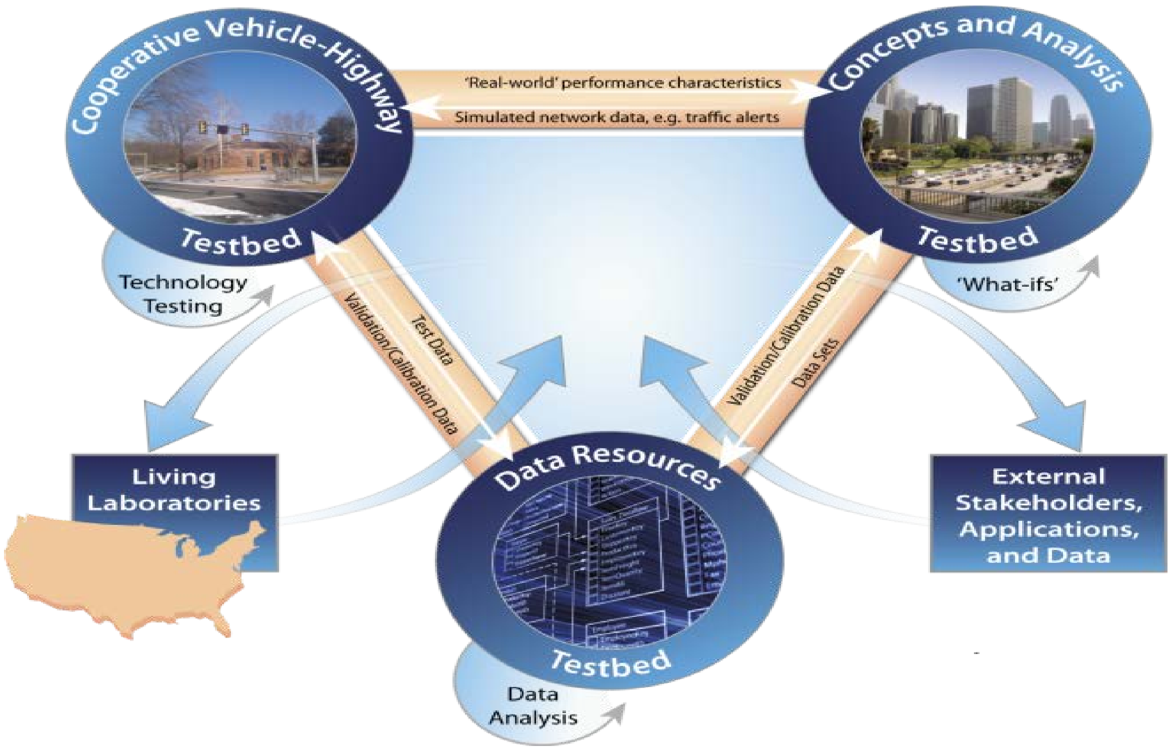


Figure 4-2 Three Test Beds Form the Saxton Traffic Operations Laboratory

- The CVHT emphasizes real-world testing of technology and procedures as related to vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) safety and traffic management applications.
- The Data Resources Testbed focuses on research related to data management associated with traffic operations, and
- The Concepts and Analysis Testbed focuses on transportation modeling and management strategies.

The primary objective of the CVHT is to support evaluation of technologies for Connected Vehicle deployment, and to identify areas where technology improvements or integration are needed. The CVHT consists of a test corridor with a signalized intersection that supports testing of technologies related to Signal Phase and Timing (SPaT) applications. It is comprised of three core subsystems:

(1) The Vehicle Technology Test Support Subsystem(s) (V-TTSS), which can be deployed in multiple vehicles;

(2) An Infrastructure Technology Test Support Subsystem (I-TTSS), which is deployed with the other roadside equipment in the signal controller cabinets; and

(3) A Test Monitoring and Management Subsystem (TMMS), which is located in the lab itself.

The CVHT also includes cameras that can track test vehicles as they progress through test runs, and typical Traffic Management Center software.

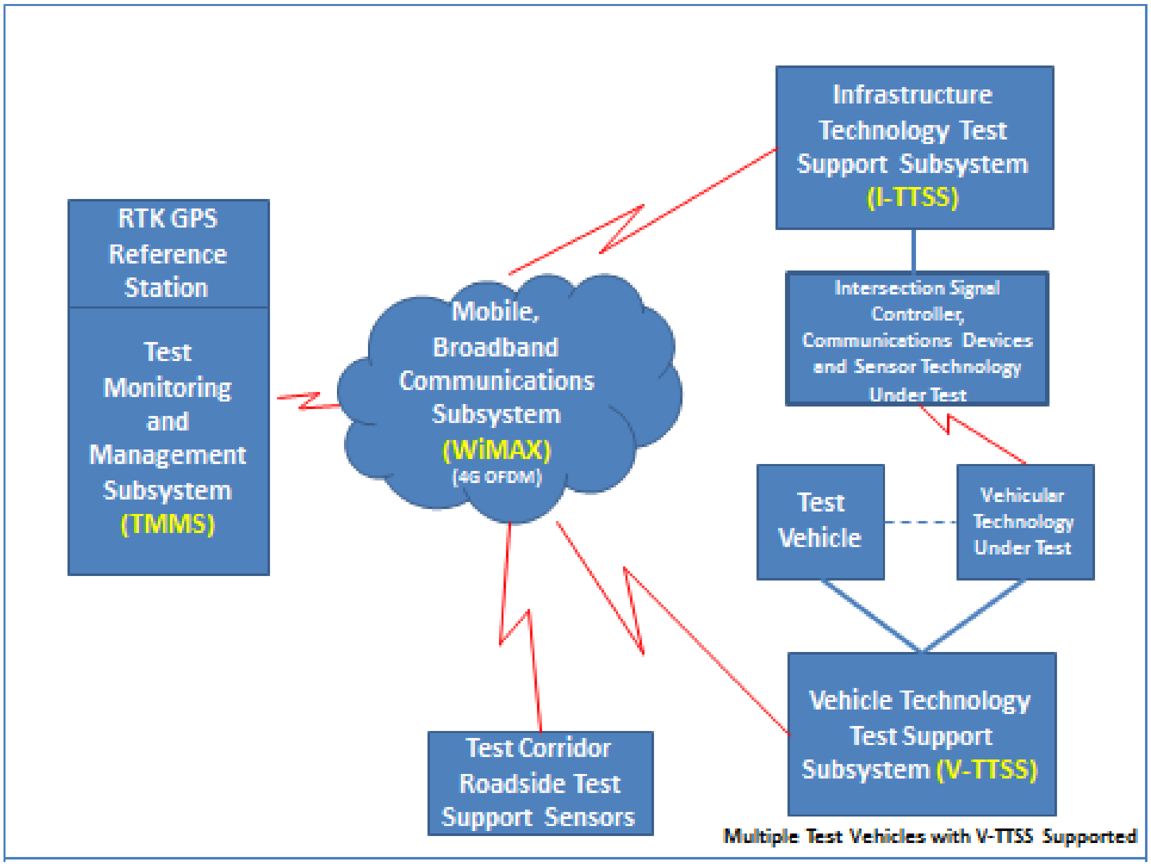


Figure 4-3 Simplified Overview of CVHT System

CAPABILITIES:

The CVHT provides the following capabilities which can be used for evaluation of DSRC and unlicensed device interactions:

- Event-based data logging of a variety of data sources, accurate to within ± 100 nsec;
- High-accuracy determination of test vehicle's position (<10 cm at 95% confidence), with the ability to compare the performance of a vehicle positioning technology under test to the Ground Truth[18];
- Event-based position stamping, interpolated between GPS fixes at 10 microsecond intervals (e.g., position stamping resolution of approximately 3 mm);
- Display of test vehicle location on a GIS map of the test corridor;
- Technology Test Support Subsystems that are compatible with most standard technology interfaces;
- Visualization of test data in the STOL lab;
- Archiving of test data for use by various research projects;
- Evaluation of traffic management processes and technologies;
- Capabilities for remote access, and control, of data acquisition from CVHT subsystems;
- Modularly expandable test system capable of growth to meet future testing requirements associated with cooperative vehicle-highway applications.

[18] Position from Real-Time Kinematic Global Positioning Satellite (RTK-GPS) equipment.

The roadway course consists of a controlled access road through the facility and a signal and its associated roadside equipment. Figure 3 contains an image of the facility with the test route highlighted.

Figure 4-3 TFHRC test route.

4.3.2.4 Field Site 3 – Federal Law Enforcement Training Center (FLETC)

On October 1, 2014, the Federal Highway Administration (FHWA) signed a memorandum of agreement (MOA) with the U.S. Department of Homeland Security, Federal Law Enforcement Training Centers (FLETC) that allows FHWA to use the FLETC facility in Cheltenham, Maryland, for road/vehicle testing. The 372-acre FLETC facility, located 15 miles from downtown Washington, DC, includes a 2.2-mile driving track for testing emergency and non-emergency vehicle operations on highways and in urban grids. The FLETC facility provides FHWA with access to a secure, flexible testing environment to meet a variety of research needs. The MOA allows the U.S. Department of Transportation (USDOT) to install equipment on the test track for research and development purposes.

FEATURES:

Wire-mounted traffic signals

Closed-loop test track (with straightaways)

Ramps

Pole-mounted traffic signal

Flat space for open testing

Skid pad

Figure 4-4 Vehicles at an intersection on the FLETC track. The facility includes multiple traffic signals that can be configured for a variety of testing needs.

4.3.2.5 Field Test Site 4 – Maryland Eastern Shore

Maryland's Eastern shore's level geography, minimal roadside infrastructure, long sight distances, and proximity to the test team offers a unique capability for real world testing on actual roadways. While the other facilities offer controlled environments, they do not provide the long site distances with minimal reflective surfaces, allowing for highly repeatable measurements as found on Maryland's eastern shore.

As with the FLETC facility, the equipment for the Easter Shore sites will be portable and easily removed at the end of the work day or data collection runs, as appropriate.

4.3.2.6 Mobile Data Collection Platform

The Mobile Data Collection Platform captures emissions from transmitters in and adjacent to the 5850-5925 MHz band. It can be used to survey existing emitters or to capture emissions from unknown sources such that they can be recreated later with a signal generator.

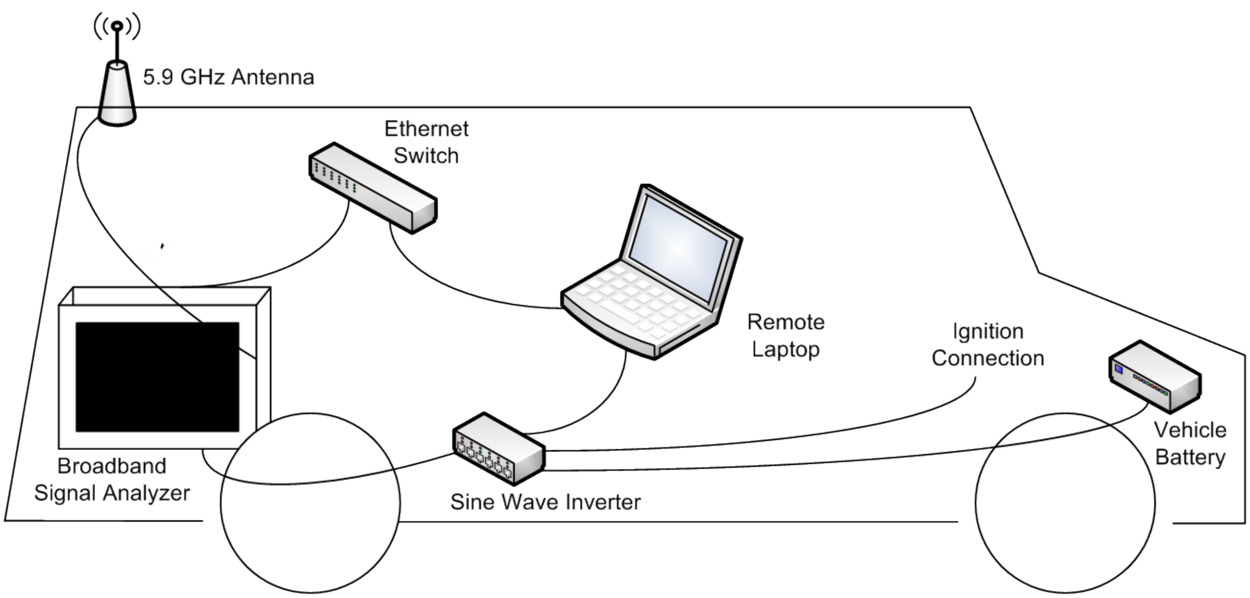


Figure 4-5 RF Signal Measurement Mobile Configuration

4.3.3 Tools

4.3.3.1 Software

To the extent possible, all software will be open source such that others can duplicate the testing.

Custom software to control the SDK surrogates UNII4 devices.

JPERF message traffic generation and analysis software for analyzing link performance (TCP/IP). (Open source shareware.)

Offline analysis software that came with the Vector Analyzer.

4.3.3.2 Hardware

Equipment specifications and technical data sheets are included in appendix F when available.

Hard drives.

2 Ford Edge SUVs, transferred from the USDOT SE Michigan testbed project. They include AC power inverters and cabling for data collection. We will add data network cabling.

20 foot, Telescoping tripods for mounting antennas in the field to simulate RSU and Wi-Fi access point installations.

4.4 Checkout of equipment, test procedures and personnel

4.4.1 Purpose

The purpose is to make sure all equipment works as needed, that the test procedures are sound and efficient, and that personnel become qualified to conduct all test activities and make the necessary measurements.

4.4.2 Activities

This section describes initial activities of this DSRC Interference test program, including development of safety and security measures, identification of test resources, and definition of test procedures and test reports. The developed test hierarchy and test methodology is also provided. And finally, a standard test procedure is defined for interference field measurements.

4.4.2.1 Safety and Security Measures

There are no specific safety requirements identified for the laboratory bench activities or the field survey measurements. Normal electrical power safety practices will be followed and attention paid to harmful radio radiation to persons in close proximity over long time duration. Battery connections to the test vehicle for the mobile operations will be performed by qualified Rockwell Collins technicians.

4.4.2.2 Test Resources

All activities will generally be performed by Rockwell Collins staff with test instrument assistance/support from Aeroflex Test Solution in Annapolis, MD. CAMP personal will share previous interference measurements and participate in selected field tests. Personnel from USDOT and other organizations may be present to witness task preparation activities as well as actual field measurements.

4.4.2.3 Test Procedures and Test Results

This interference field survey is investigative in nature and includes preparation in terms of familiarization with operation and configuration of sophisticated test instrument. Consequently, step-by-step test procedures will be developed as part of the work during the laboratory segment. The lab-proven procedures will used to facilitate the actual field measurements. It may be found that test procedures have to be modified during field testing. Interference field measurements will be collected primarily in computer media supplemented by a test log.

To achieve early benefits, interference measurement data will be promptly returned to the office for processing, interpretation, interference assessment, and documented in a series of reports.

4.4.2.4 Mobile unit validation

Rockwell Collins will perform the Initial checkout of mobile mounted signal analyzer, test procedures, and train engineers local to their facility in Maryland. They will validate that the interference survey mobile lab is fully operational prior to traveling to target sites. This activity will include initial field data analysis, portrayal and archiving practice.

4.4.2.5 UNII3 Software Development Kit Validation

The Software Development Kits (SDKs) were delivered with software to configure the devices. This configuration includes but is not limited to power out, center frequency, and bandwidth. This allows us to test UNII-3 transmissions and then modify a UNII-3 device to operate in the proposed UNII-4 band. Validation will consist primarily of verifying that all parameters were set as directed by the software.

4.4.3 Power calibration

4.4.3.1 Purpose

The signal analyzer will be the reference instrument because it is more sensitive and will be calibrated to standards traceable to NIST. Therefore it will make the background and noise level measurements for the baseline tests and monitor for interference during other tests. In addition, variables recorded from the DSRC and unlicensed devices under test include RSSI and the received signal power of background noise level, intentional and interfering signals. We will calibrate the devices under test to the signal analyzer. This serves two purposes. First, allow all power measurements to be normalized to a common reference. Second, allow us to detect if one of the devices under test malfunctions or drifts out of compliance with the manufacturer's specifications.

4.4.3.2 Activities

We will make power calibration tables for each device to be tested by measuring the same signal with the signal analyzer and the devices under test. The test signals will be generated by the vector signal analyzer and include continuous wave (CW) power, simulated BSMs, and simulated U-NII-3 video packets. The background noise level will also be a test signal for the calibration table. From there power will be incrementally increased until near the saturation range of the receiver. The measurements will be repeated at least three times to capture natural variations in operation and measurement. We will make additional runs if the variation seems unusually large.

One key output will be the noise level measured in a 10 MHz channel by each DSRC device compared to the signal analyzer. This establishes benchmarks we will use to detect equipment problems in later tests.

These tests can be done in one of the laboratory or short range test facilities.

Table 4-1 Power calibration runs

Device	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	Modulation	Power measured by spectrum analyzer dBm	Packet Sizes (octets)
Vector signal Generator (VSG) transmitter	10 20 40 80 160	*172 174, 176, 178, 180,184* *175 183,* 173 175 171 163	TBD, Same for all tests	Background level, Step up incrementally in 1 dB steps up to -10 dBm[19]	CW 300 @ 10 Hz 3000 UNII 9000 UNII 1,000,000 UNII
IEEE 802.11p Receivers	10 20	*172 174, 176, 178, 180,184* *175, 183*	n/a	n/a	n/a
IEEE 802.11ac U-NII-3 Receivers	20	TBD	n/a	n/a	n/a
IEEE 802.11ac U-NII-4 Receivers	20 40 80 160	173 175 171 163	n/a	n/a	n/a

[19] DSRC receivers saturate and become nonlinear in this range. They can burn out at -0dBm so care must be taken not to test higher than indicated by the manufacturers specifications for burn out.

4.5 Baseline Environmental Signal Data Collection

4.5.1 Purpose

The purpose of the baseline data collection is to measure background RF noise levels on roadways and the test facilities to be used in later tests. It is also to measure existing signals in the environment that include the co-primary users in the band: government radars and FSS earth stations. We will also record other interference that can be found opportunistically, like unlicensed ISM, secondary users like amateur radio, and users in adjacent bands. Those could be licensed users like FSS above the DSRC band and unlicensed users, like U-NII-3 (e.g., wireless CCTV links) below the DSRC band.

These measurements will confirm that the current signal environment by known emitters in the DSRC band presents no risk to connected vehicle communications or identify RF issues that should be considered before rollout.

USDOT OBJECTIVES	
2	Measure existing interference
	Secondary:
1	Develop RF test capability
3	Effects on background noise levels
6	Effects on channel quality
7	Detection sensitivities

4.5.2 Description

The baseline environmental signal data collection consists of measuring and recording spectrum energy with a mobile listening station. We will equip a vehicle with a spectrum analyzer, antenna, and data recorder to create the mobile listening station. We will apply front-end amplification and filtering as necessary. Then drive it on representative roads to collect background noise and signals in the DSRC band and adjacent bands. This includes recording in the proximity of radars and satellite earth stations to measure the known signal sources. If it is possible to identify locations with Amateur radio links or ISM equipment, we will measure near those as well.

4.5.3 Equipment

Listed in section 4.3.1.2

4.5.4 Data to Collect

The Aeroflex broadband analyzer may be used for two general forms of data collection, channel power and high resolutions waveform capture. The channel power with GPS tracking is useful while the mobile test vehicle is in motion continuously logging channel power on the defined channel plan. When a possible interferer is identified, the high resolution measurement may be taken. This measurement generates enormous data files so must be used judiciously. The following table lists variables that should be recorded during the field measurements of potential sources of interference.

Table 4-2 RF Environmental data to collect[20]

	Range	Resolution	Notes
Spectrum analyzer configuration			
model, ID			
Antenna height			
Antenna orientation	0-360°		
Other fixed settings			
Spectrum analyzer measurements			
Bandwidth setting			
Frequency vs power plots			
Spatial measurements			
Speed during data collection	0-60mph		
GPS location			
Timestamp			
Location on road network			
Distance to co-primary transmitter			GPS and mapping software

4.5.5 Test Activities

4.5.5.1 Preparation and Safety

Rockwell Collins will configure a rental van as described in section 4.3.2.6 with the equipment listed in

[20] Grey boxes indicate information that either doesn't exist or does not impact measurement taken. In this chart, the range and resolution for the model and ID of the spectrum analyzer is not a parameter and the antenna height resolution and the antenna rotation resolution are not significant factors in the data collection while their absolute values are.

section 4.3.1.2. That equipment includes the signal analyzer, power converters, and a suite of antennae. The analyzer will be secured in the back seat such that the driver and navigator cannot view or control it while underway. A separate operator will make measurements when the vehicle is moving. Mobile field measurements will be performed strictly on public access roads and streets including roadway shoulders where it is safe to pull over and stop. Measurements along high-speed highways will be performed when the vehicle is moving at prudent speeds.

Prior to driving around sensitive government facilities, Rockwell Collins will work with USDOT personnel to establish a local government employee point of contact (POC) who has been briefed on the nature of the test activities. This POC should be present at the government facility during local testing activities for any security related issues.

4.5.5.2 Test Resources

Rockwell Collins staff will generally perform all activities with test instrument assistance/support from Aeroflex Test Solution in Annapolis, MD. CAMP personnel will share previous interference measurements and participate in selected field tests. Personnel from USDOT and other organizations may be present to witness task preparation activities as well as actual field measurements.

4.5.5.3 Test Sites

The mobile lab will travel to target sites to capture real-world in-band and out-of-band signals from existing licensed and unlicensed sources. The initial tests will measure spectral energy near a Federal radar at Wallops Island, In-band and Above-band FSS sites as well as Wi-Fi installations near roads in Maryland and Virginia. Appendix E provides details of the candidate test sites under consideration. Due to the investigative nature of this survey, the actual sites visited will be subject to change based on early experiences.

4.5.5.4 Tasks

This field survey includes the following tasks:

1. **Identify potential sources of out-of-band interference, licensed and unlicensed.**

   The first phase will measure the noise spectrum to characterize RF emissions at locations near roads. The field survey should include a grid map of roads identifying the sites of the measurement. Select outdoor roadside locations to target the following three types of emitters:

   a. **Licensed**: Three Fixed Satellite Service (FSS) ground stations, with uplink carriers near the 5.925 GHz boundary with ITS. They may operate at different frequencies and output power levels. Locate higher power ground stations, if possible.

   b. **Unlicensed**: Three outdoor 5 GHz Wi-Fi Access Points (802.11a/n likely).

   c. **Unlicensed**: Clusters of lower-power 5 GHz Wi-Fi client devices measured at roadside (optional survey, subject to 5 GHz availability).

   The second phase will survey a wider variety of sites to assess differences in noise levels and emitters in different road environments. Measurement sites will include:

a. Urban areas with high density residential;

b. Urban areas with high usage commercial;

c. Suburban areas;

d. Rural areas;

e. Special event high-density venues (optional; events at parks or stadiums).

2. **Identify potential in-band sources of interference, licensed and unlicensed.**

   These survey measurements are also part of Phase 2. It is important to characterize the RF noise and spectral occupancy of emitters at locations near roads. Government radars will have keep-away zones. The survey data should include a map identifying the sites of the measurement. Two types of licensed emitters should be measured:

   a. One Fixed Satellite Service (FSS) ground station, with uplink carriers in the ITS band. This may be same transmit profile as stations operating above 5.925 GHz.

   b. One US Government high-power radar (potentially Wallops Island).

At a minimum, measurements will be screenshots of RF spectrum registers captured in the analyzer's internal memory and subsequently transferred to portable computer media taken to the office for analysis. These spectrum registers are essentially a plot of power versus frequency measured in the band.

4.5.5.5 Outputs

When a potential source is detected the objective will be to determine its precise geographical location, frequency and power, in particular how its power varies across the frequencies it emits at. Another objective will be to capture the signals such that Rockwell Collins engineers will be able to emulate these signals later for controlled interference testing in the lab or test facility.

The data collected in this activity will characterize potentially interfering signals. Characterizing the licensed and unlicensed, in and out of band sources will allow the USDOT to construct scenarios representative of the RF environments DSRC will have to operate in even without sharing the spectrum. This information can be used for further modeling (e.g., ITS-Boulder) and to guide subsequent field tests. Signals from unlicensed devices will add to RF emissions measured in this activity. That must be accounted for in any consideration of sharing. Another output of this activity will be requirements, constraints and heuristics for successful DSRC operation in the presence of these other transmitters. Examples might be minimum signal level or minimum carrier to interference ratio for reliable DSRC operation. These can be used by developers of DSRC equipment, unlicensed device designers and manufacturers, and those trying to develop sharing mechanisms.

4.5.6 CAMP Data

CAMP LLC had collected similar data in parallel with the test team and also collected data on the West Coast. After Camp has finished internal review of their collected data, it will be made available to the Test Team and, where appropriate, compared with results of similar data collection runs. Additionally, the data that was collected on the West Coast will be included in the overall analysis of the existing emitters in the 5850-5925 MHz band.

4.6 Unmanned Aerial Vehicle (UAV) Data Links

4.6.1 Purpose

This task will measure energy in the DSRC and adjacent bands in the presence of downlinks from UAVs to see how they affect the ambient RF environment for DSRC. The recently released FAA rules on UAVs pave the way for a proliferation in the use of UAVs for private purposes. All UAVs have RF uplinks to send commands to the UAV. They also have downlinks to return telemetry data on aircraft status, sensor data and usually streaming video as well. The video downlink would be the most likely source of interference if there is any. Even if those links are not in the DSRC band, if they are nearby and don't have a tight transmission mask, they will leak energy into the DSRC band. Just as the previous task will characterize possible interference from ground-based sources, this task will do the same for UAV mounted transmitters.

Measurements from these tests will indicate if UAV communications pose a risk to connected vehicle communications.

USDOT OBJECTIVES	
2	Measure existing interference
	Secondary:
1	Develop RF test capability
3	Effects on background noise levels
6	Effects on channel quality
7	Detection sensitivities

4.6.2 Description

The environmental data collection in the presence of a UAV consists of measuring and recording spectrum energy with a mobile or fixed listening station using the same equipment as for the baseline environmental data collection. In this case, we will first procure sample uplink and downlink transmitters used by UAVs and operate them near the listening station to see if they introduce energy into the DSRC spectrum. Based on these results, we may purchase an UAV and make spectral measurements during flight tests if they appear to be a potential source of interference.

4.6.3 Equipment

Same as for 4.5 but add the UAV hardware listed in the Section 4.3.1.1 table

4.6.4 Data to Collect

Table 4-3 UAV test data to collect

	Range	Resolution	Notes
Spectrum analyzer configuration			
model, ID			
Antenna height			
Antenna orientation	0-360°		
Other fixed settings			
Spectrum analyzer measurements			
Bandwidth setting			
Frequency vs power plots			
Spatial measurements			
Speed during data collection	0-60mph		May be zero for all tests
GPS location			
Timestamp			
Location on road network			TFHRC
Distance to co-primary transmitter			
UAV Transmitter(s) configuration			
Type, model, ID			
Antenna height			Need tower or building to simulate aerial coverage?
Antenna orientation	0-360°		
Antenna gain in direction of receiver			
Other fixed transmitter settings			
Transmitter Variables			
Transmitter channel (frequency)			
Transmit channel bandwidth			
Distance between transmitter and receiver			For fixed and not flight testing
Orientation between transmitter and receiver			“
Transmitted power			
Transmitted modulation			
Transmitted data rate			
Time stamped flight path or geo-location			For flight tests if necessary

4.6.5 Test Activities for UAVs

Based on the literature, there are several different types with different operational characteristics. These will be further researched and appropriate test will be added here to assess their impact, if any, on DSRC operations

4.7 Surrogate U-NII-4 setup & verification

4.7.1 Purpose

It is essential to have a U-NII-4 device to study potential interference with DSRC devices. This task prepares a surrogate U-NII-4 device from commercially available U-NII-3 devices to test until a potential U-NII-4 device becomes available.

Data from these tests will insure that the modified U-NII-3 SDKs properly model U-NII-4 devices operating under U-NII-3 rules before using them as surrogate U-NII-4 radios in the following tests.

USDOT OBJECTIVES	
1	Develop RF test capability
3	Effects on background noise levels
4	Interference with transmitted BSMs
5	Suppression of BSMs by CCA
6	Effects on channel quality
7	Detection sensitivities
8	Effect of UNII-4 channel width
9	Impact on UNII-4 performance

4.7.2 Description

The U-NII-3 bands come up to the lower edge of the DSRC band. The U-NII-3 device becomes a U-NII-4 device easily enough by programing it to run at the slightly higher frequencies of the U-NII-4 band, which overlaps the DSRC band. The difference with a potential U-NII-4 device is that we will have a U-NII-4 device operating under U-NII-3 rules. That will be good enough to measure interference. Testing a sharing mechanism customized for the DSRC band will require a potential U-NII-4 device operating under proposed U-NII-4 rules.

There are two fundamental tests in this task. The first is to use a vector analyzer to verify that the modified U-NII-3 device is mimicking a U-NII-4 device properly. The second test will be to identify which modulations to use in the interference tests.

We are modifying production UNII-3 radios to operate under UNII-3 rules in the proposed U-NII-4 band. Therefore, this testing will occur under the experimental license the USDOT has from the FCC. See appendix.

4.7.3 Equipment

U-NII-3 Wi-Fi development kits

Software drivers to operate as U-NII-4
Embedded Processor Computers (EPCs)
Vector analyzer
DSRC device

4.7.4 Data to Collect

Table 4-4 Surrogate U-NII-4 Modulation test data

	Range	Resolution	Notes
Vector analyzer			
model, ID			
Variable1 -			
Receiver configuration			DSRC
Type, model, ID			
Antenna height			
Antenna orientation	0-360°		
Antenna gain in direction of transmitter			
Other fixed receiver settings			
Receiver measurements			
Received channel (frequency)			
Channel bandwidth	10-20MHz		
Received RF power			
Received Signal Strength Indicator (RSSI)			Power above noise level DSRC
Signal-to-Noise (S/N)			Get from vector A. or calculate
Packet Error Rate (PER)			From DSRC box
Packet Reception Rate (PRR)			From DSRC box
Channel availability /access time			Access time from DSRC box
Transmitter(s) configuration			DSRC
Type, model, ID			
Antenna height			
Antenna orientation	0-360°		
Antenna gain in direction of receiver			
Other fixed transmitter settings			
Transmitter Variables			
Transmitter channel (frequency)			
Channel bandwidth	10-20MHz		
Distance between transmitter and receiver			

	Range	Resolution	Notes
Orientation between transmitter and receiver			
Transmitted power			
Transmitted modulation			
Transmitted data rate			
Packet size			
Transmitter(s) configuration			U-NII-4
Type, model, ID			
Antenna height			
Antenna orientation	0-360°		
Antenna gain in direction of receiver			
Other fixed transmitter settings			
Transmitter Variables			
Transmitter channel (frequency)			
Channel bandwidth	10-20MHz		
Distance between transmitter and receiver			GPS or survey
Orientation between transmitter and receiver			
Transmitted power			
Transmitted modulation			
Transmitted data rate			
Packet size			

4.7.5 Test Activities

Verify surrogate U-NII-4 operation

Verification of correct operation of surrogate U-NII-4 radio sets will include the following:

- Channelization per proposed channel plan in NPRM
- Center frequency
- Bandwidth
- Receiver sensitivity
- Transmit emission mask
- Transmit power
- Transmit power adjustment
- Basic data transmission

- Basic sharing etiquette[21]

This testing is complete once the surrogate U-NII-4 device operates properly.

<u>Select Modulation</u>

Table 4-4 shows that there are many possible modulations for 802.11ac as there are for 802.11p. There is some overlap. Modulations used by both devices will be recognized and can suppress messages via the CCA mechanism. In the interference tests, we will test one or two modulations that both devices recognize. On the other hand, interference could be worse when 802.11ac and 802.11p devices are using modulations the other doesn't recognize. This test is to see which modulations are most disruptive to the DSRC device. The most disruptive modulation will be used later in some interference tests.

Table 4-5 802.11ac modulation options

Data rates

Theoretical throughput for single Spatial Stream (in Mb/s)										
MCS index	Modulation type	Coding rate	20 MHz channels		40 MHz channels		80 MHz channels		160 MHz channels	
			800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	BPSK	1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	65
1	QPSK	1/2	13	14.4	27	30	58.5	65	117	130
2	QPSK	3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195
3	16-QAM	1/2	26	28.9	54	60	117	130	234	260
4	16-QAM	3/4	39	43.3	81	90	175.5	195	351	390
5	64-QAM	2/3	52	57.8	108	120	234	260	468	520
6	64-QAM	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
7	64-QAM	5/6	65	72.2	135	150	292.5	325	585	650
8	256-QAM	3/4	78	86.7	162	180	351	390	702	780
9	256-QAM	5/6	N/A	N/A	180	200	390	433.3	780	866.7

This bench test is to simply set up the DSRC and U-NII-4 radios in the lab and measure performance of the link between the DSRC radios as the modulation of the U-NII-4 radio is changed. Performance measures will include the PER to quantify quashed packets and access time to quantify suppressed packets.

[21] Most likely the U-NII-3 rules that the Wi-Fi devices use to avoid interfering with each other.

5. Baseline Device Performance Tests

5.1 DSRC Band Background Noise Level Testing

5.1.1 Purpose

To measure ambient noise and then measure changes to it in the presence of different transmitters in-channel and in adjacent channels for a few select configurations. Transmitters tested will be DSRC, U-NII-3 and U-NII-4. This strictly looks at energy injected into the band independent of modulation.

Data from these tests will establish the noise level for subsequent tests and measure energy leaked in from adjacent bands and channels. It may also be used in NTIA models investigating deployment scale effects.

USDOT OBJECTIVES	
3	Effects on background noise levels

5.1.2 Description

Calibration: First, we will measure the ambient noise level in a DSRC channel specified by table 5-4 with a DSRC OBE receiver.

Adjacent channel interference: Then measure ambient noise level as DSRC units in adjacent channels transmit at a selection of ranges or powers and modulations. That includes anticipated operation of both RSEs and OBEs including high power channel 184. This measures the effect of DSRC operations on the noise level in adjacent channels.

Then we will measure noise level in the DSRC channel as the U-NII-3 and U-NII-4 devices transmit in the adjacent band according to their anticipated operation in a few select configurations.

Note that in the absence of potential U-NII-4 devices we will simulate U-NII-4 with U-NII-3 devices operating under U-NII-3 rules but in the DSRC band. That means dialing up the frequency.

In channel interference: We measure signal power in a DSRC channel with an in channel DSRC transmitter including distances where it is supposed to be out of range to look for effects on the noise level. We will test closer ranges as well to consider the hidden terminal problem. This test measures the effect on noise level from nearby DSRC radios at ranges where the CCA will not suppress transmissions.

We then measure noise level with U-NII-4 transmitters in the same channel at different powers and ranges according to typical anticipated scenarios. That includes distances just out of range where the CCA mechanism will make the radio back off. This will show what U-NII-4 devices that do not cease transmission will do to the noise level.

Multiple runs of each test will account for natural variances. A signal analyzer will monitor the channel throughout all the above measurements to detect spurious signals that could introduce error into the baseline measurements. In addition, at the beginning and end of each day, every device under test that day will have a sample of received power measurements compared to the simultaneously received power of the signal analyzer. These measurements must be in range of measurements made during the power calibration tests of section 4.4.3.

5.1.3 Equipment

List in section 4.3.1.1 minus the following:

- CCTV hardware
- UAV hardware

5.1.4 Data to Collect

Table 5-1 DSRC noise level data to collect

	Range	Resolution	Notes
Receiver configuration			
Type, model, ID			
Antenna height			
Antenna orientation	0-360°		
Antenna gain in direction of transmitter			
Other fixed receiver settings			
Receiver measurements			
Received channel (frequency)			
Channel bandwidth	10-20MHz		
Received RF power			
Transmitter(s) configuration			
Type, model, ID			
Antenna height			
Antenna orientation	0-360°		
Antenna gain in direction of receiver			
Other fixed transmitter settings			
Transmitter Variables			
Transmitter channel (frequency)			
Channel bandwidth	10-20MHz		
Distance between transmitter and receiver			GPS or survey
Orientation between transmitter and receiver			
Transmitted power			
Transmitted modulation			
Transmitted data rate			

Note receiver type will be DSRC. Transmitter type may be DSRC, U-NII-3 and U-NII-4.

5.1.5 Test Activities

To look at how in-band and adjacent band DSRC and U-NII transmitters affect the ambient noise level we will measure the noise level in all 6 DSRC channels that are not being used while operating a DSRC or U-NII radio in one of the channels. We will measure the noise level in all 7 DSRC channels while operating a U-NII-3 radio in the adjacent U-NII-3 band below the DSRC band.

To minimize the number of runs we will start with the highest power scenarios and step down the power until no effect is observed. This will spare us from doing runs where any effects will not be measureable. We will do a number of runs, to be determined in the field, to characterize the natural variability in the background. This is to be able to distinguish the effect of unlicensed signals from natural variations in the background. Fewer runs will be necessary if the background variation has a Gaussian distribution than a more irregular distribution. This needs to be determined with the first set of measurements.

We will use a fixed RSU as the receiver and transmit from a test vehicle nearby. If transmission adds to the noise level in other channels we will slowly drive the vehicle away from the transmitter until any effects are not measureable. The result will show the interaction of DSRC receiver sensitivity with the transmission masks of DSRC and U-NII-3 radios characterized by power and range. A spectrum analyzer will monitor the background to catch spurious signals that might occur during the tests so we can discard invalid measurements.

Appendix C lists the candidate transmit powers considered for these tests. Table 5-2 lists the transmit powers selected for the tests.

Table 5-2 Radiated DSRC power levels selected for test

EIRP[22] dBm	EIRP *mW*	**Remarks**
0	*1.0*	Baseline for handheld DSRC and class A (15 m range) RSUs
10	*10*	Baseline for class B RSU (100 m range)
20	*100*	Baseline for class C RSU (400 m range)
23	*200*	Baseline for the low power 10 MHz service channels and the 20 MHz channels
30	*1 W*	Baseline for U-NII access point and close to baseline for class D (1000 m range) RSUs
33	*2 W*	Baseline for the high power DSRC service channels (all 10 MHz). Most common power likely to be used.
40	*10 W*	Baseline for max power on channel 184
44.8	*30 W*	Baseline for max power on channel 178

Testing will simply be to measure power in each DSRC channel during every test run. Table 5-3 summarizes the type of runs that are detailed in Tables 5-4 and 5-5.

[22] The Effective Isotropic Radiated Power (EIRP) can be larger than the transmitter output power because it includes antenna gain. [EIRP = transmitter output power – cable losses + antenna gain]

Table 5-3 Summary of test runs

Transmitter(s)	Number of Device Pairs	Tx Frequency
NONE		
DSRC	Single	In-channel
		Adjacent channel
	Multiple	In-channel
		Adjacent channel
U-NII-3	Single	Adjacent band
	Multiple	Adjacent band
U-NII-4	Single	In-channel
		Adjacent channel
	Multiple	In-channel
		Adjacent channel

Measure RF power in every DSRC channel for every test condition shown in tables 5-4 & 5-5 below.

Table 5-4 Baseline DSRC noise level test runs

Radio Pair (1 Mobile & 1 Stationary)	Test Range (m)	Bandwidth (MHz)	Tx Channel Number (DSRC band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
Baseline – no transmitters	n/a	n/a	n/a	n/a	n/a	n/a
Single IEEE 802.11p (DSRC)	10 until no signal	10	172	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	33, 23, 20, 10, 0	300 & 1500
Single IEEE 802.11p (DSRC)	10 until no signal	10	178	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	44.8, 33	300 & 1500
Single IEEE 802.11p (DSRC)	10 until no signal	10	184	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	40, 33	300 & 1500
Single IEEE 802.11p DSRC	10 until no signal	20	175, 181	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	23	300 & 1500
Multiple IEEE 802.11p (DSRC)	10 until no signal	10	172	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	33, 23, 20, 10, 0	300 & 1500
Multiple IEEE 802.11p (DSRC)	10 until no signal	10	178	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	44.8, 33	300 & 1500

Radio Pair (1 Mobile & 1 Stationary)	Test Range (m)	Bandwidth (MHz)	Tx Channel Number (DSRC band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
Multiple IEEE 802.11p (DSRC)	10 until no signal	10	184	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	40, 33	300 & 1500
Multiple IEEE 802.11p DSRC	10 until no signal	20	175, 181	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	23	300 & 1500

Table 5-5 Baseline U-NII noise level test runs

Radio Pair (1 Mobile & 1 Stationary)	Test Range (m)	Bandwidth (MHz)	Tx Channel Number (U-NII-4 band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
Baseline – no transmitters	n/a	n/a	n/a	n/a	n/a	n/a
Single U-NII-3	10 until no signal	20	U-NII-3 CH 161		36	300 & 1500
Multiple U-NII-3	10 until no signal	20	U-NII-3 CH 161		36	300 & 1500
Single U-NII-4	10 until no signal	20	173, 177, 181		36, 20	300 & 1500
Multiple U-NII-4	10 until no signal	20 40[23]	173, 177, 181 175		36, 20	300 & 1500

[23] One or more 40 MHz runs will be done to see if the energy it puts into the 10 MHz DSRC channel is half the energy that a 20 MHz channel injects. This will test whether the effect on the noise level by the wider U-NII-4 channels can be simply scaled from the 20 MHz measurements. If not, then we w will add measurement runs at 40, 80 and 160 MHz.

5.2 DSRC Device Baseline Performance Testing

5.2.1 Purpose

Determine the baseline performance of DSRC reception in terms of power, error rate and the selected channel quality metrics in order see how these change when unlicensed radios are introduced in later tests. This creates the reference data for subsequent tests and inputs for NTIA/ITS models.

These tests characterize normal operation of DSRC devices, which is necessary to be able to tell the difference between interference and normal operation in the interference tests that follow. This data may also be used in NTIA/ITS models investigating deployment scale effects.

USDOT OBJECTIVES	
4	Interference with transmitted BSMs
5	Suppression of BSMs by CCA
6	Effects on channel quality
7	Detection sensitivities
8	Effect of UNII-4 channel width
9	Impact on UNII-4 performance

5.2.2 Description

Signal power and other channel control metrics will be measured and recorded at a DSRC receiver as a DSRC transmitter is moved toward and away from the receiver. Distance will be measured by GPS and all data will be time-stamped to correlate the RF and position measurements. This will provide the baseline signal power over distance data for each type of radio. The tests will be done separately, first with DSRC equipment and then with U-NII equipment in the following test (See section 5.3). Multiple runs will account for natural variances. Data will be collected for an OBU using an external antenna on the roof of the car and the integral antenna in an aftermarket OBU for installation inside the vehicle. In addition, a spectrum analyzer will be monitored in the background to detect spurious signals that could introduce error into the baseline measurements.

The antennas of the DSRC RSUs and OBUs are not isotropic so their antenna gains vary with elevation angle. Therefore, the tests must be repeated for multiple elevation angles of the fixed mounted RSU and the vehicles carrying the OBUs must travel on a flat surface on order to generate repeatable signal over distance measurements.

5.2.3 Equipment

List in section 4.3.1.1 minus the following:

- UNII-3 Wi-Fi development kit

- CCTV hardware
- UAV hardware
- EPCs

5.2.4 Data to Collect

Table 5-6 DSRC performance baseline data to collect

	Range	Resolution	Notes
Receiver configuration			DSRC
Type, model, ID			
Antenna height			
Antenna elevation angle			
Antenna orientation	0-360°		
Antenna gain in direction of transmitter			
Other fixed receiver settings			
Receiver measurements			
Received channel (frequency)			
Channel bandwidth	10-20MHz		
Received RF power			
Received Signal Strength Indicator (RSSI)			From DSRC box
Signal-to-Noise (S/N)			Calculate or from Vector A
Packet Error Rate (PER)			From DSRC box
Packet Reception Rate (PRR)?			From DSRC box
Channel busy percentage?			Maybe from vector analyzer
Packet transmit time			Logged by the transmitter
Packet receive time			Logged by the receiver
Inter-packet gap?			From Tx & Rec times?
Channel availability? /access time			From DSRC box
Transmitter(s) configuration			DSRC
Type, model, ID			
Antenna height			
Antenna elevation angle			
Antenna orientation	0-360°		
Antenna gain in direction of receiver			
Other fixed transmitter settings			
Transmitter Variables			
Transmitter channel (frequency)			
Channel bandwidth	10-20MHz		
Distance between transmitter and receiver			GPS or survey
Orientation between transmitter and receiver			
Transmitted power			
Transmitted modulation			
Transmitted data rate			

	Range	Resolution	Notes
Packet size			
Vehicle window position	Up-down		Not needed for DSRC?
<u>Spectrum analyzer configuration</u>			Monitor background to verify that observed signals are DSRC and not something else in the ambient RF environment.
model, ID			
Antenna height			
Antenna orientation	0-360°		
Other fixed settings			
<u>Spectrum analyzer measurements</u>			
Bandwidth setting			
Frequency vs power plots			
Channel power			One value per 10 MHz channel per sec, all channels almost simultaneously
Waveform			High resolution power with time if a spurious signal is detected

Note both transmitter and receiver device type will be DSRC.

5.2.5 Test Activities

Testing the DSRC radios without interference provides a benchmark needed to see how performance changes in the presence of unlicensed device signals. We will install an IEEE 802.11p DSRC device at the TFHRC test intersection and have a second one in a test vehicle. The fixed DSRC device will be mounted on the traffic signal mast arm and will connect to the Infrastructure Technology Test Support Subsystem (I-TTSS) at TFHRC and the mobile DSRC unit will connect to the Vehicle Technology Test Support Subsystem (V-TTSS) to collect the test data. This will provide an RSU to OBU baseline.

The test vehicle will start at the East Gate at TFHRC and proceed through the intersection to the West gate, and then turn around and repeat the test path in the opposite direction. Figure 5-1 illustrates the test path. The signalized intersection is approximately 160 m from the West gate, and approximately 660 m from the East gate. The velocity of the test vehicle will be 20 mph.

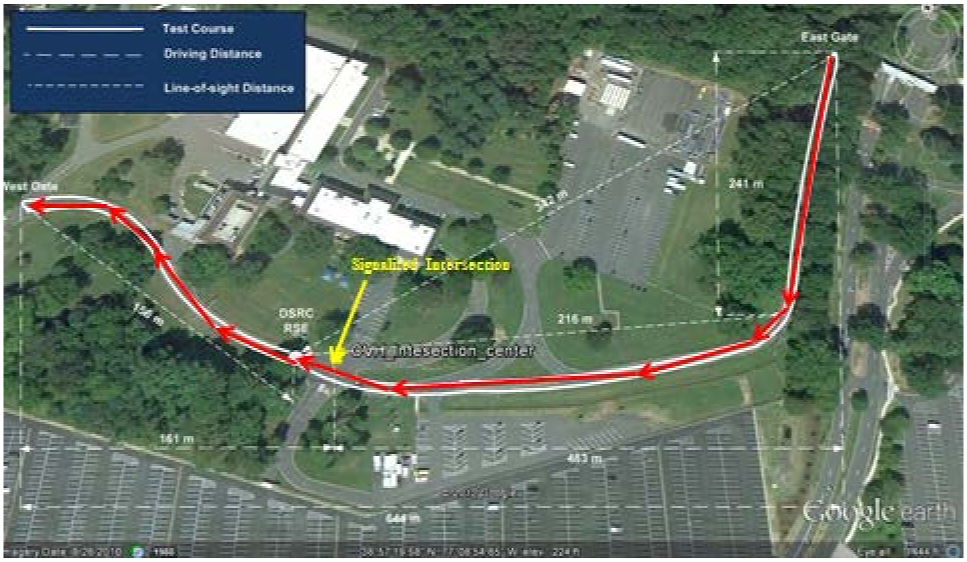


Figure 5-1. Baseline Test of IEEE 802.11p and IEEE 802.11ac Radios

The test team will repeat the test replacing the fixed RSU with a stationary vehicle parked at that location to characterize an OBU to OBU baseline.

Transmit power: Table 5-4 in the previous section lists the transmit powers selected for the tests.

Packet length: We selected two packet lengths for testing DSRC messages.

1) 300 bytes which is typical for a BSM.
2) 1500 bytes which is the maximum allowable WAVE short message size. Note that larger packets might occur when exchanging V2I data with a data warehouse.

Channel width: We will test in both 10 MHz and 20 MHz DSRC channels. The 10 MHz channels will be 172, 178 and 184. Channel 172 is representative of all the service channels and will be overlapped by U-NII-4 channels in any sharing scenario. Channel 178 allows for the highest DSRC EIRP (30W), and Channel 184 is allowed 10W signals. Because it will also be overlapped in any sharing scenario we will test channel 175 as the 20 MHz channel.

Repetition: We will repeat each test run to total at least three runs to get a sense of the natural variability in performance and catch any runs with an outlier condition. More runs will be necessary if the background variation is not Gaussian but a more irregular distribution. This needs to be determined with the first set of measurements. We will run a spectrum analyzer in the background to catch any spurious signals that could show up in the environment during measurements. We will compute the average signal level versus distance and average PER versus RSSI and range from the data collected.

Modulation: Test data will be collected using 3 or 4 different modulations. Three of the modulations supported by both 802.11p and 802.11ac radios are: QPSK ½ rate; 16 QAM ½ rate; and 64 QAM ¾ rate. If testing described in section 4.7 above identifies a modulation that is more disruptive to DSRC it will replace one of these in the test procedure. An identical baseline test will be conducted using IEEE 802.11ac radios (see Section 5.3).

Range: From 5 meters until there is no measurable signal OR the limit of the test facility is reached.

Elevation angle: Initial tests will be with the RSU antenna aimed at the horizon (zero degrees) which is the first bounding case since RSUs will rarely if ever be aimed upward. The other bounding case with maximum tilt downward will be determined in the field. Then tests will be run with two other elevation angles equally spaced in between these bounding cases. This should provide enough data to interpolate to other angles for testing or simulation.

Power calibration check: In addition, at the beginning and end of each day, every device under test that day will have a sample of received power measurements compared to the simultaneously received power of the signal analyzer. These measurements must be in range of measurements made during the power calibration tests of section 4.4.3.

Tables 5-7 and 5-8 summarize the baseline DSRC tests.

Table 5-7 DSRC RSU-to-OBU baseline performance tests – no interference

Radio Pair (1 OBU Mobile & 1 RSU Stationary)	Bandwidth (MHz)	Channel Number (DSRC band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
IEEE 802.11p – external antenna (DSRC)	10	172	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	33, 23, 20, 10, 0	300 & 1500
IEEE 802.11p – internal antenna (DSRC)	10	172	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	33, 23, 20, 10, 0	300 & 1500
IEEE 802.11p – external antenna (DSRC)	10	178	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	33, 44.8	300 & 1500
IEEE 802.11p – external antenna (DSRC)	10	184	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	33, 40	300 & 1500
IEEE 802.11p – external antenna (DSRC)	20	175, 181	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	23	300 & 1500

Repeat tests in Table 5-7 with the RSU aimed at elevation angle zero (horizontal) and three other angles tilted downward to be determined in the field.

Table 5-8 DSRC OBU-to-OBU baseline performance tests – no interference

Radio Pair (1 OBU Mobile & 1 OBU Stationary)	Bandwidth (MHz)	Channel Number (DSRC band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
IEEE 802.11p (DSRC)	10	172	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	33, 23, 20, 10, 0	300 & 1500
IEEE 802.11p (DSRC)	10	178	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	33, 44.8	300 & 1500
IEEE 802.11p (DSRC)	10	184	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	33, 40	300 & 1500
IEEE 802.11p DSRC	20	175, 181	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	23	300 & 1500

5.3 U-NII-3 and U-NII-4 Device Baseline Performance Testing

5.3.1 Purpose

Determine the baseline performance of U-NII-3 and U-NII-4 reception in terms of power, error rate and the selected channel quality metrics in order see how these change when these unlicensed radios are introduced into DSRC communication scenarios in later tests. These tests also provide inputs for NTIA models.

These tests characterize normal operation of U-NII-3 and U-NII-4 devices, which is necessary to be able to tell the difference between interference and normal operation in the interference tests that follow. This data may also be used in NTIA models investigating deployment scale effects.

USDOT OBJECTIVES	
4	Interference with transmitted BSMs
5	Suppression of BSMs by CCA
6	Effects on channel quality
7	Detection sensitivities
8	Effect of UNII-4 channel width
9	Impact on UNII-4 performance

5.3.2 Description

Signal power and other channel control metrics will be measured and recorded at a U-NII-3 or 4 receiver as a U-NII-3 or 4 transmitter is moved toward and away from the receiver. Distance will be measured by Real time Kinematic GPS (RTK-GPS) and all data will be timestamped to correlate the RF and position measurements. This will provide the baseline signal power over distance data for each type of radio. The test will be done separately, first with DSRC equipment in the previous test and then with U-NII equipment in this test. Multiple runs will account for natural variances. In addition, a spectrum analyzer will be monitored in the background to detect spurious signals that could introduce error into the baseline measurements.

There are more use cases for the 802.11ac devices so we need to run more configurations than for the DSRC devices (See section 5.2). The first configuration will be the same as the DSRC RSU-to-OBU test. That is an unlicensed access point mounted on the traffic signal mast arm with another mounted on a vehicle or with an external antenna as would be the case for a vehicle with an installed Wi-Fi option.

The next configuration accounts for U-NII-4 devices that will be in handheld and portable devices like laptops, tablet computers and cellular phones. These would operate at lower powers and be carried inside the vehicles, where the windows might be up or down.

The third configuration is the same but with an indoors Wi-Fi access point.

Note that these are the same surrogate U-NII-4 devices that were setup and qualified in Section 4.7.

5.3.3 Equipment

List in section 4.3.1.1 minus the following:

- Fixed DSRC radio
- Mobile DSRC radio – external antenna
- Mobile DSRC radio – integral antenna
- CCTV hardware
- UAV hardware

5.3.4 Data to Collect

Table 5-9 U-NII-4 performance baseline data to collect

	Range	Resolution	Notes
<u>Receiver configuration</u>			
Type, model, ID			
Antenna height			
Antenna elevation angle			
Antenna orientation	0-360°		
Antenna gain in direction of transmitter			
Other fixed receiver settings			
<u>Receiver measurements</u>			
Received channel (frequency)			
Channel bandwidth	10-20MHz		
Received RF power			
Received Signal Strength Indicator (RSSI)			From SDK?
Signal-to-Noise (S/N)			Calculate or from Vector A
Packet Error Rate (PER)			From SDK?
Packet Reception Rate (PRR)?			From SDK?
Channel busy percentage?			Maybe from vector analyzer
Packet transmit time			Logged by the transmitter
Packet receive time			Logged by the receiver
Inter-packet gap?			From Tx & Rec times?
Channel availability? /access time			From SDK?
<u>Transmitter(s) configuration</u>			
Type, model, ID			
Antenna height			
Antenna elevation angle			
Antenna orientation	0-360°		
Antenna gain in direction of receiver			
Other fixed transmitter settings			
<u>Transmitter Variables</u>			
Transmitter channel (frequency)			
Channel bandwidth	10-20MHz		
Distance between transmitter and receiver			GPS or survey
Orientation between transmitter and receiver			
Transmitted power			
Transmitted modulation			
Transmitted data rate			

	Range	Resolution	Notes
Packet size			
Vehicle window position	Up-down		
Spectrum analyzer configuration			Monitor background to verify that interfering signals are 11ac and not something else in the ambient environment.
model, ID			
Antenna height			
Antenna orientation	0-360°		
Other fixed settings			
Spectrum analyzer measurements			
Bandwidth setting			
Frequency vs power plots			

Note both transmitter and receiver device type will be either U-NII-3 or U-NII-4.

5.3.5 Test Activities

The test description in section 5.2.5 applies here only with unlicensed radios instead of DSRC radios with the following exception:

Packet length: We selected four packet lengths for testing DSRC messages.

1) 300 bytes, to represent the equivalent of BSM sized data packets and streaming audio
2) 1500 bytes, which is a typical video packet in Ethernet and some of the 802.11 protocols.
3) 9000 bytes, the packet in a "jumbo" frame used for streaming video and not uncommon.
4) 1,000,000 (a million bytes), which is permitted by the 802.11ac standard

802.11ac video packets can be as large as a million bytes long. Longer packets provide small gains in efficiency and capacity by reducing the fraction of overhead bytes at the expense of latency. As a result we have added the two larger sized packets to represent streaming video. We will use theU-NII-3 video packet of 9000 bytes as a standard in the U-NII-4 tests. We will use the million byte packet to stress a few scenarios to see the impact. Those results will indicate if it needs to be investigated further.

All channels tested are proposed U-NII-4 channels that overlap the DSRC band as shown in Figure 1-3.

At the beginning and end of each day, every device under test that day will have a sample of received power measurements compared to the simultaneously received power of the signal analyzer. These measurements must be in range of measurements made during the power calibration tests of section 4.4.3.

Table 5-10 provides baseline signal over distance data for the U-NII-3 & 4 devices. Tables 5-11 and 5-12 provide baseline data for portable devices communicating with a curbside or building mounted access point for both windows open and windows closed scenarios. Tables 5-13 and 5-14 lists the test runs for portable devices communicating with indoor Wi-Fi access points.

Table 5-10 U-NII baseline performance tests – no interference

Radio Pair (1 Mobile-external ant. & 1 pole mounted Stationary AP)	Bandwidth (MHz)	Channel Number (U-NII band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
IEEE 802.11ac U-NII-3	20	U-NII-3 CH 161		36	300, 1500 & 9000
IEEE 802.11ac U-NII-4	20	173, 177, 181		36, 20	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4	40	175	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	36	300, 1500 & 9000
IEEE 802.11ac U-NII-4	80	171	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	36, 20	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4	160† (80)	163	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	(33, 17)	300, 1500 & 9000

† Simulate 160 MHz (channel 163) by running the 80 MHz (channel 171) test at half power. The energy in any overlapped 10 MHz band will be the same as a 160 MHz channel at full power. We can also use the vector signal generator to transmit at 160 MHz.

Table 5-11 Portable U-NII baseline performance tests, windows CLOSED – no interference

Radio Pair (1 Portable-inside car & 1 pole mounted Stationary AP)	Bandwidth (MHz)	Channel Number (U-NII band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
IEEE 802.11ac U-NII-3	20	U-NII-3 CH 161		AP: 36 Port: 20, 10	300, 1500 & 9000
IEEE 802.11ac U-NII-4	20	173, 177, 181	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 20 Port: 20, 10	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4	40	175	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 20 Port: 20, 10	300, 1500 & 9000

Radio Pair (1 Portable-inside car & 1 pole mounted Stationary AP)	Bandwidth (MHz)	Channel Number (U-NII band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
IEEE 802.11ac U-NII-4	80	171	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 20 Port: 20, 10	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4	160† (80)	163	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	(AP: 33, 17 Port: 17, 7)	300, 1500 & 9000

Table 5-12 Portable U-NII baseline performance tests, windows OPEN – no interference

Radio Pair (1 Portable-inside car & 1 pole mounted Stationary AP)	Bandwidth (MHz)	Channel Number (U-NII band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
IEEE 802.11ac U-NII-3	20	U-NII-3 CH 161		AP: 36 Port: 20, 10	300, 1500 & 9000
IEEE 802.11ac U-NII-4	20	173, 177, 181	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 30, 20 Port: 20, 10	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4	40	175	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 30, 20 Port: 20, 10	300, 1500 & 9000
IEEE 802.11ac U-NII-4	80	171	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 30, 20 Port: 20, 10	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4	160† (80)	163	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	(AP: 33, 17 Port: 17, 7)	300, 1500 & 9000

Table 5-13 Indoors AP to Portable U-NII baseline performance tests, windows CLOSED – no interference

Radio Pair (1 Portable-inside car & 1 indoor fixed AP)	Bandwidth (MHz)	Channel Number (U-NII band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
IEEE 802.11ac U-NII-3	20	U-NII-3 CH 161		AP: 36 Port: 20, 10	300, 1500 & 9000
IEEE 802.11ac U-NII-4	20	173, 177, 181	QPSK, ½; 16 QAM, ½; 64	AP: 36, 20 Port: 20, 10	300, 1500 & 9000

Radio Pair (1 Portable-inside car & 1 indoor fixed AP)	Bandwidth (MHz)	Channel Number (U-NII band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
			QAM, ¾		1Mb@36dBm
IEEE 802.11ac U-NII-4	40	175	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 20 Port: 20, 10	300, 1500 & 9000
IEEE 802.11ac U-NII-4	80	171	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 20 Port: 20, 10	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4	160† (80)	163	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	(AP: 33, 17 Port: 17, 7)	300, 1500 & 9000

Table 5-14 Indoors AP to Portable U-NII baseline performance tests, windows OPEN – no interference

Radio Pair (1 Portable-inside car & 1 indoor fixed AP)	Bandwidth (MHz)	Channel Number (U-NII band)	Modulations *(TBD depending on results of Section 4.7 testing)*	EIRP dBm	Packet Sizes (octets)
IEEE 802.11ac U-NII-3	20	U-NII-3 CH 161		AP: 36 Port: 20, 10	300, 1500 & 9000
IEEE 802.11ac U-NII-4	20	173, 177, 181	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 30, 20 Port: 20, 10	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4	40	175	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 30, 20 Port: 20, 10	300, 1500 & 9000
IEEE 802.11ac U-NII-4	80	171	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	AP: 36, 30, 20 Port: 20, 10	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4	160† (80)	163	QPSK, ½; 16 QAM, ½; 64 QAM, ¾	(AP: 33, 17 Port: 17, 7)	300, 1500 & 9000

5.4 Detectability Testing between DSRC and U-NII-4 devices

5.4.1 Purpose

The purpose of this test is to see if the sensitivities of DSRC and U-NII-4 receivers are different in such a way that increases the risk of interference. The more sensitive device will hear the other and keep quiet, the less sensitive device may transmit on top of the other device when it shouldn't.

Data from these tests show if interference stems from different sensitivities between DSRC and unlicensed devices. It may be used in NTIA/ITS models investigating deployment scale effects.

USDOT OBJECTIVES	
7	Detection sensitivities
10	Potential mitigation

5.4.2 Description

A DSRC receiver and a U-NII-4 receiver will receive progressively lower powered signals until the minimum power receivable by each is determined. We will similarly determine the minimum signal that will cause the CCA to suppress transmission for both types of radio. Then the DSRC and U-NII-4 radios will operate in range of each other such that the level of both the DSRC and U-NII-4 transmissions at both receivers will be at a value in between the two minimum sensitivities that were determined. We will measure channel metrics to determine if the CCA mechanism favors one type of radio over the other when they use the same EDCA (enhanced distributed channel access) parameters. In order to see the effect of different receiver sensitivities we set the EDCA parameters to be the same. The same EDCA parameters should grant equal access. The test could be repeated with EDCA parameters that give priority to the DSRC communications to see if that is overwhelmed by the difference in sensitivities or can mitigate it. All of this testing can occur in the lab.

Too much energy will saturate or possibly damage the receiver of a DSRC radio. An additional test conducted outdoors will determine if it is possible for a DSRC radio to be close enough to an unlicensed access point to saturate or be damaged. This testing will also determine the range at which a DSRC radio will suppress transmission because it receives signals from an unlicensed access point and also the range at which the unlicensed access point would suppress transmission because it recognizes signals from a DSRC radio.

5.4.3 Equipment

List in section 4.3.1.1 minus the following:

- CCTV hardware
- UAV hardware

5.4.4 Data to Collect

Not all variables below needed to be collected for all tests in this section. For example, received power is the only measurement at the receiver in the initial sensitivity test.

Table 5-15 Detectability data to collect

	Range	Resolution	Notes
Receiver configuration			
Type, model, ID			
Antenna height			
Antenna orientation	0-360°		
Antenna gain in direction of transmitter			
Other fixed receiver settings			
Receiver measurements			
Received channel (frequency)			
Channel bandwidth	10-20MHz		
Received RF power			
Received Signal Strength Indicator (RSSI)			
Signal-to-Noise (S/N)			
Packet Error Rate (PER)			
Packet Reception Rate (PRR)			
Channel busy percentage			
Inter-packet gap?			
Channel availability – access time			Key measurement for this test
Transmitter(s) configuration			
Type, model, ID			
Antenna height			
Antenna orientation	0-360°		
Antenna gain in direction of receiver			
Other fixed transmitter settings			
EDCA parameters (SIFS & contention window maximum)			
Transmitter Variables			
Transmitter channel (frequency)			

	Range	Resolution	Notes
Channel bandwidth	10-20MHz		
Distance between transmitter and receiver			GPS or survey
Orientation between transmitter and receiver			
Transmitted power			
Transmitted modulation			
Transmitted data rate			
Packet size			
Vector analyzer			Monitor spectrum for other interference
model, ID			

5.4.5 Test Activities

Receiver sensitivity
Set up the DSRC receiver near the spectrum analyzer (which will be an external reference). Transmit a test signal from the vector signal generator. Monitor the RSSI and received power signal at the DSRC receiver as the transmit power of the test signal is turned down to zero. Record the power at which the test signal can be distinguished from the noise. Record the signal on the spectrum analyzer. Repeat the test several times to gauge variability. The averaged result is the minimum receiver sensitivity.

Repeat the test with the U-NII-4 device.

Table 5-16 Receiver sensitivity lab tests

Device	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	Modulation	EIRP dBm	Packet Sizes (octets)
Vector signal Generator (VSG) transmitter	10 20 40 80 160	*172, 184* *175,* 173 175 171 163	TBD, Same for all tests	10 dBm stepped down incrementally until no power received	CW 300 @ 10 Hz
IEEE 802.11p Receiver	10 20	*172, 184* *175*	n/a	n/a	n/a
IEEE 802.11ac U-NII-4 Receiver	20 40	173 175	n/a	n/a	n/a

	80	171			

<u>CCA detectability</u>
Set up the DSRC radio near the spectrum analyzer (which will be an external reference). Set the device to transmit BSMs or an equivalent short 10 Hz signal. Transmit a test signal from the vector signal generator. Starting at no power turn the transmitter power up slowly until the test signal causes the DSRC transmitter under test to suppress DSRC transmissions because the DSRC device believes the channel is occupied. Record the RSSI and received power at the receiver. Record the signal on the spectrum analyzer. Repeat the test several times to gauge variability. The averaged result is the minimum receiver detectability. This is the minimum signal that will make the radio back-off.

Repeat the test with the U-NII-4 device to determine at what minimum power the unlicensed device will conclude the channel is occupied.

Table 5-17 Minimum detectability lab tests

Device	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	Modulation	EIRP dBm	Packet Sizes (octets)
Vector signal Generator (VSG) transmitter	10 20 40 80 160	*172, 184* *175*, 173 175 171 163	TBD, Same for all tests	Power stepped up until all devices under test are suppressing	CW 300 @ 10 Hz
IEEE 802.11p Tx & Rec	10 20	*172, 184* *175*	TBD, Same for all tests	6[24]	300
IEEE 802.11ac U-NII-4 Tx & Rec	20 40 80	173 175 171	TBD, Same for all tests	6[25]	300

<u>Minimum signal interference</u>
We will have DSRC and unlicensed devices transmit simultaneously while monitoring how they interact. Program a DSRC device and U-NII-4 device to have the same EDCA parameters. Set up a DSRC radio and a U-NII-4 radio in proximity to each other at the lowest transmit power that is common to both so that neither can detect each other. This might require range separation beyond what is possible indoors. Have both radios transmit 300 byte messages at a 10 Hz repetition rate. Then slowly step up the transmit power of both devices so the transmit power stays the same. Record the transmit power of the U-NII-4 device at which the DSRC radio's CCA mechanism kicks in and it starts suppressing messages. Record the transmit power at which the U-NII-4 radio's CCA mechanism kicks in and it starts suppressing messages. If the detection thresholds that activate suppression are not the same one radio will stifle the other at certain powers and ranges. If the DSRC device will always hear the unlicensed device and

[24] Any small power is fine as long as it is consistent in all tests.
[25] Any small power is fine as long as it is consistent in all tests.

suppress its transmission before the unlicensed device hears the DSRC transmitter then detect-and-vacate cannot work in the regime between those two thresholds.

Once the CCA mechanism of both radios has been activated, monitor channel access times and suppression for both while incrementally turning up the power well beyond the minimum detectability of both radios. Repeat the test several times. With the same EDCA parameters channel access should be the same. Any differences are noteworthy.

Effect of packet size
Repeat the experiment but this time change the packet size of the U-NII-4 device to represent streaming video packets of 1500 bytes, 9000 bytes and 1 million bytes.

Effect of EDCA selection
Change the EDCA parameters so as to advantage the DSRC device and repeat the packet size tests. Note the reduction in DSRC BSM suppression particularly in the regime between the minimum detectability of the two devices. Appendix B describes how these parameters work and ends with a table of illustrative values for enforcing different priorities.

Table 5-18 Minimum signal, packet size and EDCA interference tests

Single radios transmitting simultaneously	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	Modulations	EIRP dBm	Packet Sizes (octets)
IEEE 802.11p Tx & Rec	10 20	*172, 184* *175*	TBD, Same for all tests	Minimum stepped up until double the largest minimum detectability	300
IEEE 802.11ac U-NII-4 Tx & Rec	20 40 80	173 175 171	TBD, Same for all tests	Identical to 802.11p at each step	300, 1500 & 9000 1Mb@36dBm

Field tests for range related effects on detectability
Too much energy will saturate or possibly damage the receiver of a DSRC radio. An additional test conducted outdoors will determine if it is possible for a DSRC radio to be close enough to an unlicensed access point to saturate or be damaged. This testing will also determine the range at which a DSRC radio will suppress transmission because it receives signals from an unlicensed access point and also the range at which the unlicensed access point would suppress transmission because it recognizes signals from a DSRC radio.

An unlicensed access point will be mounted 5 meters above the ground at a fixed location. A portable unlicensed device will be mounted 1 meter above ground at the same location. The DSRC device will be a vehicle mounted OBU. The vehicle will drive slowly in a straight line up to the mount holding the unlicensed devices. Runs for the AP and the portable unlicensed devices may have to be done separately.

These tests have the following specific objectives:

1. Determine the range at which a DSRC device will start suppressing BSMs due to unlicensed signals.
2. Determine the range at which the 802.11ac devices will start suppressing messages due to DSRC signals.
3. Determine how close the DSRC device can approach the U-NII-4 access point before the receiver saturates or there is a risk of damage if at all. Stop the vehicle when the received power reaches 10 dB below the burnout threshold if it gets that high.

The key output will be the ranges which these various transitions occur.

Table 5-19 Field tests for range related effects on detectability

Single radios transmitting simultaneously	Range	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	EIRP dBm	Modulations[26]	Packet Sizes (octets)
IEEE 802.11p – external antenna Tx & Rec	Start 300m or too far to detect until 0 or close to burn out	10 10 10 20	*172,* *184* *178* *175*	33 44.5 40 33	QPSK, ½; 16 QAM, ½; 64	300
IEEE 802.11p – internal antenna Tx & Rec	Start 300m or too far to detect until 0 or close to burn out	10	*172*	33	QPSK, ½; 16 QAM, ½; 64	300
IEEE 802.11ac U-NII-4 Tx & Rec	Fixed	20 40 80	173 175 171	36 36 36	QPSK, ½; 16 QAM, ½; 64	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4 Tx & Rec	Fixed	20 40 80	173 175 171	20 20 20	QPSK, ½; 16 QAM, ½; 64	300, 1500 & 9000 1Mb@36dBm

In addition, at the beginning and end of each day, every device under test that day will have a sample of received power measurements compared to the simultaneously received power of the signal analyzer. These measurements must be in range of measurements made during the power calibration tests of section 4.4.3.

[26] If a better modulation is identified later it can substitute for those shown here.

6. Interference Testing

6.1 Purpose

It is to measure the effects on DSRC communications in the presence of unlicensed U-NII-4 transmitters. Specifically to test anticipated real world scenarios of OBEs communicating with the OBE's in other vehicles and infrastructure mounted RSEs in the presence of unlicensed access points mounted outdoors, indoors and within a vehicle. Each test described separately below is for a different scenario.

Data from these tests will demonstrate whether or not unlicensed devices interfere with DSRC devices in common scenarios and if so to try to quantify it. It will also be input to NTIA/ITS models investigating deployment scale effects.

USDOT OBJECTIVES	
4	Interference with transmitted BSMs
5	Suppression of BSMs by CCA
6	Effects on channel quality
8	Effect of UNII-4 channel width
9	Impact on UNII-4 performance
10	Potential mitigation

Note that the format of Section 6 differs from the previous section to avoid repeating identical information for each scenario. The Equipment and Data to Collect sections that follow pertain to all the subsequent scenarios in Section 6.

As summarized in Section 4.1 these scenarios will be:

6.4 Outdoor 802.11ac Access Point near an intersection with RSE-to-OBE and OBE-to-OBE communications.

6.5 Indoor 802.11ac Access Point near an intersection with RSE-to-OBE and OBE-to-OBE communications.

6.6 In-vehicle 802.11ac Access Point and clients during RSE-to-OBE and OBE-to-OBE communications.

6.7 High speed rural V2V encounter near 802.11ac Access point with OBE-to-OBE communications.

6.8 Multiple 802.11ac Access points and client devices along a corridor with RSE-to-OBE and OBE-to-OBE communications.

6.2 Equipment

The same equipment is used for all the interference tests described in this section so appears here just once.

List in section 4.3.1.1 minus the following:

- CCTV hardware
- UAV hardware

6.3 Data to Collect

The same data is collected for all the interference tests described in this section so is listed here just once.

Table 6-1 Interference data to collect

	Range	Resolution	Notes
Receiver configuration			
Type, model, ID			Can be for 1 or 2 OBUs & 1 RSU
Antenna height			
Antenna orientation	0-360°		
Antenna gain in direction of transmitter			
Other fixed receiver settings			
Receiver measurements			
Received channel (frequency)			
Channel bandwidth	10-20MHz		
Received RF power			
Received Signal Strength Indicator (RSSI)			
Signal-to-Noise (S/N)			
Packet Error Rate (PER)			
Packet Reception Rate (PRR)			
Channel busy percentage			
Inter-packet gap			
Channel availability – access time			
Transmitter(s) configuration			For multiple DSRC and U-NII devices
Type, model, ID			
Antenna height			
Antenna orientation	0-360°		
Antenna gain in direction of receiver			
Other fixed transmitter settings			
Transmitter Variables			
Transmitter channel (frequency)			
Channel bandwidth	10-20MHz		
Distance between transmitter and receiver			GPS or survey
Orientation between transmitter and receiver			
Transmitted power			
Transmitted modulation			

	Range	Resolution	Notes
Transmitted data rate			
Packet size			
Vehicle window position	Up-down		
Vector analyzer			
model, ID			

The Vector Analyzer will be used to monitor background to verify that interfering signals are from the devices under test and not something else in the ambient environment.

6.4 Outdoor 802.11ac Access Point

6.4.1 Purpose

Same as 6.1 Purpose.

6.4.2 Description

This test looks at the effect of an externally mounted unlicensed access point on the ability of an OBU to communicate with an RSU and another OBU. This type of access point can be found on a commercial building as a Wi-Fi hub for passing client devices, to receive streaming video from CCTV surveillance cameras or be a building to building link. The DSRC communications tested are the ability of RSU and OBU to receive BSMs from an OBU and the OBU to receive SPaT messages from the RSU.

6.4.3 Equipment

Same as 6.2.

6.4.4 Data to collect

Same as 6.3.

6.4.5 Test activities

The radio equipment will be staged as shown in Figure 6-1. An RSU to transmit SPaT messages will be mounted on a mast arm at the TFHRC test intersection. The RSU will receive BSMs from the moving OBU as well. An OBU will be in a vehicle parked there or mounted there to receive BSMs from the moving OBU. The second OBU will be in a vehicle that will move to change range. It will transmit BSMs and receive SPaT messages.

The unlicensed access point will be mounted on a building or a structure near the intersection about 5 meters above the ground.

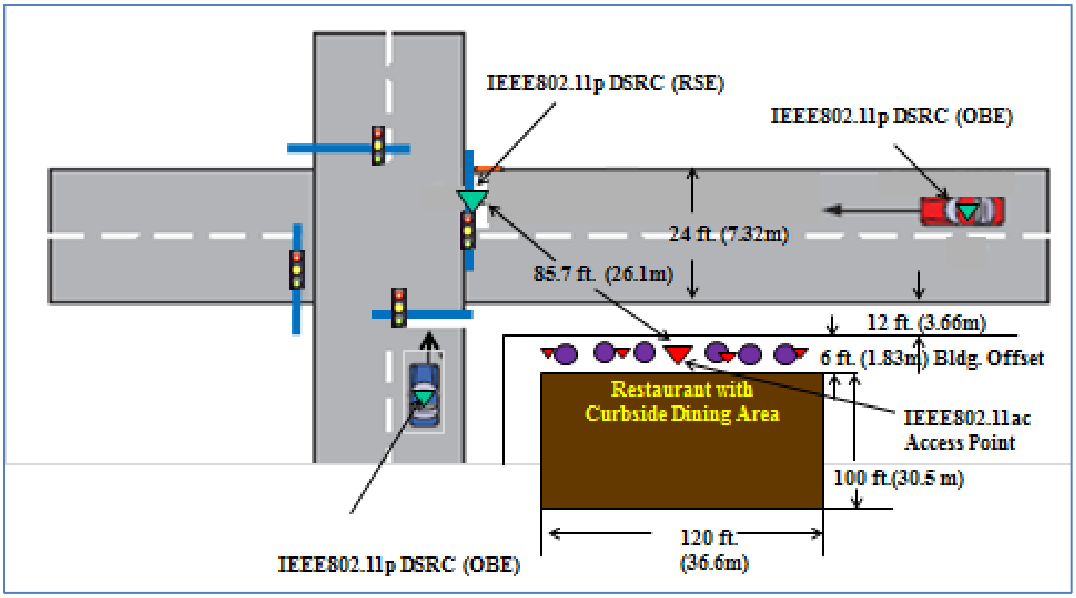


Figure 6-1. Test Geometry for Outdoor Restaurant with an IEEE 802.11ac Access Point at an Intersection with an Installed RSE

The initial test will be for the vehicle to drive from maximum range to the intersection to measure how well it receives the SPaT messages from the RSU and how well the RSU and stationary OBU receives its BSMs. If necessary, these will be done as separate runs. We will vary the RSU power to simulate all four RSU classes described in the FCC R&O. We will also do runs with the OBU powered turned down to simulate a handheld DSRC device.

We will then repeat these tests while the unlicensed access point communicates with multiple portable client devices. We will test both data and video scale packets. The first test will be with no sharing method active in the unlicensed device and then repeated with sharing via the U-NII-3 rules of the surrogate U-NII-4 device. No sharing method means the device will just transmit and not respond to signals it may receive from other devices. The first test will indicate how far out an unlicensed device will cause the DSRC radio to suppress its transmissions. The second test will measure DSRC performance with this kind of sharing. It will indicate how U-NII may affect the DSRC devices and vice versa.

A last test will be to change the EDCA parameters in both devices to advantage the DSRC device to see if there is a configuration that adequately mitigates the interference. Appendix B describes how these parameters work and ends with a table of illustrative values for enforcing different priorities.

In addition, at the beginning and end of each day, every device under test that day will have a sample of received power measurements compared to the simultaneously received power of the signal analyzer. These measurements must be in range of measurements made during the power calibration tests of section 4.4.3.

Table 6-2 Configuration variables for external access point tests

DSRC and UNII radios transmitting and receiving	Range	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	EIRP dBm	Modulations *(TBD depending on results of Section 4.7 testing)*	Packet Sizes (octets)
IEEE 802.11p OBU – external antenna Mobile Tx & Rec	Start at max range to 0 and then to max range at the other gate	10 20	*172* *175*	33, 0 23	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p OBU – internal antenna Mobile Tx & Rec	Max range to 0 & then to max range at other gate	10	*172*	33	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p OBU Stationary Rec	0	10 20	*172* *175*	n/a	n/a	n/a
IEEE 802.11p RSU Stationary Tx & Rec	0	10 10 10 10 20	*172* *172* *172* *172* *175*	33 20 10 0 23	QPSK, ½; 16 QAM, ½; 64	1500@ 10 Hz SPaT equivalent
IEEE 802.11ac U-NII-4 External AP Stationary Tx & Rec	Fixed	20 40 80 160 (80)	173 175 171 163	36 36 36 (33)	QPSK, ½; 16 QAM, ½; 64	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4 Portable Clients Stationary Tx & Rec	Fixed	20 40 80 160† (80)	173 175 171 163	20 20 20 (17)	QPSK, ½; 16 QAM, ½; 64	300, 1500 & 9000 1Mb@36dBm

The test vehicle closes on the intersection for each test in this sequence:

1. Mobile OBU transmits BSMs, stationary OBU and RSU receive. Measure baseline performance and message logs at both stationary receivers.

2. RSU transmits SPaT messages while the moving OBU receives. Measure baseline performance and message logs at the moving OBU.
3. **Unlicensed access point transmitting with no sharing rules.** This should be a worst case scenario. Mobile OBU transmits BSMs, stationary OBU and RSU receive. Measure performance and message logs at both stationary DSRC receivers. Determine range at which communication is disrupted.
4. **Unlicensed access point transmitting with no sharing rules.** This should be a worst case scenario. Fixed RSU transmits SPaT messages while the moving OBU receives. Measure performance and message logs at the moving OBU. Determine range at which OBU is not reliably receiving SPaT messages.
5. Unlicensed access point transmitting with **U-NII-3 sharing rules**. Mobile OBU transmits BSMs, stationary OBU and RSU receive. Measure performance and message logs at both stationary DSRC receivers and the U-NII receiver. Determine range at which communication is disrupted.
6. Unlicensed access point transmitting with **U-NII-3 sharing rules**. Fixed RSU transmits SPaT messages while the moving OBU receives. Measure performance and message logs at the moving OBU and the U-NII receiver. Determine range at which OBU is not reliably receiving SPaT messages.
7. Unlicensed access point transmitting with U-NII-3 sharing rules. **Longer EDCA back off parameters in the unlicensed radio and shorter EDCA back off parameters in the mobile OBU.** Longer back off means the device waits longer when it hears the channel is occupied before it listens again for an opening to transmit in (see Appendix B). Mobile OBU transmits BSMs, stationary OBU and RSU receive. Measure performance and message logs at both stationary receivers and the U-NII receiver. Determine range at which communication is disrupted.
8. Unlicensed access point transmitting with U-NII-3 sharing rules. **Longer EDCA back off parameters in the unlicensed radio and shorter EDCA back off parameters in the RSU.** Fixed RSU transmits SPaT messages while the moving OBU receives. Measure performance and message logs at the moving OBU and the U-NII receiver. Determine range at which OBU is not reliably receiving SPaT messages.

Repeat the tests for the configuration parameters shown in Table 6-2. Do multiple runs of each test to measure variability except the tests with the 1 million byte video packet. Do one or few runs unless it appears to have a major impact on interference that requires further investigation.

Locations of the unlicensed Access Point and the portable clients with respect to the intersection are still TBD.

6.5 Indoor 802.11ac Access Point near road corridor

6.5.1 Purpose

Same as 6.1 Purpose.

6.5.2 Description

This test looks at the effect of an internally mounted access point for an unlicensed device on the ability of an OBU to communicate with an RSU and another OBU. This type of access point can be found in residential buildings as a Wi-Fi hub for connecting peripherals like printers, tablets, game-boxes, camcorders and HDTV. The DSRC communications tested are the ability of RSU and OBU to receive BSMs from an OBU and the OBU to receive SPaT messages from the RSU.

6.5.3 Equipment

Same as 6.2.

6.5.4 Data to collect

Same as 6.3.

6.5.5 Test Activities

The radio equipment will be staged as shown in Figure 6-2. An RSU to transmit warning messages will be mounted on a pole 3 m high to simulate a school zone or curve warning application. We simulate it with Class B power which might be appropriate for that kind of warning. It will only transmit. Two vehicle-mounted OBUs will approach each other from opposite directions crossing near the unlicensed access point. Both will transmit their BSMs.

The unlicensed access point will be mounted inside a building near the intersection about 6 meters above the ground. Four portable client devices will operate in the same building. We will look for impacts on the U-NII as well as DSRC performance. We will do a few runs to simulate a handheld DSRC since those devices may be most vulnerable to interference.

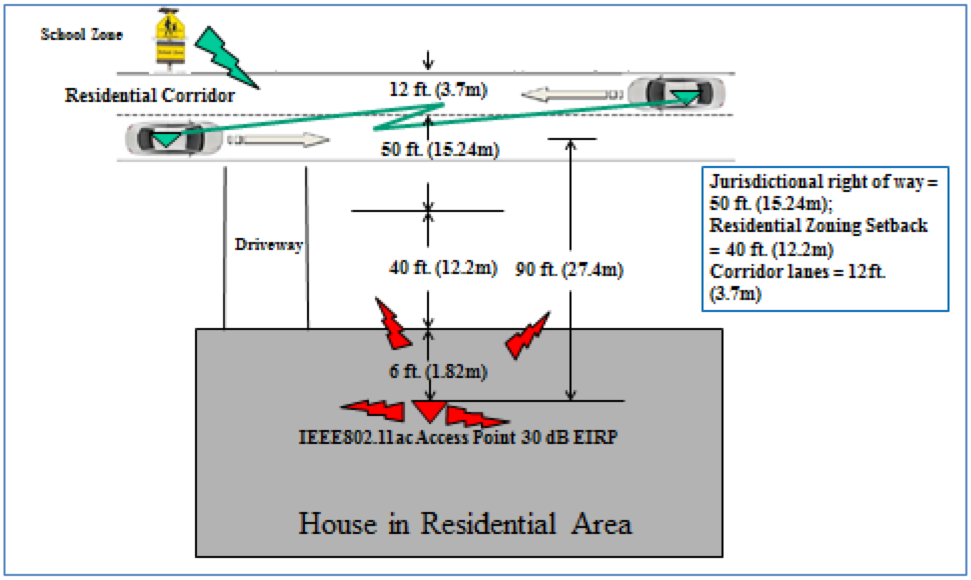


Figure 6-2. Residential Street with Homes Having IEEE 802.11ac Access Points with Passing Vehicles Having DSRC Devices and Possibly a School Zone Warning RSE

This test assumes residential zoning that requires a 40 foot (12.2m) setback from the jurisdictional right-of-way of 50 feet (15.24 m) and road corridors are 12 ft. (3.7m) wide per AASHTO. We locate the unlicensed Access Point 6 feet (1.8m) from the front wall of the home. Based on the geometry shown in Figure 6-3, the AP will be 90 feet (27.4m) from the nearest residential corridor lane (center). Figure 6-3 shows one possible set up for these tests at TFHRC.

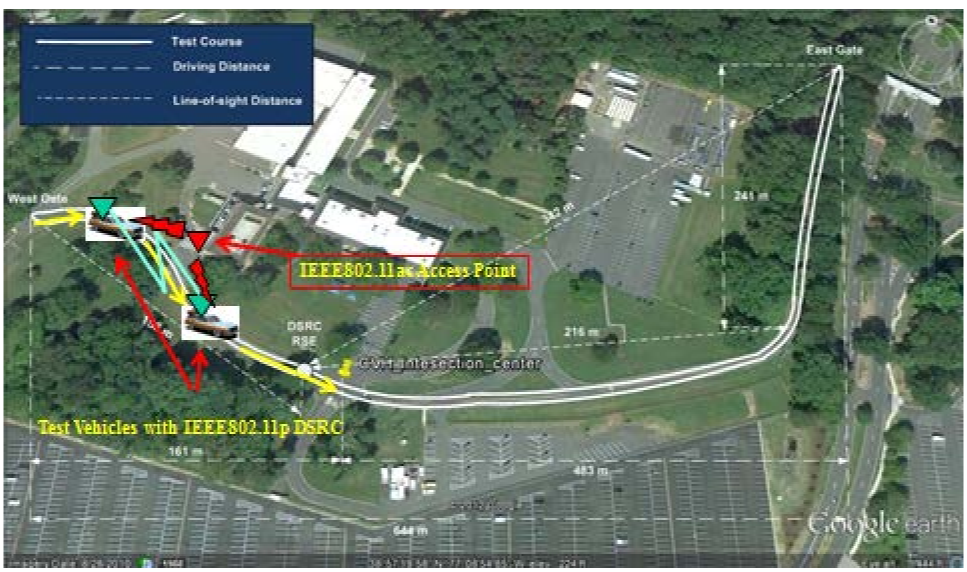


Figure 6-3. Possible Building to Set Up an IEEE 802.11ac AP within 90 feet (27.4m) of a Test Corridor

Table 6-3. Configuration variables for residential access point tests

DSRC and UNII radios transmitting and receiving	Range	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	EIRP dBm	Modulations *(TBD depending on results of Section 4.7 testing)*	Packet Sizes (octets)
IEEE 802.11p OBU – external antenna Mobile Tx & Rec	Start at range max to 0 and then to range max at the other gate	10 20	*172* *175*	33, 0 23	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p OBU – internal antenna Mobile Tx & Rec	Max range to 0 & then to max range at other gate	10	*172*	33	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p OBU Mobile Tx & Rec	Start at opposite gate	10 20	*172,* *175*	33 23	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p RSU-class C Stationary Tx	Fixed, TBD	10 20	*172* *175*	10 23	QPSK, ½; 16 QAM, ½; 64	300@ 10 Hz advisory equivalent
IEEE 802.11ac U-NII-4 Internal AP Stationary Tx & Rec	Fixed	20 40 80 160 (80)	173 175 171 163	36 30 30 (27)	QPSK, ½; 16 QAM, ½; 64	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4 Portable Clients Stationary Tx & Rec	Fixed	20 40 80 160 (80)	173 175 171 163	20 20 20 (17)	QPSK, ½; 16 QAM, ½; 64	300, 1500 & 9000 1Mb@36dBm

Test vehicles close on each other from opposite directions driving gate-to-gate for each test in this sequence:

1. Both Mobile OBUs transmit BSMs and the stationary RSU transmits a warning message. Measure baseline performance and message logs at both mobile OBUs.

2. **Unlicensed access point transmitting with no sharing rules.** This should be a worst case scenario. Both Mobile OBUs transmit BSMs and the stationary RSU transmits a warning message. Measure performance and message logs at both mobile OBUs. Determine ranges at which communication is disrupted.
3. Unlicensed access point transmitting with **U-NII-3 sharing rules**. Both Mobile OBUs transmit BSMs and the stationary RSU transmits a warning message. Measure performance and message logs at both mobile OBUs and the U-NII access point. Determine ranges at which communication is disrupted.
4. Unlicensed access point transmitting with U-NII-3 sharing rules. **Longer EDCA back off parameters in the unlicensed radios and shorter EDCA back off parameters in the mobile OBUs.** Both Mobile OBUs transmit BSMs and the stationary RSU transmits a warning message. Measure performance and message logs at both mobile OBUs and the U-NII access point. Determine ranges at which communication is disrupted.

Repeat the tests for the configuration parameters shown in Table 6-3. Do multiple runs of each test to measure variability except the tests with the 1 million byte video packet. Do one or few runs unless it appears to have a major impact on interference that requires further investigation.

In addition, at the beginning and end of each day, every device under test that day will have a sample of received power measurements compared to the simultaneously received power of the signal analyzer. These measurements must be in range of measurements made during the power calibration tests of section 4.4.3.

6.6 In-vehicle 802.11ac devices

6.6.1 Purpose

Same as 6.1 Purpose.

6.6.2 Description

This test looks at how portable unlicensed devices in a vehicle affect DSRC communications. It tests how unlicensed transmissions might suppress messages from the on-board OBU or the RSU being approached. It also tests how they might interfere with the on-board OBU's ability to receive SPaT messages from RSUs and BSMs from other OBUs. These will be portable unlicensed devices inside the vehicle communicating with an unlicensed bus in the vehicle. These types of unlicensed devices are used to get internet connectivity and stream video.

6.6.3 Equipment

Same as 6.2.

6.6.4 Data to collect

Same as 6.3.

6.6.5 Test activities

The radio equipment will be staged as shown in Figure 6-4. An RSU to transmit SPaT messages will be mounted on a mast arm at the TFHRC test intersection. We simulate all four RSU power classes. It will receive BSMs from both moving OBUs as well. The two vehicles with OBUs will approach each other from opposite ends of the range crossing near the intersection. The test could also be run with the vehicle without the unlicensed devices just parked. Figure 6-5 shows one possible set up for the test at TFHRC.

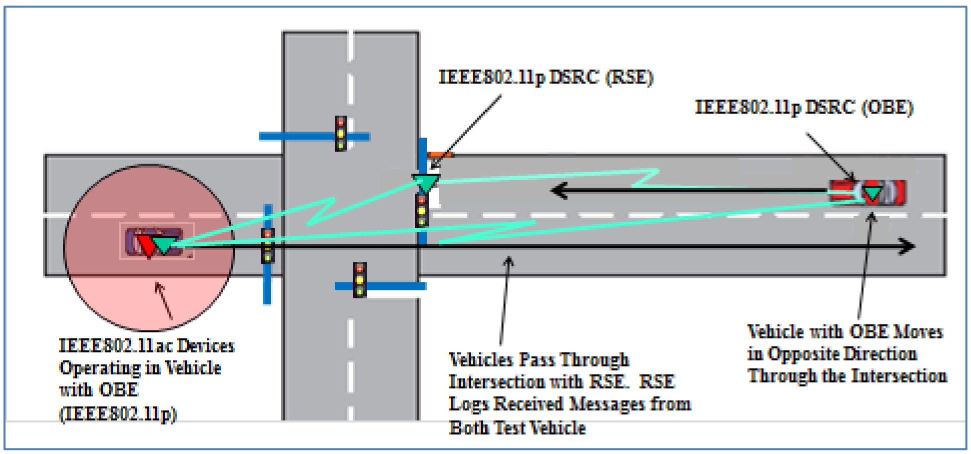


Figure 6-4. Test with IEEE 802.11ac Devices Transmitting in a Vehicle

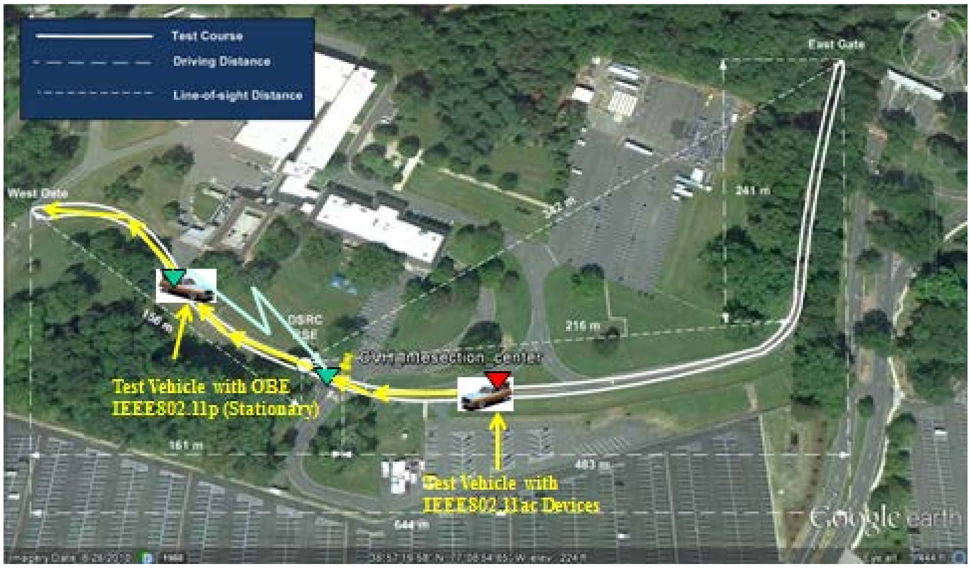


Figure 6-5. Location of Test Vehicles Associated with In-Vehicle IEEE 802.11ac Compatibility Testing with OBEs in Other Vehicles and RSE

Table 6-4 Configuration variables for external access point tests

DSRC and UNII radios transmitting and receiving	Range	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	EIRP dBm	Modulations *(TBD depending on results of Section 4.7 testing)*	Packet Sizes (octets)
IEEE 802.11p OBU Mobil Tx & Rec	Start at max range to 0 and then to max range at the other gate	10 20	*172* *175*	33 23	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p OBU Mobil Tx & Rec	Start at opposite gate	10 20	*172* *175*	33 23	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p RSU Stationary Tx & Rec	0	10 10 10 10 20	*172* *172* *172* *172* *175*	33 20 10 0 23	QPSK, ½; 16 QAM, ½; 64	1500@ 10 Hz SPaT equivalent
IEEE 802.11ac U-NII-4 In-vehicle AP Tx & Rec	In-vehicle with OBU 1	20 40 80 160† (80)	173 175 171 163	20 20 20 (17)	QPSK, ½; 16 QAM, ½; 64	300, 1500 & 9000 1Mb@36dBm
IEEE 802.11ac U-NII-4 Portable Clients In-vehicle Tx & Rec	In-vehicle with OBU 1	20 40 80 160† (80)	173 175 171 163	10 10 10 (7)	QPSK, ½; 16 QAM, ½; 64	300, 1500 & 9000 1Mb@36dBm

Test vehicles close on each other from opposite directions driving gate-to-gate for each test in this sequence:

1. Both mobile OBUs transmit BSMs and the stationary RSU transmits SPaT messages. All receive. Car windows closed. Measure baseline performance and message logs at all 3 DSRC receivers.
2. **Unlicensed devices transmitting in-vehicle with no sharing rules.** This should be a worst case scenario. Both mobile OBUs transmit BSMs and the stationary RSU transmits SPaT messages. All receive. Car windows closed. Measure performance and message logs at all 3 DSRC receivers. Determine ranges at which communication is disrupted with the RSU and with the other OBU.

3. Unlicensed access point transmitting with **U-NII-3 sharing rules**. Both mobile OBUs transmit BSMs and the stationary RSU transmits SPaT messages. All receive. Car windows closed. Measure performance and message logs at all 3 DSRC receivers and a U-NII receiver. Determine ranges at which communication is disrupted with the RSU and with the other OBU.
4. Repeat step 3 above using aftermarket OBUs with integral antenna mounted placed inside the vehicle. First with one internal OBU and the other with external antenna and then both OBUs with internal antenna. If the variability in the results is significantly different from testing with two OBUs with external antenna, repeat the tests in steps 2 and 4 using internal OBUs as well. If the results using internal versus external antenna are similar such that results for internal OBUs can be easily extrapolated from the external antenna results, then data from this one step with internal OBUs will be enough.
5. Unlicensed access point transmitting with U-NII-3 sharing rules. **Longer EDCA back off parameters in the unlicensed radio and shorter EDCA back off parameters in the mobile OBU.** Both mobile OBUs transmit BSMs and the stationary RSU transmits SPaT messages. All receive. Car windows closed. Measure performance and message logs at all 3 DSRC receivers and a U-NII receiver. Determine ranges at which communication is disrupted with the RSU and with the other OBU.
6. Repeat all of the above with windows open.

Repeat the tests for the configuration parameters shown in Table 6-4. Do multiple runs of each test to measure variability except the tests with the 1 million byte video packet. Do one or few runs unless it appears to have a major impact on interference that requires further investigation.

In addition, at the beginning and end of each day, every device under test that day will have a sample of received power measurements compared to the simultaneously received power of the signal analyzer. These measurements must be in range of measurements made during the power calibration tests of section 4.4.3.

6.7 High Speed Rural V2V encounter near an unlicensed access point

6.7.1 Purpose

Same as 6.1 Purpose.

6.7.2 Description

This test looks at the effect of an externally mounted unlicensed access point and an internal unlicensed access point on the ability of two OBUs to communicate with each other as they approach at high speed. This would be the case of two vehicles driving by each other on a rural road late when there is no other traffic. In this scenario the density of radios is low so signal-to-noise or energy in the band should not be an issue. But any access of the channel by unlicensed devices that suppresses one or more BSMs, by activating the CCA mechanism in a DSRC device, may have a greater safety impact than the more urban scenarios because the closing distance between the vehicles changes so much between BSMs.

6.7.3 Equipment

Same as 6.2.

6.7.4 Data to collect

Same as 6.3.

6.7.5 Test activities

The two test vehicles will start at a distance such that both will still be out of DSRC range by the time they reach rural highway speed. An unlicensed access point will be mounted in between. The vehicles will approach and pass each other at the speed limit in the vicinity of the unlicensed access point. The tests will be done with OBUs using both external and internal antennas. It will be conducted with the unlicensed devices operating without sharing rules or essentially jamming the channel to determine how close the vehicles have to be before they start exchanging safety messages. Then it will be repeated with the unlicensed device operating under the U-NII-3 sharing rules.

Table 6-5 Configuration variables for external access point tests

DSRC and UNII radios transmitting and receiving	Range	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	EIRP dBm	Modulations *(TBD depending on results of Section 4.7 testing)*	Packet Sizes (octets)
IEEE 802.11p OBU Mobil Tx & Rec	~1000 m from access point	10 20	*172* *175*	33 23	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p OBU Mobil Tx & Rec	~1000 m from AP in other direction	10 20	*172* *175*	33 23	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11ac U-NII-4 External AP Stationary Tx & Rec	Fixed	20 40 80 160 (80)	173 175 171 163	36 36 36 (33)	QPSK, ½; 16 QAM, ½; 64	300, 1500 & 9000 1Mb@36dBm

Test vehicles close on each other from opposite directions at the rural highway speed limit passing near the fixed access point for each test in this sequence:

1. Both mobile OBUs transmit and receive BSMs. Measure baseline performance and message logs at both DSRC receivers. Repeat the test often enough to understand natural variation in the results. The number of runs to be determined in the field.
2. **Unlicensed device transmitting with no sharing rules.** This should be a worst case scenario. Both mobile OBUs transmit and receive BSMs. Measure performance and message logs at both DSRC receivers. Determine ranges at which DSRC communication is disrupted. Repeat the test often enough to understand natural variation in the results. The number of runs to be determined in the field.
3. Unlicensed device transmitting with **U-NII-3 sharing rules**. Use the same EDCA parameters in the DSRC and unlicensed devices. Both mobile OBUs transmit and receive BSMs. Measure performance and message logs at both DSRC receivers. Determine ranges at which DSRC communication is disrupted. Repeat the test often enough to understand natural variation in the results. The number of runs to be determined in the field.
4. Repeat steps 1-3 above using **aftermarket OBUs with integral antenna** mounted placed inside the vehicle. First with one internal OBU and the other with external antenna and then both OBUs with internal antenna. Measure performance and message logs at both receivers. Determine ranges at which DSRC communication is disrupted. Repeat the test the number of runs determined in step 3 that accounts for natural variation.

5. Unlicensed access point transmitting with U-NII-3 sharing rules. **Longer EDCA back off parameters in the unlicensed radio and shorter EDCA back off parameters in the mobile OBUs.** Both mobile OBUs transmit and receive BSMs. Measure performance and message logs at both DSRC receivers. Determine ranges at which DSRC communication is disrupted. Repeat the test the number of runs determined in step 3 that accounts for natural variation.

Car windows closed for all runs. That won't affect OBUs using external antennas. Windows closed should be worst case for the internal OBUs. These two bounding cases are sufficient.

In addition, at the beginning and end of each day, every device under test that day will have a sample of received power measurements compared to the simultaneously received power of the signal analyzer. These measurements must be in range of measurements made during the power calibration tests of section 4.4.3.

6.8 Multiple 802.11ac Access points and client devices along a corridor

6.8.1 Purpose

Same as 6.1 Purpose.

6.8.2 Description

All previous tests have been device level tests. This test investigates a possible deployment scenario at small scale. Similar to the first scenario this one tests RSU-to-OBU and OBU-to-OBU communications but along a corridor with multiple unlicensed devices in operation.

6.8.3 Equipment

Same as 6.2.

6.8.4 Data to collect

Same as 6.3.

6.8.5 Test activities

An RSU to transmit SPaT messages will be mounted on a mast arm by a test intersection. The RSU will receive BSMs from the moving OBU as well. An OBU will be in a vehicle parked there or mounted there to receive BSMs from the moving OBU. The second OBU will be in a vehicle that will move to change range. It will transmit BSMs and receive SPaT messages.

Up to 25 unlicensed devices will be configured to act as both access points and clients. They will be positioned to simulate commercial, residential and personal use as might occur along a road corridor the way unlicensed devices are typically deployed now. The results of the previous scenario tests will inform the specific positioning of the unlicensed devices for this scenario. The unlicensed devices will operate under U-NII-3 sharing rules. We will test with OBUs with both external and internal antennas.

Table 6-6 Configuration variables for external access point tests

DSRC and UNII radios transmitting and receiving	Range	Bandwidth (MHz)	Channel Number (*DSRC* & U-NII band)	EIRP dBm	Modulations *(TBD depending on results of Section 4.7 testing)*	Packet Sizes (octets)
IEEE 802.11p OBU – external antenna Mobile Tx & Rec	Start at max range to 0 and then to max range at the other gate	10 20	*172* *175*	33, 0 23	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p OBU – internal antenna Mobile Tx & Rec	Max range to 0 & then to max range at other gate	10	*172*	33	QPSK, ½; 16 QAM, ½; 64	300 @ 10 Hz BSM equivalent
IEEE 802.11p OBU Stationary Rec	0	10 20	*172* *175*	n/a	n/a	n/a
IEEE 802.11p RSU Stationary Tx & Rec	0	10 10 10 10 20	*172* *172* *172* *172* *175*	33 20 10 0 23	QPSK, ½; 16 QAM, ½; 64	1500@ 10 Hz SPaT equivalent
Multiple IEEE 802.11ac UNII-4 External AP Stationary Tx & Rec	Fixed	20 40 80 160 (80)	173 175 171 163	36 36 36 (33)	QPSK, ½; 16 QAM, ½; 64	Mix of 300, 1500 & 9000 1Mb@36dBm distributed across the devices
Multiple IEEE 802.11ac UNII-4 Portable Clients Stationary Tx & Rec	Fixed	20 40 80 160† (80)	173 175 171 163	20 20 20 (17)	QPSK, ½; 16 QAM, ½; 64	Mix of 300, 1500 & 9000 1Mb@36dBm distributed across the devices

The test vehicle closes on the intersection for each test in this sequence:

1. Mobile OBU transmits BSMs, stationary OBU and RSU receive. Measure baseline performance and message logs at both stationary receivers.

2. RSU transmits SPaT messages while the moving OBU receives. Measure baseline performance and message logs at the moving OBU. Repeat the test often enough to understand natural variation in the results. The number of runs to be determined in the field.
3. Unlicensed devices transmitting with **U-NII-3 sharing rules**. Mobile OBU transmits BSMs, stationary OBU and RSU receive. Measure performance and message logs at both stationary DSRC receivers and the U-NII receivers. Determine ranges at which communication is disrupted. Repeat the test often enough to understand natural variation in the results. The number of runs to be determined in the field.
4. Unlicensed devices transmitting with **U-NII-3 sharing rules**. Fixed RSU transmits SPaT messages while the moving OBU receives. Measure performance and message logs at the moving OBU and the U-NII receiver. Determine range at which OBU is not reliably receiving SPaT messages. Repeat the test often enough to understand natural variation in the results. The number of runs to be determined in the field.

If a suitable set of differing EDCA parameters is found in earlier testing to give priority to the DSRC devices, then continue testing with steps 5 & 6 below. If not, then skip these steps.

5. Unlicensed devices transmitting with U-NII-3 sharing rules. **Longer EDCA back off parameters in the unlicensed radio and shorter EDCA back off parameters in the mobile OBU.** Longer back off means the device waits longer when it hears the channel is occupied before it listens again for an opening to transmit in (see Appendix B). Mobile OBU transmits BSMs, stationary OBU and RSU receive. Measure performance and message logs at both stationary receivers and the U-NII receiver. Determine range at which communication is disrupted.
6. Unlicensed devices transmitting with U-NII-3 sharing rules. **Longer EDCA back off parameters in the unlicensed radio and shorter EDCA back off parameters in the RSU.** Fixed RSU transmits SPaT messages while the moving OBU receives. Measure performance and message logs at the moving OBU and the U-NII receiver. Determine range at which OBU is not reliably receiving SPaT messages.

Repeat the tests for the configuration parameters shown in Table 6-6. Do multiple runs of each test to often enough to understand natural variation in the results. The number of runs to be determined in the field.

7. Baseline Device Performance Tests with potential U-NII-4 devices

The purpose of this set of tests is to establish baseline performance for 802.11ac devices in the proposed UNII-4 band. That means 802.11ac devices operating with U-NII-4 rules and sharing mechanisms.

This section still TBD but will be a repeat of portions of section 5 with no or small modifications. We want to characterize the same way to avoid introducing any bias.

At least two possible device types covered here

1. USDOT developed 802.11ac prototype
2. Industry provided devices

8. Interference Testing with potential U-NII-4 devices

The purpose of this section is to measure the effects on DSRC communications in the presence of unlicensed 802.11 ac devices operating in the proposed U-NII-4 band with sharing mechanisms enabled. Specifically to test anticipated real world scenarios of OBEs communicating with the OBE's in other vehicles and infrastructure mounted RSEs in the presence of unlicensed access points mounted outdoors, indoors and within a vehicle. Each test described separately below is for a different scenario.

This section still TBD but will be a repeat of section 6 with modifications based on what we learn running the scenarios for section 6.

At least two possible device types covered here

1. USDOT developed 802.11ac prototype
2. Industry provided devices

9. Naturalistic Testing

This will be to test performance and interference in a real world environment similar to a pilot test but to approximate deployment scale radio densities. That means having enough OBU equipped vehicles, RSUs and unlicensed devices operating simultaneously in range undertaking normal activities. It is too early to quantify but such a test would likely require hundreds of both kinds of devices. It may require more area than can be provided by a test facility and therefore occur in a community.

This section is still TBD. It will be developed later in the year after we learn from the interference tests.

10. References

Appendix A: DSRC Terminology

Term	Definition

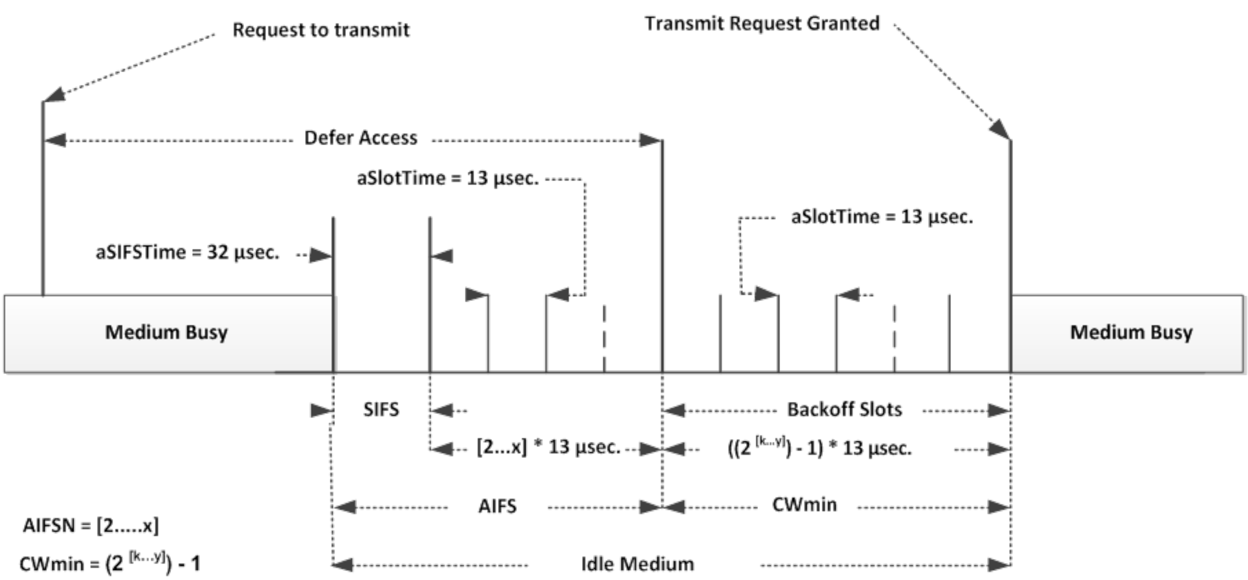
Appendix B: Clear Channel Access Mechanism

Clear Channel Access (CCA) is a mechanism by which radios listen to the channel and wait until they hear it is clear before transmitting to avoid packet collisions. DSRC uses Enhanced Distributed Channel Access (EDCA) parameters to control its CCA mechanism. The following text are two excerpts from a whitepaper not yet published, "Radio Density versus Traffic Density," by Alan Chachich, USDOT/OST-R/Volpe Center, 2014.

B.1 First excerpt to explain what happens in the time between packets:

But that's not all. The total time a message ties up the channel has two components. Most obvious is the time the message is being sent. Less obvious is the forced idle time on the channel to keep transmitters from clashing. *ARINC determined that was typically half as long as a BSM message or roughly a third of the total message time.*

This idle time is called the interframe spacing. See the following text box and Figure 1 below.



B-1 Figure 1. Breakdown of interframe spacing

AIFS: Arbitration Interframe Spacing

CWmin: Minimum contention window

SIFS: Short Interframe Space

INTERFRAME SPACING

Interframe spacing has two parts.

The first is to make sure the channel is clear and the second is to avoid clashing with others also waiting for the channel to clear.

Part 1. Make sure the channel is clear

This is the AIFSN (Arbitration Interframe Space Number)

The AIFSN is composed of the SIFS (Short Interframe Space) + a certain number of slot times.

The Short Interframe Space gives the radio time to switch back into receive mode so it can receive the acknowledgement of the message frame it just sent. It is a constant determined by the appropriate 802.11 standard. *ARINC used 32 microseconds (μs) for 10 MHz since it is specified by the 802.11-2007 standard (see Table A-1).*

The Slot time is twice the time it should take a pulse to travel to the farthest node on the network. Waiting one slot time should allow the intended receiver to get the message before it can collide with the next transmission. *ARINC used 13 μs for 10 MHz since it is specified by the 802.11-2007 standard (see Table A-1).*

The default number of slot times waited is either, 2, 3, 6 or 9.

BSMs aren't acknowledged, so in the 802.11p standard the AIFSN is for prioritizing messages. The highest priority would be given the smallest AIFSN so it waits less.
Part 2. Avoid clashing with other transmitters who may also be waiting for the channel to clear

That is the CWmin (minimum Contention Window)

This is an additional random time delay added to the AIFSN so that all radios waiting to transmit don't start at the same time. It is an integer number of slot times chosen randomly from a range of numbers. *ARINC used the ranges specified in the VAD standard, n=31. See Table A-1. They based their calculation on the value in the middle of range to calculate the average wait time (i.e., half the maximum or 31/2 = 15.5).*

B.2 Second excerpt to explain EDCA parameters:

Background

EDCA was added to the IEEE 802.11 standard in 2005 via 802.11e to introduce a way to prioritize messages that try to access the channel at the same time. The 802.11p WAVE (DSRC) standard that followed 5 years later built on it.

EDCA was introduced in 802.11 for typical mixed Wide Area Network (WAN) traffic. That includes video and voice which are delay sensitive but loss tolerant and best effort or background data that tends to be delay tolerant but loss sensitive.

DSRC safety data is not like either of these two types of message traffic. It tends to be periodic and not streaming data. It is latency sensitive but not like real-time data. Delay in channel access of tens of milliseconds is OK, which is more than video or voice data can tolerate. It is more sensitive to delay than file transfer data but less sensitive than video and voice.

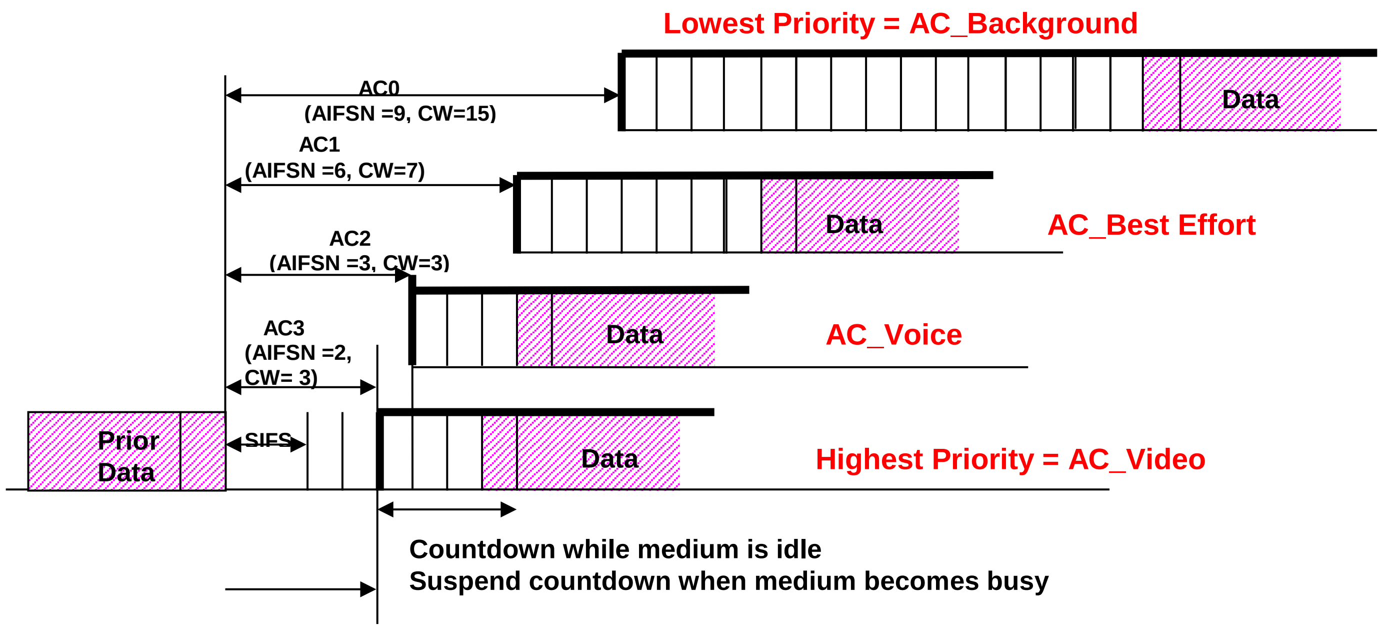
It is loss sensitive, but not as sensitive as file transfer data. So it is more sensitive to loss than video and more sensitive to delay than file transfer data. Table 5 summarizes the different types of data assigned priority in 802.11p. Figure 2 shows how the EDCA parameters implement priority in time.

B-1 Table 5. Packet Data Types

Data type	Latency	Packet Loss	Characteristic
Video	Extremely sensitive	Tolerant	Streaming – real-time
Voice	Extremely sensitive	Tolerant	Streaming – real-time
Best effort data	Tolerant	Extremely sensitive	Streaming Large files
Background data	Tolerant	Extremely sensitive	Large files
DSRC BSMs	Tolerant to delay < 10's of ms Sensitive > 10's of ms	Sensitive	Periodic, smaller, not quite real-time

So the optimum EDCA parameters for DSRC should minimize packet collisions and keep latencies to a few tens of milliseconds.

B-2 Figure 2. Depiction of 802.11 default EDCA parameters (Source: John Kenny, Toyota)



As described above, the mechanism to assign priority is the AIFSN. Remember that smaller AIFSN means shorter wait so preferential access to the channel. Assign this to higher priority packets.

The mechanism to avoid collision is the CWmin parameter that sets the contention window. Larger CWmin can reduce packet collisions, but if the channel is not congested it adds delay.

The 802.11 standard provides for 8 levels of priority, half are essentially unused by DSRC. It suggests options for the values these parameters can take which are summarized in Table 2. But since channel 172 is just for safety traffic, that priority scheme isn't particularly helpful. The VAD and RSU specifications essentially say that AIFSN and CWmin can be determined by the chip set as provided by the vendor.[27]

End excerpts

Selecting the EDCA parameters is very complicated. Choosing the best values depend on whether or not the traffic in the channel is all at the same priority (homogeneous) or different priorities (heterogeneous) and the density (number of radios in range trying to access the channel). Those are factors that can change by time and location.

As a result, the selection of EDCA parameters for DSRC messages as well as the mechanism to define and enforce them is still a work in process.

The following table, also excerpted from the Volpe White paper, indicates the range of values that could be considered for DSRC. Note that these values are simply illustrative because the actual number of priority levels hasn't been decided and there are other schemes beside the virtual division scheme used as an example in this table.

Even though the selection of EDCA parameters for traffic internal to DSRC is still TBD the detectability tests described in section 5.4 of this test plan will experiment with different EDCA values for DSRC and unlicensed devices to determine how they might factor into potential sharing of the band.

[27] USDOT, "SYSTEM REQUIREMENT DESCRIPTION - 5.9GHz DSRC Vehicle Awareness Device Specification" V3.6, 1/24/2012 and v3.8, 3/18/2014; "DSRC Roadside Unit (RSU) Specifications Document" V4.0 4/15/2014

B-2 Table 7. Summary of Recommended EDCA parameters

	IEEE 802.11p Default EDCA Parameter Set		Recommendation for homogenous traffic		Toyota's recommended defaults for heterogeneous traffic and virtual division with 3 priority levels	
Access Category	**AIFSN**	**CW_{min}**	**AIFSN**	**CW_{min}**	**AIFSN**	**CW_{min}**
AC0	**9**	**15**	**X**	**X**	**x**	**x**
AC1	**6**	**15**	**X**	**X**	**14**	**15**
AC2	**3**	**7**	**X**	**X**	**6**	**7**
AC3	**2**	**3**	**2**	**15 or 31**	**2**	**3**

Appendix C: Candidate RF Power Levels to Test

Table C-1 Candidate transmit powers for testing

EIRP[28]	Max Tx power	Significance	Reference
0 dBm *(1.0 mW)*		maximum allowed EIRP for handheld DSRC devices	CFR 47 § **95.639**
0 dBm *(1.0 mW)*		maximum output power for RSU class A (15 meter range)	CFR 47 § **90.375**
10 dBm *(10 mW)*		maximum output power for RSU class B (100 m range)	CFR 47 § **90.375**
20 dBm *(100 mW)*		maximum output power for RSU class C (400 m range)	CFR 47 § **90.375**
23 dBm *(200 mW)*	10 dBm *(10 mW)*	maximum allowed for all RSU and public OBU on channels 175, 180, 181 & 182 (antenna with minimum 6 dBi gain)	CFR 47 **§ 90.377**
23 dBm *(200 mW)*	20 dBm *(10 mW)*	maximum allowed for private OBU channels 180, 181 & 182	CFR 47 **§ 90.379**
28.8 dBm *(750 mW)*	28.8 dBm *(750 mW)*	maximum input power for RSU class D (1000 m range)	CFR 47 § **90.375**
30 dBm *(1 Watt)*		maximum allowed for IEEE 802.11ac devices for point-to-multipoint wireless communications	47 CFR Part 95
33 dBm *(2 Watts)*	28.8 dBm *(750 mW)*	maximum allowed for all DSRC on channels 172, 174, 176 and private RSU & OBU on 178 & 184	CFR 47 **§ 90.377**
40 dBm *(10 Watts)*		maximum allowed for public safety RSU & OBU on channel 184	CFR 47 **§ 90.377**
44.8 dBm *(30 Watts)*	28.8 dBm *(750 mW)*	maximum allowed for public safety RSU & OBU on channel 178	CFR 47 **§ 90.377**

[28] The Effective Isotropic Radiated Power (EIRP) can be larger than the transmitter output power because it includes antenna gain. [EIRP = transmitter output power – cable losses + antenna gain]

Appendix D: Experimental FCC License

All activities in this test plan are permitted by the following experimental license granted by the NTIA to the USDOT.

Appendix E: Candidate Field Survey Sites

Candidate Sites for DSRC Interference Survey		
Emitter & Location	**Type**	**Comment**
Eglin Air Force Base Edwards Air Force Base White Sands Wallops Island	Federal radar	• Observe 3km security distance
Clarksburg, MD (near I270)	In-band FSS earth station	• Sat uplink in ITS band (Int'l) • Intelsat • Limited to international inter-continental systems
Alexandria, VA	In-band FSS earth station	• Sat uplink in ITS band (Int'l) • SES Americom • Limited to international inter-continental systems
New Skies Networks Inc 8000 Gainsford Court Bristow, VA Phone: (703) 330-3305	Above-band FSS earth station	• Sat uplink above ITS band • Domestic FSS earth station
1. CableWiFi 1434 Center St MC Lean, VA 22101 Site type: Outdoor Network Name: CableWiFi **2. CableWiFi** 1389 Chain Bridge Rd MC Lean, VA 22101 Site type: Outdoor Network Name: CableWiFi **3. CableWiFi** 6671 Old Dominion Dr MC Lean, VA 22101 Site type: Outdoor Network Name: CableWiFi **4. CableWiFi** 1455 Chain Bridge Rd MC Lean, VA 22101 Site type: Outdoor Network Name: CableWiFi **5. CableWiFi** 1360 Old McLean Village Dr MC Lean, VA 22101 Site type: Outdoor Network Name: CableWiFi	**Unlicensed Wi-Fi**	• McLean, VA area • Verify unlicensed Wi-Fi AP emitters below 5.85GHz • Notional list only • Outdoor • Limit testing if spectral profiles are similar

Wi-Fi___33 noise from Urban high-occupancy dwellings	**Unlicensed Wi-Fi noise aggregate**	• Notional
		  • Arlington
		  • Fairfax
		  • Washington, DC

Candidate Sites for DSRC Interference Survey		
Emitter & Location	**Type**	**Comment**
1. **CableWiFi** 3126 Carlsbad Blvd Carlsbad, CA 92008 Site type: Outdoor Network Name: CableWiFi 2**. CableWiFi** 458 Carlsbad Village Drive Carlsbad, CA 92008 Site type: Outdoor Network Name: CableWiFi **3. CableWiFi** 117 Walnut Avenue Carlsbad, CA 92008 Site type: Outdoor Network Name: CableWiFi **4. CableWiFi** 158 Sycamore Avenue Carlsbad, CA 92008 Site type: Outdoor **5. CableWiFi** 135 Chestnut Avenue Carlsbad, CA 92008 Site type: Outdoor Network Name: CableWiFi	**Unlicensed Wi-Fi**	• DENSO tests (close to DENSO) • Verify unlicensed Wi-Fi___33 AP emitters below 5.85GHz • Notional list only • Outdoor • Limit testing if spectral profiles are similar

Appendix F: Specifications for key equipment

COMPEX

2.4G/5G MIMO Junior Outdoor Access Point

Model: MMJ344 plus

ac wave series

Features

- IEEE 802.11ac compliant and backward compatible with 802.11abgn
- Atheros 533MHz Networking Processor
- 2.4G/5G concurrent radios,each with 26dBm aggregate power
- Data rates of up to 867Mbps in 802.11ac 80 MHz channels
- Built-in 17dBi@5GHz dual-polarization antenna and 2 x 7dBi@2.4G Omni Dipole array antenna
- Antenna Alignment Site Survey - LEDs/Buzzer
- Distance Adjustment for long range transmission
- Integrated Power-over-Ethernet
- Weatherproof casing
- 2 x RP-SMA Male Connector for External Antenna (optional)[1]

Applications

- Dual band,Dual concurrent AP
- 802.11ac+802.11bgn AP / 802.11an+802.11bgn AP
- Point to Point / Point to MultiPoint/Coverage
- CPE

Technical Specifications

System Information	
Processor	Atheros AR9344 (533MHz)
Memory Size	128MB DDR2
NOR Flash	8MB (max 16MB optional)[1]
LAN Interface	2 X 10/100/1000 Base TX Ethernet Port (with Auto MDI / MDIX)
Antenna	Built-in 17dBi@5GHz dual-polarization antenna and 7dBi@2.4G patterns for Dipole array antenna
Power consumption	10w
Power method	Passive PoE
RoHS Compliant	Yes
Humidity	Operating: 5% to 95% (non-condensing) Storage: Max.90% (non-condensing)
Temperature Range	Operating:-20ºC to 70ºC Storage: -40ºC to 90ºC
Dimensions (H x W x D)	278.5 x 122.2 x 94.5 (mm)

Max of concurrent associations	Encryption	Client Latency	TCP [each client upload and download randomly from 384Kbps to 768Kbps]		UDP [each client upload and download 2Mbps]	
	WPA2-PSK	<100ms	Single radio	Dual radio	Single radio	Dual radio
			40 clients	70clients (35 per radio)	20 clients	30clients (15 per radio)

Transmit Power & Receiver Sensitivity			
2.4G On-board Radio	**Transmit Power**	Data Rate	Aggregate Power
		6M	26dBm
		54M	22dBm
		HT20 MCS0	26dBm
		HT20 MCS7	20dBm
		HT40 MCS0	26dBm
		HT40 MCS7	20dBm
	Receiver Sensitivity	Data Rate	RX
		6M	-90dBm
		54M	-75dBm
		HT20 MCS0	-90dBm
		HT20 MCS7	-72dBm
		HT40 MCS0	-88dBm
		HT40 MCS7	-70dBm

1 Depends on ordering configuration

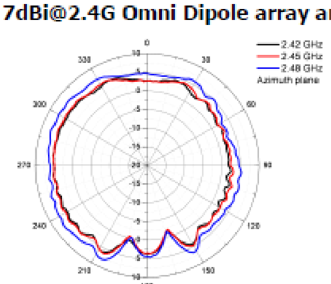
WLE600V5-23 Mini PCIe Radio							
TX Specifications				RX Specifications			
	DataRate	TX Power (2 chains)	Tolerance		DataRate	Sensitivity (2 chains)	Tolerance
802.11a	6Mbps	26dBm	±2dB	802.11a	6Mbps	-94dBm	±2dB
	9Mbps	26dBm	±2dB		9Mbps	-94dBm	±2dB
	12Mbps	26dBm	±2dB		12Mbps	-94dBm	±2dB
	18Mbps	26dBm	±2dB		18Mbps	-92dBm	±2dB
	24Mbps	26dBm	±2dB		24Mbps	-89dBm	±2dB
	36Mbps	26dBm	±2dB		36Mbps	-86dBm	±2dB
	48Mbps	24dBm	±2dB		48Mbps	-82dBm	±2dB
	54Mbps	22dBm	±2dB		54Mbps	-80dBm	±2dB
5GHz 11n/ac HT20	MCS 0	26dBm	±2dB	5GHz 11n/ac HT20	MCS 0	-94dBm	±2dB
	MCS 1	26dBm	±2dB		MCS 1	-94dBm	±2dB
	MCS 2	26dBm	±2dB		MCS 2	-92dBm	±2dB
	MCS 3	26dBm	±2dB		MCS 3	-88dBm	±2dB
	MCS 4	26dBm	±2dB		MCS 4	-84dBm	±2dB
	MCS 5	26dBm	±2dB		MCS 5	-81dBm	±2dB
	MCS 6	24dBm	±2dB		MCS 6	-78dBm	±2dB
	MCS 7	22dBm	±2dB		MCS 7	-77dBm	±2dB
	MCS 8	20dBm	±2dB		MCS 8	-74dBm	±2dB
5GHz 11n/ac HT40	MCS 0	26dBm	±2dB	5GHz 11n/ac HT40	MCS 0	-93dBm	±2dB
	MCS 1	26dBm	±2dB		MCS 1	-91dBm	±2dB
	MCS 2	26dBm	±2dB		MCS 2	-90dBm	±2dB
	MCS 3	26dBm	±2dB		MCS 3	-85dBm	±2dB
	MCS 4	26dBm	±2dB		MCS 4	-82dBm	±2dB
	MCS 5	25dBm	±2dB		MCS 5	-78dBm	±2dB
	MCS 6	24dBm	±2dB		MCS 6	-77dBm	±2dB
	MCS 7	22dBm	±2dB		MCS 7	-75dBm	±2dB
	MCS 8	20dBm	±2dB		MCS 8	-73dBm	±2dB
	MCS 9	18dBm	±2dB		MCS 9	-71dBm	±2dB
5 GHz 11ac HT80	MCS 0	26dBm	±2dB	5GHz 11n HT80	MCS 0	-89dBm	±2dB
	MCS 1	26dBm	±2dB		MCS 1	-88dBm	±2dB
	MCS 2	26dBm	±2dB		MCS 2	-85dBm	±2dB
	MCS 3	26dBm	±2dB		MCS 3	-81dBm	±2dB
	MCS 4	26dBm	±2dB		MCS 4	-79dBm	±2dB
	MCS 5	25dBm	±2dB		MCS 5	-75dBm	±2dB
	MCS 6	24dBm	±2dB		MCS 6	-74dBm	±2dB
	MCS 7	22dBm	±2dB		MCS 7	-72dBm	±2dB
	MCS 8	20dBm	±2dB		MCS 8	-70dBm	±2dB
	MCS 9	18dBm	±2dB		MCS 9	-68dBm	±2dB

Firmware Features

1.Multiple SSID
Supports up to 16 virtual access points (VAP) per radio, with unique BSSID. Each VAP can configure their own security
2.Long Range Support
Suitable for long range wireless deployment with Proprietary Long Distance Algorithm for ACK and CTS timeout adjustment support.
Provides recommended values for the parameters as well as allow for manual fine-tuning for optimal performance.
3.Selectable Spectrum Bandwidth Support
Options to select operation over 20MHz and 40MHz spectrum bandwidth

Firmware Information	
Operating Modes	• Access Points • Station • Station WDS • Repeater WDS • Wireless Adapter • Access Point + Router • Station + Router
WAN Type	• Static IP • Dynamic IP • PPPoE • DHCP
Device Management	• HTTP / HTTPs Web Server • SNMP V3 • Telnet / Secure Shell (SSH)
Data Capture & Notification	• System Log • Kernel Log
Advanced Features	• Built-in DHCP server • Transmission Power Control (One dB per step) • Closed System (Suppress SSID) • Transmission Rate Control • Spanning Tree Protocol
Other Prominent Features	**Description**
Long Range Parameter Settings	Suitable for Long Range wireless deployment with high receiver sensitivity
CPE Point-to-Point (PtP)	Ideal as CPE device connecting PtP with a central AP
IEEE 802.11h (DFS & TPC)	Enables worldwide operation through support for standards-based Dynamic Frequency Selection (DFS) and Transmission Power Control (TPC)
SNMP	For multiple SSID, firmware upgrades. Easy for customers to integrate with SNMP-based controller
Signal Strength LEDs Indicators	4 Step Progressive Bars. Each bar represents a progressive increase in Signal strength, with 4 bars representing maximum signal strength (100%)
VLAN Management	Can manage the AP through VLAN ID
VLAN Ethernet Trunk	Map VLAN IDs to multiple SSID
Chillispot (Hotspot)	Can use with/without Radius Server
OpenWRT-derived	Easy to add in features from OpenWRT
Customization (with SDK)	Customers can add in packages of OpenWRT, and also modify webpages on their own, with SDK upon approval

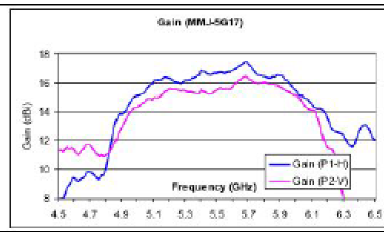
7dBi@2.4G Omni Dipole array antenna



Frequency (GHz)	Peak Gain (dBi)*
2.42	6.124
2.45	6.284
2.48	7.958

Peak gain refers to the maximum gain value in the azimuth plane.
Please note that the nulls occurring at around 165 and 195 is most probably due to the cable effects. Excluding these nulls, typical gain variation is around 3-4 dB.

17dBi@5GHz dual-polarization antenna

<table>
<tr><td>Gain</td><td colspan="2">17dBi</td></tr>
<tr><td>Radiation</td><td colspan="2">Directional</td></tr>
<tr><td>Frequency Range</td><td colspan="2">5.1-5.9 GHz</td></tr>
<tr><td>Polarization</td><td colspan="2">Dual – Polarization</td></tr>
<tr><td>Azimuth -3dB Beamwidth</td><td colspan="2">Horizontal(Port 1): 30 degrees
Vertical(Port 2): 33degrees</td></tr>
<tr><td>Elevation -3dB Beamwidth</td><td colspan="2">Horizontal(Port 1): 17 degrees
Vertical(Port 2): 17degrees</td></tr>
<tr><td>Isolation</td><td colspan="2">-40dB (Max)</td></tr>
<tr><td>Front-to-Back Ratio</td><td colspan="2">-30dB (Max)</td></tr>
<tr><td>VSWR</td><td colspan="2">Horizontal (Port 1) : < 1: 1.87; Vertical (Port 2): < 1: 1.55</td></tr>
<tr><td>Cross Polarisation Isolation</td><td colspan="2">-28dB (Max)</td></tr>
<tr><td>SideLobe</td><td colspan="2"><-12dB</td></tr>
<tr><td>Gain Plot</td><td colspan="2">
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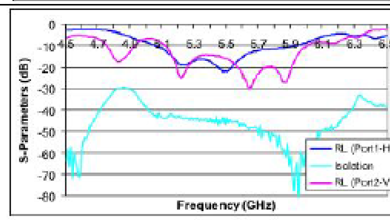
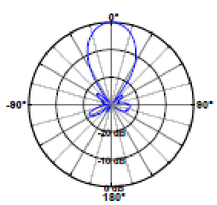
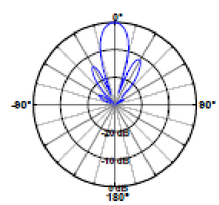
& Isolation Plot</td><td colspan="2">
</td></tr>
<tr><td colspan="3">Polar Plots (At 5.6GHz)</td></tr>
<tr><td colspan="2">H-Pol Azimuth (Port 1 - H)</td><td>H-Pol Elevation (Port 2 – V)</td></tr>
<tr><td colspan="2">
</td><td>
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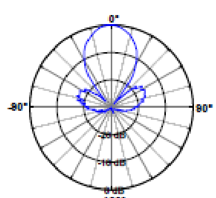
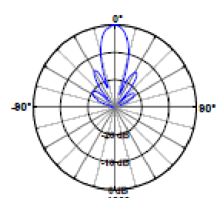
<tr><td colspan="2">V-Pol Azimuth (Port 2 – V)</td><td>V- Pol Elevation (Port 1 – H)</td></tr>
<tr><td colspan="2">
</td><td>
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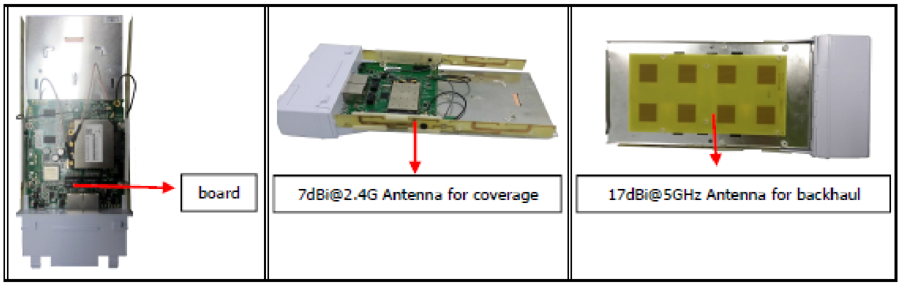
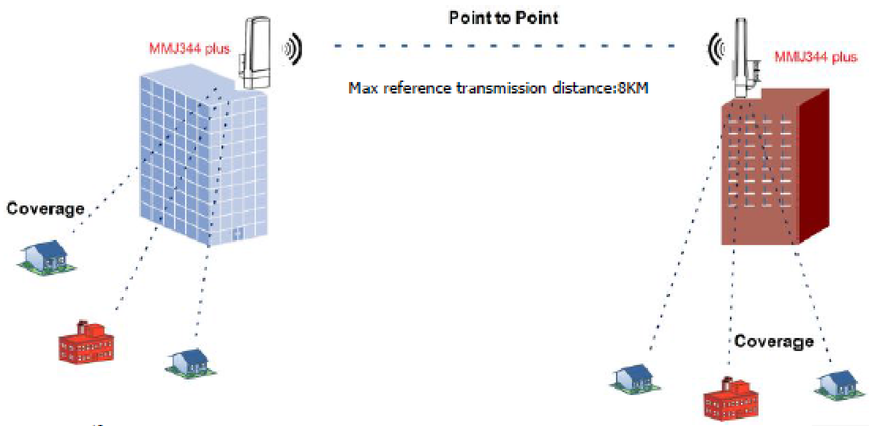
Internal Structure



Product application:



Codes	Integrated Antenna	Version	Radio Output
MMJ344LV 6A06DFCUBRV523	2x7dBi@2.4G&17dBi@5GHz ANT	CompexWRT US	26dBm
MMJ344LV 6A06DFCEBRV523	2x7dBi@2.4G&17dBi@5GHz ANT	CompexWRT EU	26dBm
MMJ344HV 6A06DFCEBRV523	2x7dBi@2.4G&17dBi@5GHz ANT	CompexWRT US	26dBm
MMJ344HV 6A06DFCUBRV523	2x7dBi@2.4G&17dBi@5GHz ANT	CompexWRT EU	26dBm
P-PSE-M-6A03-SPL	PoE pass-Thru module		

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