

Before the
**NATIONAL TELECOMMUNICATIONS AND INFORMATION
ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE**

In the Matter of)
)
Spectrum Sharing Innovation) **Docket No. 120322212–2212–01**
Test-Bed Pilot Program)
)

Comments of Shared Spectrum Company

Shared Spectrum Company (SSC) respectfully submits these Comments in response to the “Spectrum Sharing Innovation Test-Bed Pilot Program, Phase II/III Test Plan”, prepared in March 2012 by the Institute for Telecommunication Sciences of the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce.

SSC notes that the Test-Bed Pilot Program will evaluate the ability of Dynamic Spectrum Access (DSA) devices employing spectrum sensing and/or geo-location techniques to share spectrum with Land Mobile Radio (LMR) systems operating in the 410-420 MHz Federal band and in the 470-512 MHz non-Federal band.

I. Introduction. SSC is a small business founded in 2000. Since its inception, SSC has been a pioneer in the development and deployment of DSA devices employing spectrum sensing and/or geo-location techniques to share spectrum. SSC has been an

active participant in the Test-Bed Pilot Program since its beginning, and SSC previously provided comments to NTIA in 2008 regarding the first phase of the Test-Bed Pilot Program. In fact, SSC is one of the providers of DSA devices currently tested by NTIA.

The NTIA has established that the Test-Bed Pilot Program will be performed in three phases:

Phase I Equipment Characterization. Equipment employing DSA techniques will be tested by NTIA and characterization measurements of the DSA capabilities in response to simulated environmental signals will be performed.

Phase II Evaluation of Capabilities. After successful completion of Phase 1, the DSA capabilities of the equipment in the geographic area of the Test-Bed will be evaluated.

Phase III Field Operation Evaluation. After successful completion of Phase II, the DSA equipment will be permitted to transmit in an actual radio frequency signal environment.

II. Initial Comments.

A. Background. SSC commends NTIA for its successful completion of Phase I of the Test-Bed Pilot Program. SSC recognizes that additional work needs to be done in Phases II and III to analyze and test the interaction of DSA and LMR radios, both in a controlled environment and in a “real-world” type of operational environment.

The purpose of DSA technology is to enable better sharing of spectrum in an increasingly spectrum-hungry world. DSA accomplishes this by enabling a radio to select operating frequencies that can be used that cause minimal interference to the incumbent uses. The advantage of DSA compared to other spectrum sharing methods such as smart antennas or femtocells is that DSA requires minimal hardware changes or recurring costs. DSA also has advantages such as reducing planning costs and robustness to interference from other sources.

The FCC and NTIA both place value on the benefit of sharing the limited spectrum resource. Without the ability to create new spectrum from scratch, scientists, government decision-makers, and business leaders are faced with the fact that we must make better use of the spectrum resources. Toward that end, DSA technology promises to permit the more efficient use of the limited spectrum resources available to government, public safety, and commercial users alike.

SSC is proud to be at the forefront of this effort. Recent NTIA proposals to share the 1755-1850 MHz band and other bands illustrate the importance of this effort to both the government and non-governmental users. The advent of TV White Space policies and the introduction of sharing-based devices raise exciting possibilities for future broadband deployment in both rural and urban environments. As NTIA noted in its report on an “Assessment of the Viability of Accommodating Wireless Broadband in the 1755-1850 MHz Band”, “spectrum sharing is a vital component of satisfying the growing demand for access to spectrum and that both federal and non-federal users will need to adopt innovative sharing techniques to accommodate this demand.” All of these developments help to fuel the information technology engine that is increasingly the source of power for the American economy. And spectrum sharing will make this dual-use of spectrum possible for current and future generations of Americans.

B. Technical Proposals. In Phase III, the NTIA has before it the somewhat challenging task of trying to test the potential impact of DSA usage in a realistic LMR environment. Based upon our more than 10 years of experience, we believe the best approach is to set-up, operate, and measure a test LMR system to provide a baseline. This would account for the presence of man-made noise and other system or

environmental factors which may be related to the introduction of DSA devices.

Then, we suggest as the second half of Phase III, that NTIA should introduce a DSA system to the LMR area of operations, and test the impact, if any, that the DSA system has upon the LMR system in that area of operations. This type of direct, controlled field test comparison would yield valuable results, which could then be translated into expectations of a real-world DSA deployment.

Unfortunately, we believe the draft Phase III Test Plan is not sufficient to permit a robust understanding of the results of a DSA deployment. There are several reasons we believe Phase III should be modified as proposed, which we explain below. We also note that NTIA has a deep understanding of both LMR radio operation and how DSA operates. NTIA has identified “corner cases” that are the most challenging for DSA radio (also known as “DUTS”) to operation.

We believe that the current tests will not achieve NTIA’s objective in Section 1.1: ‘To assess the ability of DUTs to share spectrum with LMR systems in the 410-420 MHz frequency band.’ The reason is that the tests are focused on engineering corner cases and not on operational scenarios. Attached in Table 1 is a list of the non-operational aspects of each portion of the Test. There is no test that has realistic LMR traffic, distribution of LMR subscriber locations, realistic geometries or other features that are related to the users of the LMR systems.

Table 1 The NTIA Tests Are Focused on Non-Operational, ‘Corner Case’ Scenarios

Section	Test	Non-Operational Aspect
3.1	Phase III LMR Hidden Node Downlink Test	<ul style="list-style-type: none"> • LMR subscriber doesn't transmit • LMR base station transmit power is reduced • The only LMR subscriber location considered is at the maximum link range • DUT forced to transmit at maximum transmit power • DUT is limited to operate on a single frequency
3.2	Phase III LMR Hidden Node Uplink Test	<ul style="list-style-type: none"> • LMR base station doesn't transmit • Only a single LMR subscriber in the network • The only LMR subscriber location considered is at the maximum link range • DUT forced to transmit at maximum transmit power • DUT is limited to operate on a single frequency
4.1	Phase III DUT Sharing with Conventional LMR System Downlink Test	<ul style="list-style-type: none"> • LMR subscriber doesn't transmit • LMR base station transmit power is reduced • The only LMR subscriber location considered is at the maximum link range (presumed, not clearly define in test plan) • DUT forced to transmit at maximum transmit power • DUT is limited to operate on a single frequency
4.2	Phase III DUT Sharing with Conventional LMR System Uplink Test	<ul style="list-style-type: none"> • LMR base station doesn't transmit • Only a single LMR subscriber is in the network • The only LMR subscriber location considered is at the maximum link range (presumed, not clearly define in test plan) • DUT forced to transmit at maximum transmit power • DUT is limited to operate on a single frequency
5.1	Phase III DUT Sharing with Trunked LMR System Uplink Test	<ul style="list-style-type: none"> • LMR system switched off for a long period and then suddenly switched on • The only LMR subscriber location considered is at the maximum link range • Only a single LMR subscriber is in the network • DUT location is at the worst position where it can't detect the LMR base station • DUT forced to transmit at maximum transmit power • DUT is limited to operate on a single frequency
5.2	Phase III DUT Sharing with Trunked LMR System Downlink Test	<ul style="list-style-type: none"> • LMR system switched off for a long period and then suddenly switched on • The only LMR subscriber location considered is at the maximum link range • DUT location is at the worst position where it can't detect the LMR subscriber • DUT forced to transmit at maximum transmit power • DUT is limited to operate on a single frequency

Assuming that these tests show that the DUT causes interference to the LMR system, it is unclear how often these corner cases occur and how often other effects, such as man-made noise, radio mis-configuration, strong adjacent channel interference, or mistakes in spectrum planning would also cause a similar loss of LMR service. A detailed modeling and simulation effort would be needed to put these corner cases into perspective to provide decision-makers with information on how much operational impact the DUT would have on the LMR users.

C. Operational Scenarios Would Yield Better Results. SSC suggests that NTIA include an operational scenario in the test plan and focus on this scenario to assess the ability of DUTs to share spectrum with LMR systems in the 410-420 MHz frequency band. This scenario would use typical uplink and downlink LMR traffic statistics, typical LMR subscriber locations relative to the LMR base station, and multiple LMR subscriber units. This test would be repeated with and without DUT devices present to determine the impact of the DUT on the LMR message completion rate or similar metric.

The test approach, instrumentation, and metrics in the NTIA test plan support an operational test. Because of the NTIA's instrumentation capability, significant engineering insight can also be obtained from operational tests (perhaps removing the need for the other tests). SSC believes that operational tests offer much better decision-maker input and equivalent engineering value.

D. The Test Plan Needs to Include Several DUT Parameters. The proposed NTIA tests are a validation type test, yet there are no industry or government approved LMR DSA parameters. For a sensing-based DSA approach, the DSA parameters include: the DUT transmit power level; the non-occupancy period; the channel availability check time; and the sensing threshold. SSC suggests that

there should be a general agreement on the DSA parameters so that the NTIA tests provide maximum value. For example, most interference effects scale with the DUT transmit power level. It is nearly certain that some combination of DSA sensing and DSA geo-location algorithms will provide satisfactory performance. It is the government's best interest to use the Tests to determine what DSA parameter values are acceptable.

By contrast, in both the Dynamic Frequency Selection (DFS) and the TV White Space evaluations, the testing bodies established DSA rule sets, and then the field tests validated these rules. The values of the DSA sensing threshold and transmit power can be determined using a Monte Carlo simulation or by experiment. SSC developed a Monte Carlo simulation for detecting low power wireless microphones in the TV white spaces.¹ A similar approach was used by NTIA in the DFS analysis.² SSC developed a Monte Carlo model for the NTIA Testbed scenario (Appendix A) that examines different scenarios and radio parameters. A key test plan goal should be to validate a model like this so that extensive parametric analysis can be made. The NTIA Testbed could validate the model by collecting propagation loss values (to calibrate the propagation loss model) and by doing some parametric tests (i.e. vary the DSA sensing threshold) so that differential interference predictions could be compared.

¹ Erpek, T., McHenry, M.A., Stirling, A., "DSA Operational Parameters with Wireless Microphones", IEEE DySPAN 2010 (April 2010), available at <http://www.sharedspectrum.com/wp-content/uploads/SSC-DySPAN-2010-PMSE-protection-reqts.pdf>.

² Drocella, E.F., Brunson, L., Glass, C.T., "Description of a Model to Compute the Aggregate Interference from Radio Local Area Networks Employing Dynamic Frequency Selection to Radars Operating in the 5 GHz Frequency Range", NTIA Technical Memorandum 09-461 (May 2009), available at http://www.ntia.doc.gov/legacy/osmhome/reports/2009/TM_09-461.DOC.

If the NTIA chooses not to obtain consensus on the DSA parameters, then they should examine in parallel a few of the parameters in the field tests to determine what values would work and why those would work best. At a minimum, a single operational scenario should be examined and the various DSA parameter values investigated.

E. The Test Plan Needs to Consider DUT Benefits in the Metrics. Currently all of the metrics are based on the possibility of interference to the LMR system, and the metrics do not include the benefits of the DUT to users. For example, the DUT could use very conservative DSA parameter values to pass the NTIA test, but then prematurely abandon channels; such a configuration would provide little to no value to end users. *The optimal DUT behavior is when the DUT abandons the channel just before it causes LMR interference because it provides the maximum spectrum to the entrant.*

In the real-world deployment of DSA, the devices will often be operated by Federal users and it is therefore in NTIA's interest to examine the device's ability to correctly select channels when no LMR interference occurs. This could be accomplished by adding to the metrics of the test an analysis of when the DUT prematurely abandoned the channel. This information is readily available (and is already included in Section 6.4) when a baseline is run with the DUT forced to continually operate on the channel (i.e. there is no channel abandonment).

III. Detailed Comments.

A. Exclusive Focus on Maximum Link Range Scenario. In Section 1.8, the interference criteria for LMR is based on a worst-case link range scenario and is not based on a distribution of link ranges found in operational scenarios. There is no

baseline failure rate at this worst-case link range due to man-made noise, strong adjacent channel interference, or any other operational factors.

B. Man-made Noise. It is not clear in Section 1.10 why NTIA wants the spectrum survey to reject man-made noise: ‘Customized signal processing of the RSMS data reduces in-band impulsive noise for an accurate determination of usage profiles for each LMR channel in the band.’ The spectrum survey goal is to determine the LMR activity and other signals that might impact the tests. Man-made noise may cause interference to the LMR radios, which might mistakenly be blamed on the DUT systems. Man-made noise might cause false DUT detections. We recommend that the spectrum survey use conventional FFT-based spectrum analysis so that the true spectrum conditions will be recorded.

C. Data Analysis and Interpretation. Section 2.6 of the Test Plan does not present clear success/fail criteria. The RF path loss A-C and A-D in Figure 1 could be significant and will impact the sensitivity of the DUT. It is not clear how this loss is accounted for in the Performance Metrics.

D. LMR Hidden Node Test. We respectfully suggest that the “hidden node” scenario as described would not be operationally relevant. An LMR transmitter transmits over some period of time (whether for seconds or minutes). If the “Channel Availability Check” period of a DUT is made longer than the LMR transmit period, then there are no “hidden nodes”.

If this were an operational scenario, then the DUT detection threshold or, preferably, the DUT transmit power must be reduced 20 dB to 30 dB compared to a non-hidden node scenario to avoid causing significant interference. *We recommend that this*

test be deleted or that the DUT transmit power be reduced 20 dB to 30 dB compared to a non-hidden node scenario.

E. Pre-conditions of Section 3.1.2. The LMR base station transmit power should not be reduced. It should be at a typical operational value. Reducing the LMR base station transmit power reduces the DUT detection distance and increases the chance of interference to the LMR radios. It is unclear how to scale these results with the low LMR power to operational conditions.

F. Scenario Assumption. In Section 3.1.3, it is unclear what this sentence means: ‘The DUT transmission will be attenuated to balance the loss in the combiner in its receiver path’. The test plan should clarify what this sentence means.

Also, the DUT transmit power level should be varied and not be set to the maximum power value. As described earlier, the DSA parameters should be based on industry-government collaboration before the tests.

G. Phase III Downlink Test. SSC respectfully suggests that this downlink test is not an operationally relevant scenario because the uplink transmissions are minimized artificially or eliminated. The DSA spectrum sharing concept for this band is that the DUT’s Channel Availability Check time is set to be larger than the LMR base station and LMR subscriber off-periods, so that there are no “hidden nodes”. If an artificial scenario is created where the LMR base station and/or subscriber are not transmitting with typical values, then the Channel Availability Check time needs to be increased.

H. Traffic Statistics. The uplink and downlink traffic statistics are not described. These parameters are critical to the DSA spectrum sharing concept. *We*

recommend that both this downlink test, and the uplink test described in Section 4.2.1, be deleted from the final Test Plan document.

I. Unclear Scenario Assumption. In Section 4.1.3, it is unclear what this sentence means: ‘The DUT transmission will be attenuated to balance the loss in the combiner in its receiver path ‘. The test plan should clarify what this sentence means.

J. Section 4.1.4 -- Test Procedure. The following statement supports our recommendation that this test is not operational and should be deleted: “Subscriber units should minimize their uplink transmissions, since excessive uplink transmissions may trigger DUT detections and potentially taint the controlled LMR downlink assessment nature of this test.” The purpose of this test is to examine the hypothetical isolated “LMR downlink assessment nature”, which we believe has no operational value.

K. Data Analysis and Interpretation. Section 4.1.6 describes data analysis and interpretation, proposing to manually study each loss of service event to determine the cause; this will require large amounts of effort and will be highly subjective. SSC believes that a much simpler and more accurate method to analyze the data would be to run two tests: (1) DUT on, and (2) DUT off. A direct comparison of these results would show the loss in LMR service due to the DUT system.

It is also unclear to SSC what the results of this manual test results process will mean. If DUT-related interference events occur X% of the time, what is the conclusion relative to the NTIA goal, which is “To assess the ability of DUTs to

share spectrum with LMR systems in the 410-420 MHz frequency band”? SSC respectfully suggests that these test results will have limited usefulness because this scenario is not operational, and there is no described method to translate these results to an operational scenario.

L. PHASE III--DUT Sharing with Trunked LMR System. In this test, the LMR system is switched off for a long period; this is a period of time which is greater than the DUT’s Non-occupancy Period, typically tens of minutes. Then, the DUT radios initiate operation on the frequency. The LMR radio is then switched on and a single 32.9 ms LMR packet is sent to initiate LMR communications. The delay in LMR communications while the DUT abandons the channel is recorded.

SSC believes that NTIA has identified an important issue with this call initialization blockage issue. However, the important issue is the DSA channel availability check time compared to the LMR traffic statistics (i.e. the distribution of transmission gaps) and the special LMR/DSA geometry required (how often the problem might occur) and how much delay is created until the DSA radio abandons the channel. By implementing a slow hopping DSA strategy (change channels every few seconds), the LMR channel setup time can be minimized.

SSC suggests that this particular test is based on a non-operational scenario (the LMR system is switch off for a long period) and should be modified to investigate the above issues.

M. DUT Geo-Location Characteristics. The Test Plan does not describe how the exclusion zones will be calculated. Nor does the Test Plan stipulate how interference events will be interpreted.

In this test, if the DUT transmits outside of the exclusion zone, but still causes LMR interference, then the problem is likely to be with the definition of the “exclusion zone” itself. This should be considered apart from the scenario where the DUT transmits within the exclusion zone and causes interference.

IV. CONCLUSION.

The draft Test Plan for Phases II and III is a good starting point of further discussion. SSC welcomes the opportunity to participate in this comment period and looks forward to working closely with NTIA on an ongoing basis to continue the work we have jointly started.

SSC commends NTIA for its progress made to date, including its work done on Phase I of the Test Plan. SSC believes that the valuable benefits of sharing spectrum will continue to be recognized by policy-makers, government users, and telecom industry leaders. As our society learns to better use the limited resources given to us by Nature, we reap the benefits of increased knowledge and cooperation among diverse groups of users of those limited resources. Dynamic Spectrum Access (DSA) is one such technology that can benefit our society both today and for generations to come.

Respectfully submitted,

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APPENDIX A

Dynamic Spectrum Access (DSA) Radio Parameters for Operation with Land Mobile Radios (LMR)



Dynamic Spectrum Access (DSA) Radio Parameters for Operation with Land Mobile Radios (LMR)

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1.0 Introduction

This memo provides an analysis of the interference of a DSA radio to an LMR radio similar to what is proposed for the NTIA Testbed field tests. This is a Monte Carlo simulation with parametric analysis where a wide variety of parameters are varied.

In Section 2, the simulation approach is described. In Section 3, the results are described. Section 4 provides a conclusion.

2.0 Simulation Description

This section describes the simulation and the radio parameters.

2.1 Simulation Design

A Monte Carlo simulation approach is used. The simulation uses a pair of LMR radios and a single DSA radio. The LMR radios were randomly located within a 30 km by 30 km area as shown in Figure 1. The link loss values between the radios are shown by the L1, L2, and L3. Different uplink and down link propagation losses are assumed when the uplink and downlink frequencies are different. The DSA radio was randomly located within a 50 km by 50 km area. The LMR and DSA radio areas were not the same size to insure that a significant number of DSA radios were located in the region between ‘easy detection’ and ‘interference not possible’ as shown in Figure 2. It is within this region that all interference events are generated.

Each scenario was run 2500 times, which was found to provide a result that didn’t significantly change if additional runs were used. In each simulation the DSA detection threshold was varied from -140 dBm to -40 dBm in 1 dB steps. At high DSA detection threshold values, the DSA radio effectively never turns off. This represents the worse case of a conventional radio on the same channel as the LMR radio. At low DSA detection threshold values, the DSA radio effectively never turns on. This represents the baseline condition of the DSA radio not being present.

Three DSA sensing algorithms were investigated: (1) The DSA transmitter turned on if the received signal level from the LMR uplink was less than the threshold value, (2) The DSA transmitter turned on if the received signal level from the LMR downlink was less than the threshold value, and (3) The DSA transmitter turned on if the received signal level from the LMR downlink and the LMR uplink was less than the threshold value.

Two DSA detection algorithms were investigated: (1) A single sample was used to make a transmission decision. This represents the case when the propagation losses are absolutely stationary, which may occur over short periods if the LMR and DSA radios are fixed and there was minimal clutter movement (i.e. no motion of cars, person, trees, etc). Thus, deep nulls due to multipath fading may cause the DSA radio to not detect the LMR radio. (2) The maximum received signal level over multiple samples was used to make a transmission decision. This represents the case when the propagation losses are not stationary, which may occur over long periods if the LMR and DSA radios are fixed, or if the LMR or DSA radios are mobile. Thus, deep nulls due to multipath fading limit the DSA radio’s ability to detect the LMR radio.

For each DSA detection threshold value, the number of successful LMR link closures was determined. The link closure was based on the SINR (signal to noise and interference ratio). Link failure could be caused by excessive propagation loss between the LMR radios or interference from the DSA radio.

The downlink frequency was 410 MHz. The uplink frequency was 410 MHz or 419 MHz depending on the scenario.

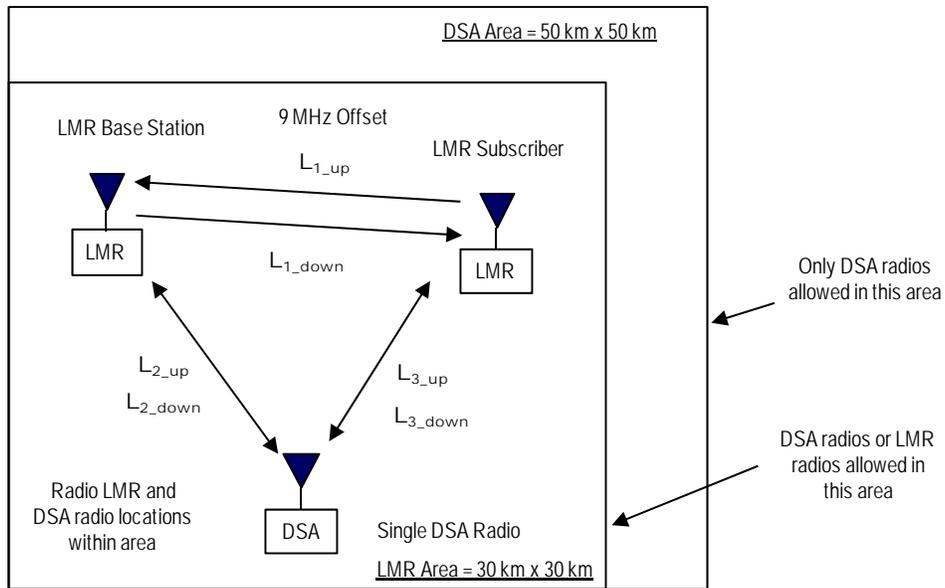


Figure 1. The scenario geometry uses different sized distribution areas for the LMR radios and the DSA radios.

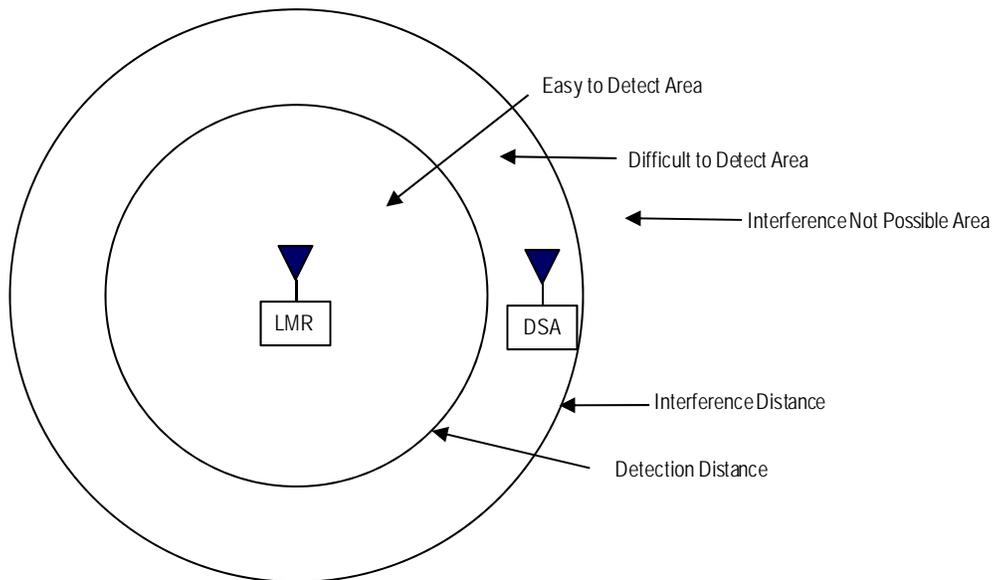


Figure 2. The distribution of DSA radios relative to the LMR radios is critical. If the DSA radios are too close to the LMR radios, the LMR radios are easy to detect and DSA doesn't transmit. If the DSA radios are too far from the LMR radios, interference to the LMR radios isn't possible.

2.2 LMR Radio Description

Table 1 shows the default LMR radio parameters used in the simulation.

Table 1 LMR Radio Parameters

Parameter	Value	Units
Uplink and Downlink Transmit Power	36	dBm
Signal Bandwidth	8.1	kHz
Minimum SINR for Link Closure	15	dB
Noise Figure	10	dB
Noise Power	$-174 \text{ dBm/Hz} + 10 + 10 \cdot \log_{10}(8100) = -125$	dBm
Maximum Link Loss	$36 + 125 - 15 = 146$	dB
Antenna Gain	0	dBi
Downlink frequency	410	MHz
Uplink frequency	419	MHz

2.3 DSA Radio Description

Table 2 shows the default DSA radio parameters used in the simulation. The DSA detection threshold value is varied in the simulations. SSC's current radio has a minimum detection threshold value of -110 dBm. With a 36 dBm transmit power LMR radio, the detection link loss is -146 dB. Whenever an LMR radio is within 146 dB of the DSA radio, the DSA radio will not transmit. This sets the scale of the DSA distribution. It is a coincidence that the DSA detection link loss and the LMR maximum link loss have the same 146 dB value.

Table 2 DSA Radio Parameters

Parameter	Value	Units
Transmit Power	40	dBm
Signal Bandwidth	1750	kHz
Antenna Gain	0	dBi

2.1 Propagation Model

The propagation model provides the link loss between the DSA radios and the LMR radios as well as between the LMR radios. The model is a function of link range and frequency and depends on if there are buildings in the region or not. The model represents multipath and irregular terrain effects with a large random component that changes each time the model is called. This model was used in a similar NTIA Monte Carlo analysis.¹ The propagation model MATLAB software is shown in Figure 3.

¹ Drocella, E.F., Brunson, L., Glass, C.T., "Description of a Model to Compute the Aggregate Interference from Radio Local Area Networks Employing Dynamic Frequency Selection to Radars Operating in the 5 GHz Frequency Range", NTIA Technical Memorandum 09-461 (May 2009), available at http://www.ntia.doc.gov/legacy/osmhome/reports/2009/TM_09-461.DOC.

```
function L=prop_loss_NTIA(d_m, fMHz, ibuilding)
% Propagation loss function
%   Drocella, E.F., Brunson, L., Glass, C.T., "Description of a Model to
%   Compute the Aggregate Interference from Radio Local Area Networks
Employing Dynamic Frequency
%   Selection to Radars Operating in the 5 GHz Frequency Range",
%   NTIA Technical Memorandum 09-461 (May 2009), available at
http://www.ntia.doc.gov/legacy/osmhome/reports/2009/TM_09-461.DOC.
%
%   Mark McHenry
%   Shared Spectrum Company   March 2012
%
%d = Distance between transmitter and receiver (m)
%f = Frequency (MHz)
%ibuilding =0 to neglect building effects, =1 to include building effects.
%
%L = Propagation loss with the distance exponent represented by a uniform
random variable (dB)

%Loss due to buildings.
Ll=0;
if (ibuilding ==1) Ll=rand(1)*20; end;

A=20+rand(1)*15;%A = A uniform random number between 20 and 35;

L = - (32.44 + 20*log10(fMHz) + A*log10(d_m/1000) + Ll);
```

Figure 3. MATLAB Propagation Model

The propagation loss versus link range for 410 MHz and no building loss factor is shown in Figure 4. The propagation loss increases with range and includes a large variance due to blockage and multipath.

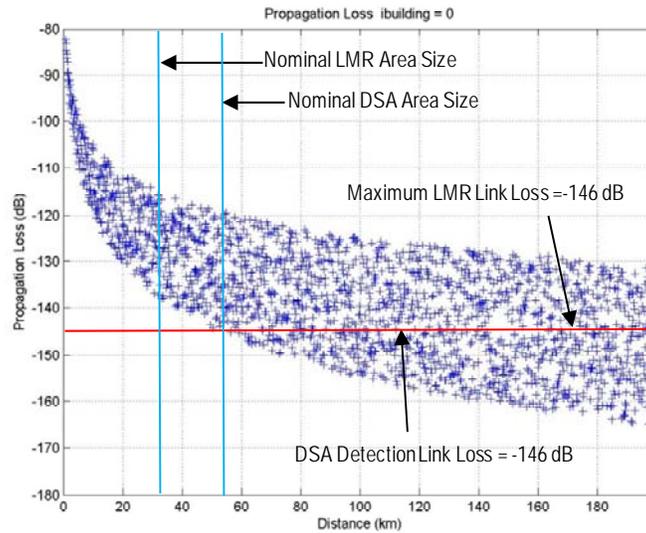


Figure 4. Propagation Loss Versus Link Range (no Building Loss Term)

The propagation loss versus link range for 410 MHz including the building loss factor is shown in Figure 5. The larger variance and higher average loss due to the buildings is seen when compared to the previous figure.

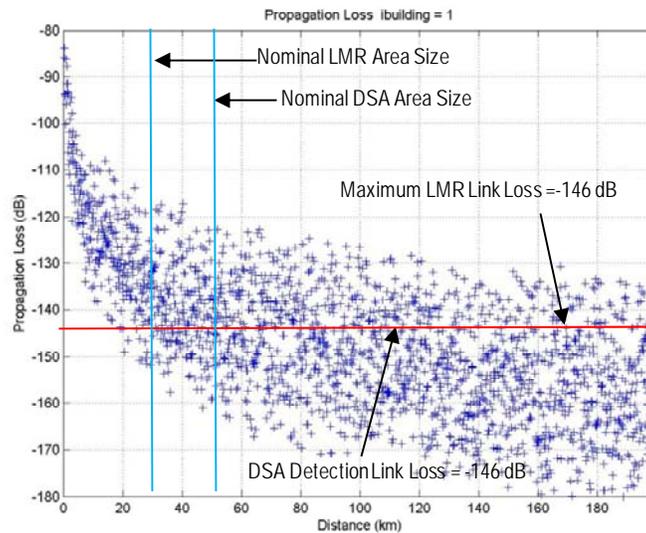


Figure 5. Propagation Loss Versus Range (with Building Loss Term)

3.0 Simulation Results

This section describes the simulation results. The first section describes the nominal scenarios. The second scenario describes other scenarios where parameters were varied.

3.1 Nominal Cases

This section describes two nominal cases that use all of the previously described radio and scenario parameter values.

3.1.1 Operational Scenario

Figure 6 shows the LMR radio link failure probability versus the DSA sensing threshold value for the frequency duplex (9 MHz offset uplink to downlink) LMR scenario. The LMR and DSA radio parameters are as shown in Table 1 and Table 2. The geometry is shown in Figure 1. The DSA radio uses the maximum of five samples to determine the LMR receiver power level. The propagation model uses the building effects factor. At very low DSA sensing threshold values, the LMR link fails (either uplink or downlink fails) about 5% of the time within the 30 km rectangular area due to high propagation losses. With a DSA sensing threshold below -95 dBm, there is no impact to the LMR failure rate. If the DSA radio never stopped transmitting, the LMR link failure rate is 42%. The SSC DSA radio's minimum DSA sensing threshold is -110 dBm, thus, the DSA radio causes an insignificant amount of interference to the incumbent LMR system.

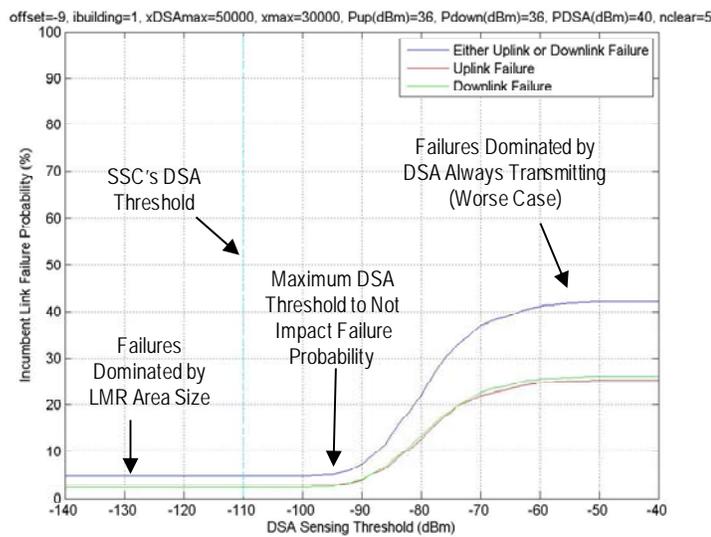


Figure 6. Frequency Duplex (9 MHz offset) LMR Incumbent Link Failure Probability versus DSA sensing Threshold Value.

3.1.2 Hidden Node Scenario

Figure 7 shows the LMR downlink radio link failure probability versus the DSA sensing threshold value for a downlink only (hidden node) LMR scenario. This case is identical to the previous case except that the uplink transmit power level is zero. With a DSA sensing threshold below -105 dBm, there is no impact to the LMR failure rate. To account for the hidden node issue, the DSA sensing detection threshold needs to be approximately 10 dB lower than in the previous frequency duplex scenario. The SSC DSA radio's minimum DSA sensing threshold is -110 dBm, thus, the DSA radio causes an insignificant amount of interference to the incumbent LMR system.

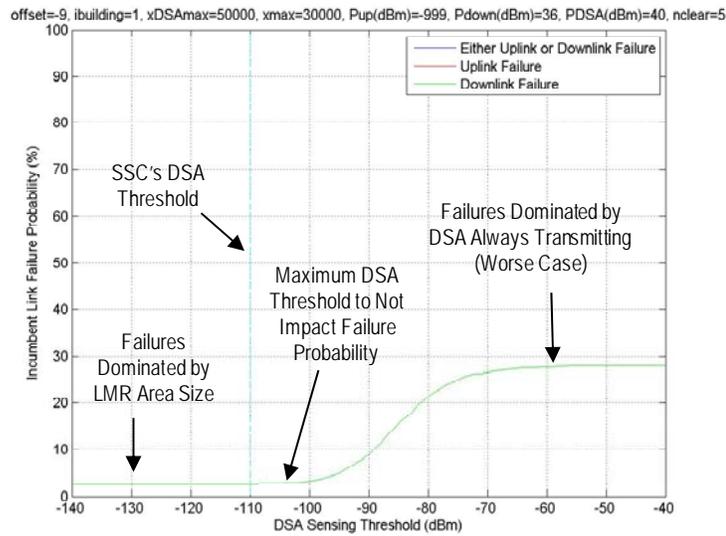


Figure 7. Hidden Node (Downlink Only) LMR Incumbent Link Failure Probability versus DSA Sensing Threshold Value.

3.2 Sensitivity Analysis

This section is a sensitivity analysis where various radio and scenario parameters are varied.

3.2.1 Building Blockage Impact

Figure 8 shows the LMR downlink radio link failure probability versus the DSA sensing threshold value for a downlink only (hidden node) LMR scenario except the building blockage factor previously described is not used. This is the frequency duplex LMR configuration. At very low DSA sensing threshold values, the LMR link fails doesn't fail within the 30 km rectangular area due to the lower propagation losses. With a DSA sensing threshold below -90 dBm, there is no impact to the LMR failure rate. This example shows that the DSA performance is highly dependent on the variability of the propagation losses.

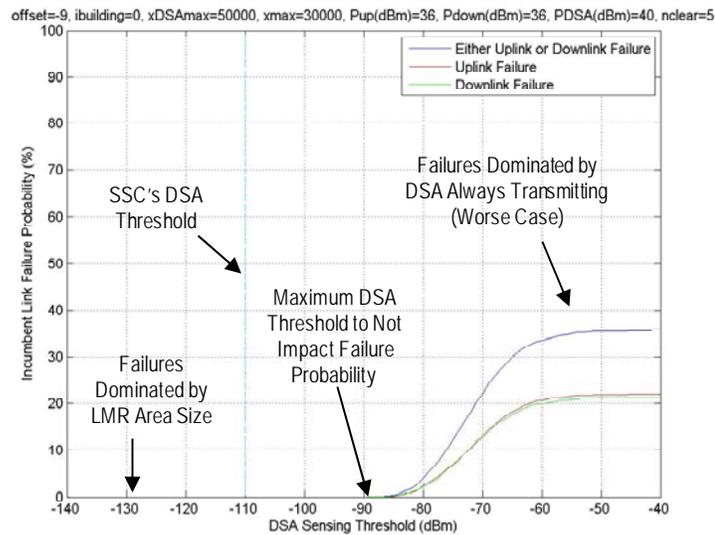


Figure 8. Frequency Duplex (9 MHz offset) LMR Incumbent Link Failure Probability versus DSA Sensing Threshold Value with no Extra Building Blockage Propagation Factor.

3.2.2 Same Uplink and Downlink Frequencies Impact

Figure 9 shows the LMR radio link failure probability versus the DSA sensing threshold value for the frequency duplex LMR scenario except that the uplink and downlink frequencies are the same (410 MHz). With a DSA sensing threshold below -95 dBm, there is no impact to the LMR failure rate. This example shows that the DSA performance is about the same the frequency duplex case because the multi-sample DSA sensing approach is mitigating the large errors in measuring the propagation loss at one frequency (the DSA sensing path) to estimate the propagation loss on the interference to the LMR radio path.

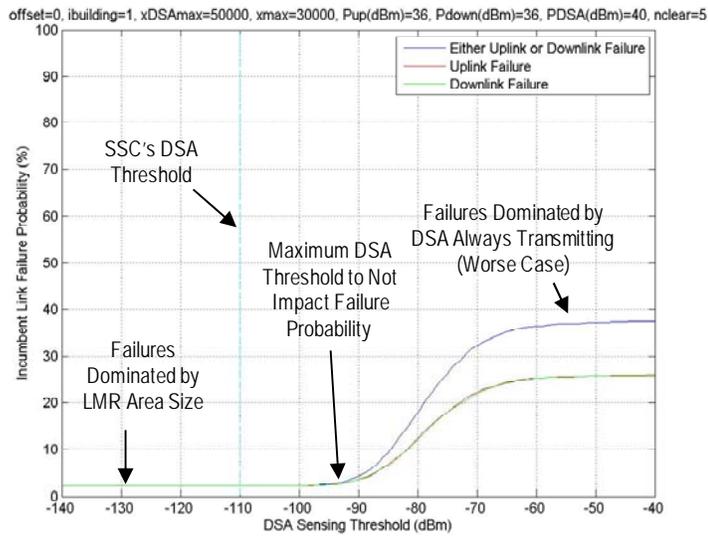


Figure 9. Same Frequency (0 MHz offset) LMR Incumbent Link Failure Probability versus DSA Sensing Threshold Value.

3.2.3 DSA Transmit Power Level Impact

Figure 10 shows the LMR radio link failure probability versus the DSA sensing threshold value for the frequency duplex LMR scenario except that DSA transmit power level is low (20 dBm instead of 40 dBm). With a DSA sensing threshold below -90 dBm, there is no impact to the LMR failure rate. This example shows that the DSA performance is improved because the lower DSA transmit power level reduces the chance of causing interference to the LMR system. Most DSA systems will use transmit power control, hence, this lower DSA transmit power level would occur often.

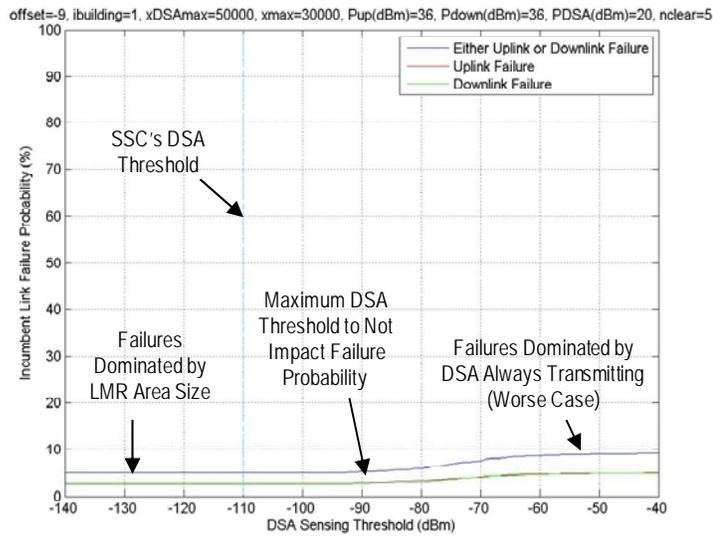


Figure 10. Frequency Duplex (9 MHz offset) Incumbent LMR Radio Link Failure Probability versus DSA Sensing Threshold Value with low (-20 dBm) DSA transmit power level.

3.2.4 LMR Transmit Power Level Impact

Figure 11 shows the LMR radio link failure probability versus the DSA sensing threshold value for the frequency duplex LMR scenario except that the LMR transmit power level is low (20 dBm instead of 36 dBm). Note that the LMR link failure rate is significantly higher due to the lower transmit power level. With a DSA sensing threshold below -110 dBm, there is no impact to the LMR failure rate. This example shows that the DSA performance is reduced because of the lower LMR transmit power level, which reduces the chance of the DSA radio detecting the LMR radio. Most DSA systems will use transmit power control, hence, this lower DSA transmit power level would occur often.

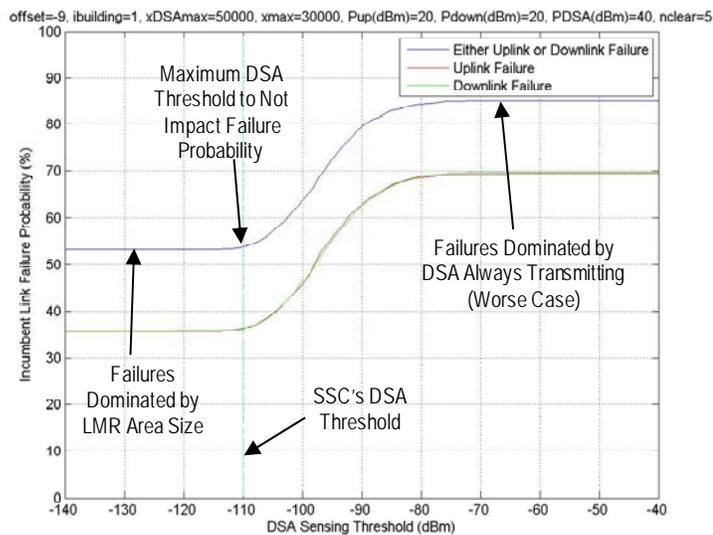


Figure 11. Frequency Duplex (9 MHz offset) LMR Incumbent Link Failure Probability versus DSA Sensing Threshold Value with low (-20 dBm) LMR transmit power.

3.2.5 DSA Multi-path Mitigation Sampling Impact

Figure 12 shows the LMR radio link failure probability versus the DSA sensing threshold value for the frequency duplex LMR scenario except that the DSA sensing algorithm was changed. This study considers two DSA detection algorithms: (1) A single sample was used to make a transmission decision. This represents the case when the propagation losses are absolutely stationary, which may occur over short periods if the LMR and DSA radios are fixed and there was minimal clutter movement (i.e. no motion of cars, person, trees, etc). Thus, deep nulls due to multipath fading may cause the DSA radio to not detect the LMR radio. This is the approach used in all of the previous examples. (2) The maximum received signal level over multiple samples was used to make a transmission decision. This represents the case when the propagation losses are not stationary, which may occur over long periods if the LMR and DSA radios are fixed, or if the LMR or the DSA radios are mobile. Thus, even with deep nulls due to multipath fading the DSA radio detects the LMR radio. This is the approach used in Figure 12.

With a DSA sensing threshold below -110 dBm, there is no impact to the LMR failure rate. This example shows that the DSA performance is reduced because of greater uncertainty between the uplink sensing (used to infer the propagation loss in the downlink interference path).

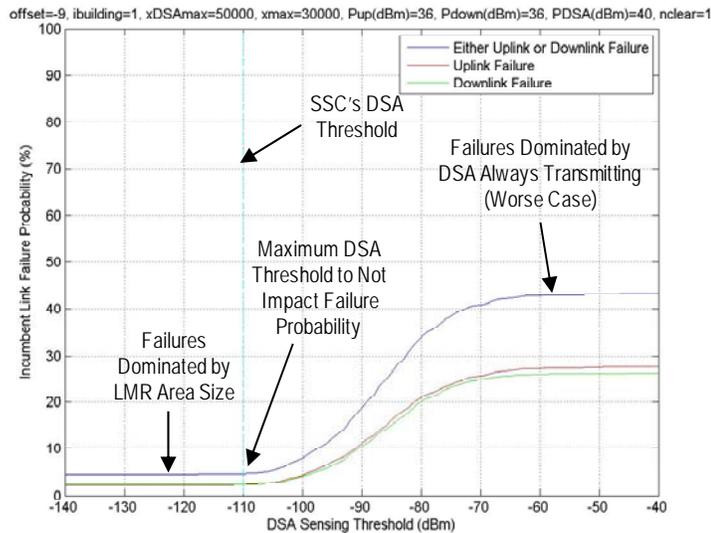


Figure 12. Frequency Duplex (9 MHz offset) LMR Incumbent Link Failure Probability versus DSA Sensing Threshold Value with a single detection DSA sensing approach (versus using the maximum threshold over five samples).

3.2.6 DSA Geographic Area Size Impact

Figure 13 shows the LMR radio link failure probability versus the DSA sensing threshold value for the frequency duplex LMR scenario except that the DSA geographic area length is larger (100 km versus 50 km). The larger DSA geographic area reduces the number of DSA radios within the interference distance to the LMR radios, but puts more DSA radios within the area where it is difficult to detect the LMR radios (potentially causing interference). With a DSA sensing threshold below -105 dBm, there is no impact to the LMR failure rate. By comparison, in the nominal case, the DSA sensing threshold was -95 dBm. This example shows that LMR interference statistics are a function of the DSA geographic area.

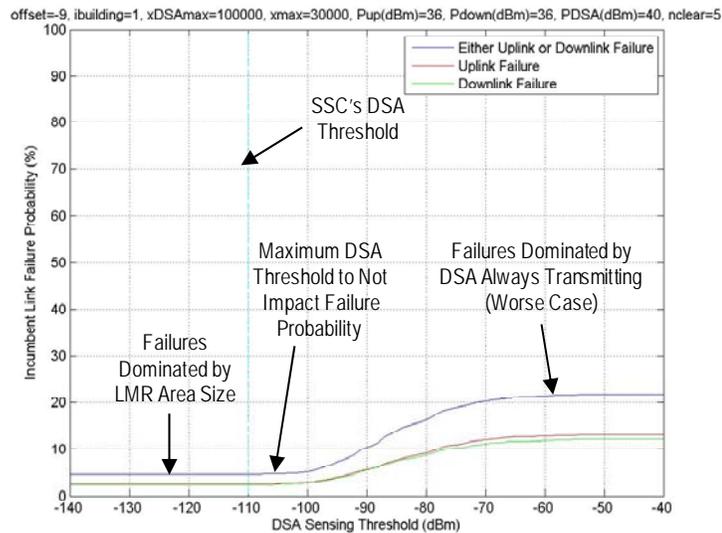


Figure 13. Frequency Duplex (9 MHz offset) LMR Incumbent Link Failure Probability versus DSA Sensing Threshold Value.

4.0 Conclusions

This report describes an analysis of the interference of a DSA radio on an LMR radio similar to what is proposed for the NTIA Testbed field tests. This is a Monte Carlo simulation with parametric analysis where a wide variety of parameters are varied.

The results show that the DSA sensing approach causes minimal interference to the incumbent LMR radio system. This is true even for a high power (40 dBm, 10 W) DSA radios. Table 3 shows the specific conclusions from different scenarios.

Table 3 Maximum DSA Detection Threshold Value for Different Scenarios

Scenario	Maximum DSA Detection Threshold (dBm)	Discussion
Nominal Frequency Duplex	-95	The DSA radio with a high, (10 W) transmit power level causes an insignificant amount of interference to the LMR system.
Nominal Hidden Node	-105	A 10 dB lower DSA sensing threshold is required to overcome the hidden node problem when the uplink transmitter never operates. This scenario is not operationally relevant, because the uplink never transmits.
Frequency Duplex with No Building Propagation Loss Factor	-90	The LMR interference level is strongly impacted by the difference in the uplink and downlink propagation losses. DSA sensing assumes that the uplink and downlink propagation losses are nearly the same.
Frequency Duplex with Same Uplink and Downlink Frequencies	-95	The same frequency scenario has the same DSA performance and the frequency duplex cause because the multiple detection DSA sensing methods mitigates the multipath fades that might cause large differences between the propagation loss at the two frequencies.
Frequency Duplex with Reduced DSA Transmit Power	-90	The LMR interference level is strongly impacted by the DSA transmit power level. Limiting the maximum DSA transmit power or implementing transmit power control tends to reduce the LMR interference level.
Frequency Duplex with Reduced LMR Transmit Power	-110	The LMR interference level is strongly impacted by the LMR transmit power level. Low power LMR signals are harder to detect and avoid.
Frequency Duplex with Single DSA Sampling Algorithm	-110	The LMR interference level is strongly impacted by; the ability of the DSA sensing algorithm to remove multipath fading by taking many samples or having the DSA radios being mobile. The worse case is when the LMR and the DSA radios are fixed, which makes it difficult for the deep multi-path fades to be avoided during DS sensing.
Frequency Duplex with Increased DSA Geographic Area	-105	The LMR interference level is impacted by the geographic distribution of the DSA radios. Certain DSA to LMR ranges have a much higher chance of causing interference. It is critical to determine the probability distribution of these bad locations compared to operational scenarios.

Various factors that would tend to further reduce the interference were not included in the analysis. These include:

- Allowing the DSA radio to use multiple channels instead of being forced to operate on the same channel as the LMR radio. For example, if there were 10 channels available, and one LMR system, then the LMR link failure rate would be 1/10 of what is predicted in this study.
- Having multiple DSA radios in the network (a single DSA was assumed here) increases the DSA network's detection probability. The reason is that DSA radios only use a channel if all users in the local net sense that the spectrum is unoccupied.

- Having multiple LMR subscribers in the area (a single LMR subscriber was assumed here), this increases the DSA networks detection probability. The reason is that more LMR radios increase the probability that the DSA radios sense that the channel is occupied.