Subject: WRC 03 Agenda Item 1.5

AN *AGGREGATE MODEL ANALYSIS* OF SHARING BETWEEN RADIO LOCAL AREA NETWORK (RLAN) DEVICES AND METEOROLOGICAL, RADIOLOCATION AND AERONAUTICAL RADIONAVIGATION RADARS OPERATING IN THE RANGE 5250-5725 MHZ

Prepared by The Wireless Ethernet Compatibility Alliance (WECA)

1. Summary

A model was developed considering aggregate RF characteristics of a population of RLAN devices (RLANs) in a separate paper prepared by WECA. This paper considers frequency band sharing between RLANs and radars as well as the potential effect of a representative radar transmitter on an RLAN, using the model in the separate paper. Ground based, maritime and airborne radars are considered.

2. Introduction

Potential Radar Interference from the Aggregate of RLANs

An analysis was performed using the effective RLAN densities, transmit power levels, and propagation factors defined in the separate WECA paper. It is assumed that the powers from each RLAN add linearly in the radar receiver and that the RLANs are distributed from a minimum range of 1 km from the radar. The received power in the radar receiver is calculated using the radar parameters defined in Appendix B.

A representative distribution of RLAN devices is shown in Figure 1. The rings show the urban, suburban, and rural areas. The density of points on the plot shows the differences in density between the regions. And the color of the points corresponds to the signal level received by the radar receiver. The higher signal levels are caused by closer devices, and by devices in the main beam. For the purpose of this plot the main beam was kept stationary (not rotated) so that the effect from this beam can be seen. That different signal levels are caused by devices in the same general geographic location is the result of some of the devices being indoors, and others being outdoors.

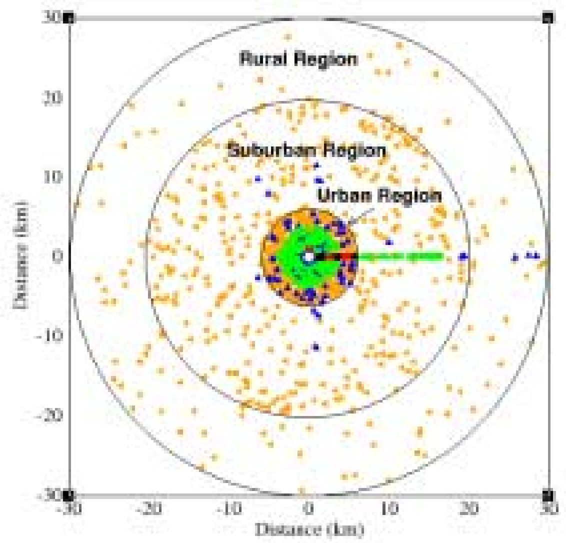

Figure 1: Representative distribution of users in the analysis area. Colors refer to the signal detected by a radar at the center of the analysis area.

The received signal level into ground radar “A” when it is located at the center of the simulation region is illustrated in Figure 2. The resultant aggregate I/N (interference to noise ratio) in the radar receiver is illustrated in Figure 3.

These results show that the aggregate power received is determined by the nearest RLANs.

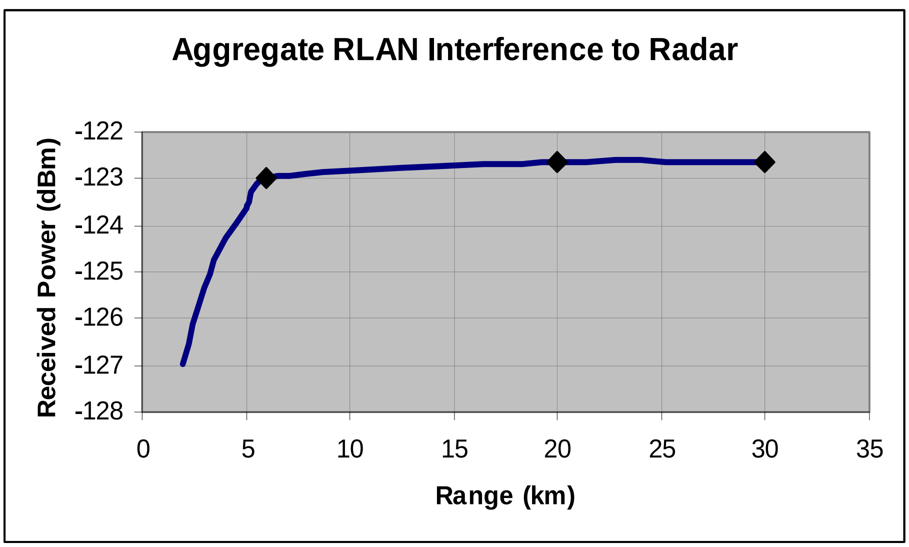

Figure 2 : The aggregate interference seen by a radar receiver at the center of the analysis area, as a function of the size of this area.

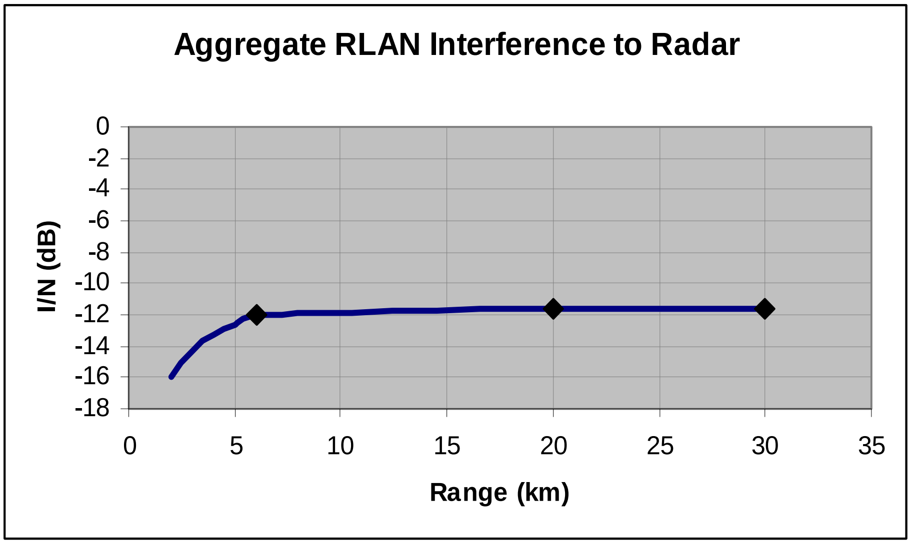

Figure 3: The aggregate interference to noise level seen by a radar receiver at the center of the analysis area, as a function of the size of this area.

The same analysis was be performed for all of the sets of radar parameters in Appendix B. When the appropriate loss parameters are used for the ground and airborne radar types, the modeled I/N values for each radar type are shown in Figure 4.

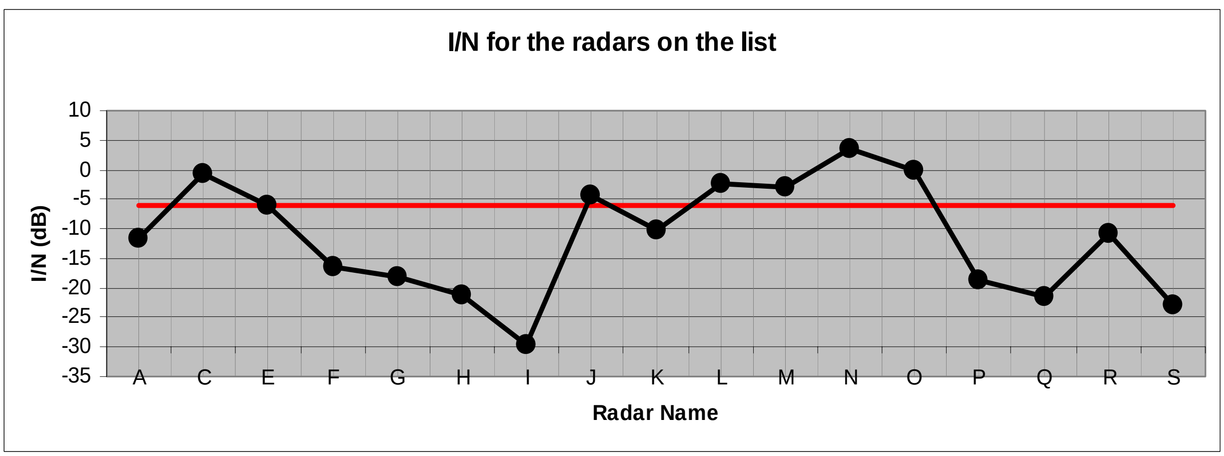

Figure 4: The aggregate interference to noise ratio (I/N) in dB for each set of radar parameters in document USWP8B02/10R2, dated April 2nd, 2002

In the airborne case, the geometry used is illustrated in Figure 5.

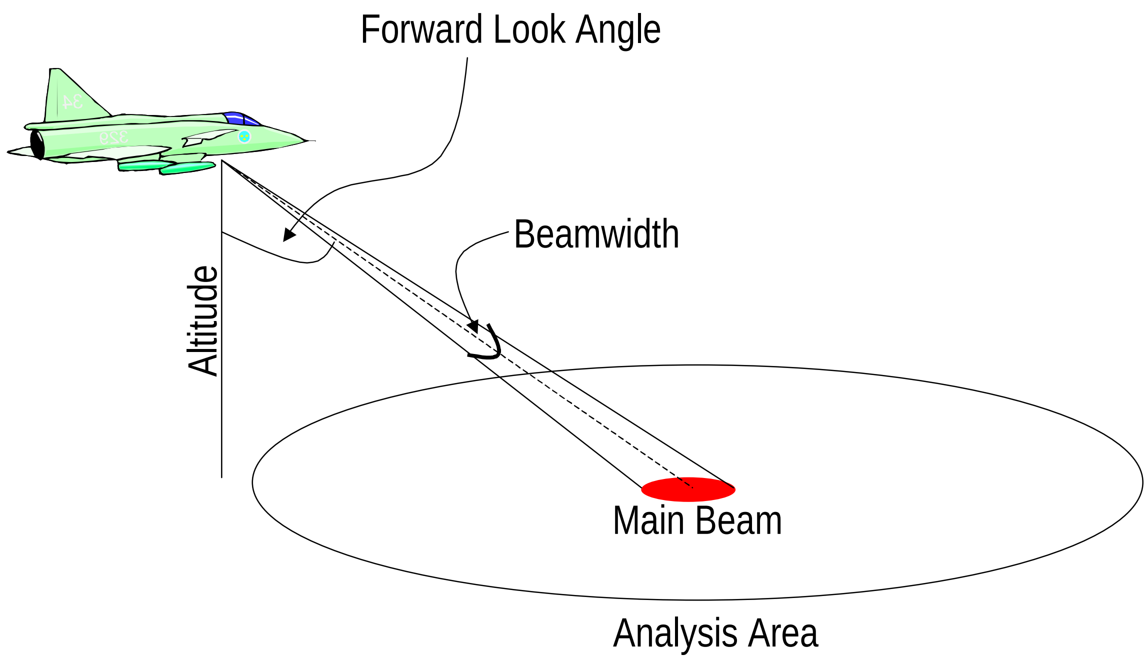

Figure 5 : Geometry used to analyze potential interference to airborne radar devices

The altitude of the radar was taken to be 9 km, and the forward look angle was taken to be 80°. The geometry was chosen so that the main beam was located at the center of the analysis region, so the radar itself was displaced from this location by 51 km. (51/9 = tan[80°].) The distribution of interferers in this case is shown in Figure 6 below.

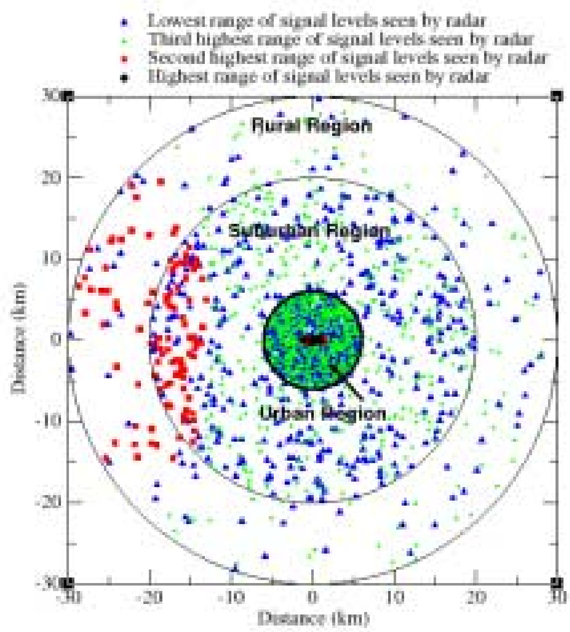

Figure 6: Representative diagram showing varying levels of potential interference presented to an airborne radar from RLAN devices within the analysis region

While the highest levels of potential RLAN energy come from the devices within the main beam (the set of dark points at the center of the analysis area), high levels of RLAN energy also come from devices near the edge of the region, since they are closer to the airborne radar and there is less path loss. This indicates that the highest potential aggregate interference may come when the radar is directly over the population area, even though the main lobe will be pointing elsewhere. To verify this concept , we have analysed the potential interference for various horizontal displacements of the radar from the city center in the case of the two airborne radars. Those results are shown in Figures 7 & 8 below.

As is shown in both of these figures, even as the radar passes directly over the city center, the radar receiver will not receive significant interference from the aggregate population of RLANs.

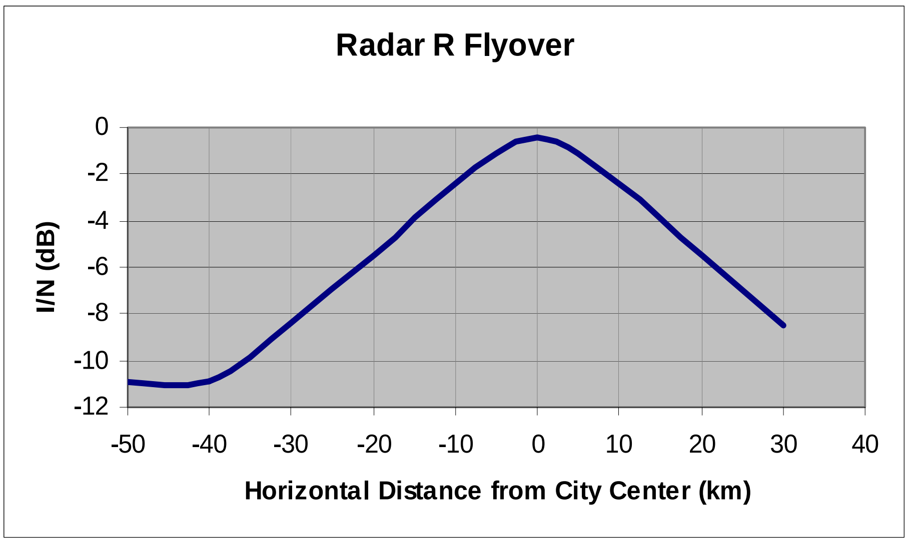

Figure 7 : I/N (dB) seen by Radar R as it passes over the analysis area

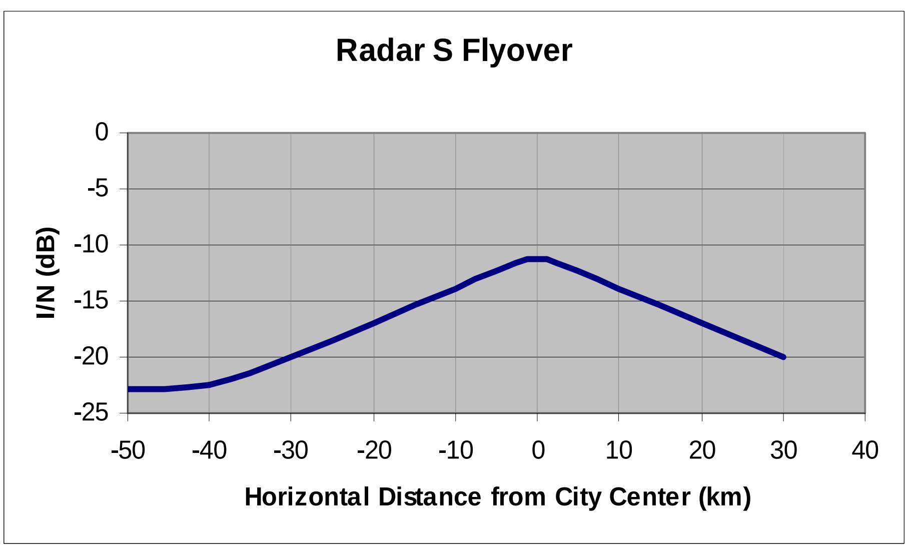

Figure 8 : I/N (dB) seen by Radar S as it passes over the analysis area

3. Effect of Radar Interference on the RLAN

This analysis will examine the potential radar interference into an RLAN for two different types of radar, one high-power radar and one low-power radar.

Ground Radar N

The radar signal in the RLAN receiver is illustrated in Figure 9. The receiver signal from the radar mainlobe, a – 22 dB radar sidelobe signal and the RLAN receiver noise are all shown. The signal from the radar mainbeam is always above the RLAN receiver noise floor out to the maximum plotted range near the edge of the analysis area.

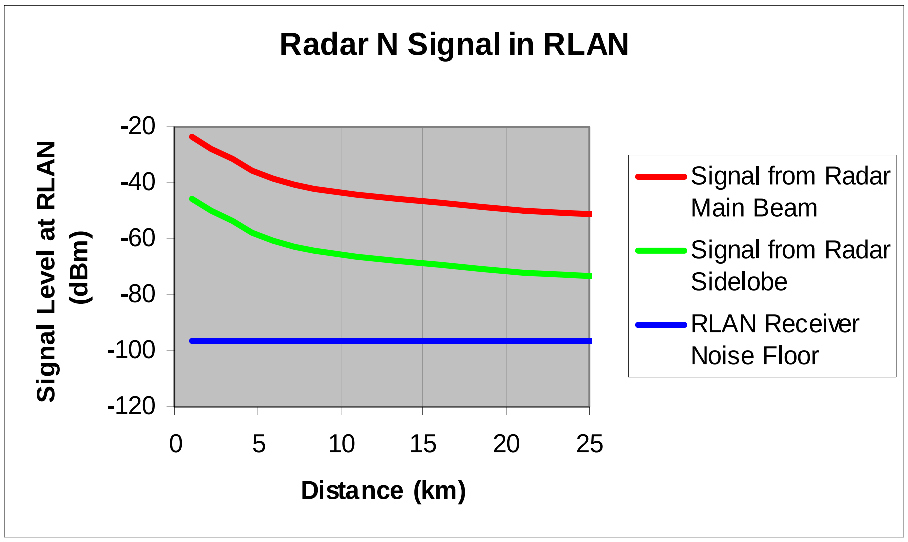

Figure 9 : Ground / Ship Radar A Signal in RLAN Receiver

The radar signal in the RLAN receiver is much greater than the corresponding RLAN signal in the radar receiver. The main contributor to this large difference is the relative transmitter power of the two devices. (The RLAN power is about 23 dBm, while the radar power is about 1000 kWatts, plus 46 dBi in the main beam, or about 136 dBm.) The radar signal into the RLAN, in this case, is 42.5 dB higher than the RLAN signal into the radar. Thus, RLAN devices may need to cope with interference from this radar system.

Airborne Radar J

The signal from airborne radar J in the RLAN receiver is illustrated in Figure 10. Except at short distances in the main beam, the transmitter power from this radar is much lower than that for the previous radar (only 22.5 Watts), hence, the signal levels from this radar will cause only limited interference to RLANs.

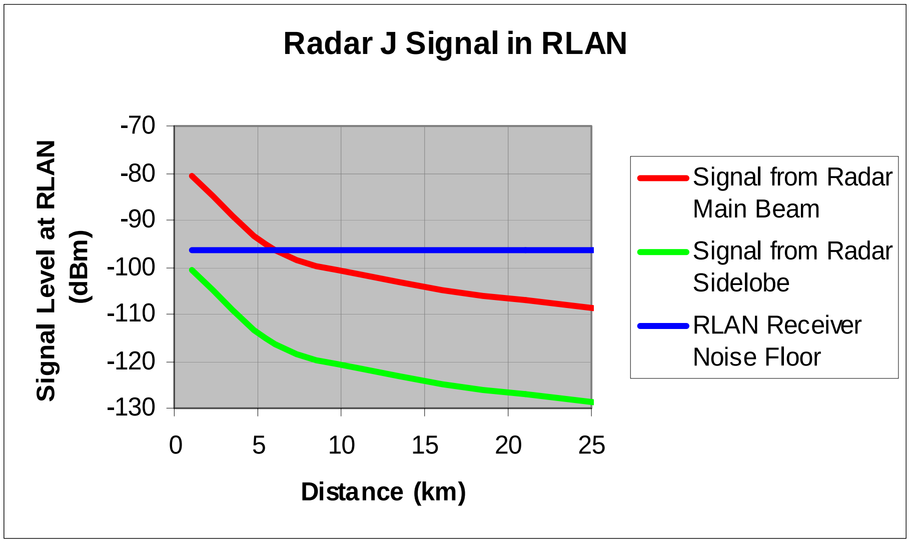

Figure 10 : Airborne Radar J Signal in RLAN Receiver

4. Conclusions

Several conclusions can be drawn from the analysis presented in this document.

- For most of the sets of radar parameters analysed (described as A to S), the predicted signal received from a future, high density of RLAN devices is found to be below receiver noise, and for many radars, below the -6 dB INR value.

- The potential interference levels caused by radar systems and seen by RLAN devices is, in the case of high powered, high gain, radar systems, orders of magnitude larger than the potential interference caused by RLANs and seen by the radars.

In addition, there are several conservative assumptions made in this document that imply that the actual sharing scenario in the future, if/when RLAN's achieve the high deployment levels used in this paper, is likely to be better than that shown:

- A high population density for the urban center is used. In the vast majority of cases, population densities will not be this high, and the aggregate energy will be correspondingly less.
    - For the specific case of maritime radars, this analysis is overly pessimistic in another way. Since maritime radars are used on ships, they will receive RLAN energy from a population density less than that used in this analysis. Water will comprise modest to significant percentages of the environment surrounding the radar.. Therefore, the potential interference levels shown here for maritime radars are larger than should be expected.

- The RLAN transmitter power, in this analysis, is 2 dB below the regulatory maximum. However, in the current environment, RLAN devices do not transmit at powers at even that level. RLAN devices are most often small, battery operated, mobile implementations. The incentive for manufacturers and users is for those devices to use as little power as possible, and this requires minimizing transmit power as much as possible. That is the case today, and all indications are that this trend will continue in the future.

- In the cases that show the highest potential for interference, the results are sensitive to the sidelobe gains of the radar antennas. For example, the analysis for Radar N uses a peak gain of 45.9 dBi and a sidelobe level that is only 22 dB lower than that peak. Data from actual radar antennas, however, indicates that substantially higher levels of sidelobe suppression can be expected in practice. For example, Figure 11 shows the azimuthal pattern from the Government Antenna Systems part of the Andrews Company. As can be seen, in this case the sidelobe levels quickly drop to levels 30 dB below the peak gain. Other data from this company on both S-Band and C-Band (5 GHz) radar antennas confirms that first sidelobe levels of 30 dB below the peak are typical.

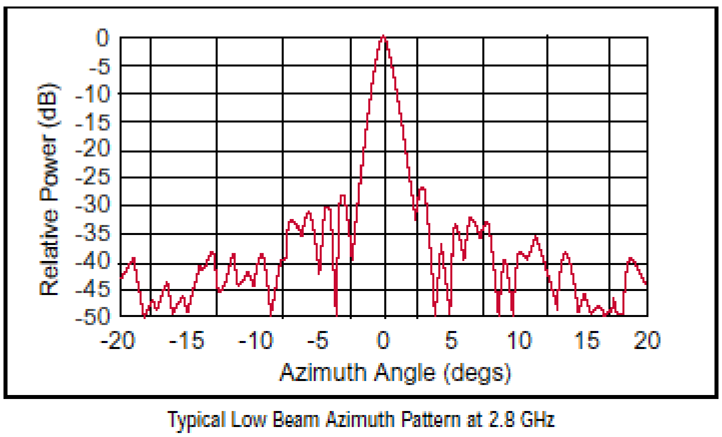

Figure 11 : Antenna Pattern for S-Band Air Traffic Control Radar Antenna

As shown in Figure 4, the analysis for Radar N predicts an I/N level of 3.7 dB. However, if a sidelobe level of 30 dB below the peak (rather than 22 dB below the peak) is used in the analysis, the I/N level drops to only –0.8 dB. Many military radar systems are designed with ultra-low sidelobe patterns. To the extent the sidelobe levels are lower than the values represented in USWP8B02/10R2, resulting I/N levels in this study would be equivalently reduced.

- These analyses (other than the airborne radar cases) have been performed only for a configuration in which the radar is located at the urban center. This is the most pessimistic assumption leading to the highest aggregate RLAN signal levels. As can be seen in Figure 12, when the radar is displaced from the city center the level of aggregate RLAN energy is lowered by many dB. In the case in which the radar systems are mobile, the highest possible levels of RLAN energy will only occur for the short duration, and over the short distances, corresponding to the time when the radar is directly in the city center. Depending on the type of radar and its mission, there exist various solutions in which this area of peak potential interference due to deployment of the radar at the dense urban center could be avoided.

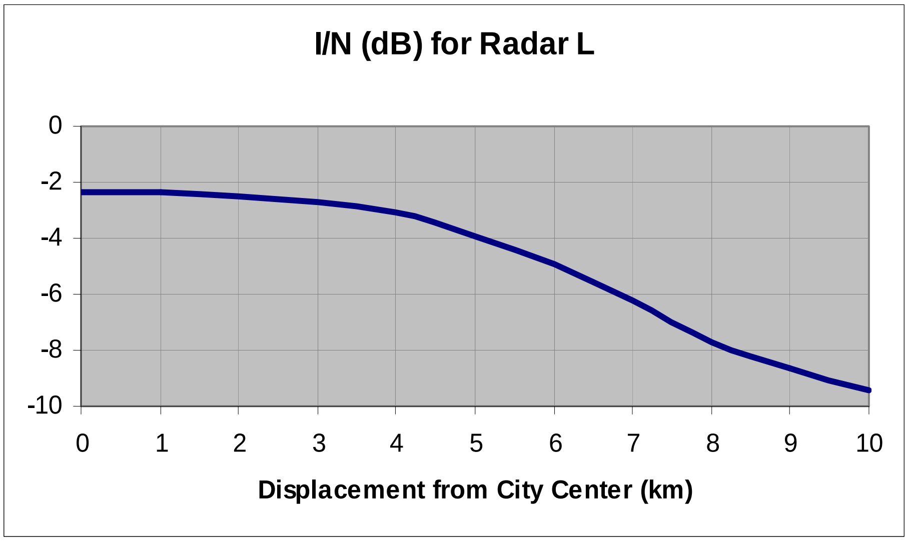

Figure 12: I/N reduction when radar is removed from urban center

- Finally, this analysis does not take into account interference avoidance mechanisms designed into many critical radar systems that will achieve continued operation of the radar system in the face of many types of unintentional and intentional interference in the environment.

  For example, the following features and characteristics of most modern military radar systems may provide further confidence that future dense populations of RLAN's will not cause harmful interference to these radar systems.

  Clutter Map: Many radars employ a clutter map capability where areas of heavy return are identified by the radar. This will facilitate separate processing in regions of high clutter (near cities for instance). In this case, the radar receiver may be adjusted when pointed toward a large population area thereby reducing receiver sensitivity to RLAN energy that may also be present in a large population area.

  Elevation beam tilt: Many surface based air search radars will tilt the elevation beam up to avoid the potential strong return from possible nearby reflection objects or areas. Many of these radars have multiple beams in elevation and perform processing on the lower beam to filter out areas of high reflectivity. In this case, the radar gain can be considerably lower near the surface where RLANs will operate.

  Radar EP: Most military radars have Electronic Protection (or Electronic Counter-Counter Measures, ECCM) employed. One feature provides capability whereby the radar surveys the spectrum in which it seeks to operate to detect any intentional or unintentional interference. For the case of a critical military radar deployed very near a dense population, the radar in this case would take the appropriate measures to ensure continued operation.

  As a group, radar parameters described as *Ground-based Instrumentation* in document USWP8B02/10R2 receive the highest predicted I/N values when placed in the urban center.

It would be informative to receive further data on the typical mission of any deployed radar systems that corresponds to those radar parameters given in USWP8B02/10R2. Review of characteristics of actual radar systems would indicate the likelihood of deployment within any dense urban area as well as the likely interference mitigation and avoidance features which may be expected for the type of radar.

Furthermore, identification of specific radar systems would provide further confidence that radar systems of particular concern by the radar community, would not be adversely affected by future aggregate levels of RLAN energy present in dense areas. It is believed that analysis using more specific radar deployment and mission characteristics would be far more indicative of potential for harmful interference impacting a radar’s mission, in contrast to a generic I/N level criteria.

5. Recommendations

Based on the analysis and conclusions above, for RLAN devices operating in the mobile service and radars operating in the radiolocation service, sharing is feasible within the 5150-5350 and 5470-5725 MHz bands. Therefore worldwide spectrum allocation for the mobile service designated for use by RLAN devices should be supported.

6. References

JPTG(02)30 "Study of Interference from 5 GHz RLANs into Wideband SAR Satellites (EESS)

ITU-R Recommendation M.1461, Procedures for Determining Potential for Interference Between Radars Operating in the Radio Determination Service and Systems in other Services (Question ITU-R 226/8 (2000).

ITU-R Recommendation M.1390 Methodology for the calculation of IMT-2000 terrestrial spectrum requirements

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US submission to Working Party 8B document USWP8B02/10R2, dated April 2nd, 2002

"Empirical formula for propagation loss in Land Mobile radio services," IEEE Transactions on Vehicular Technology, Vol. 29, No. 3, Aug 1980

"Field Strength and Its Variability in VHF and UHF Land-Mobile Radio Service," by Yoshihisa Okumura, et.al., Review of the Electrical Communications Laboratory, Vol. 16, No. 9-10, September-October 1968

Document: USWP8B-DFS/01v8, Date: July 8, 2002, Wireless Access Systems (WAS), Including RLANs & Radiodetermination and EESS Deployment Scenario at 5 GHz for Analysis of Sharing

Document 3M/129-E, 18 May 1999, Average Building Attenuation Relating to the Protection of the NGSO MSS Feeder Links Operating in the Band 5 150 – 5 250 MHz from RLAN Interference

Document 3k/69-E, Document 3m/153-E, 29 May 2000, Ericsson Radio Systems Ab, Sweden,

Building Attenuation Loss Measurements at the 5.1 Ghz Band in an Office Building Area

Document 4a/77-E, Document 3m/5-E, 28 September 2000, Joint Rapporteur Group 8A-9B, Liason Statement to WP 3M & 4A Concerning Building Attenuation at Around 5 GHz.

Appendix A: Equations used in the Analysis

The received signal in the radar receiver from a single RLAN at a range of R in the antenna mainlobe is given by

$$P_{RML}(R) := ERP_L \cdot FSL(R) \cdot L_{LR} \cdot BRL \cdot EPL \cdot BSL \cdot G_R$$

The aggregate signal received at the radar from all the RLANs transmitting at the radar RF in a range interval from Rmin to Rmax is

$$I_{Tot} := \int_{Rmin}^{Rmax} ERP_L \cdot L_{LR} \cdot BRL \cdot EPL \cdot BSL \cdot \frac{d}{10^6} \cdot \frac{ABW}{57.3} \cdot \left(\frac{\lambda}{4 \cdot \pi}\right)^2 \cdot \frac{1}{R} \cdot G_R \, dR \cdot \left(1 + RASL \cdot \frac{360}{ABW}\right)$$

Where typically

ERP_L	= 200 mW	is the ERP of the RLAN
FSL(R)		is the free space loss as a function of range R (FSL = -127 dB @ 10 Km)
LLR	= - 6 dB	is the internal / misc losses of the RLAN and radar
BRL	= - 15.6 dB	is the receiver bandwidth reduction ratio
EPL	= - 13 dB	is the excessive path loss due to the RLAN being inside a building
BSL	= - 30 dB	is the building shadowing loss
GR	= 46 dBi	is the gain of the radar antenna
d	= 0.037 per Km2	is the net density of RLANS transmitting at the radar RF
ABW	= 0.65 deg	is the radar antenna beamwidth
λ	= 0.055 m	is the radar wavelength (5.5 GHz)
$1 + RASL \cdot \frac{360}{ABW}$	= 3.8 dB	is the added power from RASL = -26 dB (+ 20 dBi) radar antenna sidelobes
R		is the range from the radar to the RLAN in meters
Rmin	= 1 Km	is the range to the first RLAN
Rmax	= 16 Km	is the range to the furtherest RLAN

Appendix B: Radar Parameters

(Derived from USWP8B02/10R2, dated April 2nd, 2002)

Radar Name	Power (kWatts)	Peak Gain (dBi)	Bandwidth (MHz)	Beamwidth (degrees)	Sidelobe Gain (dBi)
A	125	46	0.5	0.65	20
C	1.5	44	20	0.95	9
E	250	50	0.91	0.5	23
F	250	40	0.6	0.5	15
G	250	40	0.25	1.65	15
H	0.150	40	0.7	0.5	5
I	0.150	40	0.1	0.5	5
J	0.0225	35	10	1.5	15
K	250	38.3	1	2.5	18.3
L	2,800	54	0.25	0.4	34
M	1,200	47	1	0.8	27
N	1,000	45.9	8	1	23.9
O	165	42	8	1	20
P	360	28	1.5	2.6	8
Q	285	30	1.2	1.6	5
R	16	26	90	3	4
S	0.10	30	1	2	5