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North American Broadcasters Association (NABA)

ANALYSIS OF ADJACENT BAND MOBILE WIRELESS SERVICE INTERFERENCE

Introduction

The North American Broadcasters Association (NABA, www.nabanet.com) is an association of broadcasters in Canada, Mexico and the United States, and the NABA Technical Committee is its standing technical body. NABA is thus in a position to present the technical viewpoints of the most authoritative association of professional North American Broadcasters in television and sound programme production, post-production, and distribution for terrestrial, satellite, and cable broadcasting.

NABA is a Sector Member of ITU-R and a long-time participant in ITU-R Study Groups, Working Parties, Task Groups, Rapporteur Groups, etc. NABA numbers among its members Chairmen, Vice-Chairmen and members of the above groups. NABA also participates widely in the ITU work on radio, television and multimedia services.

Purpose

To assist the Joint Task Force (JTG) in determining interference issues caused by some wireless assignments, NABA is submitting this Contribution which is an analysis of wireless interference conditions in order to deduce the overload levels that would be seen from adjacent services in the desired signal band. NABA believes that in order to eliminate such interference concerns that improved co-ordination rules based on criteria outlined in this Contribution are required.

Abstract — Subscribers to wireless services face brute-force overload interference caused by nearby transmitters operating in the adjacent frequency bands. Overload interference can create large static “dead zones” – muting reception of the subscriber signal near the transmitting base stations, or it can create unpredictable mobile dead zones around transmitting user terminals. This situation can be more pronounced when a terrestrial network with a large number of mobile and base station transmitters operates adjacent to satellite downlink frequencies. This paper provides an analysis of the overload interference problem and describes various methods to simulate the downlink and uplink interference conditions. Practical spectrum coordination methods are presented that would eliminate such interference concerns, including rules founded in part on street-level signal density limits that could also foster deployment of more advanced and more effective networks.

Keywords— Mobile, satellite, wireless, communications, interference

1 Introduction

Operators, technical standards agencies and federal communications regulatory agencies must have ways to analyze the impact of adjacent channel interference between diverse wireless systems. In various instances of regulatory protection rules, incumbent broadcasters are afforded protection from new in-band or adjacent services to a high degree. Some licensed services are granted protection through required separation distances, or assured protection through the use of Desired to Undesired (D/U) signal level ratios that comport to installed receiver capabilities. Other protections limit the power of new interference sources. Yet, some rules do not even protect sufficiently from just one nearby interfering transmitter in high use case scenarios.

One of the major interference mechanisms is out-of-band emissions (OOBE) generated by the strong undesired signals spilling over into the frequency spectrum of the weak desired signals. If the OOBE is sufficiently high, the noise floor of the desired signal band will excessively increase. Above a certain level, the Signal to Noise Ratio (SNR) of the desired signal will not be properly demodulated. This would occur in conditions where the desired signal would be successfully received and demodulated in the absence of the interferer. Intermodulation products from nearby transmitters may show up as out of band interference signals, as well.

A digital receiver relies on a relatively high signal level to demodulate the desired content in the presence of nominal thermal noise. When OOBE from an undesired signal fall into the receiver's in-band frequency spectrum, these emissions add to the noise floor. Thus, the SNR decreases. As this ratio decreases, the desired signal becomes less detectable by the receiver. The receiver's Forward Error Correction (FEC) operation can offer limited help to mitigate the increased noise floor effects and therefore continue demodulating the desired signal. Once the desired SNR falls below a certain limit, the receiver can no longer detect the desired signals in the presence of excessive noise, and loss of service occurs. No filtering method can prevent the impact of OOBE interference that occurs within the desired signal band.

Overload is another major form of interference that typically occurs in the receiver tuner, and is purely linear and results in the desensitization of the receiver circuitry. Interference occurs when an undesired signal (or signals) from an adjacent frequency band is sufficiently strong to cause the Automatic Gain Control (AGC) system of the desired signal's receiver to respond to the undesired signal rather than the desired signal. The AGC system's task is to control the amount of the aggregate signal power in the analog tuner circuitry before it is carried to the base-band circuitry for signal demodulation. As the interference increases, the AGC attenuates the aggregate signal, so as to not exceed the dynamic range of the receiver. Note that in the presence of a strong interferer, the entire received signal is attenuated by the AGC, and therefore the much weaker desired signal is also attenuated. Eventually, the desired signal is pushed below the threshold of recoverability, resulting in a loss of service.

Available filters make it impractical to reduce to a reasonable level interference originating from adjacent bands. Normally, antenna modules contain relatively broadband filters to sufficiently reject undesired signals originating from large frequency separations in the order of more than tens of MHz. Also, the state-of-the-art filter designs suffer from a combination of high pass band insertion loss and amplitude ripple, and manufacturing tolerances for temperature drift that obviate their utility in addressing this interference.

Figure 1 illustrates excess overload and noise floor increase impact from an undesired signal interferer on the desired signal.

FIGURE 1

Illustration of Overload and OOBE Impact

This paper analyses the overload and OOBE interference impact in the following sections. First, we describe past regulatory approaches to protect broadcast systems. Then, we examine interference from wide scale deployment of adjacent band interferers, discuss blocking levels, and describe the extent of potential interference areas using actual site deployments in specific markets. Based on an extensive analysis in publications and our own measurements and analysis, we show methods for determining overload interference impact levels and coordination requirements based on simple methods that could be used to evaluate the interference impact, and can be used in regulatory coordination efforts to limit interference between services operating in the adjacent frequency bands.

2 Introduction to Conventional Coordination Standards

In the ITU Regulations and in the WiMAX forum, coexistence issues between adjacent services are well known. Issues were described in the ITU's Report on TDD/FDD coexistence in Reference 1, and the WiMAX Forum's papers on coexistence in Reference 2. Both reports acknowledge the severity of "potentially crippling" mobile-to-mobile interference. In addition, the WiMAX Forum identifies a 1 dB rise in the satellite receiver's noise floor as a coordination criterion for the interference that it creates to the satellite receivers operating in the 3.5 GHz band as described in Reference 3. The United States Federal Communications Commission (FCC) used the same approach to develop the rules to coordinate the interference from adjacent terrestrial bands into the US satellite digital audio radio service (SDARS) bands in 1997 (See Reference 4).

For the 700 MHz Wireless Communication Services (WCS) band, and TV Broadcast, the FCC authorizes base stations, fixed stations, control stations, and mobile transmitters in the 698-763 MHz, 775-793 MHz, and 805-806 MHz frequency bands. Details of the TV and FM service rules can be found in Reference 5 and 6. According to Section 27.60 of the FCC rules (Title 47, Part 15), the transmitters must be operated only in accordance with the rules to reduce the potential for interference to public reception of the signals of existing TV and DTV broadcast stations transmitting on TV Channels 51 through 68. The FCC provides protection to the existing TV and Digital TV broadcasters, as seen in Section 27.60, which require locations of new base stations so that they are of sufficient distance away from TV and DTV stations, such that the D/U ratio (in dB) at a receiver is more than specific values. In other words, the FCC requires significant geographical spacing to assure that the transmitters are located far enough away from existing TV broadcasters that they do not impinge on the coverage region (e.g. the listening public) of existing TV and DTV stations. It is clear that the FCC provides sufficient protection to incumbent broadcasters when a new adjacent channel mobile wireless service is launched using a D/U ratio type method. Radio manufacturers and the FCC typically define a D/U ratio for FM co-channel and adjacent-channel band users. A review of FCC rules for the FM radio service indicates that most common broadcast receivers are required to design for co-channel interference D/U levels of +17 dB to +30 dB. Also, as shown subsequently, Digital Television requires +23 dB D/U.

The process for determining whether a TV channel is available for use by unlicensed TV Band devices is based on protecting the service contours of the primary services. Contours based on propagation path loss models (often free space) allow each broadcast transmitter to define its coverage area. Note from Table 1 that the FCC protects Digital TV with a D/U of +23 dB for co-channel protection. Table 2 shows that the FCC provides a minimum distance of 6 km to protect the primary TV broadcaster from co-channel interference, and 0.1 km to protect the primary TV broadcaster from adjacent channel interference. A protection distance is used to ensure that protected receivers are not overloaded, or that the noise level is not artificially raised so as to weaken the link margin of the protected broadcast signal.

TABLE 1

TV Interference Protection Criteria

Type of station	Protection ratios	
	Channel separation	D/U ratio (dB)
Analog TV, Class A, LPTV, translator and booster	Co-channel	+34
	Upper adjacent	-17
	Lower adjacent	-14
Digital TV and Class A	Co-channel	+23
	Upper adjacent	-26
	Lower adjacent	-28

TABLE 2

Minimum Required Separation Distances for Fixed Unlicensed TV Band Devices

Antenna Height of Unlicensed Device	Required Separation (kilometers) From Digital or Analog TV (Full Service or Low Power) Protected Contour	
	Co-channel	*Adjacent Channel*
Less than 3 meters	6.0 km	0.1 km
3 – Less than 10 meters	8.0 km	0.1 km
10 – 30 meters	14.4 km	0.74 km

3 Overload Interference Analysis

To demonstrate the overload problem and the current coordination methods, we use the interference conditions from the Wireless Communications Services (WCS), a fixed and mobile cellular service, to US satellite digital audio radio services (SDARS) operating in the adjacent spectrum (See Reference 7 for spectrum allocation details). SDARS spectrum is assigned in the U.S. to the band between 2 320 and 2 345 MHz; the lower half is dedicated to the Sirius and the upper half is dedicated to the XM operations of the Sirius XM network (See Reference 8 for detailed description of satellite radio systems). WCS is assigned spectrum in the 2 305-2 320 MHz and the 2 345-2 360 MHz bands. This arrangement creates the risk that WCS transmitters that operate on both sides of the satellite spectrum will interfere with the reception of low-power satellite broadcasts. The absence of any guard band between the high power terrestrial signals and low power satellite signals eliminates any opportunity for effective receiver filtering to alleviate this interference mechanism. As in some other spectrum assignments, WCS licensees have yet to deploy wide area operational systems. As a result, the effectiveness of the current interference provisions has not been tested.

The SDARS system is a broadcast system designed for simplex transmissions (receive-only) and, unlike cellular systems, has no feedback capability to report interference or other performance issues to a network control subsystem. The SDARS satellites are constructed to provide a specific amount of signal coverage on earth, without the ability to provide additional downlink power and hence link margin. If the interference fully erodes the available link margin, the receiver's reception will fail. Pratt and Bostian show that commercial satellite links are designed for Carrier to Noise (C/N) ratios on the order of 10 to 20 dB for reception on earth, where the minimum acceptable C/N for acceptable reception is on the order of 5 dB to 8.5 dB (See Reference 9).

On the other hand, cellular operators can install new base stations whenever link margins become saturated with interference or whenever new subscribers require more capacity. Also, given the large dynamic range of received signal levels in a cellular system, it is evident that many subscriber units can experience carrier to noise ratios of 30 dB to 50 dB or more from a serving base station, which is a much greater link margin than what is achievable by satellite systems. These aspects allow cellular systems to tolerate much higher levels of interference.

a) Identification of Overload Interference Impact Levels

The impact of overload interference has been quantified for a Sirius satellite signal band. Measurements were made utilizing the latest state-of-the-art receivers currently in production, providing the highest dynamic range available, thus minimizing the impact of signal overload. The overload impact of adjacent C and D block WCS signals into the Sirius satellite signal has been tested, and shown in the following table. Test results indicate that the WCS C-Block signal overloads the Sirius TDM1 satellite signal reception when received at -57 dBm level, while the satellite receiver can tolerate up to -24.5 dBm interference from the D-block at 21 MHz away. This is not a surprising result since the WCS C-Block is directly adjacent to the TDM1 band with no guard band to facilitate filtering. As this interference mechanism relates to the physics of large terrestrial signals directly adjacent to weaker satellite signals, this condition is not unique to Sirius. Where the Sirius signal is most affected by a strong adjacent C-Block interferer, XM's satellite reception is most affected by the D-Block that is directly adjacent to XM's SDARS spectrum allocation that extends up to 2 345 MHz. Comparable XM receivers perform similarly.

TABLE 3

Measured Overload Interference Levels (dBm)

Onset of Muting	WCS C-Block (2 315-2 320 MHz)	WCS D-Block (2 345-2 350 MHz)
Satellite Band (2 320-2 324 MHz)	-57	-24.5

b) Downlink Interference Impact Analysis (Base Station Interference into Satellite Radio)

1) Individual Site Downlink Overload Interference Impact

The single base station downlink interference region has been calculated for the existing 2 kW W-peak limit and an overload interference threshold of -57 dBm for various propagation conditions. The following table presents the calculated overload interference zones. For these calculations, it is assumed that a WCS transmitter transmits at a peak power of 2 kW (or a 500 W average Coded Orthogonal Frequency-Division Multiplex (COFDM) signal with 6 dB peak to average power ratio), a power level that would be permitted under the current FCC rules and assumes the utilization of a 4 MHz wide COFDM signal centered in the 5 MHz WCS block. Note that the 3GPP LTE and WiMax waveforms can actually cover larger spectrum in a 5 MHz channel, thus potentially creating larger impact. In the calculation of path loss, conventional clear line of sight, suburban and urban path loss models were used (See Reference 10). Lastly, an average impact region was calculated assuming 5:3:1 ratio for the urban, suburban and clear coverage areas.

TABLE 4

Size (Sq. Km)of the Overload Region

Clear line of sight	81.7
Suburban	5.3
Urban	1.5
Average environment	**6.1**

Assuming an average consumer environment, the service area impacted by overload interference would be 6.1 sq. km surrounding the interferer's location. Within this large area, the satellite signals can become unusable due to this blanketing interference. Assuming such interfering base stations are located typically to serve high traffic or population areas, this would create noticeable impact to the general population.

2) Aggregate Downlink Overload Interference Impact

To expand on the previous single interferer base station site analysis, a network operation with multiple interferers was simulated for the Philadelphia, PA market to demonstrate an example for the aggregate interference impact to SDARS service. The following analysis indicates the effects on population coverage and traffic volume. Predicted interference is generated by signal overload on the SDARS receivers from individual WCS base station transmitters. The WCS base stations were assumed to be located at the current SDARS repeater sites located in the Philadelphia region.

Approximately 50,000 vehicles are estimated to travel daily on a particular point on Interstate-95 in the urban Philadelphia area. The same vehicle could experience interference effects from several interferers during its travel. Resulting effects could degrade the interfered system's service quality. In Table 5 below, Population Affected is the number of people that reside within the interference area. Mean Average Daily Traffic (ADT) volume is the total count of vehicles passing a point or segment of a US Interstate/Highway/Major Road/Residential street, in both directions, during a 24-hour period averaged over an entire region. ADT is a general average for number of vehicles passing a point on a street or highway, thus it could underestimate the count of vehicles with receivers within the interference zone. By considering the number of streets and highway sections within the interference zone, one can estimate the number of vehicular users affected by interference. The interference impact extends from heavy traffic urban areas to light traffic residential/rural areas, therefore creating gradually decreasing mean traffic count as the interference zone expands.

TABLE 5

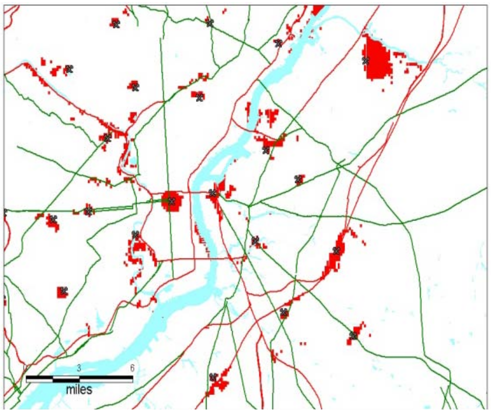
Assessment of Aggregate Interference Impact in Philadelphia, PA

Interference Mechanism	Total Area of Interference	Population Affected	Average Daily Traffic Volume
WCS C-Block Overload	737 sq. km	595,303	19,812

The following plot, Fig. 2, depicts the areas of interference in red. This analysis was generated using the CRC-Predict propagation model using terrain and clutter data sets, and demonstrates that significant portions of the Philadelphia market would be subject to interference. The areas of potential service loss could exceed 700 sq. km and cause service loss to nearly 20,000 vehicles on average per day. Considering the additional interference from operations in other blocks in the nearby spectrum, the impact could increase significantly. Also, remember that this simulation was made for a relatively low number of repeater sites to simulate the base station interference conditions. Should the interfering network be deployed in a fashion similar to a cellular/PCS network, a high number of interfering sites could create a noticeable blanketing interference into the interfered signal's service capability.

FIGURE 2

Overload Interference Areas for WCS C-Block for a 500 W (avg.) Transmitter



c) Uplink Interference Impact Analysis (WCS Mobile Interference into Satellite Radio)

The FCC allowed the power level of WCS mobile transmitters to be 250 mw. We now consider the power levels at which the SDARS receivers may experience overload. WCS overload presents itself to satellite radio receivers as adjacent-channel interference. Using the common broadcast interference coordination criteria discussed earlier, it can be seen that most FCC rulemakings call for adjacent-channel interference (for FM, TV and Digital TV) D/U ratios of 20 to 30 dB. This means that the interference power operating in the adjacent band should not be more than 20 dB to 30 dB greater than the desired signal that is intended for reception in its own protected band. Similarly, the 3GPP-UMTS specifications point to an adjacent channel selectivity requirement of 33 dB (See Reference 11). Measurements show that a typical satellite receiver is able to tolerate interference from a WCS transmitter within the first adjacent WCS (C and D blocks) up to a maximum level of -56 dBm as the receiver attempts to receive a desired satellite signal level of -100 dBm. The tolerance of a typical satellite receiver to interference from the 2nd adjacent WCS band (B-lower and A-upper blocks) is -46 dBm for a serving signal level of -100 dBm. As a result, the satellite radio receiver's 1st and 2nd adjacent channel D/U ratios are 44 dB and 54 dB, respectively. These measurements show that a typical satellite receiver is able to tolerate a much higher level of interference than typical consumer receivers used for FM or TV, and also exceed the suggested levels defined in the cellular phone standards. SDARS systems require robust receiver performance because of the fact that satellite radio systems must operate in challenging environments. However, the following example shows that even robust receivers can be unable to protect from close-in WCS transmissions when the regulations allow emission coordination rules that are excessively relaxed.

Lets now analyze the maximum tolerable interferer transmit power levels. In order to receive a -56 dBm adjacent channel WCS power level at an interfered receiver, consider a 49 dB path loss at three meters of separation, and add an additional 10 dB path loss from other factors. From this model, it is clear that no more than a 3 dBm transmit power should be allowed in the adjacent frequency blocks. Similarly, if we consider the interfered receivers tolerance to the emissions from the second adjacent channels (A and B) in the WCS blocks, 15 dBm would be determined as the maximum interference power allowed above which the receiver would be muted due to interference. Also, considering that the above examples use a simple case of a single nearby interferer, it would be clear that the real world deployments with multiple interfering transmitters would create further complex interference situations with varying interference distances, and the overall interference impact is certain to be much greater than what was presented above.

It is also important to take into account that when the interfered-with receiver is in a linear operating range, interference will linearly increase the noise floor, and thus degrade the receiver sensitivity in a predictable manner. When the interference forces the receiver into the non-linear operation region as the receiver becomes overloaded by close-in interference that create non-linearities throughout the analog and digital receiver circuitry, the additional noise floor caused by the intermodulation products of the interferer will further reduce the adjacent channel rejection capabilities of the receivers.

Coordination at the transmit antenna by limiting EIRP is simple from the interfering base station or mobile terminal operator's perspective. However, the interference problem does not occur at the transmitting antenna, but occurs at the receiver antenna. It would be clear that if EIRP is used as the coordination criterion, then the regulations should also specify the transmitting antenna's down-tilt, height and RF emission parameters to make up a complete solution. But, that would be far more complex than coordinating based on the interferer's ground field strength (power flux density, PFD). A PFD limit would limit the interference at the receiver in a quantifiable manner while allowing a reasonable interference occurrence probability limit. This simple approach could ensure service flexibility, lowest complexity and a universal solution.

4 Conclusions

This paper analyzed wireless interference conditions by making reasonable engineering judgments in order to deduce the overload levels that would be seen from adjacent services in the desired signal band. As a result, we sought to determine impact levels and practical coordination guidelines.

This paper has conclusively demonstrated that the wireless receivers are subject to brute-force overload interference from base station transmitters. Analysis shows that 6.1 sq. km area around an individual interfering base station or an aggregate area exceeding 700 sq. km from an example deployment with multiple interfering sites could be subject to interference levels exceeding tolerable levels. This could impact service to nearly 20,000 receivers in this given example.

Receiver blocking due to overload from mobile transmitters was also discussed. It was demonstrated with a simple analysis that overload will be a problem for an interferer located 3 m away from a receiver at excessively high transmitted power levels exceeding a certain interference tolerance value. In heavy traffic, the impact of overload is likely to be non-trivial, which should provide reasons for caution to protect broadcast receivers from non-linear overload.

To eliminate such interference concerns, coordination rules founded in part on ground level received signal density would foster deployment of more advanced and more effective networks in the interfering bands while providing sufficient protection to the adjacent band services; whether satellite or terrestrial based services.

5 References

[1] Report ITU-R M.2030, “Coexistence between IMT-2000 TDD and FDD terrestrial radio interface technologies around 2 600 MHz operating in adjacent bands and in the same geographical area,” 2003.

[2] “Service Recommendations to Support Technology Neutral Allocations – FDD/TDD Coexistence,” WiMAX Forum (Apr. 10, 2007), (“FDD/TDD Coexistence”).

[3] “Compatibility of Services using WiMAX Technology with Satellite Services in the 2.3-2.7 GHz and 3.3-3.8 GHz Bands”, WiMAX Forum, 2007, Section 4.

[4] “Establishment of Rules and Policies for the Digital Audio Radio Satellite Service in the 2 310-2 360 MHz Frequency Band, Report and Order, Memorandum Opinion and Order and Further Notice of Proposed Rulemaking”, 12 FCC Rcd 5754 (1997).

[5] Unlicensed TV Band Devices/TV Broadcast Services (FCC No. 08-260).

[6] “Summary of ATTC FM IBOC Compatibility Tests”, http://www.nrscstandards.org/Reports%20ref%20docs/USADR%20test%20data%20report/Appendixd.pdf

[7] Rappaport, DiPierro, Akturan, “Analysis and Simulation of Adjacent Service Interference to Vehicle-Equipped Digital Wireless Receivers from Cellular Mobile Terminals”, IEEE Transactions on Vehicular Technology, May 2011.

[8] DiPierro, Akturan and Michalski, “Sirius XM Satellite Radio System Overview and Services”, Conference Proceedings, September, 2010.

[9] Pratt and Bostian, “Satellite Communications”, p. 119, Wiley, 1986.

[10] Lee, “Mobile Cellular Telecommunications”, McGraw-Hill, 1995.

[11] Section 7.5 on Adjacent Channel Selectivity, Universal Mobile Telecommunications System (UMTS); User Equipment (UE) radio transmission and reception (TDD) (3GPP TS 25.102 version 10.3.0 Release 10), 2011.