L3 communications

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Contention Channel Analysis
for
L3 VMES System

January 14, 2013

ITC Document No:
400_20121103m01v02.2_WinT_ContentionChannel.docx

Prepared by:
Intellicom Technologies, Inc.

Approved by:	
Paul Moller Vice-President, Intellicom Technologies Inc.	

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iNTELLICOM Technologies, Inc.
PO Box 27056, San Diego, CA 92198
Tel: (858) 486-1115, www.ITCcom.net

Revision History

Revision History:	Date	Document Revision Description
V01	2012-09-30	Initial drafts
V02	2012-12-07	Release to L3
V02.2	2013-01-14	Signed, Release to L3

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1 CONTENTION CHANNEL

This section provides an analysis of the contention channel performance within a sub-meter communications-on-the-move (COTM) system. FCC rules and proposed rules have been reviewed in order to determine requirements for usage of contention channels.

1.1 FCC Rulings

Following are extracts of FCC rules and proposed rule changes related to the use of contention channels. Key phrases are highlighted.

1.1.1 Current Commission Proposals

FCC 08-246 EIGHTH REPORT AND ORDER [1]
IV. OTHER ISSUES
A. Contention Protocols

81. Accordingly, **we adopt an exception to Section 25.134 that allows VSAT system operators to exceed the -14 dBW/4 kHz power limit, in the aggregate when multiple earth stations simultaneously transmit, for purposes of "reasonable use" of a contention protocol.** In this Order, we do not define "reasonable use" in terms of specific limits for probability of collision, length of collision, or increase in power during collisions, as the Commission has proposed in the past. Instead, we allow licensees flexibility in their contention protocol usage. We anticipate that we will resolve any issues regarding "reasonableness" of contention protocol usage in the complaint process. If a Commission licensee believes that its operations are experiencing harmful interference as the result of another licensee's unreasonable contention protocol usage, that licensee will have the burden of showing that it is experiencing harmful interference, and that the other licensee is the cause of that interference. If the complainant can meet this burden of proof, the burden will then shift to the defendant to show that its use of contention protocols is reasonable. By requiring reasonable contention protocol use rather than specifying limits for length of collision and increase in power allowed during a collision, we expect that our contention protocol rule will not interfere with technological developments in the area of contention protocols. We also expect that requiring contention protocol usage to be reasonable will provide sufficient regulatory certainty to address the concern raised by ViaSat.244

FCC 08-246 EIGHTH REPORT AND ORDER [1]
APPENDIX B
Rule Changes

2. In Section 25.115, add paragraphs (h) and (i) to read as follows:
25.115 Application for earth station authorizations.
* * * * *

(h) Any earth station applicant filing an application pursuant to 25.218 of this chapter must file three tables showing the off-axis EIRP level of the proposed earth station antenna of the plane of the geostationary orbit, the elevation plane, and towards the horizon. In each table, the EIRP level must be provided at increments of 0.1° for angles between 0° and 10° off-axis, and at increments of 5° for angles between 10° and 180° off-axis.

(1) For purposes of the off-axis EIRP table in the plane of the geostationary orbit, the offaxis angle is the angle in degrees from the line connecting the focal point of the antenna to the target satellite, within the plane determined by the focal point of the antenna and the line tangent to the arc of the geostationary satellite orbit at the position of the target satellite.

(2) For purposes of the off-axis EIRP table in the elevation plane, the off-axis angle is the angle in degrees from the line connecting the focal point of the antenna to the target satellite, within the plane perpendicular to the plane determined by the focal point of the antenna and the line tangent to the arc of the geostationary satellite orbit at the position of the target satellite.

(3) For purposes of the off-axis EIRP table towards the horizon, the off-axis angle is the

angle in degrees from the line determined by the intersection of the horizontal plane and the elevation plane described in paragraph (h)(2) of this Section, in the horizontal plane. The horizontal plane is the plane determined by the focal point of the antenna and the horizon.
(4) In addition, in an attachment to its application, the earth station applicant must certify that it will limit its pointing error to 0.5° or demonstrate that it will comply with the applicable off-axis EIRP envelopes in Section 25.218 of this Part when the antenna is mispointed at its maximum pointing error.

(i) Any earth station applicant filing an application for a VSAT network made up of FSS earth stations and planning to use a **contention protocol** must include in its application a certification that it will comply with the requirements of **25.134(g)(4).**

FCC 08-246 EIGHTH REPORT AND ORDER [1]
APPENDIX B
Rule Changes

3. In Section 25.134, add paragraph (g)(4) to read as follows:
25.134 Licensing provisions of Very Small Aperture Terminal (VSAT) and C-band Small Aperture Terminal (CSAT) networks.
* * * * *
(g) * * *

(4) Any earth station applicant filing an application to operate a VSAT network after **[Insert effective date of rule]** in the Ku-band and planning to use a contention protocol must certify that its contention protocol usage will be reasonable.

1.1.2 Past Commission Proposals

The following were proposed (Para 68, 71) but not adopted. They are provided here to provide some quantitative comparison with the L3 contention channel.

FCC 08-246 EIGHTH REPORT AND ORDER [1]
IV. OTHER ISSUES
A. Contention Protocols

68. In the *Third Further Notice*, the Commission observed that all the new contention protocol rule proposals suggested by commenters in response to the *Further Notice* had four elements:
(i) a power density limit on individual earth stations in the VSAT network;
(ii) a limit on the power generated during collisions,
(iii) a limit on the probability of collisions, and
(iv) a limit on the duration of any collision.
The Commission also found that the record at that time provided an adequate basis to adopt some of these contention protocol elements, but needed further development on other elements.

1.2 L3/Linkabit NCW Contention Channel Approach

1.2.1 Network Architecture

The Network Centric Waveform (NCW) system consists of a hub terminal or Network Controller (NC) and remote terminals or Network Members (NM). Up to 254 NMs are possible in one network. Any NM with sufficient RF performance may be configured as NC capable. NC capable terminals can take over NC duties if the active NC fails. Any terminal may communicate with any other terminal as long as they have sufficient RF performance.

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1.2.3 Resource Management

The Network Centric Waveform (NCW) system is a Multi-Frequency Time

FCC 08-246 EIGHTH REPORT AND ORDER [1]
IV. OTHER ISSUES
A. Contention Protocols

71. In summary, the Commission requested comment on the following proposal:

(i) For VSAT networks using a contention protocol, the aggregate off-axis EIRP shall not exceed the applicable off-axis EIRP envelope by more than the amounts set forth in Table 5 below;
(ii) The maximum duration of any single collision is **less than 100 milliseconds.**

Table 4 is the off-axis EIRP envelope adopted in this Order for digital transmissions from a single earth station in the Ku-band in the plane of the geostationary satellite orbit as it appears at the particular earth station location:

Table 4
Off-Axis EIRP Envelope for Ku-Band Digital Earth Station Applications for an Individual Earth Station

$15 - 25\log_{10}\theta$	dBW/4 kHz	For	$1.5° \le \theta \le 7°$
-6	dBW/4 kHz	For	$7° < \theta \le 9.2°$
$18 - 25\log_{10}\theta$	dBW/4 kHz	For	$9.2° < \theta \le 48°$
- 24	dBW/4 kHz	For	$48° < \theta \le 85°$
- 14	dBW/4 kHz	For	$85° < \theta \le 180°$

where θ is the angle in degrees from the line connecting the focal point of the antenna to the target satellite, within the plane determined by the focal point of the antenna and the line tangent to the arc of the geostationary satellite orbit at the position of the target satellite.

Table 5 below allows VSAT network operators to exceed the aggregate off-axis EIRP envelope by 2 dB for each decrease in order of magnitude in percentage of time. This was based on proposals from SIA and Spacenet. However, SIA and Spacenet recommended allowing VSAT network operators to exceed the off-axis EIRP envelope for as much as 10 percent of the time. Therefore, the Commission modified the proposal to allow VSAT network operators to exceed the envelope for no more than 1 percent of the time, as set forth in Table 5 below.

Table 5
EIRP Limits For VSAT Networks Using Contention Protocols Proposed By the Commission in the *Third Further Notice*[213]

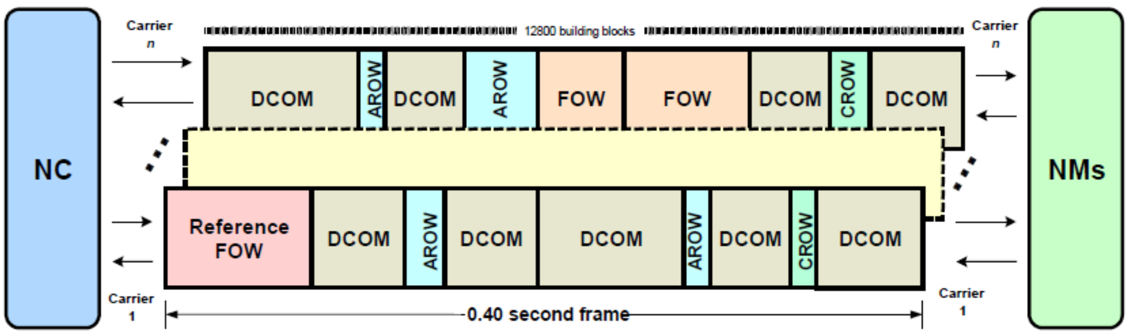
Percentage of Time	Increase in Aggregate EIRP Allowed
10% (10^{-1})	0 dB
1% (10^{-2})	2 dB
0.1% (10^{-3})	4 dB
0.01% (10^{-4})	6 dB
0.001% (10^{-5})	8 dB
0.0001% (10^{-6})	10 dB
0.00001% (10^{-7})	12 dB
0.000001% (10^{-8})	14 dB
0.0000001% (10^{-9})	16 dB

Division Multiple Access (MF-TDMA) system. Carriers are BPSK, QPSK, or n-PSK modulation. The TDMA frame is 400 ms. In some cases Direct Sequence

(DS) spread spectrum is applied as an energy dispersal method to reduce power spectral density.

The NCW system manages its assigned spectrum by partitioning and distributing frequency, time, and power resources. All resources are controlled by the Network Controller (NC). No resources may be used by remote stations called Network Members (NM) unless the active NC has assigned the resources for use.

Figure 1. MF-TDMA Structure.



1.2.4 Communications Channels

Figure 1 shows how an NC will communicate to an NM. Time is shown along the bottom of the diagram, with 0.40 seconds representing one frame, while assigned frequencies (channels) are shown in depth. Time, assigned channel and # of Orderwire and DCOM bursts vary with each frame, which is based on the requests for network resources.

The NCW system uses the following channel types:

- **FOW** – Forward Orderwire – The FOW is the heartbeat of the system and is broadcast by the NC at regular intervals. The FOW contains information needed by the NMs for their effective operation. No NM may transmit until it has received the FOW. The FOW provides information on all resource assignments.
- **RFOW** – Reference Forward Orderwire – The RFOW is a synchronization burst sent at a determined rate called a NCW frame. The NC will broadcast a RFOW burst at a data rate that allows the least advantaged terminal to join the network. The RFOW's purpose is to:
  - Establish and maintain network timing
  - Advise NMs of operating parameters
  - Respond to login/logout requests and direct logouts
  - Respond to resource requests and manage services
  - Send short messages
  - Request node configuration, performance, and status

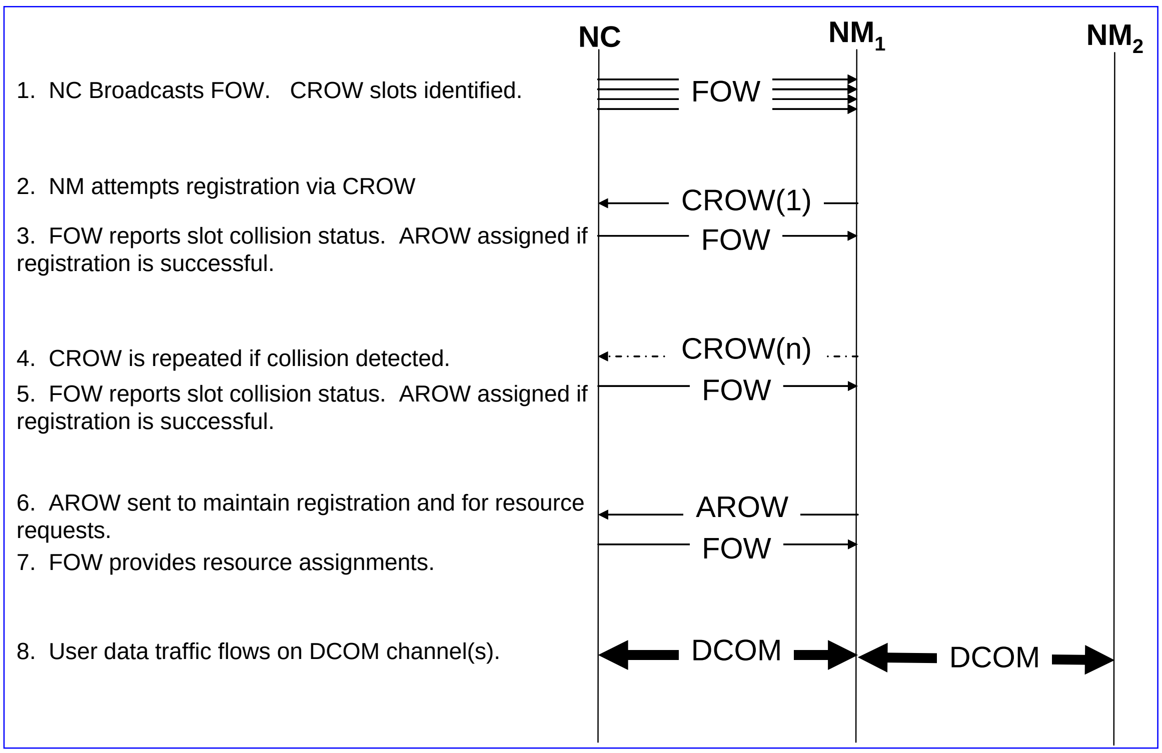
  - Perform link management for all communications.
- **ROW** – Return Orderwire – Each NM signals the NC and other nodes in the network using the ROW channel. The ROW's purpose is to:
  - Request node login and logout
  - Request resource allocations
  - Sent short messages
  - Acknowledge message/data reception
  - Submit node and communication status/performance
  - Submit configuration reports
- **AROW** – Assigned Reverse Orderwire – When a NM has achieved registration via the CROW channel; it is assigned reverse orderwire AROW timeslots by the NC. During these AROW timeslots, the NM may maintain its registration and make resource requests.
- **CROW** – Contention Reverse Orderwire – A slotted Aloha scheme with collision detection is used. Resources are assigned by the NC for unregistered NMs to signal to the NC for registration purposes. In each TDMA frame, up to 7 (15 future) time slots are assigned for unregistered NMs to signal to the NC with their registration information. CROW slots are available for signaling from any unregistered NM. Since there may be more than one unregistered NM attempting to register, collision is possible. Depending on the burst data rate configured a CROW burst is from 1.3 ms (1024 kbps) to 42 ms (32 kbps) of the 400 ms frame.
- **DCOM** – Data Communications – DCOM timeslots are used for user data transmissions. All DCOM assignments are made by the NC.

1.2.5 CROW Communications Scenario

A typical NM registration and resource request is shown in

Figure 2. The NM will continue to make registration requests via the CROW channel until registration is confirmed by the NM through the FOW channel.

Figure 2. NM Registration and Resource Request



1.2.6 Spectrum Management

All spectrum use is controlled by the NC and all usage is on an assigned basis with the exception of the CROW channels. In each 400 ms TDMA frame, bandwidth and power resources are segmented and assigned to the pool of NMs.

Spread spectrum is used as an energy dispersal method and is **never** used by multiple transmitters as a CDMA access scheme. With the exception of the CROW channels, bandwidth segments are never accessed by more than one transmitter at any one time period.

1.2.7 Collision Detection and Management

The NCW system has several methods for managing the CROW channel.

CROW Slots: The NC can assign from 1 to 7 (15 future) CROW time slots in each 400 ms frame. If registration activities are high, then more CROW time slots should be used to reduce collisions. The number of slots per frame is a configurable parameter set by the system operator based on the number of NMs in the network and the anticipated registration activity. An NM attempting registration will randomly select one of the 7 CROW slots available

Contention Backoff: The NC detects energy in CROW slots. If CROW transmissions are successful, then registration requests will be received for each slot containing energy. If there are collisions in the slot, then the NC may not be able to recover a registration request and thus has detected a collision. When collisions are detected, the NC may request unregistered NMs to randomly defer registration to later frames. The NC sets the contention back off from 1 to 31 frames as necessary to reduce collisions. If the Contention Backoff is set to 31 and there are 7 CROW slots, then each NM must randomly select from 31 frames x 7 slots, or 217 possible slots to attempt registration.

CROW Spreading Factor: CROW transmissions can utilize a direct sequence spreading factor from 1 to 16 to allow EIRP spectral density limits to be met. Power Spectral Density (PSD) reduction is typically necessary in sub-meter terminals to reduce adjacent satellite interference PSD and in the hub terminal to reduce downlink PSD.

CROW Registration Scenarios: When the CROW channel has collisions, the EIRP PSD in the CROW slot will be increased by the number of transmissions that occur in the slot. Analysis has been done to determine the probability of collisions and the probability distribution as a function of the number of simultaneous transmissions in a CROW slot. Several registration scenarios are considered:

1. **Network Installation and Start-up** – When a network is first being constructed, hub and remote stations will be installed and turned on as each station becomes available. A network with 20 or more terminals could take days, weeks or even months to install and bring up all stations. Due to the extended installation time, the progress and schedules of each site, its is improbable that a large number of stations will attempt to register using the same CROW slot in the same 400 ms frame. If a situation arose that required all stations to be turned on simultaneously, the random timing of human intervention across several minutes would very likely distribute registration requests enough to avoid or reduce collisions. If all NMs were ready for registration before an NC was established, it might be possible to have all NMs attempt registration within a few frames and thus have collisions. This situation could be mitigated by ensuring that the NC is operational before manually enabling terminals for registration. An NC that starts operation establishes 7 (15

future) CROW slots per frame and sets the contention backoff to the maximum. It is also recommended that installers plan to stagger terminal start up to avoid a large number of terminals attempting registration simultaneous.

2. **Hub (NC) Failure**
   a. **Back-up Hub Available** - if a NC fails and a back up NC is online and available, the backup NC takes over without the need for any terminal re-registration. All back-up NCs maintain registration data.
   b. **Back-up Hub Not Available** – Any NCW Modem that has both NC and NM capabilities with sufficient RF performance can be a backup NC, it is unlikely and not recommended that a network be establish without a back-up NC. It is possible in a small network that a back-up NC cannot or has not been established. In this case the number of NMs is also small and thus the number of registration collisions that could occur is also small. Equipment MTBF of the NCW modem is better than 20,000 hours or about 2 years. Thus failure events could occur every 2 years. If the system requires manual intervention for recovery, startup of the remote terminals may be staged to avoid all terminals attempting to register in a short time period. If the station recovers without manual intervention, then all terminals in the network may attempt to register in a short time period. An NC that starts operation establishes 7 (15 future) CROW slots per frame and sets the contention backoff to the maximum. This case is extremely unlikely, but analysis of this scenario is provided below to show the CROW channel performance. This is believed to be a worst case scenario, but is also a low probability of occurrence.
3. **Steady State Operation** – Under steady state operation, most NMs will be registered with the NC and thus the CROW channel will only have traffic for recovery or registration of new NMs.
   a. **Remote Station (NM) Outage and Recovery** – If a single NM fails, resets, and/or recovers, it will re-register via the CROW channel. Since this is a single station registration, collision is unlikely.
   b. **New Remote Station (NM) Added** - If a new single NM registers, it will register via the CROW channel. Since this is a single station registration, collision is unlikely.

1.2.8 Worst Case (Scenario)

The worst case registration scenario occurs when all NMs attempt registration in a short time period. The probability of this occurring is extremely unlikely but is analyzed here to show that the collision time period and effect is limited.

A simulation of the access algorithm was performed and the results are shown in ***Figure 3*** and ***Figure 4.*** The plots show the probability of occurrence of 1 to 8 accesses per slot. There is less than 1% probability of exceeding 4 transmissions in one slot for n=50, 5 for n=100, 6 for n=150, and 7 for n=254.

CROW slots = 7
Contention Backoff = 31
Number of remote terminals (NMs) = n = {50, 100, 150, 254}

Figure 3. 2A CROW Channel Probability

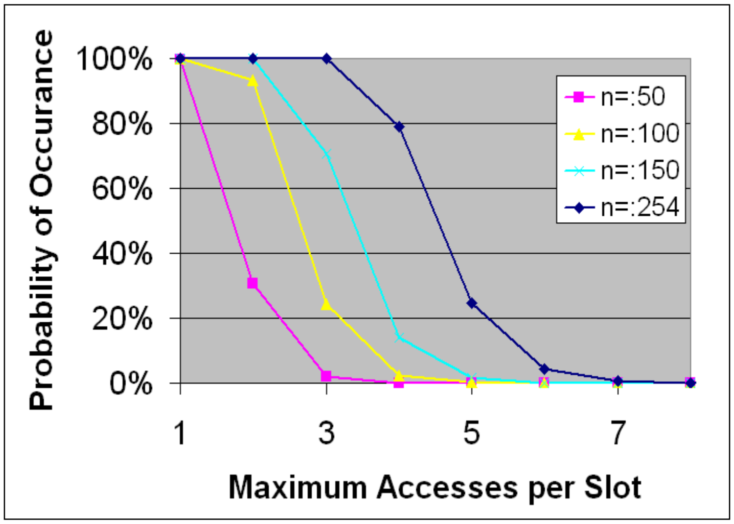
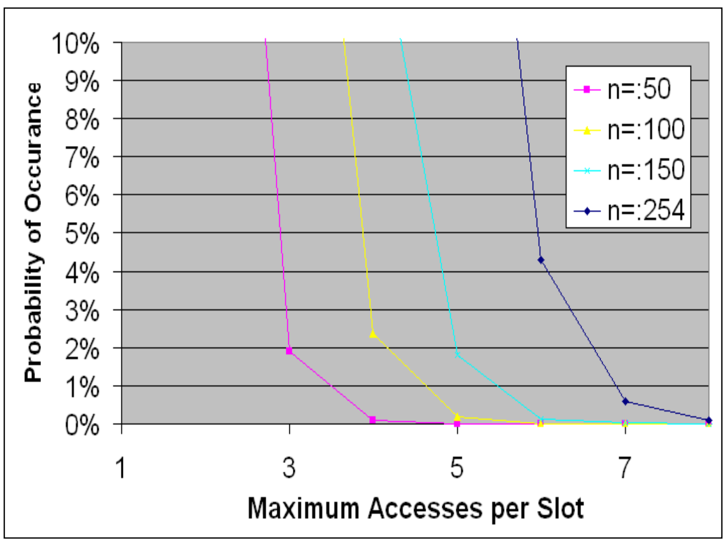


Figure 4. 2B CROW Channel Probability

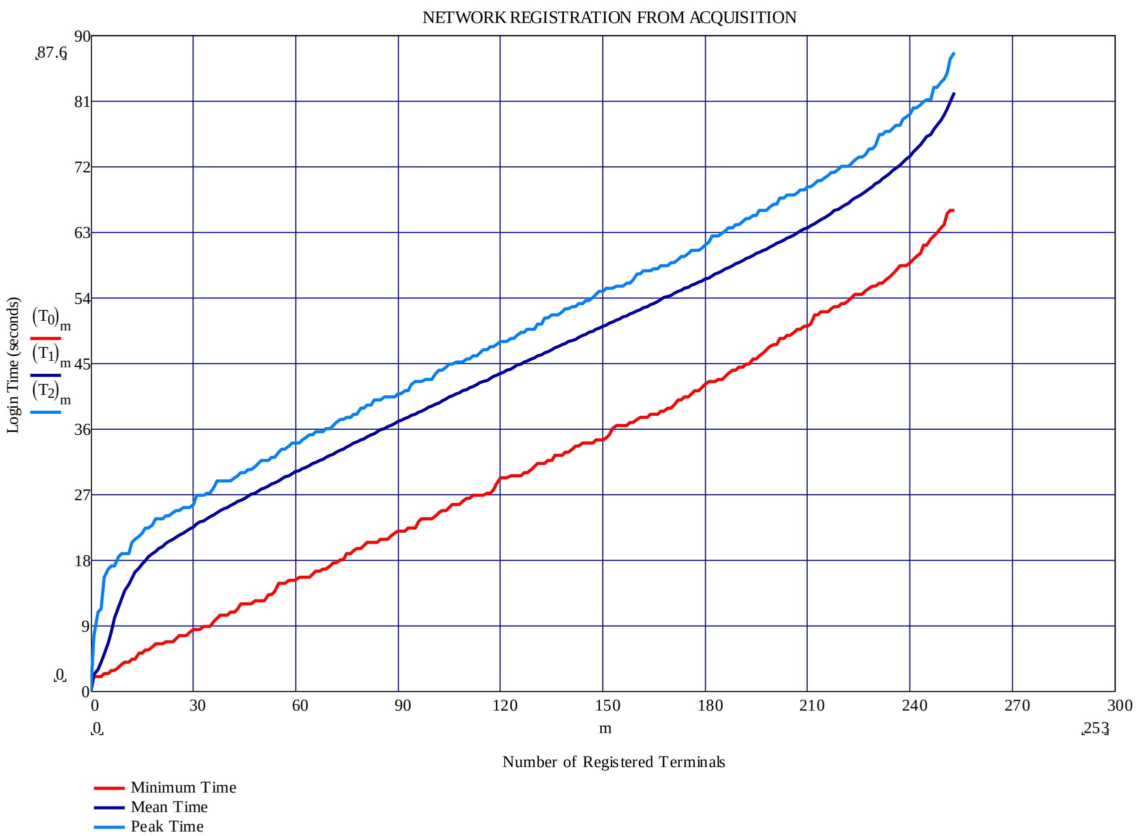


If a 1024 kbps BSPK CROW transmission is used, then the bandwidth will be 1331 kHz (3.7% of a transponder) and the burst duration will be 1.3 ms. If a 32 kbps BSPK CROW transmission is used, then the bandwidth will be 42 kHz

(0.1 % of a transponder and the burst duration will be 42 ms (less than the 100 ms identified in [1 Para 71])

Additional simulations were done to determine the time for all terminals to complete registration if all attempted to do so at once. ***Figure 5*** shows that for n = 254 terminals, the registration time period takes from 65 to 85 seconds.

Figure 5. Registration Time Duration (Maximum, Average, Minimum).



The FCC chose not to adopt ***Figure 5***[1] and instead allowed the applicant "reasonable use" of contention channels. Table-5 [1][2] is convenient for providing a quantitative limit for comparison.

***Figure** 6* shows the increase in aggregate EIRP for the NCW system resulting from the worst case scenario of all terminals attempting registration at the same time.

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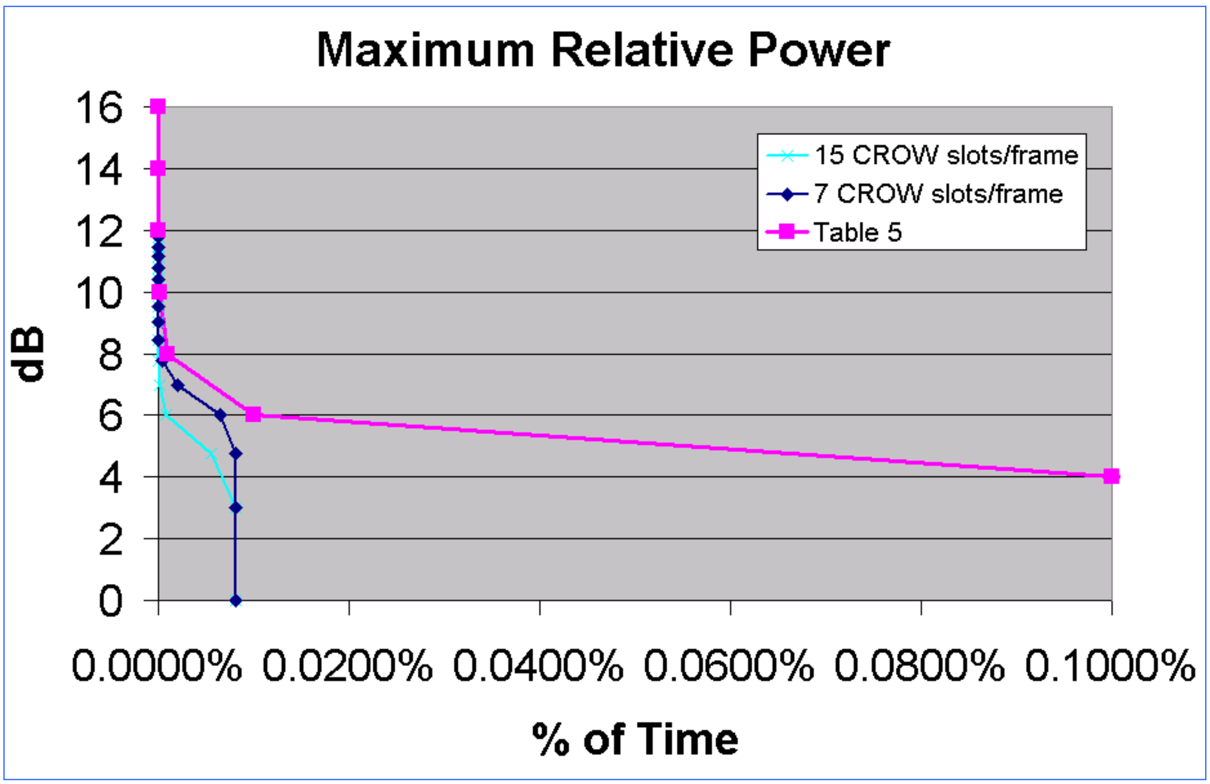
[1] **FCC 08-246 EIGHTH REPORT AND ORDER [1]**

[2] **FCC 08-246 EIGHTH REPORT AND ORDER [1]**

CROW slots = {7, 15}
Contention Backoff = 31
Number of remote terminals (NMs) = n = 254
Time Period = 1 hour

As noted previously, this worst case scenario is unlikely to occur and possibly no more than every few years. The chart below shows that the NCW contention channel can comply with Table-5 [1] even if all terminals had to simultaneously register using contention channels every hour (rather than every 2 years).

Figure 6. Increase in Aggregate EIRP for the NCW Contention Channel.



1.3 Summary

Registration scenarios have been evaluated. The worst case scenario might occur every 2 years if no NC backup has been configured. If the NC recovered without manual intervention, then a network could be subject to re-registration of all terminals. If this event were to occur, the event would be for 85 seconds or less, it would use less than 4% of a transponders bandwidth and 99% of the time would be 7 or less simultaneous transmissions in the CROW slots. Total transponder power utilized by the simultaneous CROW transmissions would be less than 7 * 4% = 28%. Allocated power on the satellite might be increased by 24% which could cause degradation to other carriers. Without additional spreading, multiple CROW transmissions from the remote terminals could increase adjacent satellite interference above the FCC recommendations for non-contention channels.

To recap, an interference event impacting spectrum of 1331 kHz or less, lasting 85 seconds or less could occur every two years if no back-up NC were available and no human interaction was possible resulting from a fault recovery. This is a worst case scenario.

During a steady state operation registrations occur seldom but collisions could occur. These collisions would be occasional bursts of duration 1.3 to 42 ms (less than the 100 ms recommended[3] [Para 71].

The NCW contention channel use complies with Table-5[4] and thus should be considered "reasonable use" per the FCC guidelines.

[3] FCC 08-246, "Eighth Report and Order on Reconsideration, 2000 Biennial Regulatory Review Streamlining and Other Revisions of Part 25 of the Commission's Rules Governing the Licensing of, and Spectrum Usage by, Satellite Network Earth Stations and Space Stations", IB Docket No. 00-248, IB Docket No. 95-117, FCC Document, October 17, 2008

[4] **FCC 08-246 EIGHTH REPORT AND ORDER [1]**