The Level of Adjacent Channel Interference into a Representative Ka-Band Satellite System When the Aggregate Interfering Earth Station EIRP Spectral Density Must Be Determined Statistically

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November 20, 2003

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Objectives of This Presentation

- **To propose the use of statistical approach, rather than or in addition to, a hard limit, to control adjacent satellite interference in the Ka-Band.**
- **To demonstrate that the Commission could incorporate statistical methods into its interference rules to ensure that adjacent satellites will not experience unacceptable interference while avoiding the imposition of rules that would apply to statistically unlikely scenarios and would stifle innovation.**
- **To provide an analysis of interference from a system under development which demonstrates that it will protect adjacent satellites to the extent contemplated by the Commission's rules.**

Introduction

- This presentation analyzes, using statistical methods, interference from a Ka-Band FSS system under development, into a victim satellite system licensed by the FCC.
- Interference to the victim Ka-Band satellite system from two adjacent satellite systems spaced 2° away on the GEO arc is analyzed.
- The analysis utilizes characteristics of the victim satellite, including EIRP, G/T, proposed BER, and other key parameters, contained in the pubic filings of the system with the FCC.
- A power envelope for the two hypothetical interfering systems is developed based on time-varying transmissions from small user Earth terminals.

Introduction (Continued)

- **The victim system is one of the Spaceway Ka-Band spacecraft.**
- **The technical information used is taken from the 1997 filings of Hughes Network Systems.**
- **An analysis of the Spaceway system based on the technical modifications filed at the FCC, is not present because:**
  - The modifications essentially reduce the beam diameter of the satellite uplink antenna beams.
  - An interference analysis based on the modifications would show decreased interference levels from that presented here.
  - Consequently, the analysis herein presents a worst-case analysis.

FIRST: An Example of Statistical Interference from a Hypothetical QUALCOMM-like System

- **Assumptions concerning transmissions of the QCOM system:**
  - **In any portion of the Ka-Band, the system has six beams re-using the same spectrum.**
  - **Each channel within a beam uses random CDMA-Aloha on the Return link (Earth-to-space). Users share the channel using classical CDMA but channel occupancy (whether an individual user is ON or OFF) is determined by Aloha random multiple access signalling techniques.**
  - **Each random access channel is designed to accommodate 1080 active simultaneous users.**
  - **The six beams can thus contain 6480 simultaneous assigned users.**
  - **The properties of the system are such that the average number of transmitting Earth terminals is 32 per channel per beam. 32 users optimizes the throughput of the channel:**
    - **A lower user count improves bit error rate but, reduces throughput.**
    - **A higher user count increases bit error rate (by reducing Eb/No) and thus also reduces throughput (due to data retransmission demand).**
    - **If a demand arises requiring significantly more than 32 emitters per channel per beam then the system will add (open) additional CDMA-Aloha channels.**

An Example of Statistical Interference from a Hypothetical QUALCOMM-like System (2)

- **The average number of simultaneous users in all six beams is:**
  (6 beams x 32 users/beam) =192.

- **And, the probability that each user in the system is ON, based on the average number of simultaneous uses, is determined to be**
  p=0.0296.

- **The statistics of this population of users can be represented quite accurately by a Gaussian probability density function with a mean of 192 and a variance of 186. The standard deviation (σ) is then given by the square root of the variance and yields: σ = 13.6 terminals.**

- **For the purpose of this analysis, we first determine what power level of simultaneously transmitting terminals is required to assure that the ESD rules given by Part 25.138(a)(1) of the FCC Rules (= 18.5 - 25log? [dBW/40kHz]) is met 99% of the time.**

- **Then we develop the statistical probability of exceedence of that value for the remaining 1% of the time.**

An Example of Statistical Interference from a Hypothetical QUALCOMM-like System (3)

- For a Gaussian probability density function, a 99% probability is given by a value of: mean + 2.33σ = 192 +2.33(13.6) = 224 transmitting terminals within the six co-frequency beams. These are the co-frequency emitters that would be required to direct their power toward one satellite on this type of channel.
- Now consider the adjacent satellite interference allowed by Part 25.138(a)(1):
  - **Satellites spaced 2° apart along the arc appear to users located in North America to be spaced approximately 2.25° degrees apart.**
  - **Thus, for ? = 2.25°, the FCC allowed ESD at Ka-Band into an adjacent system is approximately 9.70 dBW/40 kHz.**
  - **It must be considered that two adjacent systems, each transmitting at the allowed ESD, can effect any Ka-Band satellite at any position along the arc. Thus, a maximum level of (9.70 +3.01) dBW/40 kHz = 12.71 dBW/40 kHz ESD must be tolerated by any one victim satellite.**
  - **We normalize this level to a density in dBW/Hz, resulting in a value of -33.32 dBW/Hz which must be tolerated by the victim satellite.**

An Example of Statistical Interference from a Hypothetical QUALCOMM-like System (4)

- For our system, we have calculated that the FCC ESD limit will be reached at a victim satellite when the aggregate power level of 2.11 watts is generated by the simultaneous users producing off-axis emissions toward one adjacent satellite, in each of the six beams.
- This is also:

  3.24 dBW/beam/satellite → -36.33 dBW/Hz (one sat.)

  -33.32 dBW/Hz (two sats.)

  Or

  3.24 dBW +10 log (6 beams) = 11.02 dBW/satellite system

- If this power is then divided by the 224 simultaneous transmitting terminals using the Return Link, we obtain the power per terminal:

  11.02 – 10 log (224 terminals) = -12.48 dBW/terminal = 56.5 mW

An Example of Statistical Interference from a Hypothetical QUALCOMM-like System (5)

- Thus, transmitting at a power level of 56.5 mW per terminal in each beam will generate an ESD that exceeds the FCC adjacent satellite interference limit 1% of the time.

- HOWEVER, in the system being designed by QUALCOMM the power level required per terminal to operate in a CDMA-Aloha channel is 11 mW. A power greater than this amount is detrimental to the system as it increases co-channel interference levels and decreases link performance. The system is therefore, set up to produce an average Earth terminal ON population of 192 terminals per satellite and a terminal transmitter power output of 11 mW.

- At 11mW, it would take 1,150 transmitting terminals per satellite to reach the FCC ESD limit. This represents the average (mean) number of users + 70.4 σ. Therefore, the probability of this number of Earth terminals transmitting simultaneously on the system is infinitesimally small (in fact, it is less than $P = 1 \times 10^{-1078}$)

NOW: Interference to an Actual "As-Filed" Ka-Band System

- **The level of adjacent satellite interference to a real Ka-Band system from a system operating with statistical varying power levels, as QUALCOMM proposes, is considerably lower than assumed in the previous example, since:**
  - **Satellite Return Link antennas are typically spot beams covering a small fraction of the CONUS area. This provides additional isolation from adjacent satellite uplinking emitters who are outside the spot beam's area of coverage.**
  - **The sum of uplinking Earth terminals sharing a co-frequency channel radiate at ESD levels quite far below the FCC allowable limit. The terminal emission levels are first set by co-channel interference conditions, which are more stringent than adjacent channel interference requirements (See also Slide 5 and 9 for further clarification).**
  - **Earth terminal antenna off-axis performance is typically superior to that assumed in the derivation of the FCC ESD limit. This offers a small improvement.**

Spaceway Clear Sky Performance

- **Here we begin by providing a summary of the link filed by Hughes. In it we have combined some terms to simplify the presentation.**
- **The Eb/I_{total} achieved, based on Spaceway assumptions and calculations is 9.3 dB, well above the stated 8.0 dB uplink requirement to achieve ≅10E-10 bit error rate.**
- **We summarize the performance based on clear sky (no rain) conditions:**

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Clear Sky Return Uplink Performance
(Reference Link - Link #1)

• Terminal Power:	-9.73	dBW
• Line Losses:	-0.50	dB
• Terminal Antenna Gain:	+44.45	dBi
• Path Loss:	-213.16	dB
• Atmospheric Losses:	-0.96	dB
• Rain Losses:	0.00	dB
• S/C Figure of Merit (G/T):	+18.88	dB/K
• S/C Rcvr Bandwidth:	56.99	dBHz
• Data Rate:	55.87	dBHz
• Blotzmann K:	-228.6	dBW/K/Hz
• Eb/No:	11.71	dB
• Eb/I Adjacent Channel & Beams:	17.45	dB
• Eb/I Cross Pole Interference:	17.95	dB
• **Eb/I Adjacent Satellite System Interference:**	**17.83**	**dB**
• **Resultant Uplink Eb/(No+It):**	**9.28**	**dB**

Spaceway Adjacent Satellite System C/I

- **The Adjacent Satellite System Interference term (shown in bold blue in Reference Link #1) is the term we are targeting.**

- **The following analysis will consider the impact on Spaceway with reference to the following:**

  – **1.) The EIRP Spectral Density allowed to be emitted toward a neighbouring satellite under Part 25.138(a)(1) of the FCC Rules (= 18.5 - 25log? [dBW/40kHz]).**

  – **2.) A fully loaded reservation traffic channel from the proposed QUALCOMM (QCOM) system.**

  – **3.) A random access/assignment channel from the proposed QCOM system. This channel has a statistically varying number of Earth terminal signals arriving at the satellite.**

Case 1) EIRP Spectral Density in Accordance with FCC Limits

- **The level of ESD into the Spaceway system (victim system) could be as large as:**
  - Allowable FCC ESD Level (See Also Slide 7): -33.32 dBW/Hz
    (from users accessing two adjacent satellites)
  - Path Loss: -213.16 dB
  - Atmospheric Losses: -0.96 dB
  - Rain Losses: 0.00 dB
  - Spacecraft Figure of Merit (G/T): 18.88 dB/K
  - Boltzmann Constant: -228.6 dB/K/Hz
  - Total Adjacent Satellite I/No: +0.04 dB
  - Spaceway Achieved Uplink Eb/No (from Ref #1): 11.71 dB
  - Resultant Eb/I $_{\text{adj. sat.}}$: 11.67 dB

Link Performance with FCC Limit ESD Levels from Two Adjacent Systems (Link #2)

• Clear Sky Reference Link Eb/No (No Interference):	11.71 dB
• Adjacent Channel and Beam Eb/I:	17.45 dB
• Cross Polarization Eb/I:	17.95 dB
• FCC Limit ESD Levels; Eb/I (2 Adj. Systems):	11.67 dB
• Resultant Eb/(No+It):	7.71 dB

Note Re: Link #2

- **NOTE: The 7.71 dB computed in Link #2 is below the Spaceway system link requirement of 8.0 dB, however:**
  - We believe this is an acceptable (and still conservative) value because this level of interference would only be experienced by a satellite system utilizing a CONUS-wide beam.
  - Virtually all planned Ka-Band systems, including Spaceway, use much smaller spot beams on the Return Uplink.
  - This greatly reduces the reception of interference from other system user terminals radiating in the direction of the Spaceway system within the GEO Arc. (See calculations on slides 18 through 20).

Case 2) Interference from Two OCDMA Adjacent Systems into Spaceway System

- Now, we consider a source of interference which is from a group of Earth terminals occupying an OCDMA Reservation Channel of the type proposed to be used in the QCOM system.
- The OCDMA Reservation Channel is loaded approximately to the ESD limit specified by the FCC in Part 25.138(a)(1).
- The user Earth terminals are spread out within six co-frequency user beams and are radiating toward the GEO Arc.
- Each QCOM spacecraft receive beam is 0.66° in diameter at the -4 dB gain contour.
- In this type of channel, the Earth terminals compensate for the satellite beam roll-off, which increases the average power of the user Earth terminals sharing the channel by 2.50 dB, compared to that which would be required in the center of each beam.
- The net EIRP Density produced is as follows:

Case 2) Net EIRP Density from Two OCDMA Adjacent Systems into Spaceway System

• OCDMA Res. Channel Total Power (2.11 watts):	3.25 dBW
• Earth Terminal Line Loss:	-1.00 dB
• Earth Terminal Nominal On-Axis Antenna Gain:	44.10 dBi
• Ant. Gain Reduction at 2.25° Off-Axis:	-28.50 dB
• Average user S/C Beam Roll-Off Compensation:	+2.50 dB
• Number of Co-Freq. Beams in QCOM System (6):	7.78 dB
• Net EIRP into Spaceway System from Users into One Adjacent Satellite:	28.13 dBW
• Bandwidth of Channel (3 MHz):	64.77 dBHz
• EIRP Spectral Density from One Adjacent System:	-36.64 dBW/Hz
• EIRP Spectral Density from Two Adjacent Systems:	-33.63 dBW/Hz
• EIRP S.D. from Adj. Systems (ITU Units): One S/C:	9.38 dBW/40kHz
Two S/C:	12.39 dBW/40 kHz

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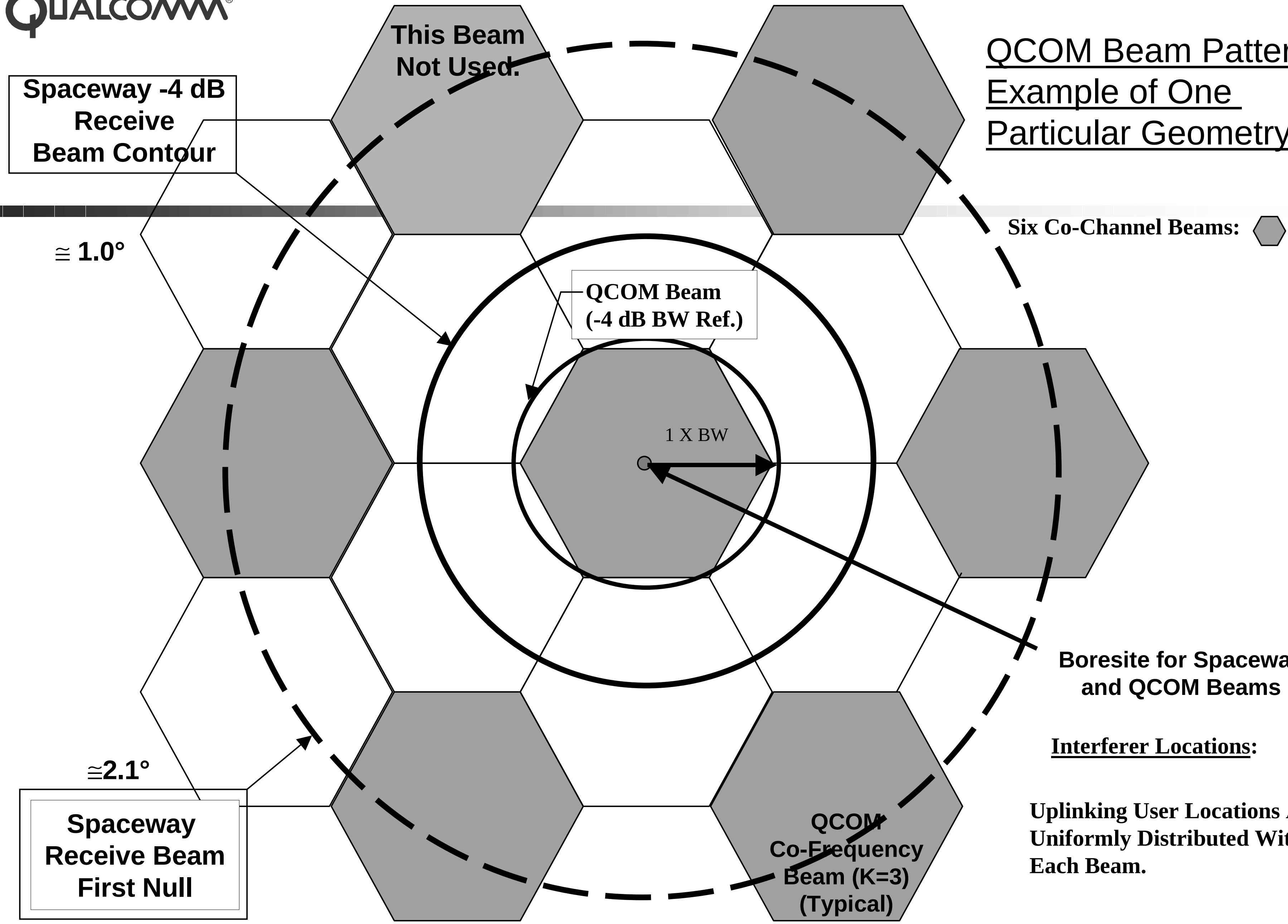
Case 2) Summary

- If all of the user terminals in the QCOM system were located at the boresight points (on Earth) within each Spaceway receive beam then the Spaceway system would perform just slightly better than that given by *Link #2 on Page 15*.
- However, the QCOM system user Earth terminals are spread out into six co-frequency beams in a K=3 reuse pattern.
- The roll-off of the Spaceway satellite receive antenna would further diminish the level of interference radiated from the QCOM terminals which are not within the main lobe of that antenna.
- If we allow one QCOM beam to be aligned with the center of the Spaceway beam then the other QCOM co-frequency beams will be distributed around this one (using K=3 spacing). We have determined that our specific geometry results in an additional 7.95 dB of isolation.
- This will produce a Spaceway Eb/(No+It) value increase to 9.19dB, now 1.19 dB above the Spaceway link requirement of 8.0 dB.

QCOM Beam Pattern: Example of One Particular Geometry



Interferer Locations:

Uplinking User Locations Are Uniformly Distributed Within Each Beam.

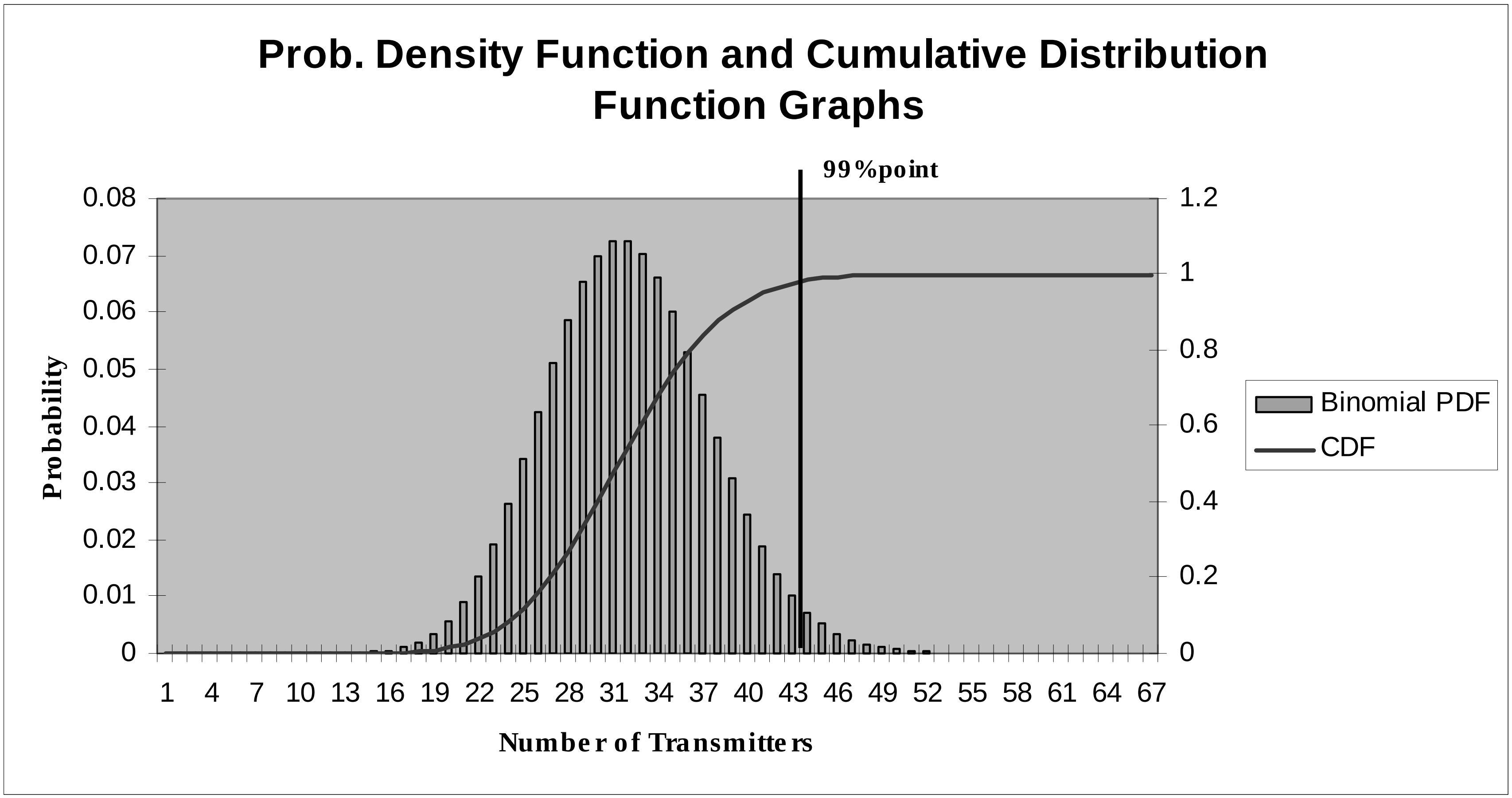
QCOM Reservation Channel at Two Adjacent Satellite Slots into the Spaceway System (Link #3)

• Clear Sky Reference Link Eb/No (No Interference):	11.71 dB
• Adjacent Channel and Beam Eb/I:	17.45 dB
• Cross Polarization Eb/I:	17.95 dB
• Eb/I for Two Adjacent Satellites Each Using QCOM OCDMA Reservation, Co-Frequency Channels:	17.23 dB
• Resultant Eb/(No+It):	9.19 dB

Case 3) Interference from Random Access Channels into the Spaceway System

- **It is now assumed that the two adjacent satellite systems employ CMDA-Aloha as a random access technique.**
- **Several CDMA signals sharing the channel transmit randomly. Because they are CDMA, more than one may transmit simultaneously within the channel, unlike TDMA-Aloha.**
- **Any one <u>R</u>andom <u>A</u>ccess <u>Ch</u>annel (RACH) may have up to 1080 users sharing (i.e. assigned to) the channel, each with a low probability of transmitting at any one time.**
- **The number of transmitters emitting at any time (and therefore the interference level produced from them) is given by a Binomial probability density, but may also be represented by a Gaussian distribution.**

QUALCOMM System CDMA Random Access Channel User Occupancy PDF & CDF



QUALCOMM System CDMA Random Access Channel User Occupancy Characteristics

- If Modeled as a Gaussian Distribution:
  - **Mean = 32 user terminals**
  - **Variance = 32**
  - **Standard Deviation (σ) = 5.66**
  - **Mean + 2.33σ = 45 user terminals (NOTE: This occurs 1% of the time.)**
- If Modeled as a Binomial Distribution:
  - **n = 1080 user terminals**
  - **p = 0.02963**
  - **q = 0.97037**
  - **var. = n*p*q =31.1**
  - **σ = 5.7**
  - **Mean + 2.33σ = 45 user terminals (NOTE: This occurs 1% of the time.)**

Interference from the RACH Channel

- **QCOM System User Terminals require approximately 11 mW to close their intended link. This generates in the channel:**
  - **0.35 watts of RF power for 32 user terminals**
  - **0.495 watts of RF power for 45 user terminals**
- In any one beam the EIRP Spectral Density in a RACH Channel is at a level w.r.t. the Reservation Channel Value of:
  - **-7.78 dB For 32 Users; Average Value**

    OR
  - **-6.30 dB For 45 Users; 99% Value**
- Thus, the RACH channel provides a reduced level of adjacent satellite interference into the Spaceway system compared to the reservation channel.

QCOM RACH Channel Used On Two Neighbouring Systems into Spaceway System

(32 Terminals Transmitting; Average Value)

(Link #4)

- Clear Sky Reference Link Eb/No (No Interference): 11.71 dB
- Adjacent Channel and Beam Eb/I: 17.45 dB
- Cross Polarization Eb/I: 17.95 dB
- Eb/I for 2 Adjacent Systems, Each Using QCOM RACH Channel: 27.51 dB
  - **32 User Terminals Transmitting**
- Resultant Eb/(No+It): 9.86 dB

QCOM RACH Channel Used On Two Neighbouring Systems into Spaceway System
(45 Terminals Transmitting, 99% Value)
(Link #5)

• Clear Sky Reference Link Eb/No (No Interference):	11.71 dB
• Adjacent Channel and Beam Eb/I:	17.45 dB
• Cross Polarization Eb/I:	17.95 dB
• Eb/I for Two Adjacent Systems, Each Using QCOM RACH Channel: – **45 User Terminals Transmitting**	26.03 dB
• Resultant Eb/(No+It):	9.83 dB

QCOM RACH Channel Power Required to Reduce Spaceway Link Eb/(No+It) to Its Minimum System Requirement Value

- **The Spaceway Eb/(No+It) Requirement is 8.0 dB for 10E-10 BER.**

- **The effective power required to reduce the Spaceway link performance to 8.0 dB (due to adjacent satellite interference) is:**

  8.15 dB above 2.11 watts = 11.40 dBW

- **This amount of power will overcome the Spaceway receive antenna roll-off isolation rejecting the adjacent co-frequency beams of the QCOM hypothetical system.**

- **The mean power level generated by two adjacent satellites, each with one beam co-aligned with the Spaceway receive beam and 5 beams off-axis from the Spaceway receive beam is:**

  1.26 watts - the sum of all transmitting terminals
  (adjusted for the roll-off of the Spaceway receive antenna)

- **The standard deviation in power from the same interferers is:**

  0.092 watts – as a result of all transmitting terminals

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The Probability that the QCOM RACH Channel Interference Power Could Reduce the Spaceway Link Eb/(No+It) to Its Minimum System Requirement Value

- The Interference power required from two adjacent QCOM satellites to reduce the spaceway link to its minimum system Eb/(No+It) requirement value of 8.0 dB:

  11.4 Watts = 10.57 dBW

  (from all simultaneous transmitting Earth terminals and corrected for the Spaceway receive antenna beam roll-off)

- The difference between the mean transmit power and the power level required to reduce (degrade) the Spaceway system to 8.0 dB is:

  110.29σ

- The probability that the interference from two adjacent QCOM satellites will reduce the Spaceway link to its minimum system Eb/(No+It) requirement of 8.0 dB:

  $$p = 1 \times 10^{-2,643}$$

Potential for Interference from Other Satellite Systems Along the Arc

- The contribution of interference from satellite systems operating in the same mode but spaced 4°, 6°, 8° and 10°along the arc into the victim Spaceway system can also be analyzed.
- The user terminals of each of the satellites spaced further away, of course, produce less interference than for those in the adjacent slots.
- Applying the ESD = 18.5-25log? rule for terminals spaced further along the arc we may determine the relative interference power produced by each spacecraft:

Orb. Arc Spacing:	Power w.r.t. 2° S/C:		
4°	-7.53 dB	17.7%	
6°	-11.93 dB	6.4%	
8°	-15.05 dB	3.1%	
10°	-17.47 dB	1.8%	TOTAL = 29.0%

Potential for Interference from Other Satellite Systems Along the Arc (2)

- In summary, if there are satellite systems of the same kind just analyzed located in all the slots to the east and west of the victim Spaceway system (±10° either side) these satellite users will add an additional 29% more interference to that created by the 2° spaced interfering systems. This can also be expressed as an increase in interference of 1.12 dB.
- This increases the average (mean) interference power from 1.26 watts to 1.65 watts and reduces the difference between this mean and the critical 11.4 watt Spaceway interference threshold to a value of 104.4σ.
- The corresponding probability that the critical 11.4 watt threshold will be exceeded by all of the adjacent systems is: $P = 10^{-2369}$

Conclusions

- **The Eb/I assumed by the Spaceway filing does not meet their stated system BER requirements when subjected to satellite systems operating in compliance with ASI limits set by Part 25.138(a)(1) of the Commission's Rules and with satellites at the two adjacent slots. This, however, does not mean the Spaceway system will, in practice, experience those levels of ASI from adjacent systems. In fact, this is unlikely.**

- **A fully loaded QCOM Reservation Channel, if operated in conjunction with two adjacent slot satellites will decrease the Spaceway Eb/(No+It) reference link only from 9.28 dB to 9.19 dB, thus still maintaining the Spaceway system Eb/(No+It) and bit error rate requirements.**

- **An increase in QCOM RACH user terminals from 32 to 45 [mean to (mean + 2.33σ)] produces less than a 0.03 dB variation in the Eb/(No+It) performance of the Spaceway link.**

Conclusions (2)

- **The net interference from a QCOM RACH channel increases the net Spaceway Eb/(No+It) by 0.67 dB compared to a fully loaded QCOM Reservation Channel. Note that the Reservation Channel is technically at the FCC ESD adjacent satellite interference limit IF the victim system used a CONUS-wide receive beam.**

- **The probability of a co-frequency QCOM RACH Channel from each of two adjacent spacecraft causing a reduction in Spaceway system performance below its system performance requirements is vanishingly small. Even if interfering systems of the same kind are added at ±4°,±6, ±8° and ±10° the probability of interference is vanishingly small.**

- In these analyses, QUALCOMM has demonstrated that adjacent satellite interference cause by an aggregate group of interferers, whose power level into an adjacent satellite varies statistically can easily be accommodated by an “as filed” Ka-Band satellite system, as one example. We believe this example to be typical.

- It is not only the results of these particular analyses but, the method used for calculating interference when the group of transmitting Earth stations exhibits a randomly varying power level (namely review of the statistical likelihood that given levels of interference will actually occur) which QUALCOMM believes will become valuable regulatory tools as the Commission fashions rules to enable the introduction of new services to permit more efficient use of the radio spectrum.