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Wireless Communications Systems Performance in Noise and Interference Limited Situations

Part 5: Recommended Methods for Technology- Independent Broadband Performance Verification

TSB-88.5 December 2016

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TSB-88.5	August 11, 2016	Original Release

FOREWORD

(This foreword is not part of this bulletin.)

Working Group WG-8.18.4 approved this document. Subcommittee TR-8.18 of TIA Committee TR-8 prepared and approved this document.

Changes in technology to support the public safety nationwide broadband network, plus increased reporting of interference have recently occurred. These events support keeping this document current and that it provide the methodology of modeling the various interference mechanisms to support frequency coordinators in determining the best assignments to be made for the available pool of frequencies and mixtures of technology.

This document, Wireless Communications Systems --- Performance in Noise-and Interference-Limited Situations ---Part 5: Recommended Methods for Technology Independent Broadband Performance Verification includes informative Annexes A and B.

This is the original release of Part 5 of this Bulletin. Other parts of this Bulletin are titled as follows:

- Part 1: Recommended Methods for Technology Independent Performance Modeling
- Part 2: Propagation and Noise
- Part 3: Recommended Methods for Technology Independent Performance Verification
- Part 4: Recommended Methods for Technology Independent Broadband Performance Modeling

Patent Identification

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INTRODUCTION

The TSB-88 series of documents is intended to address the following issues:

- Accommodating the design and frequency coordination of broadband technologies to be deployed in support of FirstNet's nationwide interoperable broadband public safety network;
- Accommodating the design and frequency coordination of bandwidth-efficient narrowband technologies likely to be deployed as a result of the Federal Communications Commission "Spectrum Refarming" efforts;
- Assessing and quantifying the impact of new narrowband/bandwidth efficient digital and analog technologies on existing analog and digital technologies; Address the methodology to minimize intersystem interference between systems at national boundaries;
- Assessing and quantifying the interference impact between narrowband technologies and broadband technologies;
- Addressing migration and spectrum management issues involved in the transition either to narrowband/bandwidth efficient digital and analog technologies or to broadband technologies. Provide information on new and emerging Land Mobile bands;
- Address the methodology of minimizing system interference between current or proposed Noise Limited Systems in spectral and spatial proximity to current or proposed Interference Limited Systems; and

The TSB-88 series of documents was prepared partially in response to specific requests from three particular user organizations: the Association of Public Safety Communications Officials, International (APCO), the Land Mobile Communications Council (LMCC) and the National Coordination Committee (NCC).[1]

This document, TSB-88.5, is intended to address coverage verification within the context described above.

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[1] The National Public Safety Telecommunications Council (NPSTC) has assumed the responsibilities of the NCC which has been disbanded.

Wireless Communications Systems -
Performance in Noise and Interference-Limited Situations

Part 5: Recommended Methods for Technology-Independent Broadband Performance Verification

1. SCOPE

1.1. The TSB-88 Series

The TSB-88 series of bulletins gives guidance on the following areas:

- Establishment of standardized methodology for modeling and simulating either narrowband/bandwidth efficient technologies or broadband technologies;
- Establishment of a standardized methodology for empirically confirming the performance of either narrowband/bandwidth efficient systems or broadband systems;
- Aggregating the modeling, simulation and empirical performance verification reports into a unified “Spectrum Management Tool Kit” which can be employed by frequency coordinators, systems engineers, software developers, and system operators;
- Recommended datasets that are available for improved results from modeling and simulation; and
- Providing current information for new and emerging bands.

The purpose of these documents is to define and advance a scientifically sound standardized methodology for addressing technology compatibility. This document provides formal structure and quantitative technical parameters from which automated design and spectrum management tools can be developed based on proposed configurations that can temporarily exist during a migration process or for longer term solutions for systems that have different technologies.

As wireless communications systems evolve, the complexity in determining compatibility between different types of modulation, different operational geographic areas, and application usage increases.

Spectrum managers, system designers and system maintainers have a common interest in utilizing the most accurate and repeatable modeling and simulation capabilities to determine likely wireless communication system performance. A standardized approach and methodology is needed for the modeling and simulation of wireless communications systems performance, considering both analog and digital practices in all frequency bands of interest.

In addition, after deployment, validation or acceptance testing is often an issue subject to much debate and uncertainty. Long after a system is in place and optimized, future interference dispute resolution necessitates application of an industry accepted and standardized methodology for assessing system performance and interference.

These documents contain recommendations for both public safety and non-public safety performance that ought to be used in the modeling and simulation of these systems. These documents also satisfy the desire for a standardized empirical measurement methodology that is useful for routine proof-of-performance and acceptance testing and in dispute resolution of interference cases that are likely to emerge in the future.

To provide this utility necessitates that specific manufacturers define various performance criteria for the different capabilities and their specific implementations. Furthermore, sufficient reference information is provided so that software applications can be developed and employed to determine if the desired system performance has been realized.

Wireless system performance can be modeled and simulated with the effects of single or multiple potential distortion sources taken into. These sources include:

- Performance parameters
- Co-channel users
- Off-channel users
- Internal noise sources
- External noise sources
- Equipment non-linearity
- Transmission path geometry and transmission loss modeling
- Delay spread and differential signal phase
- Over the air and network protocols
- Performance verification

Predictions of system performance can then be evaluated based on the desired RF carrier versus the combined effects of single or multiple performance degrading sources. Performance is then based on a faded environment to more accurately simulate actual usage and considers both signal magnitude and phase attributes.

It is anticipated that this series of documents will serve as the standard reference for developers and suppliers of land mobile communications system design, modeling, simulation and spectrum management software and automated tools.

1.2. TSB-88.5

This document, TSB-88.5, provides additional guidance for establishing a standardized methodology for verifying performance of broadband technologies for public safety systems. TSB-88.5 addresses performance verification and the parametric values used to accomplish that verification within the context described in §1.1.

Single frequency reuse technology such as LTE present new validation challenges with respect to internal and external interference. For these new broadband technologies, system traffic load impacts performance and must be properly accounted for in the validation field test. Further, a variety of metrics can be envisioned for validating broadband performance with subtleties such as the OSI layer at which the metric is measured. The potential for confusion in validation parameters and procedures demands the application of an industry accepted and standardized methodology for assessing broadband system performance.

The performance recommendations for the measurement methodology in TSB-88.5 cover best effort data systems. The scope might expand in the future to cover other classes of data such as VoLTE and streaming video.

2. REFERENCES

This Telecommunications System Bulletin contains only informative information. There are references to TIA and 3GPP standards which contain normative elements. These references are primarily to indicate the methods contained in those documents. At the time of publication, the edition indications were valid. All standards and bulletins are subject to revision and parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent edition of the standards or bulletins indicated in § 3. ANSI and TIA maintain registers of currently valid national standards published by them.

3. DEFINTIONS AND ABREVIATIONS

There is a comprehensive Glossary of Terms, Acronyms, and Abbreviations listed in Annex-A of TIA TSB-102. In spite of its size, numerous unforeseen terms still may have to be defined for the Compatibility aspects. Items being specifically defined for the purpose of this document are indicated as (New). All others will be referenced to their source as follows:

ANSI/IEEE 100-2000 Standard Dictionary	[IEEE]
TIA-603-D	[603]
TIA/EIA-102.CAAA-C	[102.CAAA]
Recommendation ITU-R P.1407-4	[ITU3]
Report ITU-R M.2014	[ITU8]
TIA -845-B	[845]
TSB-88.1-D	[88.1]
TSB-88.2-E	[88.2]
TSB-88.3-D	[88.3]
TSB-88.4	[88.4]

The preceding documents are referenced in this bulletin. At the time of publication, the editions indicated were valid. All such documents are subject to revision, and parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent editions of the standards indicated above:

3.1. Definitions

For the purposes of this document, the following definitions apply:

16QAM: 16 Quadrature Amplitude Modulation is a digital modulation requiring 4bits/symbol. It uses 16 points on the constellation diagram typically spaced on a rectangular grid with equal separation between points.

64QAM: 64 Quadrature Amplitude Modulation is a digital modulation requiring 6bits/symbol. It uses 64 points on the constellation diagram typically spaced on a rectangular grid with equal separation between points.

Application Layer Data Rate: The application layer data rate in units of bits per second is defined as the number of bits received at the application layer in a defined sample duration divided by the sample duration.

Beyond Necessary Band Emissions (BNBE): All unwanted emissions outside the necessary bandwidth. This differs from OOBE (*q.v.*) in that it includes spurious emissions.

BPSK: Binary Phase Shift Keying is a digital modulation used in communications to modulate at 1bit/symbol. It uses two phases separated by 180 degrees. BPSK is also called 2-PSK or PRK (Phase Reversal Keying), 2QAM.

Channel Performance Criterion (CPC): The CPC is the specified design performance level in a faded channel.

Confidence Interval: A statistical term where a confidence level is stated for the probability of the true value of something being within a given range which is the interval.

Confidence Level: also called Confidence Coefficient or Degree of Confidence, the probability that the true value lies within the Confidence Interval.

Coverage Acceptance Test Plan (CATP): The CATP is a document that defines the method and metric (i.e. DRCPC) that will be used to validate in the field that the predicted service area reliability or covered area reliability has been achieved.

Covered Area Reliability: The Covered Area Reliability is the probability of achieving the desired CPC over the defined covered area. A *tile-based area reliability* (*q.v.*) that is calculated by averaging the individual tile reliabilities only for those tiles that meet or exceed the minimum desired tile reliability. It can be used as a system acceptance criterion.

CPC Reliability: CPC Reliability is the probability that the prescribed CPC exists at a specified location.

Data Rate Channel Performance Criterion (DRCPC): The DRCPC is the minimum required application layer data rate in a faded channel to meet the broadband data services objectives.

Delay Spread [ITU3]: The power-weighted standard deviation of the excess delays, given by the first moment of the impulse response.

Design Traffic Load: Broadband coverage depends on traffic load since the traffic load determines the uplink and downlink interference levels in the system. The design traffic load is defined by the number of active users that are distributed throughout the service area, the data load per application in terms of bytes per user in the busy hour, and the distribution of applications amongst the users. The design traffic load directly determines the air interface resource utilization.

Dipole: A half wave dipole is the standard reference for fixed station antennas. The gain is relative to a half wave dipole and is expressed in *dBd*.

Distributed Antenna System (DAS): An antenna system that provides enhanced RF coverage and/or capacity to certain locations (e.g. indoors and/or areas with high user densities, such as stadiums and convention centers). Passive DAS systems often extend wide area coverage into buildings via bi-directional amplifiers (BDAs). Active DAS solutions often digitize RF, typically to/from a dedicated base station, and distribute the signal (typically via fiber) among remote radio units throughout a facility, adding capacity and improving RF coverage.

Doppler Frequency: The Doppler frequency is given by V/λ where V is the vehicle velocity and λ is the radio carrier wavelength (same units). Frequently this is also referred to as Doppler Shift.

Downlink (DL): From the fixed equipment outward to the "mobile" units. DL is also referred to as a forward-link.

DRCPC Reliability: DRCPC Reliability is the probability that the prescribed DRCPC exists at a specified location.

Evolved or E-UTRAN Node B (eNB): The LTE base station

Error Function (*erf*): The normal error integral. It is used to determine the probability of values in a Normal distribution (Gaussian distribution). Many statistical calculators can perform this calculation. Many spreadsheet programs have this as a function, although enabling statistical add-ins is necessary for this function to be available. Its compliment is the *erfc*. When added together they equal 1 $(erf + erfc = 1)$.

Equivalent Noise Bandwidth (ENBW): The frequency span of an ideal filter whose area equals the area under the actual power transfer function curve and whose gain equals the peak gain of the actual power transfer function. In many cases, this value could be close to the 3 *dB* bandwidth. However, there exist situations where the use of the 3 *dB* bandwidth can lead to erroneous results. Sometimes ENBW is referred to as Effective Noise Bandwidth.

Interference Limited: The case where the CPC is dominated by the Interference component of $C/(I+N)$.

Isotropic: An isotropic radiator is an idealized model where its energy is uniformly distributed over a sphere.

Minimum Coupling Loss (MCL): Minimum signal propagation loss measured between transmitter and receiver antenna connections. Includes antenna gains.

Modulation and Coding Scheme (MCS): In a data system that supports Adaptive Modulation and Coding, the Modulation and Coding Scheme (MCS) describes the type of modulation used (e.g. BPSK, QPSK, 16 QAM, or 64 QAM) and the error detection and correction coding rate used.

Multiple Input Multiple Output (MIMO): MIMO utilizes multiple antennas at the transmitter and receiver to improve system performance and spectral efficiency. Transmit diversity and spatial multiplexing are examples of MIMO implementations.

Noise Limited: The case where the CPC is dominated by the Noise component of $C/(I+N)$.

Number of Test Tiles: The number of uniformly distributed but randomly selected test locations used to measure the CPC. It is calculated using the Estimate of Proportions equation and the specified Area Reliability, Confidence Interval and Sampling Error.

Orthogonal Frequency Division Multiplexing (OFDM): OFDM is a digital modulation method which modulates data on closely spaced multiple orthogonal carrier frequencies.

Orthogonal Frequency Division Multiple Access (OFDMA): A multiple access scheme which uses OFDM technologies.

Out of Band Emissions (OOBE) [ITU8]: Emission on a frequency or frequencies immediately outside the necessary bandwidth, which results from the modulation process, *but excluding spurious emissions.* This definition is restrictive for the purpose of this document.

Propagation Loss: The path loss between transmit and receive antennas. The loss is in dB and does not include the gain or pattern of the antennas.

Quadrature Phase Shift Key (QPSK): The acronym for the Quadrature Phase Shift Keyed family of compatible modulations. Quadrature Phase Shift Keying is a digital modulation requiring 2bits/symbol. It uses 4 points on the constellation diagram with a equal spaced on a circle (90 degree spacing). (Also called 4-PSK, 4QAM)

Sampling Error: A percentage error; caused by not being able to measure the “true value” obtained by sampling the entire population.

Service Area: The specific user’s geographic bounded area of concern. Usually a political boundary such as a city limit, county line or similar definition for the users business. Can be defined relative to site coordinates or an irregular polygon where points are defined by latitude and longitude. In some Public Safety systems the Service Area could be greater than their Jurisdictional Area. This is done to facilitate mutual aid and/or interference mitigation.

Service Area Reliability: The Service Area Reliability is the probability of achieving the desired CPC over the defined Service Area. A *tile-based area reliability* (*q.v.*) that is calculated by averaging the individual tile reliabilities for all tiles within the service area. It can be used as a system acceptance criterion. If mixed tile sizes are used, the individual tile reliabilities must be weighted or normalized based on their individual tile area.

Signal to Interference plus Noise Ratio (SINR): In broadband air interface technologies the main carrier is normally divided into many different control and payload signals. Each of these signals may use different modulation and coding techniques and have different receiver sensitivity and QoS performance criterion. Therefore it is important to define the quality metric for each as the ratio of the desired signal power to the power of the received noise and interference, notated S/(I+N).

Signal to Noise Ratio (SNR): The ratio of the desired signal power to the average noise power within a specified bandwidth, typically expressed in units of dB.

Single Carrier Frequency Division Multiple Access (SC-FDMA): A multiple access scheme, sometimes also known as Discrete Fourier Transform (DFT)-spread OFDM, which is a linearly pre-coded OFDMA scheme with an additional DFT step proceeding the OFDMA processing.

Spatial multiplexing (SM): A MIMO implementation in which independent and separately encoded data signals (or "streams") are simultaneously transmitted from multiple transmit antennas to enhance spectral efficiency. The SM-MIMO streams can be transmitted from or received by a single user or multiple users, with the latter referred to as multi-user (MU) MIMO.

Standard Deviate Unit (SDU): Also "Standard Normal Deviate." That upper limit of a truncated normal (Gaussian) curve with zero mean and infinite lower limit which produces a given area under the curve (e.g., $Z = +1.645$ for Area =0.95).

Subsample: A single measured value. Part of a Test Sample.

Test Grid: The overall network of tiles where random samples of the CPC are taken.

Test Location: The beginning of the Test Sample in a Test Tile.

Test Sample: A group of subsamples which are measured at a Test Tile.

Test Tile: The location where the random subsamples for CPC are to be taken.

Tile-based Area Reliability: The mean of the individual tile reliabilities over a predefined area.

Tile Mean Data Rate: The mean data rate measured at the application layer in a Test Tile using UDP at the transport layer. Calculated as the total application layer bits received in the specified time duration divided by the time duration.

Tile Reliability: In a Monte Carlo simulation, multiple data transmission attempts are made at a geographic tile location. The tile reliability is the percentage of transmission attempts that resulted in an achieved data rate that was greater than or equal to the CPC.

Transmit Diversity: A MIMO implementation which utilizes techniques such as varying delay/frequency offsets between the transmit paths and/or via space-time channel coding to provide diversity gains.

Transport Layer Data Rate: The transport layer data rate in units of bits per second is defined as the number of bits received at the transport layer in a defined sample duration divided by the sample duration.

Uplink (UL): From the "mobile equipment" inbound to the fixed equipment. UL is also referred to as a reverse-link.

Validated Service Area Reliability: The number of test locations successfully measured with the desired parametric value divided by the total number of locations tested.

3.2. Abbreviations

16QAM	16 point Quadrature Amplitude Modulation
64QAM	64 point Quadrature Amplitude Modulation
ANSI	American National Standards Institute

APCO	Association of Public Safety Communications Officials International, Inc.
ATP	Acceptance Test Plan
BDA	Bi-Directional Amplifier
CATP	Coverage Acceptance Test Plan
CPC	Channel Performance Criterion
DAS	Distributed Antenna System
DRCPC	Data Rate Channel Performance Criteria
dBd	Decibels relative to a half wave dipole
dBi	Decibels relative to an isotropic radiator
dBm	Power in decibels referenced to 1 milliWatt
DL	Downlink
eNB	Evolved Node B
ENBW	Equivalent Noise Bandwidth
erf	Error Function
erfc	Complementary Error Function *(erfc x = 1 - erf x)*
ERP	Effective Radiated Power, relative to a $\lambda/2$ dipole
E-UTRAN	Evolved UMTS Terrestrial Radio Network
GPS	Global Positioning System
IP	Internet Protocol
MCS	Modulation and Coding Scheme
OOBE	Out of Band Emissions
PS NB	Public Safety Narrowband
QPSK	Quadrature Phase-Shift Keying
RF	Radio Frequency
SC-FDMA	Single Carrier FDMA
SINR	Signal to Interference plus Noise Ratio, same as S/(I+N)
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Network
Z	Standard Deviate Unit

4. TEST METHODS

Test methods listed in this section are either specific to the referenced normative TIA documents or informative recommendations.

Recommended test methods are defined in the following subsections:

§ 5.8 Broadband Coverage Acceptance Testing

5. PERFORMANCE CONFIRMATION

This section addresses the issues associated with the empirical validation and quantification of broadband system performance. This process is integral to a proof-of-performance or acceptance test.

5.1. Conformance Validation Overview

Conformance testing validates a user's expectation of obtaining the design reliability over the service area by collecting data at a statistically significant number of random test locations, uniformly distributed throughout the service area. The entire concept of conformance testing rests on statistics.

While it is impossible to measure every one of the infinite number of points within a given coverage area, one can measure a sufficient number to arrive at a value that is within an arbitrarily small interval of the actual reliability, with a specified statistical confidence. The measurements become simple pass or fail tests and do not represent the reliability of the tile that was sampled. The process is based on statistical spot sampling to verify if the predicted value was achieved. The number of spot measurements and their locations are selected such that the pass to (pass + fail) quotient is, to a given statistical confidence, within a given interval of the actual area reliability.

The semantics of some of the terms used is critical for a proper understanding of this methodology. The service area is divided by a grid pattern to produce a large number of uniformly sized tiles, or test tiles. In one method of vehicular outdoor performance confirmation, within each test tile one test location is randomly selected. Starting at each of these test locations, a data test is initiated and runs for a specified time duration. This test location measurement, containing the measured data rate, constitutes the test sample for this test tile. A sample may begin in one test tile and end in a different tile. The tile being measured is considered to be the tile in which the test sample measurement began.

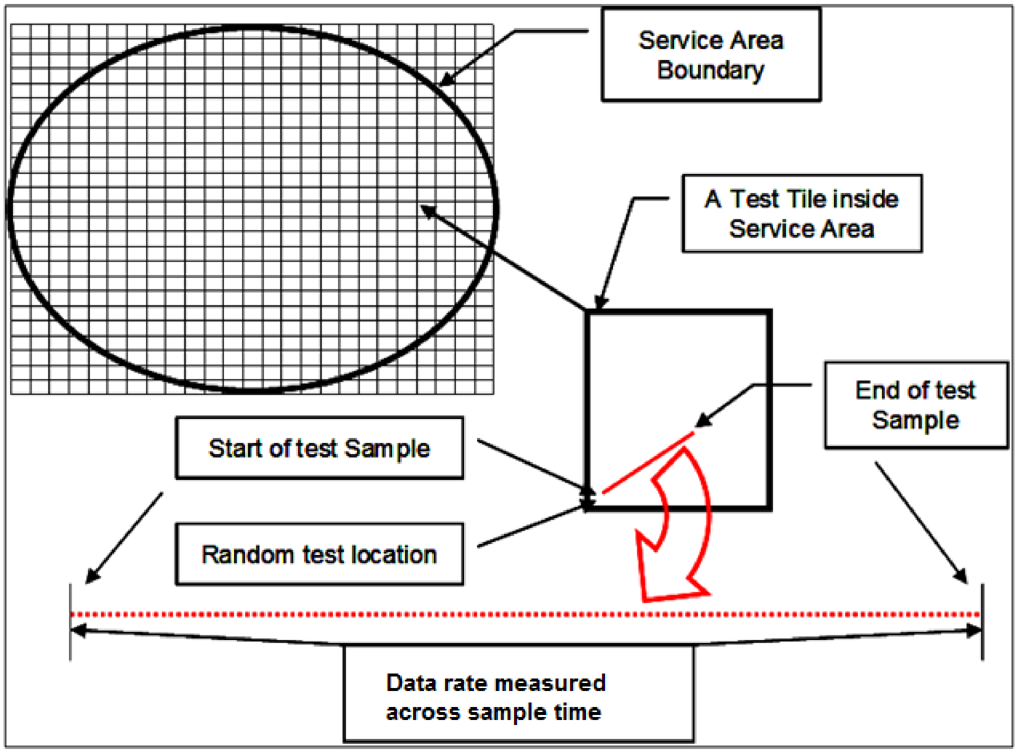

Figure 1 – Sample Definitions

Alternatively, the grid pattern is used to develop a test route that is uniformly distributed throughout the service area with an approximately equal distance traveled in each grid. This test route ought to pass once through each test tile while collecting data. Thus, a large number of test samples is collected and evenly distributed throughout the service area.

Randomly select the actual test location within each test tile when the test vehicle crosses into the tile at an arbitrary point. Overlay the Service Area with a test grid, without consideration for roads or accessibility[2]. The drive pattern compliments this random approach through the nature of the driver finding the closest way to the next test tile. Upon entering an untested test tile, have the coverage testing equipment indicate that this is a new, untested test tile and begin collecting the data rate sample while continuing to drive through the test tile.

For a vehicular outdoor service area consisting of an underground tunnel, the route is fixed and the width of the service area is relatively small. The data rate signal is sampled as above with the vehicle in motion. If the desired percentage of the data rate samples passes, the service area is considered to be covered.

For performance confirmation in indoor service areas where the majority of users are on foot, including loading platforms and stations associated with underground

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[2] Adjust user requirements that are restricted to known routes, such as a transit district, to their specific routes or needs.

tunnels, a different approach is recommended: The data rate sample is collected and evaluated over as great an area as is practical.

Whichever method is utilized, the tested tiles ought to be uniformly distributed throughout the service area and equally weighted in the area reliability calculation. This ensures that the test results are valid and unbiased.

Note: Separately state the desired service area reliability for mobile vs. portable situations and the results ought never to be combined. That is, portable indoor specifications are stated and tested separately from portable outdoor specifications, which can, in turn, be stated and tested separately from vehicular outdoor specifications.

5.2. Validated Service/Covered Area Reliability

The validated service or covered area reliability is determined by the requisite percentage of the tiles tested[3] that meet or exceed the DRCPC.

$$\text{Validated Service/Covered Area Reliability (\%)} = \frac{T_p}{T_t}(100) \qquad (1)$$

Where:

T_p = Total of tests passed

T_t = Total number of tests

5.3. Determination of Number of Test Tiles (Outdoor only)

The “estimate of proportions” is a method to determine with a high degree of confidence that sufficient test tiles have been developed to accurately validate the outdoor service or covered area reliability.

5.3.1. Estimate of Proportions

$$T_\ell = \frac{Z^2 pq}{e^2} \qquad (2)$$

Where:

T_ℓ = Number of Test Tiles
Z = Standard Deviate Unit (Corresponding to the confidence level)
p = Predicted Area Reliability (decimal, e.g. 97% = 0.97)
$q = 1 - p$
e = Sampling error allowance (decimal): the difference between the predicted Area Reliability (e.g. 97% = 0.97) and the contractual Area Reliability to be tested for (e.g. 95% = 0.95); this sets the value of e (e.g. e = 97% - 95% = 2% = 0.02).

This is subject to a limit such that:

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[3] For service area reliability, all tested tiles are included. For covered area reliability, only those tiles predicted to meet or exceed the criterion are tested. Location information obtained during testing allows tiles tested in error or by automated means to be eliminated.

$$T_l \geq 100 \qquad (3)$$

This forces T_ℓ to be the larger of the values calculated in equations (2) and (3).

Values for the standard deviate are available in most statistics books. Some typical values for one-sided (tail) tests [Z_α] and two sided (tails) tests [$Z_{\alpha/2}$] are shown in Table 1 and Figure 2.

Table 1 – Values for Standard Deviate Unit

Percentage (%)	Z_α	$Z_{\alpha/2}$
50	0	0.6745
70	0.524	1.036
80	0.841	1.281
85	1.036	1.439
90	1.281	1.645
95	1.645	1.960
97	1.881	2.170
99	2.326	2.579

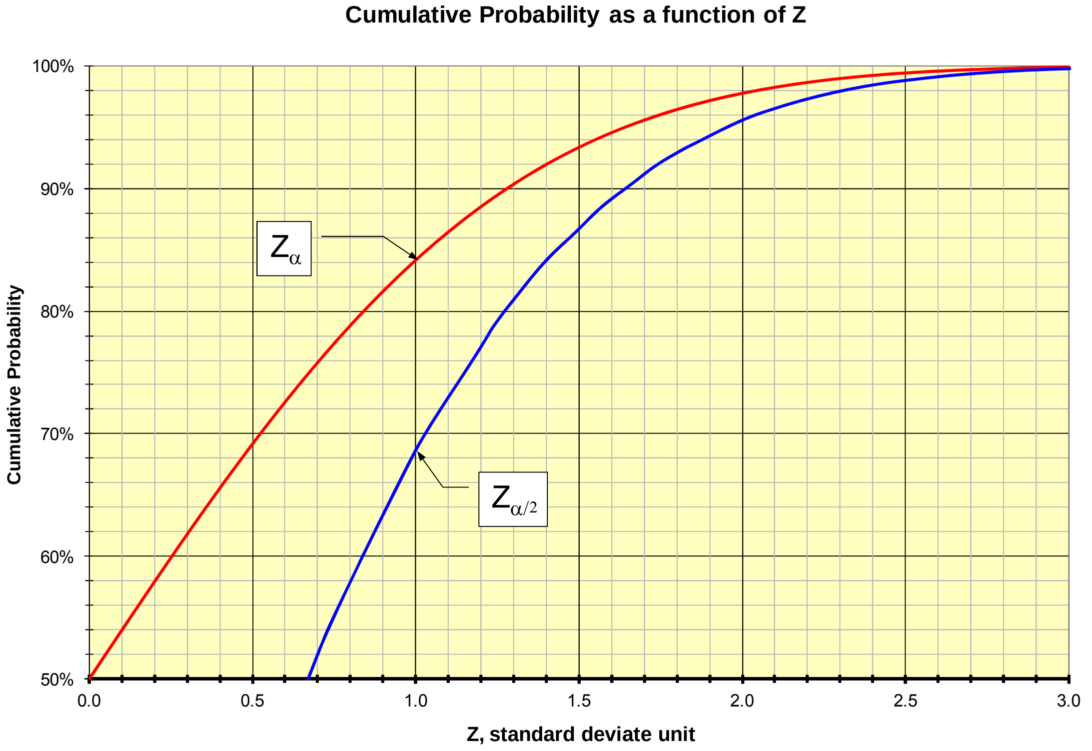

Figure 2 – Cumulative Probability as a Function of Z_α and $Z_{\alpha/2}$

5.4. Pass/Fail Test Criteria

The following pass/fail criteria are possible:

- The “Greater Than” Test
- The “Acceptance Window” Test

5.4.1. The “Greater Than” Test

The “Greater Than” Test is defined such that the percentage of test locations that meet the CPC equal or exceed the service area reliability target. This necessitates an “overdesign” of the system by *e* to provide the statistical margins for passing the conformance test as defined. For this test configuration, *Z* has one-tail [Z_α] and *e* is the amount of overdesign, expressed as a decimal fraction.

5.4.2. The “Acceptance Window” Test

The “Acceptance Window” test allows the percentage of test locations that meet the CPC to fall within an error window, ± *e*, which is centered on the service area target reliability to consider the acceptance test a pass. This eliminates the necessity for “over design”, but necessitates a two tail *Z* [$Z_{\alpha/2}$] that increases the number of test samples to be evaluated.

5.5. Confidence of Performance Verification

5.5.1. Confidence Level

The greater the number of test tiles, the higher the confidence level. The confidence level reflects the certainty that the actual area reliability falls within the confidence interval. A confidence level of 99% is recommended unless this choice reduces the test tile size such that the requisite sample distance cannot be achieved.

5.5.2. Confidence Interval

This defines the limits within which the true value ought to fall. Using the preceding definition of a “greater than” test with a 99% confidence level and 2% sampling error allowance and a contractual area reliability of 95%, the statement would be, “I am 99% confident that the true value is at least 97% if the number of test tiles is at least, $T_l = [(2.326^2)(0.97)(0.03)]/0.02^2 = 394$ tiles”. Table 2 below lists some example calculations of the required number of test tiles for some predicted area reliability and error margin assumptions.

Table 2 – Required Number of Test Tiles for Greater Than Test

	Predicted Area Reliability for CATP, p (1-tailed Z = 99%)			
Error Margin, +/- e	0.9	0.95	0.97	0.99
	Required Number of Test Tiles, T_l			
0.25%	76171	39165	23151	6444
0.50%	18606	9300	5275	1077
0.75%	8074	3914	2115	240
1.00%	4431	2078	1060	100
1.25%	2765	1250	595	100
1.40%	2170	958	435	100
1.50%	1870	812	355	100
1.75%	1337	555	218	100
2.00%	995	394	134	100
2.25%	764	286	100	100
2.50%	601	211	100	100
2.75%	481	157	100	100
3.00%	391	118	100	100
3.25%	322	100	100	100
3.50%	268	100	100	100
3.75%	225	100	100	100
4.00%	191	100	100	100

5.6. Tile Size Constraints & Accessibility

This section discusses guidelines on tile size and shapes for outdoor, tunnel, and indoor locations. Recommended practices on handling accessibility and interference issues are also discussed.

5.6.1. Outdoor

It is recommended that outdoor test tiles be ≥ 150m x 150m to ensure lognormal shadowing decorrelation[4] between tiles, but less than 2 km by 2 km, and of equivalent shape and area. A reasonable aspect ratio of 3:2 through 2:3 is considered to be square for the purpose of sizing test tiles of that shape. A tile created using other shapes, such as triangles and hexagons of equivalent areas is an acceptable alternative to a rectangularly shaped tile. Outdoor tiles ought to be contiguous.

5.6.2. Tunnel

Tunnel test grid “tiles” are normally thin rectangular areas delineated by length. Tile lengths are dependant upon the system architecture. Considerations include the lengths of tunnel segments, locations of curves in either the horizontal or vertical plane(s) and placement of bi-directional amplifiers (BDAs) or DAS radio units, and antennas.

5.6.3. Indoor

For indoor service areas where the majority of users are on foot, including loading platforms and stations associated with underground tunnels, tiles are not used. Instead, the data rate is sampled over as great an area as is practical. If individual buiding testing is necessary refer to [88.3].

5.6.4. Accessibility

Every effort ought to be made to collect measurements in every tile where users are expected to operate. Prior to testing, locations with inaccessible test tiles ought to be specified and treated per one of the following options:

- Eliminated from the calculation [Preferred]
- Estimated based on adjacent tiles (single tiles only)
- Considered a pass

If groups of inaccessible test tiles are encountered during a CATP it is recommended:

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[4] In [2] [3], measurement campaigns taken at 900 and 1900 MHz show that the maximum correlation distance of the shadowing process is on the order of 100m. Additional margin is recommended here to allow for location errors, data collection delays, etc.

- Re-model the coverage with these inaccessible locations removed from the prediction as their inability to be tested changes the predicted value.

- If removal of these groups of inaccessible test tiles causes the predicted reliability to fall below the original criterion, then change the coverage criterion to reflect the reduced area to be tested after removing the inaccessible test tiles.

5.6.5. Treating Anomalous Tiles

If the coverage test results do not meet the specified acceptance criteria, secondary coverage testing can be performed for analysis and re-configuration. These areas can then be re-tested per the specification.

Only perform the coverage test procedure once per test tile. If any portion of the test is determined to be unreliable because of proven equipment malfunctions or failures, repeat the portion of the test affected by the equipment malfunction or failure.

If a test, or a portion thereof, is suspected to have failed due to external interference, attempt to identify the interference source and resolve. Then, those test tiles suspected of being affected by an interferer ought to be re-tested. If interference is identified and can't be eliminated during the test, those test tiles ought to be excluded from the acceptance calculations and potential long-term solutions identified.

It could be possible to have multiple teams performing a broadband data CATP simultaneously. However, the drive routes ought to be carefully constructed and timed such that the probability of two test measurements using the same cell is extremely remote. The goal of the test is to measure and verify the coverage of the communications "pipe." This is best accomplished when only one device is presenting traffic to the portion of the wireless network under test. Traffic from more than one unit using the same cell and backhaul could skew the results of the test, preventing a true measurement from being obtained. In addition, as broadband systems typically have low or single frequency re-use factors, multiple test measurements ought not be simultaneously taken in adjacent or nearby cells. This avoids adding DL and UL self-interference that could skew the results of the test. If one or more test tiles fail the acceptance test, and there is a high probability that more than one device was simultaneously using the cell under test or nearby cells, then retest those tiles after ensuring that no other traffic is present on or near the associated cells.

5.7. In-Building Recommendations

There are numerous considerations in regards to coverage measurement within buildings. The reader is referred to [88.3] for information on in-building coverage measurement.

5.8. Broadband Coverage Acceptance Testing

The objective of the CATP is to demonstrate that the system achieves or exceeds the specified minimum coverage criterion for the designated service area. The radio coverage areas are defined within the service area boundary. For broadband systems, it is recommended that a data rate CPC (DRCPC) is used. The DRCPC is the minimum required application layer data rate in a faded channel to meet the broadband data services objectives.

During broadband data coverage acceptance testing, application layer data rate is measured in each of the test tiles. In order to facilitate stable and repeatable field measurements, it is recommended that the best effort data rate be measured by transmitting UDP datagrams, where the payload of the UDP datagram contains application data only with no additional application layer headers or overhead. The data rate of this received payload would then be measured. This can be considered measured transport layer data rate or application data rate for this special case of an application that consists of data only with no additional headers or overhead. Throughout this document, wherever application data rate is mentioned, it is implied that the application is this special case of no additional application layer headers or overheads, only UDP datagrams that contain application data as the payload. The reader is referred to [88.4] for information on communications protocol overheads.

It is recommended that test vehicles utilize mobile devices with external, vehicle mounted antennas for consistency. Handhelds ought to be emulated by adding attenuators to the mobile device antenna ports to account for the difference between the antenna gains as well as body or building penetration losses that were modeled in the system design.

It is recommended that all test routes be agreed upon prior to drive testing. It is recommended that the test teams use an automated test tool for executing the CATP to reduce the time and the number of people needed to perform a quantitative survey and also reduce human influence that could bias the results. It is recommended that the test package use the GPS (Global Positioning System) for determining location, time, and date information. When conditions prohibit GPS access, manually select the location based on the map display.

During the test, the actual location sampled within a test tile ought to be randomly selected by detection of entering an untested test tile. It is recommended to use a tool that provides a GPS driven map display with the coverage test grid as well as a direct interface to the broadband data modem. The fixed end can receive inbound messages from the broadband data modem, initiate outbound messages to the broadband data modem and record the measured data rate to a file.

5.8.1. Distance

The recommended distance (*D*) for each test sample within a test tile is $28\lambda \leq D \leq 100\lambda$. The preferred distance is 40λ as it smoothes out Rayleigh fading [1][5] while ensuring that the subsamples of the test sample are correlated with each other. Shorter distances have a larger impact from the Rayleigh fading. Longer distances tend to include changes in the local value due to the location variability starting to change. At lower frequencies, less than 40λ could be necessary.

5.8.2. Criterion Selection

The application layer data rate is the recommended data coverage testing criterion (DRCPC) for validating coverage for both moving and fixed wireless data systems. Data rate testing confirms that a specific data rate at the application layer can be reliably delivered throughout a defined percentage of the defined service area, typically 90 - 95% in order to produce reliable and repeatable measurements. Both the uplink (subscriber to network) and downlink (network to subscriber) communications paths ought to be tested.

Subscriber speed is a channel condition which impacts performance of the broadband data link; therefore, the system ought to be tested between 75% and 125% of the assumed (i.e. modeled) speed used to predict coverage. If the system is tested at a speed outside of this range, make adjustments to the required data rate or coverage prediction accordingly.

Another approach is to add or adjust attenuators on the mobile device antenna ports to compensate for the difference between the SINR needed to achieve the DRCPC at the modeled speed and the SINR needed to achieve the DRCPC at the testing speed. The difference between the SINR needed to achieve the DRCPC at the modeled speed and the SINR needed to achieve the DRCPC at the testing speed is determined from the link curves that specify SINR vs. data rate for the system at different speeds. A reduction in attenuation is only possible if attenuators are already being utilized, for example to emulate handheld antenna and use case assumptions when drive testing with a mobile device (as described in § 5.8). If attenuation will be fixed during the drive testing, it is recommended that the difference between the design and typical test speeds, and hence the corresponding attenuation offset, be agreed upon prior to drive testing.

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[5] The reference recommends $20\lambda \leq D \leq 40\lambda$ to average Rayleigh fading.

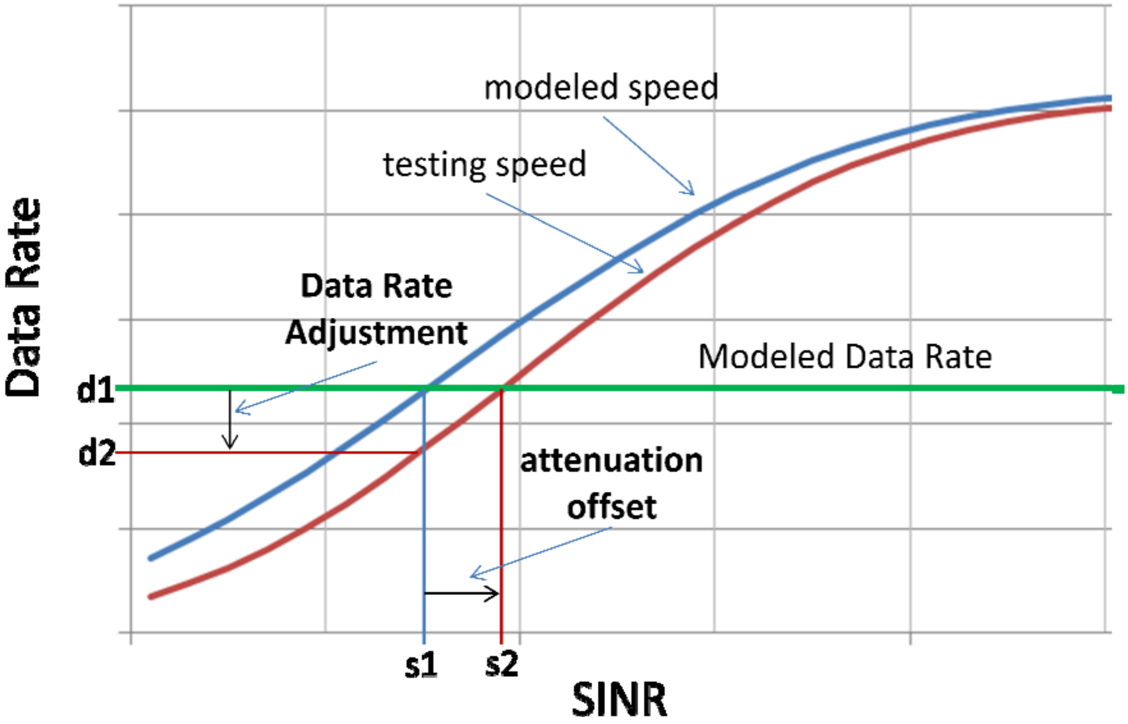

Figure 3 – Illustration of Speed Impact on Link Curves

Figure 3 illustrates example SINR vs. data rate curves for two different speeds, and the corresponding attenuation offset and data rate adjustment to compensate for the speed difference. In this example, we assume a system is designed with a DRCPC *d1* for handheld devices on-street at pedestrian speed, and that the blue curve is the link curve given these assumptions. So the required SINR to achieve the DRCPC *d1* is *s1*. The drive test configuration uses a mobile device, with attenuation added to each antenna port to account for the gain difference between vehicular mounted mobile antennas and internal antennas on a handheld device plus hand and body losses. Assume this difference is 6dB. Next consider that drive testing is carried out at a speed more than 125% of the pedestrian speed, and the red curve is the corresponding link curve. In this case, the required SINR to achieve the DRCPC *d1* is *s2*. Looking at it another way, at the SINR required to achieve the DRCPC at pedestrian speed, *s1*, the data rate is reduced to *d2* at the drive test speed. Since the system was tested at more than 125% of the speed used to predict coverage, one of the recommendations discussed above is to adjust the DRCPC to *d2*. The other approach is to keep the original DRCPC but reduce the attenuation (6dB in this case) by *s2* – *s1*. So if the offset between *s1* and *s2* were 2dB for example, the attenuation would be reduced to 4dB.

Note that the latter method is applicable to other channel conditions that impact performance of the broadband data link such as fading environment type (i.e. delay profile and delay spread) and device antenna correlation characteristics. In this case, the attenuation adjustment is based on the difference between the

SINR needed to achieve the DRCPC at the modeled channel conditions vs. the corresponding SINR at the testing channel conditions.

5.8.3. Test Parameters

Numerous applicable test options, based on the specific system, ought to be specified. These include:

- DL Traffic Load
- Test Tile Criteria
  - Number of Test Tiles
  - Test point selection within Test Tile
  - Test Procedure at Test Point
- Stationary or Moving Test
- Mobile or Portable Test Equipment
- One Way or Round Trip
- Treatment of Inaccessible Test Tiles
- Treatment of Test Anomalies

5.8.3.1 DL Traffic Load

Data rate coverage testing can be done in the uplink and downlink directions and in the loaded or unloaded condition. It is challenging to create a traffic load in the uplink direction; therefore, it is recommended to test the uplink direction unloaded, when an uplink test is desired. In the downlink direction, data rate coverage can be tested in the unloaded condition or an air interface load generation function that is available on some broadband equipment can be used to emulate the design traffic load on interfering cells while measuring data rate on the serving cell. Note that the only traffic on the serving cell during the data rate test is the traffic from the drive test unit itself.

5.8.3.2 Coverage Area and Test Point Selection

Divide the predicted coverage area into a grid of uniform sized test tiles per § 5.6. Select the actual location sampled within a test tile by detection of entering an untested test tile. It is recommended to use a tool that provides a GPS-driven map display with the coverage test grid as well as a direct interface to the test radio.

The size and number of test tiles are driven by various factors, both statistical and practical, including confidence level, desired error margin, shadowing correlation distance, and time to execute the CATP. In some cases, the size of a test area and number of test tiles (based on the confidence level and desired error margin) result in a tile size below the minimum needed to avoid shadowing correlation (§ 5.6.1). When this occurs, one option is to agree to larger, fewer tiles which will result in a larger error margin for any such areas. Another option is to aggregate test tiles from multiple areas and provide a single combined pass/fail coverage test result with the original desired error margin for the combined areas. A hybrid approach is to provide pass/fail results for each area with larger error margins as well as a combined pass/fail result for the group of areas with the original error margin.

5.8.3.3 Test Procedure

It is recommended that the following be completed before commencing the coverage data rate test:

- The core network equipment is installed and operational. Include gateway(s) between wireless/core networks, test servers, wireless network control and management equipment as appropriate
- All backhaul equipment/services needed have been installed and are operational, and provide sufficient capacity to support the throughput requirements
- Wireless network devices have been installed and tested
- Pre-testing is complete and mutually acceptable to all parties
- Test client configuration has been tested and deemed ready for coverage test
- General drive route(s) have been determined and scheduled
- Test time frames during low vehicular traffic periods have been determined and scheduled
- Internal communications between test teams/test coordinator have been set up
- Any relevant security agencies have been notified

An IP performance measurement tool is recommended for testing. The tool ought to measure data rate in a single direction. Accomplish the coverage testing using a vehicle utilizing the unit under test, traveling on streets as defined in the CATP service area. Upon entering an untested tile in the area under test, automatically initiate the measurement process. Using the IP performance tool first perform a downlink transfer for the specified data transmission session (from the test server to test radio) averaging the downlink application data rate over the sample period. Store the average data rate for the sample. Next perform a similar transfer session for the uplink direction (from a test radio to the test server) averaging the uplink application data rate over the sample period. Store the average data rate for the sample. Use the stored uplink and downlink average application data rate measurements for the acceptance test calculations. Store the GPS location for later analysis in the test tool. Upon completing and storing the data rate measurement, move to the next test tile. Consider failure to establish a connection a failed tile.

5.8.3.4 Test Results

Summarize the test results:

- Uplink: The application data rate coverage percentage meets or exceeds the uplink data rate specification in a specified percentage of the service area, e.g. 95%.

- Downlink: The application data rate coverage percentage meets or exceeds the downlink data rate specification in a specified percentage of the service area, e.g. 95%.

It is recommended that a coverage test log be completed on a daily basis by each test team. In the event a test tile is inaccessible, document the x, y test tile coordinate and document the reason for not testing (e.g. no road, fence blocking road, washed out road). [§ 5.6.4]

Immediate location values can be captured by the test configuration tool during the measurement. Based on GPS or dead reckoning information or both, the current geographical position can be determined. Correlate each coverage/data rate measurement to a geographical location.

5.8.3.5 Test Documentation

Include the configuration of the test devices as part of the CATP results documentation.

- Radio node settings
- Test configuration UDP settings
- Mobile/portable test configuration

Provide the results of each test in a database file to include:

- Immediate location of each test point (latitude/longitude in decimal degrees)
- Mean uplink data rate at each tested location
- Mean downlink data rate at each tested location
- A calculation of the application data rate coverage percentage

6. BIBLIOGRAPHY

The following is a list of generally applicable sources of information relevant to this document.

[1] Lee, Wm C. Y., “Estimate of Local Average Power of a Mobile Radio Signal”, *IEEE Transactions on Vehicular Technology*, Vol. VT-34, No. 1, Feb 1985.

[2] Marsan, M., Hess G., Gilbert S., “SHADOWING VARIABILITY IN AN URBAN LAND MOBILE ENVIRONMENT AT 900 MHz”, *Electronics Letters*, Vol. 26, No. 10, May 1990.

[3] Weitzen, J., Lowe T., “Measurement of Angular and Distance Correlation Properties of Log-Normal Shadowing at 1900 MHz and Its Application to Design of PCS Systems”, *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY*, VOL. 51, NO. 2, March 2002.

ANNEX A DATA CATP USER CHOICES (Informative)

A.1 User Choices

The main body of this document does not present a “hard and fast” methodology. It presents the user with a number of choices that can be made to perform the system design, spectrum management, and performance confirmation functions. The purpose of this Annex is to present those choices in a simplified format so that users can clearly identify to others (e.g., prospective bidders) the specifics of the desired method.

Each choice is shown as a brief description along with a reference to the appropriate subdivision of this document or the appropriate version of TSB-88.x, e.g. [88.x], where the choices are fully described. Follow the instructions where optional choices can be made. Recommended or preferred values are indicated with an asterisk and enclosed in parentheses. If no choice is made, the recommended value(s) will be selected for any evaluation.

A.2 Identify Service Area

Reference – [88.1]. Use any of the methods of service area definition indicated by the information in Annex B [88.1]

A.3 Identify Criterion

DL Data Throughput Rate ______
UL Data Throughput Rate ______

A.4 Type of Test

☐ Moving (*)
☐ Stationary

A.5 Test Units

☐ Mobiles (*)
☐ Portables / Handhelds
☐ Both Mobiles and Portables / Handhelds

A.6 Portable Testing

If portable / handheld testing is selected, what environment is applicable?

☐ Outdoor Coverage (*)
☐ In-building Coverage
☐ In-vehicle Coverage

A.7 Test Direction

☐ Outbound (*)
☐ Inbound

☐ Both Outbound and Inbound

A.8 Identify Reliability Design Targets

For advice, see [88.1]. Both percentage and whether Covered Area or Service Area

______ % (select one)

☐ Covered Area (95% Public Safety only, else 90%)
☐ Service Area (*95% Public Safety only, else 90%)

A.9 Determine Conformance Test confidence level

Reference § 5.3.1 and § 5.5.1.

______ % (*99%)

A.10 Determine which Pass/Fail Criterion to use

Reference § 5.4. Select one:

☐ "Greater than" test (*)
☐ Acceptance window test

A.11 Treatment of Inaccessible Grids

Reference § 5.6.4. Select one:

☐ All are eliminated from the calculation (*)
☐ All are considered a "pass"
☐ Single isolated inaccessible tiles are estimated based upon "majority vote" of adjacent tiles; multiple adjacent inaccessible tiles are eliminated from the calculation
☐ Single isolated inaccessible tiles are estimated based upon "majority vote" of adjacent tiles; multiple adjacent inaccessible tiles are considered a "pass".

A.12 Treatment of Test Anomolies

Reference § 5.6.5. Select one:

☐ All are eliminated from the calculation (*)
☐ All are considered a "pass"

ANNEX B 700MHz Band Transmitter Characteristics and Interference Cases (Informative)

B.1 LTE Transmitter Characteristics

LTE systems can be deployed in several different channel bandwidths with the most common being 5, 10, and 20 MHz channel bandwidths. Resource blocks are defined as the minimum allocation unit in the downlink and uplink shared channels for carrying signaling and traffic. Resource blocks are 180 kHz wide and consist of 12 15 kHz wide $\frac{\sin(x)}{x}$ subcarriers. The subcarriers can be modulated with various levels of modulation and coding to provide data rates that vary with the SINR. A scheduler determines the desired parameters based on the subscriber units received signal level.

Table B1 – LTE Channel Characteristics

Channel BW	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Resource Blocks	6	15	25	50	75	100
Resource Subcarriers	72	180	300	600	900	1200

This multiple access technology (OFDMA) assigns a sub-set of the resource blocks to different subscribers. Thus simultaneous varying data rates are available for different users based on their location and available link budget. OFDMA is also robust against multipath fading and provides high spectral efficiency.

Table B2 – Theoretical SNR vs. MCS

Theoretical SNR Requirements Vs. Coding Rate and Modulation Scheme		
Modulation	Code Rate	SNR (dB)
QPSK 2 bits/Symbol	1/8	-5.1
	1/5	-2.9
	1/4	-1.7
	1/3	-1.0
	1/2	2.0
	2/3	4.3
	3/4	5.5
	4/5	6.2
16 QAM 4 bits/Symbol	1/2	7.9
	2/3	11.3
	3/4	12.2
	4/5	12.8
64 QAM 6 bits/Symbol	2/3	15.3
	3/4	17.5
	4/5	18.6

Table B2 shows examples of modulation and coding schemes vs. required SNR for each. Linear transmitters are utilized for eNB stations while subscriber units have a different method for combining resource blocks, SC-FDMA, therein eliminating the need for a linear transmitter. QPSK, 16QAM, and 64QAM modulations are supported in the standard, however at this time device and some eNB vendors do not support the 64 QAM modulation in the uplink.

LTE eNB transmitters are generally deployed in 10, 20 and 40 Watt configurations for macro cells. Small (e.g. micro and pico) cells typically utilize lower transmitter power levels. They utilize sectored antennas with high gain values in the range of 13 and 15 dBi. After transmitter filtering the ERP generally ranges between 48 and 56 dBm. When MIMO 2x2 is deployed the ERP is 3 dB higher. If a 70 dB minimum coupling loss value is considered[6], the resulting signal levels on the ground range between -22 dBm and -14 dBm near a site. There are various different regulatory requirements such as one for the 700 MHz band[7] that does not allow Power Flux density to exceed 3000 µW/m^2 on the ground over the area extending to 1 km from the base of the antenna mounting structure. This is -12.3 dBm and -13.2 dBm for the 700 and 800 MHz bands respectively. These are strong signals that can create Near/Far blocking scenarios. Recent waivers have been granted for even higher ERP. In addition there are other sources of interfering power from transmitters such as OOBE and BNBE that can create interference as the energy falls on a victim receiver's authorized frequency.

Except for the 1.4 MHz channel bandwidth, the signal bandwidth is 90% of the channel bandwidth

Table B3 – LTE Channel vs. Signal Bandwidth

Channel BW	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Signal BW	1.08 MHz	2.7 MHz	4.5 MHz	9.0 MHz	13.5 MHz	18 MHz

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[6] 3GPP assumes 70 dB minimum coupling loss in the specifications, taking into account typical panel antenna gain directly below the antenna, typical LTE antenna height (30m), and free space path-loss.

[7] 47 CFR §27.55(c)

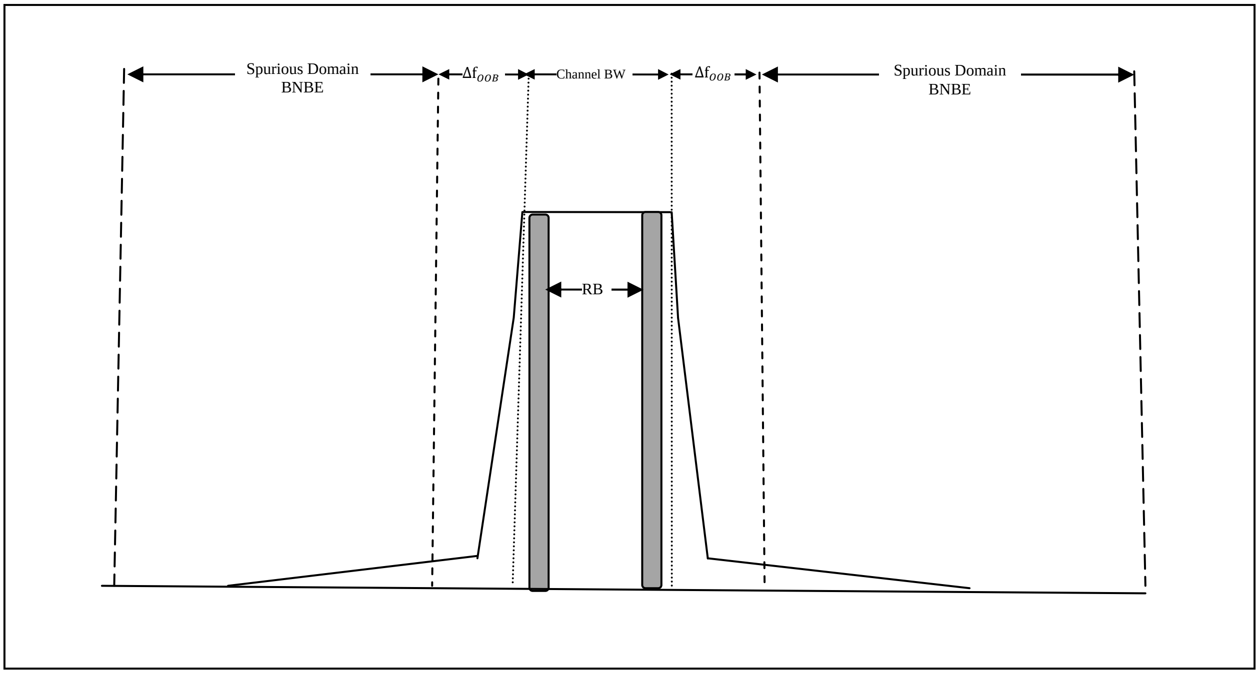

Figure B1 – LTE Transmitter Spectrum

There are FCC as well as ETSI 3GPP specifications for the OOBE and BNBE power. The FCC rules differ by frequency band while the ETSI specifications vary with channel aggregation, channel bandwidth, E-UTRAN Operating band and special network signaling options.

The measurement bandwidth for LTE is considerably wider than the narrow bandwidths used in narrowband LMR. This can be compensated by adjusting for the LMR channel bandwidths, e.g. 6.25, 12.5 and 25 KHz.

ETSI Base Station Transmitter Characteristics				
Power (EIRP) dBm/antenna		61(up to 5 MHz Channel) 64 (≥10 MHz Channel		
Max antenna gain, boresight		+18 dBi		
Emission Spectrum OOBE/BNBE Limit (dBm), as a function of the Frequency Offset of the measurement filter center frequency (ΔF) from the channel edge (MHz)		Limit (dBm)	Meas BW	ΔF (MHz)
	5 MHz BW	-15	30 kHz	0≤ΔF<1
		-13	1 MHZ	1≤ΔF
Corrections 30 kHz to 6.25 kHz = -6.8 dB 100 kHz to 6.25 kHz = -12 dB 1 MHz to 6.25 kHz = -22 dB 6.25 kHz to 12.5 kHz = +3 dB 6.25 kHz to 25.0 kHz = +6 dB	10 MHz BW	-13	100 kHz	0≤ΔF<1
		-13	1 MHZ	1≤ΔF
	15 MHz BW	-15	100 kHz	0≤ΔF<1
		-13	1 MHZ	1≤ΔF
	20 MHz BW	-16	100 kHz	0≤ΔF<1
		-13	1 MHZ	1≤ΔF

Figure B2 – ETSI Base Station Transmitter Characteristics

Device (UE) transmitter characteristics are specified in more detail over a wider spectrum. The maximum transmit power is 23 dBm with power control over a range of 63 dB (i.e. -40 to 23 dBm). Higher power units are permitted for Band 14 vehicular modems with a maximum transmit power of 31 dBm.

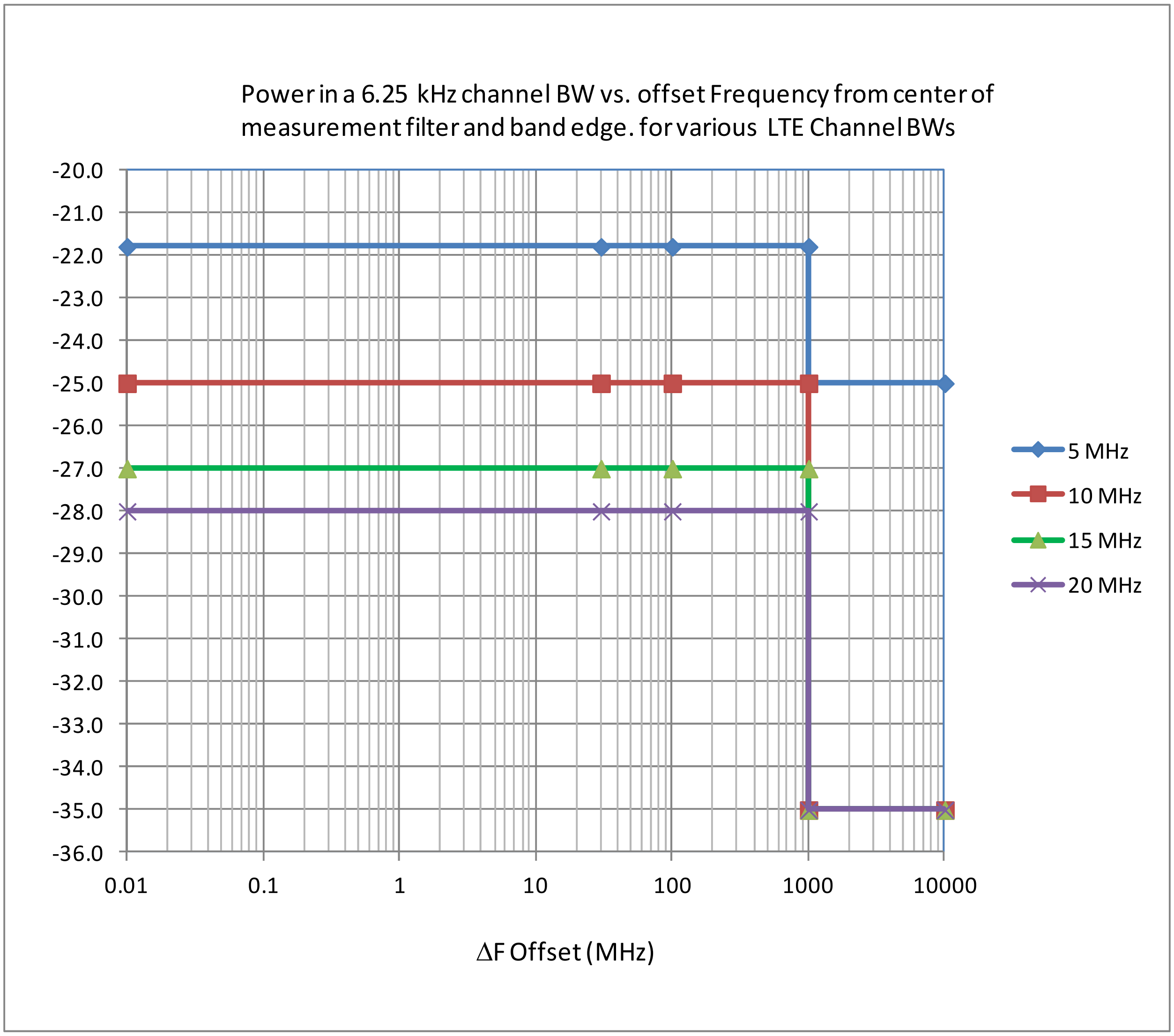

Figure B3 – LTE Transmitter Power in 6.25 kHz BW vs. Offset and LTE BW

B.2 700 MHz Band FCC Rules

FCC rules for Band 14 and adjacent bands, which include LTE (B13) and 700 MHz Public Safety Narrow Band (PS NB), were harmonized under 90.543. The relevant rules (as of this writing) for potential interference scenarios between these bands are summarized below. Since government regulations are subject to change, readers are advised to consult the latest regulations, which can be found at http://www.ecfr.gov/cgi-bin/text-idx?mc=true&node=pt47.5.90&rgn=div5

47 CFR 90.543 Emission limitations [partial listing]

Transmitters designed to operate in 769-775 MHz and 799-805 MHz frequency bands must meet the emission limitations in paragraphs (a) through (d) of this section. Class A and Class B signal boosters retransmitting signals in the 769-775 MHz and 799-805 MHz frequency bands are exempt from the limits listed in paragraph (a) of this section when simultaneously retransmitting multiple signals and instead shall be subject to the limit listed in paragraph (c) of this section when operating in this manner. Transmitters operating in 758-768 MHz and 788-798 MHz bands must meet the emission limitations in (e) of this section.

(e) For operations in the 758-768 MHz and the 788-798 MHz bands, the power of any emission outside the licensee's frequency band(s) of operation shall be attenuated below the transmitter power (P) within the licensed band(s) of operation, measured in watts, in accordance with the following:

(1) On all frequencies between 769-775 MHz and 799-805 MHz, by a factor not less than 76 + 10 log (P) dB in a 6.25 kHz band segment, for base and fixed stations. [-46 dBm]

(2) On all frequencies between 769-775 MHz and 799-805 MHz, by a factor not less than 65 + 10 log (P) dB in a 6.25 kHz band segment, for mobile and portable stations. [-35 dBm]

(3) On any frequency between 775-788 MHz, above 805 MHz, and below 758 MHz, by at least 43 + 10 log (P) dB. [-13 dBm]

(4) Compliance with the provisions of paragraphs (e)(1) and (2) of this section is based on the use of measurement instrumentation such that the reading taken with any resolution bandwidth setting should be adjusted to indicate spectral energy in a 6.25 kHz segment.

(5) Compliance with the provisions of paragraph (e)(3) of this section is based on the use of measurement instrumentation employing a resolution bandwidth of 100 kHz or greater. However, in the 100 kHz bands immediately outside and adjacent to the frequency block, a resolution bandwidth of 30 kHz may be employed.

(f) For operations in the 758-775 MHz and 788-805 MHz bands, all emissions including harmonics in the band 1559-1610 MHz shall be limited to −70 dBW/MHz equivalent isotropically radiated power (EIRP) for wideband signals, and −80 dBW EIRP for discrete emissions of less than 700 Hz bandwidth. For the purpose of equipment authorization, a transmitter shall be tested with an antenna that is representative of the type that will be used with the equipment in normal operation

B.3 700 MHz Band Base Station to Device Interference Scenarios

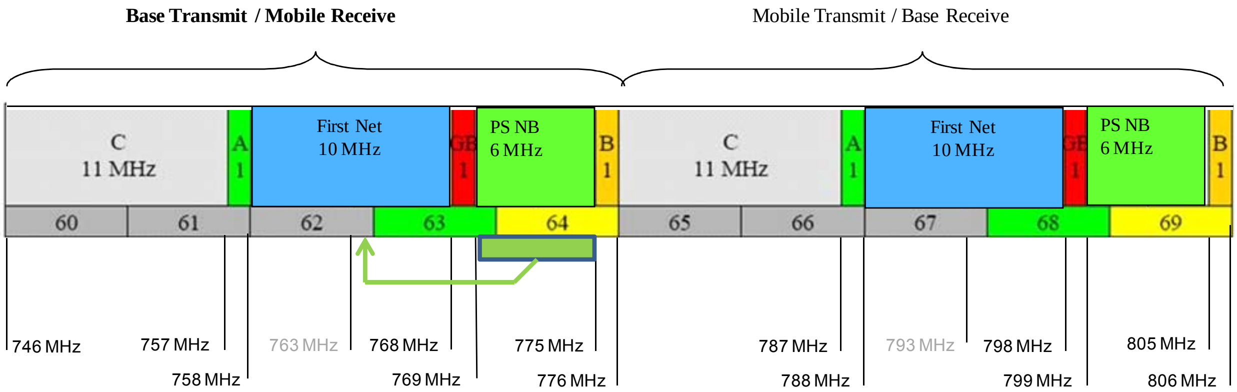

Figure B4 – 700MHz PS NB BS to B14 LTE UE Interference

Near-far interference scenario - high power narrowband base transmitters to broadband subscriber receiver when operating in close proximity; typically receiver overload or receiver intermodulation.

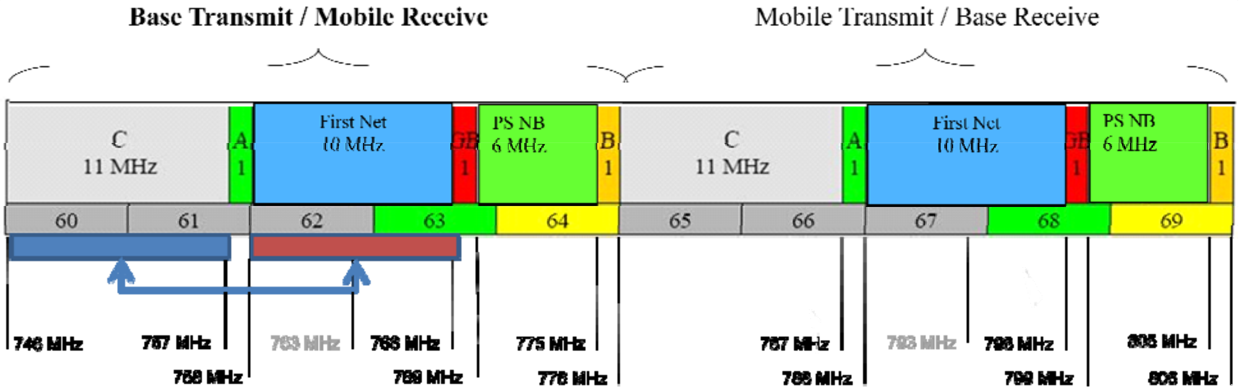

Figure B5 – B13 eNB to B14 UE and B14 eNB to B13 UE Interference

Near-far interference scenario - high power, low antenna height, broadband base transmitters to adjacent band broadband subscriber receiver when operating in close proximity; typically receiver overload or receiver intermodulation. FirstNet broadband subscribers are especially susceptible to this near-far scenario in regions where B14 eNB site density is significantly lower than C-block eNB site density.

B.4 700 MHz Band Base Device to Device Interference Scenarios

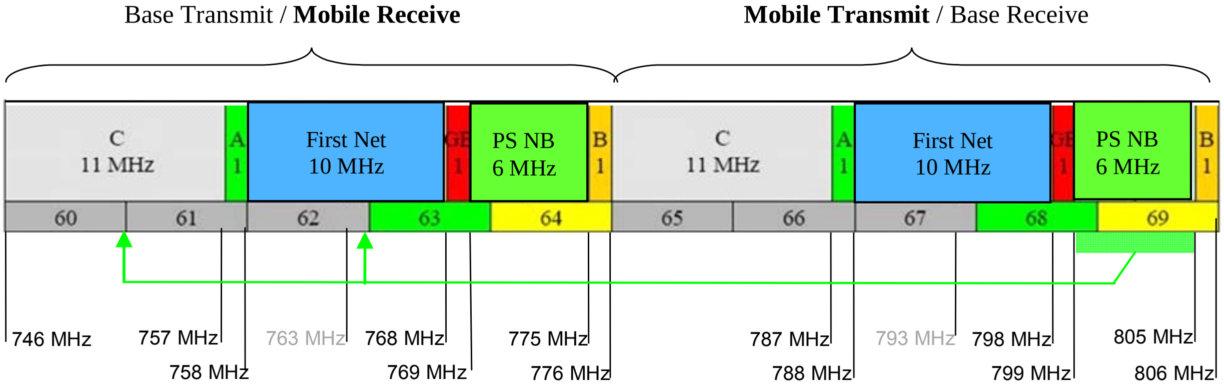

Figure B6 – 700MHz PS NB Device to B13 and B14 UE Interference

Interference scenario - PS narrowband subscriber transmitter to broadband subscriber receiver when operating in very close proximity; typically out-of-band emissions. Higher power subscribers could generate receiver intermodulation.

B.5 700 MHz Band Device to Base Station Interference Scenarios

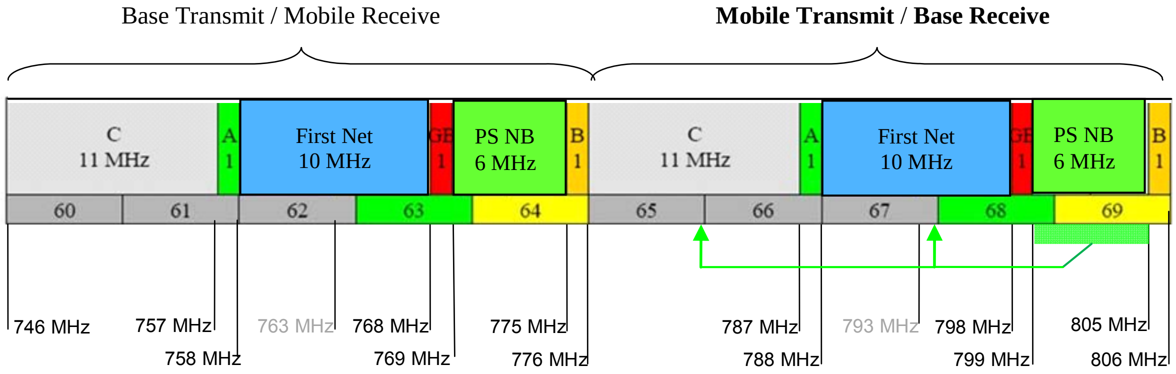

Figure B7 – 700MHz PS NB Device to B13 and B14 eNB Interference

Interference scenario – PS narrowband subscriber transmitter to broadband base receiver when operating in close proximity; typically out-of-band emissions. Higher power subscribers (mobiles, vehicular modems, control stations, and bi-directional amplifiers) could generate receiver intermodulation.

B.6 700 MHz Band Base Station to Base Station Interference Scenarios

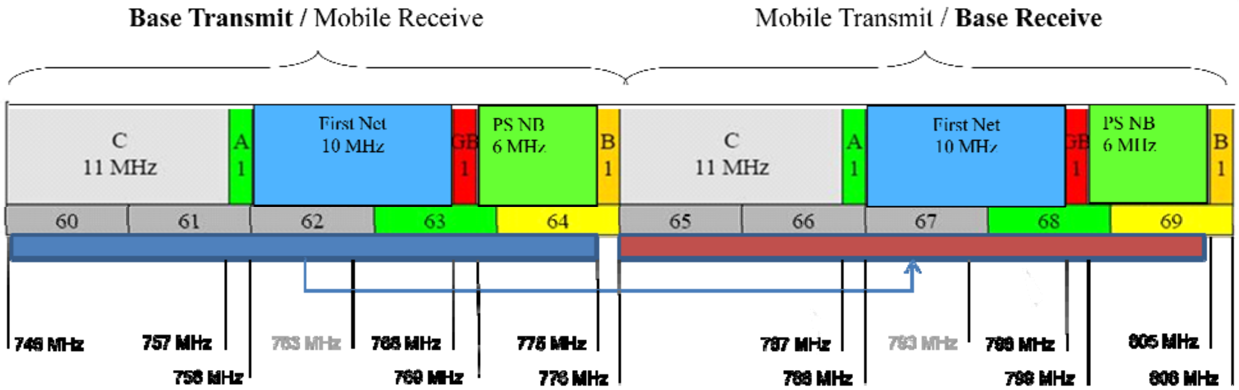

Figure B8 – 700MHz eNB or BS to other 700MHz eNB or BS Interference

Interference scenario – Co-located base stations without sufficient port-to-port isolation can interfere with each other due to OOBE, receiver overload or receiver intermodulation. In some cases, additional antenna spacing or filtering may be necessary.

B.7 800 MHz Band Overview

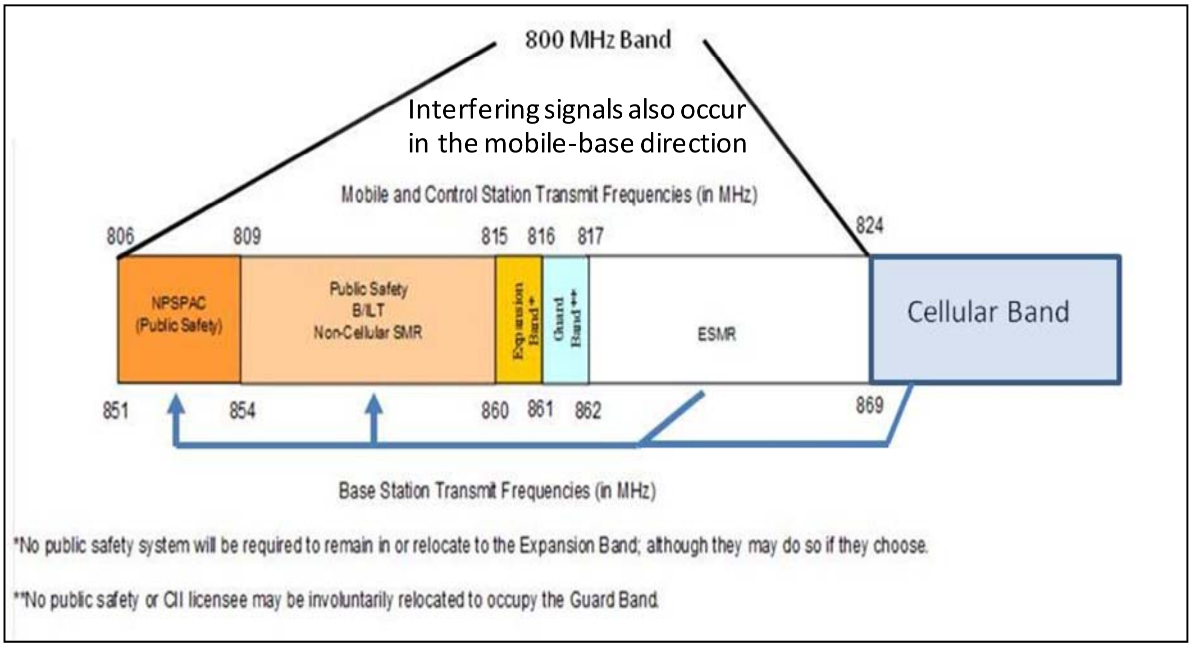

Figure B9 – 800MHz Band and Interference Overview

Narrowband subscriber to broadband base station interference scenarios may also occur in the 800 MHz band.

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