NASCTN
National Advanced Spectrum
and Communications Test Network

Aggregate LTE:
Characterizing User Equipment Emissions
Phase 1 Metrology Plan

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National Advanced Spectrum and Communications Test Network (NASCTN)

The mission of the National Advanced Spectrum and Communications Test Network (NASCTN) is to provide, through its members, robust test processes and validated measurement data necessary to develop, evaluate and deploy spectrum sharing technologies that can increase access to the spectrum by both federal agencies and non-federal spectrum users.

NASCTN was formed to provide a single focal point for engaging industry, academia, and other government agencies on advanced spectrum technologies, including testing, measurement, validation, and conformity assessment. The National Institute of Standards and Technology (NIST) hosts the NASCTN capability at the Department of Commerce Boulder Laboratories in Boulder, Colorado.

NASCTN is a membership organization under a charter agreement. Members

- Make available, in accordance with their organization’s rules policies and regulations, engineering capabilities and test facilities, with typical consideration for cost.
- Coordinate their efforts to identify, develop and test spectrum sharing ideas, concepts and technology to support the goal of advancing more efficient and effective spectrum sharing.
- Make available information related to spectrum sharing, considering requirements for the protection of intellectual property, national security, and other organizational controls, and, to the maximum extent possible, allow the publication of NASCTN test results.
- Ensure all spectrum sharing efforts are identified to other interested members.

Current charter members are:

- National Telecommunications and Information Administration (NTIA)
- National Institute of Standards and Technology (NIST)
- Department of Defense Chief Information Officer (DoD CIO)

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0 Acronyms

3GPP	3^{rd} Generation Partnership Project
AWS-3	3^{rd} group of Advanced Wireless Services bands
CDF	Cumulative Distribution Function
CIO	Chief Information Officer
CR	Coordination Request
CRE	Coordination Request Evaluation
C-RNTI	Cell Radio Network Temporary Identifier
CSMAC	Commerce Spectrum Management Advisory Committee
CW	Continuous Wave
DCI	Downlink Control Information
DISA	Defense Information Systems Agency
DL	Down Link
DoC	Department of Commerce
DoD	Department of Defense
DSO	Defense Spectrum Organization
DUT	Device Under Test
e-ICIC	enhanced Intercell Interference Coordination
EIRP	Equivalent Isotropic Radiated Power
EEPAC	Early Entry Portal Analysis Capability
eNB	evolved UTRAN Node B or Evolved Node B
FCC	Federal Communications Commission
FD	Frequency Domain
FDD	Frequency Division Duplex
FPGA	Field Programmable Gate Array
ICIC	Intercell Interference Coordination
IID	Independent and Identically Distributed
IMS	Internet Protocol Multimedia Subsystem
IP	Internet Protocol
ITS	Institute for Telecommunication Science
ITU	International Telecommunications Union
LTE	Long Term Evolution
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output

NAS	Non-Access Stratum
NASCTN	National Advanced Spectrum and Communications Test Network
NIST	National Institute of Standards and Technology
NTIA	National Telecommunications and Information Administration
OEM	Original Equipment Manufacturer
PC	Personal Computer
PDF	Probability Density Function
PRB	Physical Resource Block
RAID	Redundant Array of Independent Disks
RAN	Radio Access Network
RF	Radio Frequency
RMS	Root-Mean Square
RRC	Radio Resource Control
RSRP	Reference Signal Received Power
SISO	Single Input Single Output
SRF	Spectrum Relocation Fund
SSTD	Spectrum Sharing Test and Demonstration (also SST&D)
TCP	Transmission Control Protocol
TRP	Total Radiated Power
TTI	Transmission Time Interval
UDP	User Datagram Protocol
UE	LTE User Equipment
UL	Up Link
UTG	UE Traffic Generator
VT-ARC	Virginia Tech Advanced Research Center
VOLTE	Voice Over LTE
VSA	Vector Signal Analyzer
WG	Working Group
WNO	Wireless Network Operator

1 Introduction

The Defense Information Systems Agency (DISA) Defense Spectrum Organization (DSO) through the Spectrum Sharing Test & Development (SST&D) program proposed to NASCTN a measurement campaign to quantitatively characterize Long Term Evolution (LTE) Up Link (UL) waveforms generated by User Equipment (UE) in the 1755 MHz to1780 MHz band, with the intent to develop realistic models of UE emissions. These models will be used for assessing interference to Department of Defense (DoD) systems that, for a time, will remain in the 1755 MHz to1780 MHz band.

The test plan, developed by NASCTN and described in this document, is Phase 1 of a series of measurements designed to better understand the emission of commercial UEs, both individually and in aggregate. Phase 1 will perform a series of controlled laboratory measurements over a variety of LTE network settings and are designed to better understand UE emissions behavior, over both frequency and time, and their sensitivity to various network configurations. In contrast to field-based measurements with limited knowledge of network settings, laboratory measurements will allow control and manipulation of all aspects of the network, giving the ability to generate a quantitative predictive model of the UE emission and its dependence on specific network parameters. The work will include an analysis of the assumptions and measurement uncertainties, and their effects on the uncertainty of the estimated parameters.

2 Background

In the 2010 Presidential Memorandum on Unleashing the Wireless Broadband Revolution [1], the National Telecommunications and Information Administration (NTIA) was tasked to identify underutilized spectrum suitable for wireless broadband use. In the subsequent NTIA Fast Track Report [2], many federal bands were identified as commercially viable. From this report, the FCC identified 1695 MHz to 1710 MHz, 1755 MHz to 1780 MHz, and 2155 MHz to 2180 MHz together as the 3rd advanced wireless services group of bands (called together AWS-3) in July 2013, shown in Figure 1. The FCC adopted a Report and Order in March 2014 with allocation, technical, and licensing rules for commercial use of the AWS-3 bands [3]. The uplink blocks of interest here are the 5 MHz blocks labeled G, H, and I and the 10 MHz J block.

Through Auction 97 [4], the AWS-3 band was auctioned for commercial mobile broadband usage in the United States. The auction raised $41B in revenue for the United States Treasury and required federal agencies in the AWS-3 band to look for other ways to accomplish their missions. In the 1755 MHz to 1780 MHz portion of the AWS-3 band, the DoD is using a combination of sharing, compression, and relocation to other bands (including the 2025 MHz to 2110 MHz band).

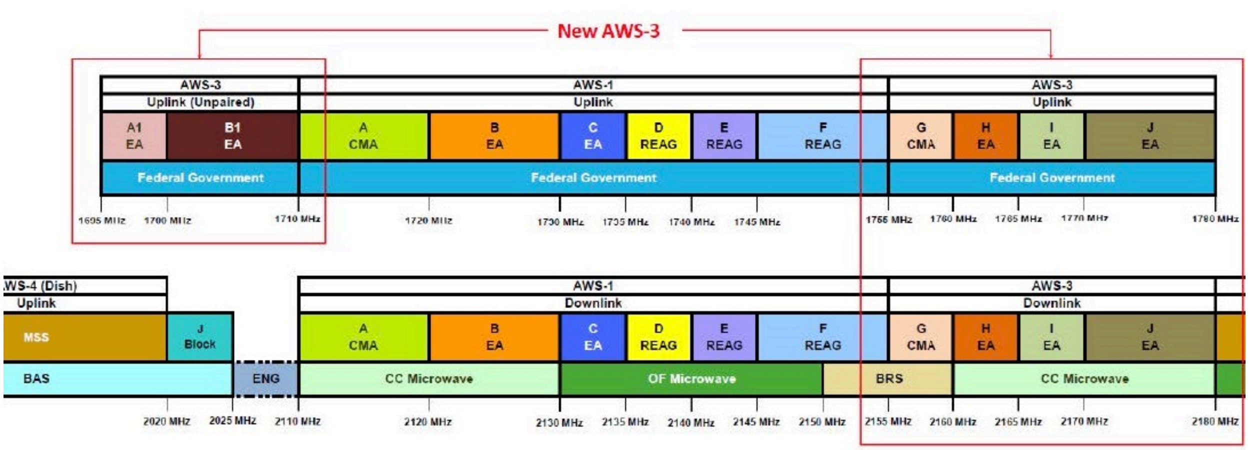

Figure 1. Description of the AWS-3 band.

In 2012, the Commerce Spectrum Management Advisory Committee (CSMAC) was tasked with exploring ways to lower the repurposing costs and/or improve or facilitate industry access to spectrum while protecting specific federal operations from adverse impact, particularly in the AWS-3 band. In carrying out their work, the CSMAC made several assumptions on the LTE UE and base station configurations, listed in Appendix A [5]. These assumptions were used to estimate EIRP distribution functions (shown in the appendix) for a UE in rural and suburban network laydownss.

From the AWS-3 auction proceeds, DoD is receiving a spectrum relocation fund (SRF) to implement its approved transition plans. The SRF is also funding evaluation of early entry coordination requests from the auction winners in the AWS-3 band through the DoD early entry portal analysis capability (EEPAC), which is managed by DISA DSO. The portal receives requests from auction winners to enter band(s) before the DoD has transitioned out of the bands. These requests must be considered carefully and impartially to deliver a fair answer. If early entry is granted and there is interference to DoD systems, it would be very costly to the DoD in terms of both financial and mission completeness. If early entry is denied to a commercial carrier for overly conservative reasons, it could be very costly to their business model. To avoid these costs, it is crucial that the findings of the EEPAC are fair and based on a well understood and openly documented methodology.

Towards this end, the DSO is evaluating entry requests by use of the updated interference equation (below) and the EIRP distributions assumed by the CSMAC. To gain further confidence in their calculations, the DSO has asked NASCTN to develop a measurement-based plan for gaining an improved quantitative understanding of LTE uplink emissions. More specifically, NASCTN will investigate how the LTE user equipment behaves in frequency and power under realistic operating conditions, and how this behavior depends on the network configuration, going beyond the CSMAC analysis with its fixed (and possibly unrealistic) network configurations.

The interference equation used by the EEPAC[1] [6] is

$$\hat{I}_k = \hat{E}^{(N)} - L_{\text{path}} - \hat{L}_{\text{clutter}} + G_{\text{r}}\left(\theta,\phi\right) - L_{\text{pol}} - L_{\text{res}} - R - \Pi, \tag{2.1}$$

where

$\hat{I}_k$ = Interference from the modeled user equipment (UE) in the k^{th} cell (in dBm)

$\hat{E}^{(N)}$ = EIRP emitted by N modeled UEs (in dBm)

L_{path} = path loss between modeled UE and DoD receiver (in dB)

$\hat{L}_{\text{clutter}}$ = clutter loss between modeled UE and DoD receiver (in dB)

$G_{\text{r}}\left(\theta,\phi\right)$ = DoD receiver antenna gain in direction of modeled UE (in dB)

L_{pol} = DoD receiver antenna mismatch loss (in dB)

L_{rec} = DoD system receiver loss (in dB)

R = Frequency-dependent rejection (in dB), known in [8] as *FRF*

Π = Network loading penalty (in dB).

Here, $\hat{E}^{(1)}$ is the EIRP of individual UEs distributed spatially over the extent of the LTE cell. Because UEs at different places in the cell behave differently, due to power control and scheduling, $\hat{E}^{(1)}$ represents the pooled behavior of the ensemble of UEs distributed throughout the cell. Because it does not refer to the behavior of a specific UE, $\hat{E}^{(1)}$ is sometimes referred to as the EIRP of a *modeled UE*. Also, $N \geq 1$ UEs

[1] We follow the notation of [6]; lower case variables denote numbers in linear units (*e.g.*, mW) while upper case variables use a logarithmic scale (*e.g.*, dBm). Random variables are denoted by a caret. The symbols for the last two terms have been changed from [6] to a single letter for readability.

may be allowed to transmit simultaneously in a cell. If it is assumed that transmissions from the UEs are incoherent, then the total instantaneous emission $\hat{E}^{(N)} = 10\log\left(\hat{e}^{(N)}\right)$ from a cell is calculated from the sum of the powers (in linear units) emitted by N individual UEs. If it is further assumed that the powers emitted from the UEs are independent and identically distributed, then the distribution of $\hat{e}^{(N)}$ (for $N > 1$) is given by the recursion relation (see [7], p. 136)

$$f_{\hat{e}^{(N)}}\left(p\right) = \int_{-\infty}^{\infty} f_{\hat{e}^{(N-1)}}\left(p-\xi\right) f_{\hat{e}^{(1)}}\left(\xi\right) d\xi\,, \tag{2.2}$$

where $f_{\hat{e}^{(\bullet)}}\left(p\right)$ is the distribution of $\hat{e}^{(\bullet)}$. Further, if N is allowed to be a random variable, the distribution of $\hat{e}$ (marginalizing over N) could be found as a weighted sum of distributions $f_{\hat{e}^{(N)}}\left(p\right)$ summed over all possible N.

The CSMAC assumed that the maximum number of simultaneously transmitting UEs in a 1 ms subframe of a 10 MHz channel is 6 (see Appendix A). However, the maximum number *N′* of UEs that are *allowed* to emit simultaneously can be controlled by settings in the Evolved Node B (eNB). The number of UEs that *actually do* emit simultaneously is a complicated function of the channel bandwidth, channel fading, greediness of the scheduler, and various details of the control messaging and grant allocation. One simulation study [8] showed that the distribution of the number of simultaneously emitting UEs is peaked at *N′* if *N′* is less than approximately 6, but is peaked at less than *N′* when *N′* =9. Further study is needed to better understand how realistic network configurations affect *N*, its distribution, and the distribution of $\hat{e}$.

The deterministic terms from (2.1) can be collected in a single term *D* for convenience:

$$D = -L_{\mathrm{path}} + G_{\mathrm{r}}\left(\theta,\phi\right) - L_{\mathrm{pol}} - L_{\mathrm{rec}} - R - \Pi\ . \tag{2.3}$$

The coupling between the UE and the victim DoD receiver is characterized by $\hat{L}_{\mathrm{clutter}} + D$. It should be noted that the loss terms in (2.3) and their interpretation, uncertainty, and correlation will affect the quality of the interference estimation. For example, if the UE orientation, local environment, and elevation are not accurately accounted for, these terms could dominate the uncertainty of the interference calculation. Furthermore, the local environment of the UE affects both the propagation path between the UE and the victim DoD receiver (characterized by $\hat{L}_{\mathrm{clutter}}$) and the propagation path between the UE and eNB, with the later affecting the power generated by the UE and its probability distribution. While the clutter loss term, in principle, handles the shadowing and fading losses between the UE and victim receiver, it does not account for similar effects in the path between the UE and eNB. This latter effect of local environment is implicit in the UE EIRP and its distribution.

The frequency-dependent rejection term *R* is a function of the government receiver selectivity and the UE emission spectra. The emission spectra are a complicated function of the UE mode of operation, resource block allocation, various details of the control channel allocation and power control, and the guard band between blocks. Furthermore, licensees with adjacent frequency blocks in the same geographic area can combine uplink bands to form 10, 15, or 20 MHz blocks. Use of realistic spectrum information that includes guard bands and control channel allocations could provide significant portions of the AWS-3 band, at the block edges, with much less interference levels than are currently calculated, based on the CSMAC assumed flat spectrum. Further study is needed to understand realistic UE spectra and realize these benefits.

The DSO has also recruited other organizations to better inform their calculation of aggregate interference with DOD assets, including the NTIA Institute for Telecommunication Science (ITS), Virginia Tech Advanced Research Center (VT-ARC), Georgia Tech Applied Research Corp., Excelis, Harris Corporation, MITRE Corporation, and others for LTE modeling, simulation, and drive testing. An extensive summary of this work is given in [9]. We do not attempt a review of the above work here, but note as an example, that the MITRE team used the Riverbed Modeler (OPNET) to model an LTE network, design simulations, and collect statistics on the LTE uplink emissions. These simulations helped to create a cumulative distribution function (CDF) of LTE uplink transmit power values from UEs throughout various locations in a cell. The CDFs were used to perform a sensitivity analysis of uplink power CDF based on inter-site distance (ISD), UL demand, and network congestion and laydown [10]. The resulting simulations deviated from the original CSMAC findings, but the cause was unknown. In addition, ISD, UL demand, and network congestion and layout were confirmed to significantly change the transmit power CDF.

The MITRE team extended their LTE emission work into drive testing to better understand the effects those added environments on the transmit power CDF curves. The drive tests considered the following factors that could affect UE transmit power statistics:

- Inter-site distance
- Cell site antenna height
- Propagation loss environment
- Neighboring cell interference
- UE traffic demand

However, multiple factors were varied simultaneously, but not systematically, making it difficult to determine the effect of any individual factor. General findings and trends included;

- The urban, suburban, and rural morphologies all have distinct CDF curves, showing how UE transmit power increases/decreases with the varying morphologies
- Using only two morphologies, based on CSMAC, may cause the UE power to be significantly under- or over-estimated in some areas. There is greater than 10 dB difference in power between the suburban drive tests by two different wireless network operators (WNOs) and the CSMAC suburban/rural CDF curve.
- The rural drive tests by two different WNOs both show power levels much higher (≈6 dB) than CSMAC suggests.

3 Objective

The objective of this NASCTN test plan is to describe how to empirically estimate parameters, pertaining to the UE emissions and physical resource block (PRB) usage, that contribute to the interference equation (2.1) while controlling or mitigating some of the uncontrolled variables of previous measurement efforts. These estimates will attempt to capture behaviors of actual deployed UEs and will include an uncertainty analysis based on an evaluation of the assumptions and sources of uncertainty in the measurements. In particular, the parameters of interest in this study are:

1. $E^{(1)}$: The distribution of EIRP emitted by a UE in a 1 ms subframe, marginalized (averaged) over the cell spatial distribution.
2. The emitted spectrum of an actively transmitting UE.
3. *N*: The number of UEs emitting into a 5 MHz or 10 MHz band per 1 ms subframe per cell (#UEs/MHz/ms/cell).

Also of interest for Phase 2, but of secondary importance is

4. Characterization of the accuracy of UE self-reported power and its correspondence to the EIRP.
5. Development, validation, and documentation of the field measurement procedures of Phase 2.

NASCTN plans to achieve the objectives in two phases. The first phase will be laboratory based and the second phase will include field measurements. Phase 1 will focus on estimates based on laboratory measurements of the above parameters, facilitating more control of critical variables than will be achievable in field tests. Specifically, laboratory experiments will allow us to control and manipulate the key variables that can affect the UE behavior, including eNB power control variables and scheduling algorithms, propagation channel, traffic type, and in-cell and adjacent-cell loading. Such control will be critical for the sensitivity analysis required for analysis of uncertainty in both the laboratory measurements and Phase 2 field measurements leading to estimates of the above parameters. Phase 1 will allow development, validation, and documentation of test procedures for Phase 2 before the start of that in-field measurement campaign.

Furthermore, controlled experiments, combined with systematic design of experiment procedures, will allow NASCTN to assemble a predictive model for the above parameters that depends on all factors tested. These models could be used by the DSO to tailor the CDF input into the EEPAC to the specific network laydownof a coordination request (CR).

4 Scope

The study will specifically address the characterization of LTE Frequency Division Duplex (FDD) signals and groups of signals (*i.e.*, emissions from multiple UEs transmitting simultaneously) in the UL frequencies of 1755 MHz to 1780 MHz. As described in Section 3, the signal statistics obtained from these measurements can feed into the interference calculation of (2.1) as implemented in the EEPAC. The goal of this characterization, with a documented methodology and uncertainty, is to give AWS-3 stakeholders more confidence in the Coordination Request Evaluation (CRE) process.

Phase 1 of the study will be limited to estimates of the variables listed in Section 3 above, based on laboratory measurements, with analysis of the effects of key variables that can affect the UE behavior: eNB power control variables and scheduling algorithms, propagation channel, traffic type, and in-cell and adjacent-cell loading.

Phase 2 will extend Phase 1 to include field tests. NASCTN will develop a separate test plan for Phase 2 incorporating results and lessons learned from Phase 1.

5 Deliverables

The deliverables of Phase 1 of this study are predictive models of the following parameters based on laboratory measurements:

1. The distribution of $E^{(1)}$; the EIRP emitted by a UE in a 1 ms subframe, marginalized (averaged) over the cell spatial distribution. Distributions of both peak and root-mean-square (RMS) EIRP in a 1 ms subframe will be reported.
2. The emitted in-band spectrum of an actively transmitting UE. This will be delivered as a series of spectra, showing the relative power level in each part of the LTE channel when the DUT UE is actively transmitting, and metadata regarding which PRBs are in use by the DUT UE.
3. N: The number of UEs emitting into a 5 MHz or 10 MHz band per 1 ms LTE subframe per cell. This will be presented as a series of distributions depicting the probability of N=1, 2, … UEs being active.

The estimates will include an analysis of the assumptions and measurement uncertainties and their effect on the uncertainty of the estimated parameters.

Secondary deliverables are:

1. Characterization of the accuracy of generated power as reported by the UEs available for testing and its correspondence to the EIRP
2. A Phase 2 plan for field measurement of the above variables.

6 Phase 1 Measurements

Conceptually, the first deliverable – distribution of EIRP emitted by a UE – can be empirically measured by measuring the output of a UE as it traverses through a cell and then pooling the data over the cell[2]. In the real world, this can be accomplished by monitoring a UE via diagnostic monitoring software as it completes a drive test. This real-world approach can be problematic because there are many uncontrolled variables and sources of error: the accuracy of the self-reported power, the repeatability of the drive test, the unknown eNB configuration, etc.

The goal of the Phase 1 measurements is to develop a realistic, laboratory based scenario that will enable empirical measurement of parametric deliverables while controlling the measurement configuration. This will not only allow measurement of the parameters of interest, but also enable the determination of the sensitivity of those parameters to the system settings and configuration. In turn, this will give an understanding of which system laydown and configuration variables are most significant in the interference aggregation calculation.

The above scheme can be replicated in a laboratory setting by use of an eNB, UE, vector signal analyzer (VSA), and channel emulator. The channel emulator can simulate changes in the propagation environment between the UE and eNB as the UE virtually changes position relative to the eNB. During these changes in propagation, the VSA can measure the power emitted from the UE in different channel conditions.

This measurement setup can also yield information on the second deliverable – the emitted in-band spectrum of a UE. Though it can easily be measured, for these data to be of value, the PRBs assigned to the UE must be known. With this information, the measured spectrum can be correlated with a given number of PRBs and plots of the emitted spectrum can be produced for each PRB configuration that was observed. Knowledge of the assigned PRBs can come from a wireless protocol analyzer in real-world measurements, or it can come from having control of all the UEs in a cell in a laboratory setting. If the fidelity of the spectrum measurement is sufficient, it is possible to infer the PRBs in use directly from the spectrum measurement. To do this, each sub-carrier in the subframe needs to be resolved and analyzed.

The third deliverable – the number of UEs emitting into a channel in each subframe – requires knowledge like that required to produce the second deliverable. One needs to have some knowledge of the other UEs in the cell, which ones are active, and what resources they are assigned. In the real-world, this can be obtained by use of the wireless protocol analyzer mentioned above. But in a controlled, laboratory setting, a UE traffic generator (UTG) can be used to generate traffic and load the eNB. When the demand for eNB resources is large, there will be more UEs requesting resources than can be accommodated in a single subframe. The eNB will then schedule – based on demand – some number of UEs to transmit in each subframe. The scheduling/resource allocation information can be obtained from the logs on the UTG or from the use of the protocol analyzer in the laboratory setting.

Fig. 2 graphically depicts the laboratory setup discussed above. In this setup, there are two adjacent cells, each populated with enough UEs to sufficiently load the scheduling algorithm in the eNB. These “loading UEs” will be distributed throughout the cells in static positions. A “device under test (DUT) UE” will

[2] Here we assume ergodicity, *i.e.*, we assume that the power emitted by a single UE, pooled over different positions in the cell is distributed identically to the distribution of power emitted by an ensemble of many UEs placed throughout the cell and emitting individually at any given instant.

then be virtually placed, at different locations in Cell $\mathcal{A}$, and its emissions measured, along with its PRB allocations and the PRB allocations of the loading UEs. The detailed use of the loading UEs will be discussed in Section 6.3.

A detail of Cell $\mathcal{A}$ from Fig. 2 is shown in Fig. 3. Here, we see that at each DUT UE location, a propagation channel between the UE and eNB will be accounted for as part of the UE emissions measurement. Also, the emissions from the loading UEs in the adjacent cell will be present (at an appropriate amplitude) within Cell $\mathcal{A}$ and at the radio frequency (RF) ports of the eNB.

Replicating this scenario in a laboratory setting will enable the control of the cell size, distribution of loading UEs, placement of the DUT UE, influence of adjacent cell emissions, eNB power control parameters and scheduling algorithms, and the propagation channel. Each of these variables can be adjusted individually, allowing for a characterization of UE emissions and resource block allocations across a variety of scenarios.

The setup depicted in Figs. 2 and 3 is realized in terms of laboratory equipment in Section 6.1 and discussed in detail in Sections 6.3-6.12. These sections outline the detailed configuration of each key piece of laboratory instrumentation required to replicate the setup described above. Section 6.2 provides a high-level overview of the instrumentation required.

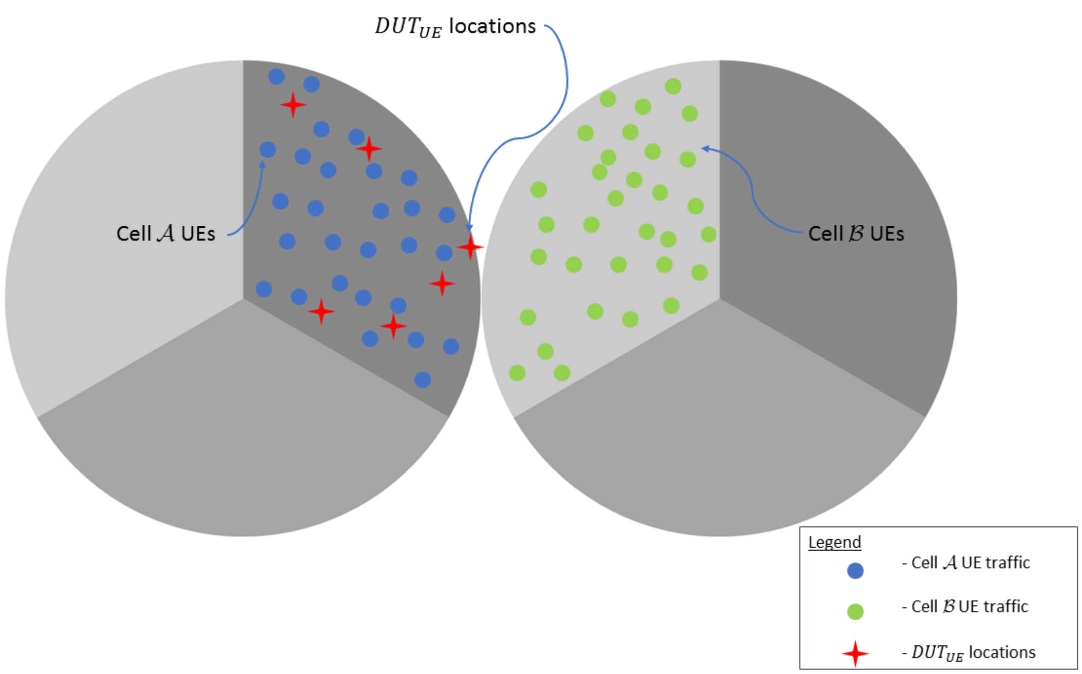

Figure 2. The hypothetical scenario being replicated by the Phase 1 laboratory testing.[3]

[3] *Note:* These figures are shown for illustrative purposes only. Technical details of the cell configurations are discussed throughout Section 6.

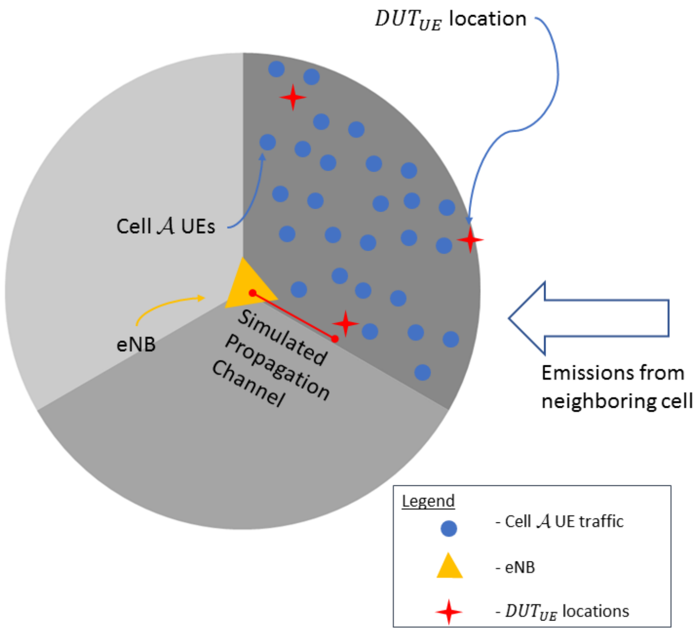

Figure 3. A more detailed schematic of the hypothetical cell shown in Fig. 2.

6.1 Test Description

The test setup shown in Fig. 4 seeks to realize the hypothetical scenario shown in Figs. 2 and 3. This realization involves two commercial macro-cell-loaded eNBs and a UE traffic generator (UTG, sometimes referred to as an "LTE radio access network (RAN) load tester") to simulate the loading UEs. The cells can be serviced with two separate commercial eNBs, or with a single eNB capable of supporting two cells. A controlled DUT UE will be inserted into Cell $\mathcal{A}$. This DUT UE will be a real, commercially available UE that attaches to the same cell as the loading UEs and is assigned resources from the eNB's scheduling algorithm. Both the loading UEs and the DUT UE will transact a specified data type (*e.g.*, UDP) at a specified data rate.

Previous work [10] posited that the emissions of UEs located in an adjacent cell can influence the radiated power level of a UE (or a group of UEs) in another sector. In essence, the adjacent cell UEs increase the noise floor in the cell-of-interest and cause the UEs to transmit more power to overcome the increased noise. This effect is accounted for in the laboratory testing proposed in Fig. 4. The amount of adjacent cell influence can be controlled via the combination of three variable attenuators and two directional couplers. The amount of influence from Cell $\mathcal{B}$ should be appropriate given the selected propagation conditions and cell size.

The DUT UE is drawn as being connected to a directional coupler with the output port connected to a diplexer (splitting/combining the uplink/downlink), and the side-arm connected to the input of a vector signal analyzer (VSA). The VSA is used to collect the emission spectra of the DUT UE during the test.

The output of the coupler is passed through the diplexer, and connected to a channel emulator. This channel emulator simulates the desired propagation channel between the DUT UE and the eNB. Both the uplink and downlink channels are passed through the emulator, but because they are at different frequencies, the channels are slightly different. The signal generator shown supplies the uplink and downlink carrier frequencies; a requirement for some channel emulators. The output of the channel

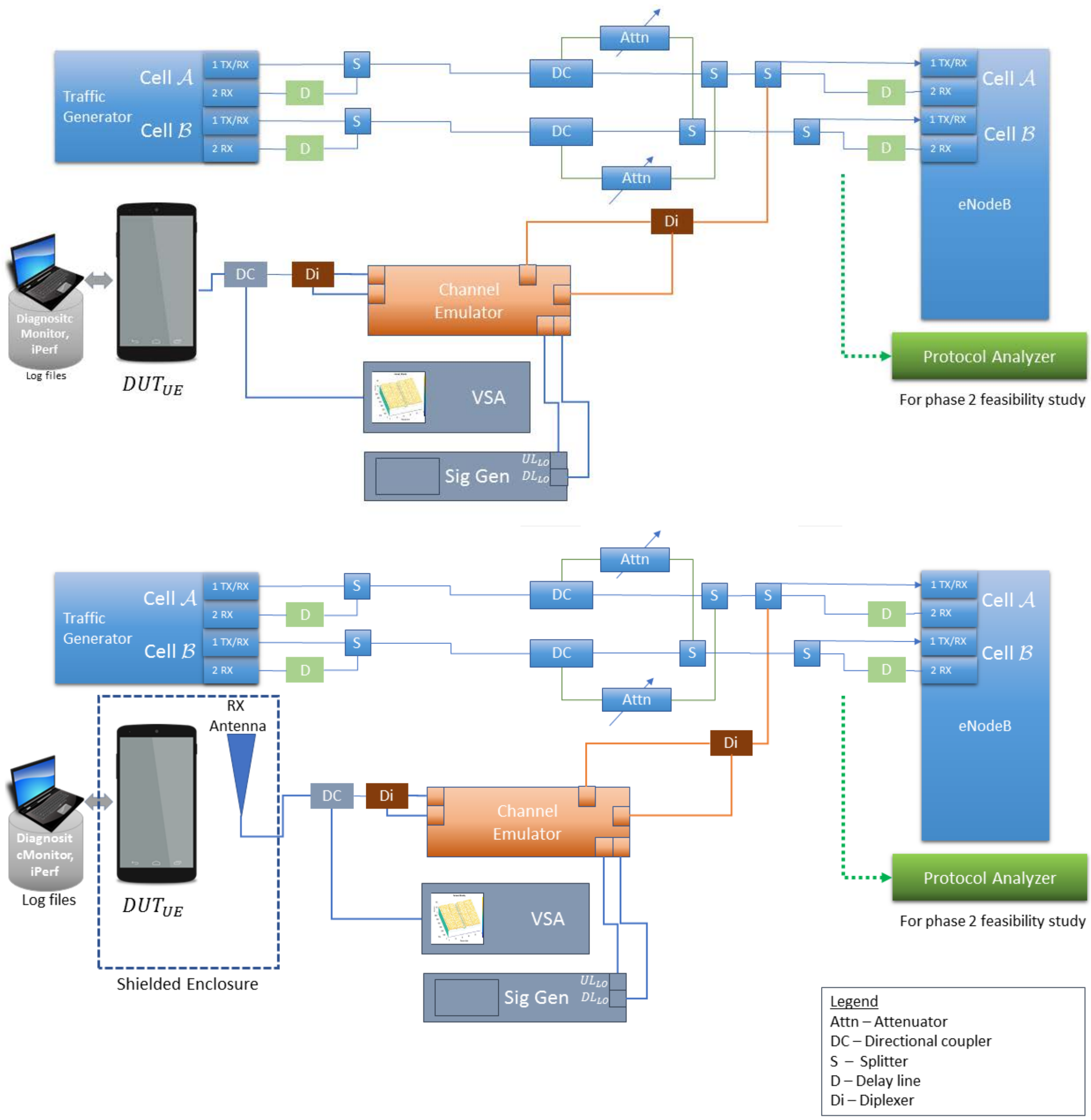

Figure 4. Phase 1 measurement system schematics. The top diagram (a) shows the configuration for conducted testing, while the bottom figure (b) shows the configuration for UEs that must be tested using a radiated method.

emulator passes through another diplexer and is combined with the loading UEs. The combined signal is fed into the eNB. Note that if the channel emulator is capable of full duplex operation, the diplexer may not be required.

During the measurement process, the DUT UE will run diagnostic monitoring software capable of capturing the self-reported transmit power. These data will be transferred to a computer and recorded. Data will be timestamped, such that they can be lined up with captures from the VSA for further analysis.

For the purposes of investigating potential Phase 2 measurements of live networks, an LTE protocol analyzer is inserted into the system adjacent to the eNB. This analyzer will capture, decode, and record the LTE traffic. These data can then be used to help understand how many UEs are transmitting in any given LTE subframe. While these data can also be gathered from a combination of the VSA and the UTG, the use of this protocol analyzer in phase 1 will help facilitate its use for in-field data collection in Phase 2 where the loading UEs are replaced with live UEs.

Note that both the uplink and downlink signals are passed through the physical layer in this measurement setup. In the case of the loading UEs, the downlink signals are passed back through the same combination of splitters and couplers as the uplink signal. The uplink/downlink signal for the DUT UE is split via a diplexer and handled separately in the channel emulator.

Below, the detailed description and configuration of each element are given, along with a sample measurement sequence. Specific configuration parameters will be varied with a design of experiment strategy (described in Section 8.3) to determine the sensitivity and cross-dependence of the measurands on each parameter.

6.1.1 Channel Emulation

One of the key aspects of this test is how the propagation channel will be emulated. The propagation channel, and its emulation, can impact the emissions of the DUT UE, allocation of PRBs, and the signals from the adjacent cell (Cell $\mathcal{B}$).

In this test, there are three different propagation channels that must be accounted for: the channel between the DUT UE and the Cell $\mathcal{A}$ eNB, the channel between the loading UEs in Cell $\mathcal{A}$ and the Cell $\mathcal{A}$ eNB, and the channel between the loading UEs in Cell $\mathcal{B}$ and the Cell $\mathcal{A}$ eNB.

In the above test description and diagram, each of these three channels are accounted for in a different manner. The channel between the DUT UE and the Cell $\mathcal{A}$ eNB is handled by a dedicated channel emulator. As described below, this channel emulator will have enough fidelity to implement custom channel models that account for path loss, fading, and clutter parameters. This fidelity is necessary as the ability to emulate this propagation channel has a direct impact on the accuracy of the final results.

The channel between the Cell $\mathcal{A}$ loading UEs and the Cell $\mathcal{A}$ eNB is implemented by use of the UTG. Most UTGs implement some form of propagation loss and channel characteristics (generally defined in 3GPP specifications). These implementations are generally done in the signaling layers, not in the physical layer. These channels will be of lower fidelity than the DUT UE/eNB channel, but in this case, the primary goal of this propagation channel is to ensure that the loading UEs are assigned PRBs in ways that are consistent with the environment they're in.

The fact that the channels are implementing in the signaling layer is not necessarily a disadvantage. The primary goal of the Cell $\mathcal{A}$ loading UEs is to load the Cell $\mathcal{A}$ eNB scheduler. Thus, as long as the Cell $\mathcal{A}$ eNB thinks the loading UEs are in a given RF condition, the scheduler will allocate resources accordingly. The RF waveform associated with the loading UEs is not of interest to the DUT UE as it won't receive or sense the UL signal of the loading UEs.

The third channel – between the Cell $\mathcal{B}$ loading UEs and the Cell $\mathcal{A}$ eNB – is accounted for via RF attenuators. In this case, there is no signaling between these UEs and the Cell $\mathcal{A}$ eNB. The Cell $\mathcal{B}$ loading UEs serve only to raise the noise floor in Cell $\mathcal{A}$. Thus, we only need to ensure that the amplitude of the RF signal impinging on the Cell $\mathcal{A}$ eNB port is appropriate given the desired propagation channel.

When selecting a channel to be emulated, it is imperative to ensure that a similar channel is modeled in each of the three implementations. Discrepancies in the channels being modeled may result in biasing the results. For example, giving the loading UEs a more favorable propagation channel than the DUT UE (when it isn't warranted) may result in the eNB scheduler allocating resources in an unrealistic manner, potentially impacting the DUT UE's distribution of radiated power.

6.2 Summary of Test Equipment

The equipment needed to conduct these measurements are as follows:

1. Macro-cell eNB hardware capable of serving two cells, with the ability to handoff from one cell to the other. If possible, testing should be performed with hardware from multiple vendors (*e.g.*, one test with two Nokia cells, one test with two Ericsson cells)[4].
2. An LTE UE Emulator/Traffic Generator capable of generating LTE traffic in two cells and capable of loading both cells such that UEs are requesting more resources than are available in a single frame. The number of UEs in a cell during a test is discussed in Section 6.3 and is analyzed in the factor selection tests discussed in Section 8.3.
3. Channel emulator capable of emulating both uplink and downlink channels for mobile scenarios. The signal generator shown in Fig. 4 is included as some channel emulators require that a continuous wave (CW) carrier be provided as an external input; one at the uplink frequency, and one at the downlink frequency. The emulator should support the input of user-defined channel models for rural, suburban and urban canyon environments and for terrain (flat and hilly) features.
4. Wireless LTE Protocol Analyzer capable of capturing the LTE traffic. This traffic may be decoded in real-time, or stored and decoded after the measurement. The analyzer must be capable of capturing the downlink control information (DCI) messages, as well as the cell radio network temporary identifier (C-RNTI) information.
5. UE Diagnostic Software capable of recording the UE transmit power. Note that not all diagnostic software applications are compatible with all UE chipsets. The output of this software should be timestamped so it can be correlated with data from other instruments (*e.g.*, VSA and UTG).
6. Vector signal analyzer (VSA) or real-time spectrum analyzer, capable of continuous data streaming over greater than the channel bandwidth without loss of data. If possible field programmable gate array (FPGA)-based trigger on events with a defined frequency-domain threshold.
7. Several DUT UEs that are representative of the UEs deployed in the band of interest:
    a. If the DUT UE output signal is conducted, then appropriate cabling will be required to connect the UE to the rest of the measurement system.
    b. If the DUT UE output signal is radiated, then a shielded enclosure (preferably anechoic) will be necessary to isolate the emissions from the ambient signals. An antenna will be placed inside the shielded enclosure and connected to the measurement system.
8. Directional couplers that have a flat response across UL and DL bands.
9. 3 dB splitters that have flat response across UL and DL bands (6 dB resistive splitters can also be used).
10. Variable attenuators.
11. Delay lines that can delay the transmitted signal arriving at the eNB, or the downlink signal arriving at the UTG. These delay lines enable the UTG and eNB to utilize receive diversity.
12. Diplexers for the selected UL and DL bands.

6.3 UE Traffic Generator Configuration

The UTG should emulate enough UEs to load the scheduler in the eNB. A loaded cell is crucial to demonstrating uplink scheduling behavior.

UEs will be simulated in locations spread throughout the cell coverage area to determine the effect of UE placement on eNB scheduling behavior. Three UE distributions will be used: 1) UEs placed in a tight

[4] Trade names are used here to describe possible measurement configurations and do not imply an endorsement by NIST or NASCTN. Other equipment may work as well or better for the work described here.

cluster immediately adjacent to the eNB, 2) UEs distributed around the edge of the cell, but configured such that they do not get handed off to the adjacent cell, and 3) with a random distribution throughout the cell. Note that the geographic size of the cell is also defined in the UTG.[5] The cell size used should correspond to the different morphologies of interest. Information on the statistics of cell sizes could come from WNOs, or approximations of cell sizes for different morphologies can be found in [5] and [11-13]. The size of the cell is one of the variables considered in testing, and is discussed in Section 8. Channel models for the emulated UEs will be determined later, based on the final morphologies selected for testing. However, it is important to note that different traffic generators model channels differently. Some UTGs model channels in the signaling layer, some in the physical layer, and some use a combination of both. Any of the three can be adapted for the testing described here.

In a similar vein, UTGs do not account for the antenna pattern of the base station, it's height, or it's down tilt. The height and down-tilt of the base station antennas is roughly accounted for when a sector is defined to have a given radius in the UTG software. Base station antenna patterns are generally assumed to be uniform and not specifically accounted for in the UTG.

The uplink traffic will be of user datagram protocol (UDP) type, which requires no handshaking from the receiving end. Since minimal downlink traffic is required, the uplink traffic flow will not be interrupted if the downlink traffic is restricted. Voice or voice over LTE (VOLTE) traffic[6] can be generated if the UTG can do so, but the network infrastructure (*e.g.*, internet protocol multimedia subsystem (IMS)) behind the eNB must also be able to support such traffic.

The exclusive use of UDP traffic is not without drawbacks. There is some indication [13] that the amount of power a UE will transmit varies based on whether the UE is in "voice mode" or "data mode." Though calls (voice or VOLTE) are still made, in terms of PRBs, they represent a small fraction of the total allocated PRBs. That is, the use of other data functions on UEs (*e.g.*, video, web browsing, etc.) are so prolific that the clear majority of allocated LTE PRBs in the United States are allocated for the use of data, rather than voice traffic [14].

The UE's data rate can be one of the variables investigated. To load the eNB scheduler, it can be set to the maximum (and the transmit buffer kept full with data). Data rates (also referred to as "data demand" or "offered load") can be made variable if further information on the number of active UEs or their data rates in a given scenario is available (from a WNO or from Phase 2). Scenarios involving UEs that are periodically idle, or UEs that have less than full transmit buffers can be tested by use of this method. Tests under these conditions may result in different outcomes for the number of UEs transmitting/frame (deliverable #3).

In addition to the UTG, some supporting hardware that isn't shown in Figure 5 may be necessary. This hardware includes server(s) for generating the loading UE traffic and server(s) that act as a destination for the DUT UE and loading UE traffic. Servers used will need to be configured in such a way as to not interfere with the physical layer testing being performed. That is, these servers should be capable of supporting a sufficient amount of throughput.

6.4 Macro-cell eNodeB Configuration

The eNB will be configured as closely as possible to the configuration that is used by WNOs[7]. However, some variations should be explored to determine if there are significant effects on the UE output power and the number of UEs using any given subframe.

[5] Because the testing is conducted, UTGs generally ignore the pattern and tilt of the base station antenna.

[6] A UE with VOLTE traffic will appear in more subframes than when loaded with UDP traffic. The use of VOLTE traffic is not likely to affect the measurement results of Phase 1. Traffic type will change the frequency at which any given UE appears in multiple subframes.

[7] WNO feedback is critical for this aspect of the measurements.

It is crucial that the eNB(s) used in these measurements can support enough active connections to sufficiently load the scheduling algorithm. Certain software defined implementations may not be able to support enough simultaneous active connections to create the desired loading effect. Most eNBs have a configurable parameter that determines the maximum number of connections. For the tests described here, that parameter should be set high enough that it does not impinge on the number of UEs transmitting in each subframe and allows for the scheduling algorithm to be loaded.

There can be over 2400 parameters that control the behavior of an eNB. The quantities that control the UE uplink transmissions are fewer, but still a significant number. Some parameters of interest are (*Note:* the exact name of these parameters may vary based on eNB vendor):

- Maximum number of users per transmission time interval (TTI) in UL
- Method for UL power control
- UL improved latency reaction timer
- Scheduling method of the UL scheduler
- Initial maximum amount of PRBs in UL
- Extended uplink link adaptation low PRB threshold
- UL scheduler frequency domain (FD) type

Handovers can be controlled in multiple ways, for example, to provide load balancing between cells, to provide maximum coverage, or to provide maximum capacity. One particular eNB make and model has more than 50 parameters to control handover. Load balancing handovers may significantly increase the UE transmit power as it will attempt to push UEs from an overloaded cell to a neighboring lightly loaded cell despite the increased distance (and loss) between the UE and eNB. Therefore, load balancing handover configurations should be tested with a heavily loaded cell next to a lightly loaded cell. The measurement of emissions during handover situations will be measured in a separate set of measurements, as detailed in Section 6.9.

During measurement, the serving and adjacent cells should be fixed to the same frequency channel. This will help ensure that the uplink resources are restricted to a single 5 MHz or 10 MHz channel. Giving the cells access to the full frequency band will cause the scheduling algorithm in the eNB to distribute the load across all available channels. If the cells are fixed to a frequency, the loading UEs and DUT UE will automatically use the same frequency channel when assigned resources by the eNB.

Most macro-cell eNBs utilize receive diversity when receiving signals from UEs. We only monitor a single output of the UE. Receive diversity in the eNB is implemented with splitters and delay lines as it may have an impact on the received SNR at the eNB and consequently how much power the UE transmits or the scheduling of the UE. While simplifying the hardware, this configuration forces the SIMO inputs to the eNB to be correlated. The effect of this correlation will be investigated in the early stages of the project and if a significant error is observed, a channel emulator with sufficient channels for each eNB input will be utilized for subsequent tests.

For the purposes of these tests, the same eNB vendor should be used for both Cells $\mathcal{A}$ and $\mathcal{B}$. This ensures that the cells have identical configurations. Cases where Cell $\mathcal{A}$ and Cell $\mathcal{B}$ are serviced by eNBs from different vendors could be tested, but these scenarios are expected to be rare, and may introduce additional complexity into the test.

If desired, testing can be done both with the intercell interference coordination (ICIC)/enhanced ICIC (e-ICIC) features enabled or disabled. In deployed network configurations, some eNBs may make use of e-ICIC to prevent neighboring eNBs from causing interference. e-ICIC features are most often used when a larger macro-cell encompasses a smaller pico-cell (*e.g.*, to provide improved indoor coverage).

Regardless of the configuration of ICIC/e-ICIC, the X2 interface between the eNBs should be enabled and setup. This interface will allow the eNBs to communicate during handover scenarios, as discussed in

Section 6.9. If the X2 interface is not enabled or available, it will result in the DUT UE being detached and reattached (also known as a handoff) rather than handed over.

6.5 DUT UE Configuration

The default UE configuration should be sufficient for these measurements (*i.e.*, the standard commercial configuration) because the UE’s relevant behavior will be dictated by the eNB during the measurements. Diagnostic monitoring software will be used to collect self-reported information from the UE. Such information includes: UE transmit power, number of PRBs used, modulation and coding scheme (MCS), and handover events. Depending on the software used, additional parameters of interest may be collected from the monitoring software for future use, including but not limited to power headroom and e-UTRAN messages.

The diagnostic monitoring software used should be capable of capturing the above information from the UE’s chipset. It is important to use diagnostic monitor software that does not interfere with or influence the operation of the UE. Most diagnostic monitoring software available from chipset vendors does not influence the operation of the UE. However, the use of monitoring “apps” installed on the DUT UE may unduly influence the operation of the UE and thus the measurement results.

Data sent from the UE to the eNB (and onward to the internet protocol (IP) side of the network) will be generated by use of commonly available tools for generating network data streams. This data stream will originate from the UE and go to an application server accessible from the LTE network.

The number and type of UEs tested in these experiments is an aspect of the test that is left up to the end user/sponsor. Multiple UEs may be tested to understand variations that exist from UE to UE and are another factor to consider in experimental design (see Section 8.1 and 8.3). Variations from UE to UE may be seen in the self-reported terminal power/EIRP. Variations in PRB usage are not expected as this behavior is controlled by the eNB.

6.6 Channel Emulator Configuration

The channel between the DUT UE and the eNB will be simulated via the channel emulator shown in Fig. 4. This emulator will simulate a slightly different propagation scenario as the DUT UE moves virtually around the cell to different positions. Each propagation scenario will be calculated from the ITU-R P.1546-5 [15] point-to-area propagation models or other models. These models use interpolation and extrapolation from empirically-defined field-strength curves based on distance, base antenna height, frequency and percentage of time above the median value in the area. They also add corrections to account for clutter near the base station and the terrain clearance angle of the UE antenna. The propagation loss for each scenario (*i.e.*, UE location in the cell) will be calculated and the result input into the channel emulator. Regardless of the channel emulated, the uplink and downlink channel fading should be uncorrelated. We expect that the UE EIRP will be directly related to the channel loss, so the channel model and its uncertainty will be of critical importance in this study

In the measurements discussed here, only static loading UE and static DUT UE positions are considered. The use of dynamic UEs (*i.e.*, UE following a virtual drive test path) is possible, but careful synchronization between the acquisition instruments would be required (UTG, VSA, channel emulator, and UE diagnostic monitoring software). From a statistical perspective, the meaning of the output of dynamic measurements may be less clear as the UE EIRP is then calculated over a 3D path instead of at fixed locations.

The use of static UE locations also enables better control over handover and attach/detach scenarios. These scenarios are discussed in more detail in Section 6.9.

As discussed in Section 6.3, three loading UE configurations will be used. For each of these configurations, the DUT UE will be moved virtually (via the channel emulator) to various points throughout the sector. The DUT UE locations will be determined at random for each test case. Other details related to this sampling are discussed in Section 8.

In addition to the channel emulator shown in Fig. 4, some UTGs are also capable of emulating a channel for the loading UEs. Caution must be exercised here because not all aspects of the channel model are implemented in the physical layer, and thus may not have an impact on the measured UE emissions. However, channel models not implemented in the physical layer may still have a measurable impact on the usage and allocation of resource blocks; simulated poor channels will cause a drop in MCS and the number of available resource blocks. If a channel model is implemented between the loading UEs and the eNB, the same model should be used between the adjacent cell loading UEs and the eNB. The channel model implemented for the loading UEs should be similar to the channel model used on the DUT UE.

Regardless of the DUT UE used, a correction needs to be applied to the channel loaded into the emulator to account for the effects of the path between the DUT UE and the channel emulator. For conducted DUT UEs, this correction accounts for the conducted path between the UEs and the channel emulator. When a radiated DUT UE is used, the correction will include the effects of the radiated channel between the DUT UE antenna and the receiving antenna in the shielded enclosure as well as the conducted path between the receiving antenna and the channel emulator. Any aspects of this path that can't be corrected for should be accounted for in the uncertainty of the measurement, as discussed in Section 8.4.

6.7 Use of LTE Protocol Analyzer

An LTE protocol analyzer will be used in Phase 2 field measurements. This device monitors both uplink and downlink transmissions in the cell. It can decode all messages between the eNB and the UEs in the cell (excluding payload), although encryption can influence the amount of information that can be read on a live network. The number of UEs and number of resource blocks per TTI can be determined from the captured messages. Individual UEs can be distinguished (but not identified) as their C-RNTI is also captured.

6.8 Data Measured and Collected

Data will be collected from four of the instruments shown in Fig. 4: the UTG, VSA, wireless protocol analyzer, and UE diagnostic monitor. No information will be collected from the eNB. This is because most eNBs only collect data in 15 minute increments; a resolution that is too coarse for use in these measurements. Alternatively, IP packet captures from the network connection between the eNB and the LTE network core may yield some information on UE attaches and data rates, but in these measurements, these data are more easily collected from the other instrumentation.

From the VSA, in-phase (I) and quadrature(Q) samples[8] leading to direct measurement of the UE radiated power will be collected. The waveform will be sampled at a rate high enough such that effects of the VSA anti-aliasing filter response, Nyquist sample rate effects, and local oscillator leakage effects can be minimized. The data will be streamed to a fast RAID (redundant array of independent disks) without dropping samples over a pre-determined time interval (the specific time interval will be discussed in Section 8.3). Exact data streaming rate and data storage requirements are dependent on the specific hardware used for implementation.

From the UTG, the entire DCI for each subframe, the C-RNTI, reference signal received power (RSRP), radio resource control (RRC) messages, and non-access stratum (NAS) messages will be collected. These data are not accessible in real-time, so they will be examined during post-processing.

[8] Capturing power as a function of time and frequency from sampled time-domain data would be sufficient, potentially reducing requirements on data streaming rate and data storage. Particular note should be made of the windowing and record length used with the Fourier transform, as they can affect the estimated power of waveforms that differ from white Gaussian noise.

The UE diagnostic software will provide the self-reported UE transmit power, number of PRBs used by the DUT UE, MCS, and information on handover events. Like the UTG, these data are not accessible in real-time, so they will be examined during post-processing. Additional parameters of interest may be available including, but not limited to, power headroom and e-UTRAN messages.

The wireless protocol analyzer will collect the DCI messages and C-RNTI information from all the loading UEs and the DUT UE. In post processing, this information will be compared to the data acquired from the traffic generator as a precursor to Phase 2 in-field measurements on live networks.

During acquisition, data will be collected by each piece of instrumentation independently. This is a result of the fact that most UTGs and UE diagnostic monitors do not provide real-time data for on-the-fly processing. These instruments can be triggered to perform a task, but the output of the task is generally not available until the end of the measurement. Therefore, the data from each piece of instrumentation will be timestamped during acquisition and correlated in post processing. Through post processing, we can see what each piece of instrumentation recorded for a given LTE subframe. Pre-measurement checks of the measurement system will include a test to verify that the time synchronization is accurate enough to consistently align data at the subframe level.

This correlation will be essential for the use of the wireless protocol analyzer as events recorded from it will be compared to events from the UTG. Differences between the two will be noted and considered in preparation for Phase 2 measurements.

Data recorded from the diagnostic monitor and the VSA will be time correlated to investigate how close the UE self-reported transmit power is to the measured transmit power. This fulfills one of the secondary deliverables from Section 5 and may also be useful for Phase 2 measurements.

Once the data have been time correlated in post processing, the data can be separated into sets that can be used to compute the distribution of peak and RMS EIRP emitted by a UE. These data sets will then be calibrated to account for the measurement method. That is, if the DUT UE was radiated, corrections will be applied to account for the sensing antenna, loss through the shielded enclosure, and other factors discussed in 6.10 related to the measurement of TRP. If the DUT UE is conducted, the captured data sets will be corrected to account for the effects of the antenna and RF chain that were bypassed during the measurement of RF power at the conducted terminal. The VSA data can also be processed to show the in-band spectrum (power vs. frequency) of the DUT UE in various scenarios.

Identifying the number of UEs emitting into a given subframe and their resource block allocations can be done directly from the wireless protocol analyzer, or a combination of the UTG data (proving information on the loading UEs) and the data from the UE diagnostic software (providing information on the DUT UE). Here, the C-RNTI for each UE will be captured and an analysis of each unique C-RNTI number will be done to examine the individual resource blocks it was allocated and at what times the allocation occurred.

6.9 Measurements of specific events

The measurement setups shown in Fig. 4 can be used to measure three distinctly different scenarios of interest: 1) “normal” UE operation, 2) DUT UE emissions while the UE is attaching to the eNB, and 3) DUT UE emissions while the UE is being handed over from one cell to another. In scenario #1, all test variables should be swept through and the most thorough analysis done, as this is the most common UE mode of operation. Scenarios #2 and #3 can be examined for a limited number of cases (*e.g.*, with only two propagation channels, a reduced number of eNB configurations, etc.) with the intent that these scenarios will provide information relative to Scenario #1. In other words, scenarios #2 and #3 will enable one to conclude that the emissions during these types of events are relatively similar to, or relatively different than normal UE emissions (scenario #1). If indicated by these results, a more in-depth analysis could be conducted for the latter two scenarios.

When measuring scenario #2, the configuration of the UTG (excluding loading UE distribution, as discussed earlier), VSA, and wireless protocol analyzer remain unchanged from scenario #1. That is, the loading UEs should not be attaching/detaching[9]. What does change is that the DUT UE will be forced to detach from the eNB and reattach. During this time, its spectrum will be recorded on the VSA.

The crucial part of scenario #2 is the attach process. To capture a useful spectrum of the phone during an attach, the phone must be completely detached from the eNB, not simply idle or inactive. To ensure the DUT UE is detached, it can be temporarily put into "airplane mode", which turns off the LTE radio in the phone. This can be done by hand or script, but can take time, and increase the overall amount of time required for testing. A more efficient method is to force the UE to detach by use of the UE diagnostic software, or via UE debugging software (*e.g.*, the Android Debug Bridge software). The last two options enable the phone to be detached or put into airplane mode via a remote script, thus eliminating the human interaction. The use of these methods should not influence the measurement results.

The configurations in scenario #1 can be modified to measure cell-to-cell handovers (scenario #3) by adjusting the parameters in the eNB that control cell-to-cell handovers. Examples of parameters that influence when a eNB decides to hand a UE over to an adjacent cell include:

- A3 timing and offset (a neighbor cell RSRP is better than serving cell)
- A5 timing and thresholds (a neighbor cell RSRP is above a threshold and serving cell RSRP is below a different threshold)
- Enable better cell handover (Boolean value)
- Enable coverage handover (Boolean value)
- Load balancing profile
- Handover margin

UE handovers can occur for a variety of reasons (*e.g.*, UE movement, load balancing, etc.). When load balancing handovers are the subject of testing, the UTG will need to be configured to have a significantly larger number of loading UEs in the serving cell and a significantly lower number of UEs in the handover cell.

When conducting measurements of the hand over process, it is still suggested that the DUT UE not be dynamically moved via the channel emulator. The DUT UE should be *stepped* up to and over the serving cell boundary. At discrete locations on either side of the cell boundary, the VSA may be triggered to acquire data as in scenario #1. However, during the actual handover, data may need to be streamed from the VSA for the duration of the handover event.

The measurements associated with scenarios #2 and #3 are best done during the factor selection phase of the testing. Doing this will give an indication of how different the UE emissions are during these conditions and if a deeper analysis is warranted. This aspect of the experiment design is discussed in Section 8.

6.10 Determination of EIRP

Here, we adopt the IEEE definition [16] of equivalent isotropic radiated power (EIRP):

In a given direction, the gain of a transmitting antenna multiplied by the net power accepted by the antenna from the connected transmitter. Syn: effective isotropically radiated power.

However, for a system with an integrated antenna such as a typical UE, both terms in the definition are difficult, if not impossible, to determine. Even if the DUT UE provides a conducted test port that allows direct connection between the DUT UE and test equipment, the problem is just as difficult, since we do

[9] Loading UEs attaching/detaching could raise the noise floor affecting the DUT UE power. We expect/assume this is a high-order effect that will not significantly change the EIRP distribution.

not know the RF properties of the test port, the internal transmission line, or the antenna, and do not know if connecting to the test port disconnects the antenna or leaves it connected. As an alternative, we can obtain the same result by determining the TRP (Total Radiated Power) and directivity of the DUT UE. Here, we adopt a modified the definition of EIRP:

In a given direction, the directivity of a transmitting antenna multiplied by the total power radiated by the antenna (TRP) from the connected transmitter over the frequency channel of interest.

There are two standard procedures for determining the TRP of a UE, one in an anechoic chamber [17] (which gives information on both the TRP and the directivity), and another in a reverberation chamber [18] (this procedure as written is geared towards physically larger UEs, but can be used with the UEs anticipated for these tests with no modification), and either is suitable for our purposes. Other methods may be more accurate or reliable, and any method used in Phase 1 should be fully documented and/or referenced.

Note that, EIRP is always considered across the entire band of interest. This should limit the EIRP variations from subframe to subframe.

In general, conducted DUT UE measurements will be more robust and repeatable than radiated measurements. This motivates performing conducted tests for Phase 1 measurements. Unfortunately, few UEs manufactured after around 2015 have conducted ports, so we provide procedures for tests in both conducted and radiated modes

6.10.1 Conducted Tests

For conducted tests, a measurement setup diagram is provided in Fig. 4a. Here, the UE is connected to the channel emulator through a directional coupler. The UE power is measured through the directional coupler using a VSA, and the self-reported UE power is captured by the diagnostic monitoring software.

A conservative approach is to assume that TRP is equal to measured power (resulting in the highest radiated fields), but more realistic values may be more appropriate. For Phase 1, we will assume that TRP is simply a scaled version of measured power, with some nominal scale factor and distribution. This scale factor can then be adjusted or corrected later based on additional information or actual measurements of TRP.

6.10.2 Radiated Tests

For radiated tests, a measurement setup diagram is provided in Fig. 4b. Here, the UE is mounted to a fixture and placed a fixed distance from a sampling antenna connected to the channel emulator through a directional coupler. The power received from the sampling antenna is measured using a VSA, and the self-reported UE power is captured by the diagnostic monitoring software.

The measured received power should be proportional to the TRP, assuming a flat frequency response for efficiency and mismatch of both the UE antenna and the sampling antenna.

For Phase 1, we will assume that TRP is simply a scaled version of measured power, with scale factor determined by actual measurements of TRP.

6.10.3 UE Directivity

Once TRP is estimated, this can be converted to EIRP based on estimates or measurements of the directivity D of the UE. Based on the definition for EIRP given above, which is a function of the direction away from the UE. The process can be simplified by determining the maximum directivity D_{Max} of the UE and scaling the TRP by D_{Max}. This is a very conservative approach which assumes that the UE antenna amplifies the input signal (by the antenna gain) and then radiates this amplified signal equally in all directions. The result is accurate only in the direction of maximum directivity; in all other directions this results in an overestimate of EIRP. D_{Max} can be determined by evaluating the pattern characteristics of the DUT UE, or can be estimated based on typical size of DUT UE, operating frequency, and a general desire to keep the DUT UE directivity low so that there are limited variations in signal strength as a function of DUT UE orientation. Directivity is unlikely to be less than that of a half-wave dipole (2.2 dB), so we will initially assume a directivity of 3 dB, which can be refined based on evaluations of several DUT UEs.

Once directivity has been determined, this can be used to convert TRP to EIRP. For example, if a DUT UE radiates a TRP of 20 dBm and has a directivity of 3 dBi, then the EIRP is 20 dBm + 3 dB = 23 dBm.

As in the CSMAC analysis of [5] we will assume the DUT UE is a handset located outdoors and that the antenna pattern is not loaded by its surroundings, *e.g.*, a human body or table. We will account for the expected variability due to UE orientation by a statistical model based on the above half-wave dipole (or similar) assumption. If larger DUT UEs are of interest (*e.g.*, tablets, devices mounted on vehicles, fixed machines, etc.) then there may be a need to measure the antenna pattern. If the pattern is somewhat focused, that will also need to be accounted for. Additionally, if the DUT UE is placed inside a building or vehicle further measurements and analysis would be required. These problems are outside the scope of the present test.

6.11 Frequency Band

The above proposed test plan and discussion of measurement configurations is generally frequency agnostic. However, given the band of interest is AWS-3 and deployments are still in the early stages, a similar or surrogate frequency band may be of interest. There are two E-UTRA frequency bands [19] that are close to the recently allocated AWS-3: Band 3 (uplink: 1710 MHz to 1785 MHz) and Band 4/AWS-1 (uplink: 1710 MHz to 1755 MHz). UEs and eNBs from these frequency bands may be used in place of AWS-3 hardware. If Band 3 or 4 hardware is used in place of AWS-3 hardware, the above measurement setup will likely produce results for the primary and secondary deliverables that are similar to what would be obtained if the measurements were done with AWS-3 hardware.

However, caution should be used when conducting these measurements with something other than an AWS-3 eNB. Band 3 or 4 eNBs may utilize software/firmware and a scheduling algorithm that is now out-of-date. If alternate band hardware is used, it should be running the latest firmware to ensure that it's scheduling algorithm is the same as would be found on an AWS-3 eNB.

6.12 Measurement Protocol

A sample measurement sequence is listed below. This is shown primarily for illustrative purposes and to convey the general flow of the measurement process for each of the three scenarios. A more detailed measurement sequence will be established and documented once the hardware used in the testing becomes known.

1. Initialize relevant parameters (*e.g.*, eNB configuration, loading UE distribution, initial DUT UE position, VSA, wireless protocol analyzer, etc.)
2. Initialize DUT UE and loading UE's traffic streams
3. Start data collection on UTG and DUT UE diagnostic software
4. Move DUT UE to first of some number *S* of spatial locations in the cell,
5. Dwell for enough time for emulator and eNB scheduling to stabilize at position,
6. Acquire VSA data for predetermined time,
7. Move to next spatial positon in the set *S*.
8. Repeat steps 4 through 7 until all positions have been measured.
9. Download diagnostic recordings, UTG logs, and data from wireless protocol analyzer.[10]

[10] Depending on the hardware used in the testing, this may not be necessary. It is suggested as a good practice to move these data sets off the acquisition PC and to data storage between configurations. This will prevent a situation

10. Change relevant parameters and go to step 2

6.13 Calibration/Reference Measurement Procedure

The VSA scaling will be calibrated by use of a direct comparison method or wave parameter-based method, such as described in the Appendix A of [20]. Frequency-dependent losses in the interconnecting cables and other passive components will be measured with a vector network analyzer and accounted for in the channel loss models.

In general, hardware used in these measurements should have a valid calibration, per the original equipment manufacturer's specifications.

7 Measurements to Inform Field Measurements

While laboratory measurements are useful to characterize eNB scheduling and power control behavior, there are inherent assumptions that must be made to perform the laboratory measurements. Field measurements could either validate or invalidate those assumptions.

An example is the cell loading assumptions that must be made to design the laboratory measurements. A CSMAC assumption is that all the UL PRBs are in use at all times. Field measurements would provide information on the amount of time that all PRBs are in use and how the PRB usage varies throughout a typical day. This information could be fed into a statistical analysis to determine how interference may vary as a function of time.

Another assumption made is the number of UEs connected to a cell that are vying for UL resources. CSMAC assumes that six UEs are transmitting in any TTI in a 10 MHz band, but makes no assumption on the total number of UEs active within the cell. Field tests might verify the number of UEs transmitting per TTI as well as provide the number of UEs active within the cell.

A wireless LTE Protocol Analyzer placed near the eNB antennas could capture all the DCI messages coming from the eNB and would provide the number of PRBs in use per TTI, the number of UEs transmitting per TTI, and the number of UEs vying for UL resources. Measurements should be made in urban, suburban and rural environments to characterize the usage in each scenario. It would also be advantageous to measure at different times of day on both weekdays and weekends and during major social events. Measurements can be made unattended over long periods of time with a simple setup consisting of the LTE protocol analyzer, an antenna, and a control computer. Since capturing all DCI messages over a 24-hour period involves a substantial amount of data it would make sense to capture the messages at discrete intervals, analyze the results, and store the analysis before triggering a new measurement. A sample obtained every 5 minutes in this manner might be sufficient to provide data covering eNodeB usage. Development of a program to control the analyzer and analyze the data would be required to realize this field measurement setup.

Field measurements from an airplane might be useful in validating (2.1) and in determining the power levels that would be received by the DoD victim receiver in a real usage scenario. Since signals from multiple cells would be received at the same time it would be difficult to decode all the DCI messages, but it would be advantageous to measure actual received levels with the type of antenna used by DoD. Data from this test could be combined with the field and laboratory measurements to predict how the received power would vary over time of day and day of week.

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where there is no remaining space on the acquisition PC. Should this occur during a measurement, it would halt the measurement and delay progress.

8 Statistical Considerations

This section summarizes experimental variables, experimental design, and analysis methods. In addition, potential biases and their mitigation are discussed. The discussion is focused on the Phase 1 laboratory measurements, which will inform Phase 2 field measurements.

8.1 Relevant Experimental Variables

8.1.1 Response Variables

Samples of the waveform transmitted by the DUT UE will be collected over a specified measurement interval for each combination of factors specified by the experimental design. In addition, traffic logs will be collected from the UTG, UE diagnostic software, and LTE protocol analyzer for the duration of the measurement.

8.1.2 Controlled Variables (Factors)

A list of controlled variables (factors) to be considered in this study is given in Table 1. We welcome feedback from the wireless network operators regarding the typical values and distribution of these variables in real network deployments.

Table 1 List of factors to be considered in the proposed test

eNodeB	
Make and model	Initial maximum amount of PRBs in UL
DL scheduling algorithm, *e.g.*, proportionally fair low, proportionally fair high, round-robin	UL power control algorithm
Maximum number of UEs allowed to transmit in a given 5 MHz channel in each 1 millisecond TTI	Closed-loop power control parameters: P0 = desired power from UE α = scale parameters for path loss
UL scheduling algorithm	Extended uplink link adaptation low PRB threshold
UL scheduler FD type	UL improved latency reaction timer
Receive diversity	
UE Traffic Generator	
Number of UEs in Cells $\mathcal{A}$ and $\mathcal{B}$	Channel model for simulated UEs
Spatial size of cells	Spatial distribution of UEs
DUT UE	
Make and model	Type, *e.g.*, cell phone, dongle, internet of things (IoT)
Channel Emulator	
Location of UE under test relative to eNB	Channel type, *e.g.*, urban, rural, inside building
Special Conditions	
Handover between cells	Detach/reattach

8.1.3 Uncontrolled Variables

- spurious emissions from external sources
- environmental temperature and humidity
- changes in equipment performance due to heating from power dissipation

8.1.4 Sources of Uncertainty

- eNB scheduling implementation
- eNB's power control of UEs
- UE traffic emulation
- Emulated uplink channel from UE to eNB
- Laboratory environmental conditions
- Antenna characteristics and positioning
- Measurement equipment (*e.g.*, the VSA's ability to acquire and digitize an RF signal)

8.2 Data Analysis Plan

When computing the distribution[11] of EIRP, active LTE transmissions from the DUT UE can potentially be extracted from the VSA recordings by retroactively synchronizing them with the UE diagnostic software output. If that option is determined to not be feasible, then active transmissions will be extracted from the recorded waveform by using amplitude threshold detection. The LTE transmission will be divided into one millisecond TTIs. For each set of measurement conditions, the resulting set of LTE waveforms (each of duration 1 ms) will be used to estimate the

- cumulative distribution function (CDF) of the peak and RMS EIRP for a 5 MHz block over a one millisecond TTI given that the DUT UE is actively transmitting, and the
- peak and RMS power spectrum of the DUT UE waveform over a one millisecond TTI given that the DUT UE is actively transmitting.

Furthermore, the traffic generator logs, in conjunction with the UE diagnostic monitoring software, and protocol analyzer will be used to determine the number of actively transmitting UEs in a cell for a given 1 ms TTI; these data will be used to estimate a distribution function.

Because the data described above are derived from correlated time-series, conventional estimates of uncertainty in the empirical CDF estimate may break down, since they are designed for independent samples. Therefore, it may be necessary to down-sample the data in time to reduce correlations and obtain valid uncertainty estimates for estimated CDFs.

Note that the factor-space for the experiment is multi-dimensional, and consequently, the distributions and power spectra specified above are multivariate. The analysis will aim to determine how changing each factor impacts these multivariate functions. Therefore, it will provide guidance on how a given set of parameters may be used to estimate, *e.g.*, the RMS EIRP distribution.

8.3 Experimental Design

8.3.1 Determination of Sample-Size Parameters

For any given set of experimental settings, two sample-size parameters must be specified: (1) the duration of data collection for each DUT UE location, and (2) the number of spatial locations in a cell for the DUT UE. To determine these parameters, we propose a limited set of experiments where all other experimental factors are set to nominal settings.

First, for a nominal test configuration, measurements will be collected for several durations, *e.g.*, 1, 1.5, 2, 2.5, 3, 3.5, and 4 minutes at a few representative DUT UE locations within a cell, *e.g.*, near eNB, intermediate distance from eNB, and near cell edge. From these measurements, the CDFs and power spectra described in Section 8.2 will be estimated, along with associated uncertainties. The results will then be used to deduce a minimum measurement duration that is sufficient to ensure stable estimates with

[11] Assuming that the EIRP is a strictly stationary random process with a well defined distribution.

uncertainties at or below acceptable levels. Here, a “stable” estimate means that increasing the measurement duration yields small changes in the estimated CDFs or power spectra.

Second, measurements of the decided duration will be collected for various numbers of randomized DUT UE locations, *e.g.*, 3, 5, 10, 20, 50, 100. Then, for each number of spatial locations, CDFs, power spectra, and their associated uncertainties will be estimated from the spatially-aggregated measurements, under the assumption that the UE measurements from different spatial locations are statistically independent. Finally, a minimum number of DUT UE locations will be established that is sufficient to ensure stable estimates (as the number of locations is increased) with acceptable uncertainty levels.

The sample-size parameters discussed above determine the extent of time and spatial sampling, and consequently, the degree to which the results will be averaged over time and space. In addition, for a given set of experimental conditions, these sample-size parameters control the total measurement time and the amount of data that will be produced and stored.

8.3.2 Test Matrix Design

Due to the large number of experimental factors (≈20) outlined above in Section 8.1, a full-factorial experimental design is impractical. For example, a full-factorial design with two levels (settings) for 20 factors would require 2^{20} measurements. Commonly, a small proportion of the factors (*e.g.*, 20 %) drive most of the effects (*e.g.*, 80 %); this rule of thumb is known as the Pareto principle [21]. Thus, identification of a reduced number of dominant factors is both necessary and plausible. Moreover, because higher-order effects that depend on 3 or more factors are typically weak or non-existent, the experimental design appropriately should not commit large resources to their estimation.

We propose a two-pronged factor selection process to reduce the number of factors in the final experimental design. First, engineering expertise and input from stakeholders will be used to prioritize experimental factors; an example factor prioritization is given in Appendix A. Second, given a set of prioritized factors, a factor screening experiment will be performed.

For the factor screening experiment, we propose a two-level (two-settings for each factor) fractional factorial design of resolution V. A resolution V design is a design in which no main (single factor) effect or two-factor interaction is confounded (a.k.a. aliased) by any other main effect or two-factor interaction, but two-factor interactions are confounded by three-factor interactions. Further details on fractional factorial designs can be found in [22] and [23]. The ‘FrF2’ package in R [24] can be used to create 2-level fractional factorial designs of a given resolution. For example, this program shows that 2-level designs of resolution V with 10, 15, and 20 factors can be conducted with 128, 256, and 512 runs, respectively.

To infer the sensitivity of the EIRP CDF to each factor, response differences will be assessed by measuring the distance between empirical CDFs with the Kolmogorov-Smirnov statistic [24]. The Kolmogorov-Smirnov statistic is a robust, real-valued measure of the distance between two experimentally-observed CDFs. To validate the suitability of the Kolmogorov-Smirnov measure for the proposed purpose, alternative response-difference measures based on order statistics will also be investigated. Principal component analysis of the reduced factor space may allow still further dimensionality reduction.

After the dominant main effects and associated 2nd order interactions are identified by the factor screening, a final experimental design with fewer factors will be constructed. The final design will accommodate a nonuniform number of levels per factor, and avoid confounding interactions between factors.

The proposed two-stage design plan is adaptive, allowing the data collection process to proceed efficiently and efficaciously by exploiting structure (and lack thereof) among the experimental factors. The purpose of the factor-screening stage is to reduce the dimensionality of the factor space. The fractional factorial design used in this stage has the property that in the subspace of the significant factors, the data will automatically have the resolution of a stronger design. This process allows unexpected structure to be captured as it reveals itself in the data.

8.4 Potential Biases and Their Mitigation

- Emulated system parameters may not cover the full range of real-world systems and environments. This issue will be mitigated by performing field measurements in Phase 2.
- The final experimental design may not include all relevant factors or may confound some important factor interactions. Some configuration parameters will be left fixed for all experiments and will not be explored through design of experiment. This bias will be minimized by soliciting feedback from WNOs and other stakeholders, prior to measurement, on the most relevant parameters and their typical settings.
- It may not be possible to correct for all the frequency dependent of losses in the RF paths shown in Fig. 4. High-quality cables, attenuators, and other passive components will be used to minimize these effects. Additional uncertainties may need to be added to account for uncorrected RF transfer functions.
- If it is necessary to apply amplitude thresholding to the recorded UE waveforms to extract active UE transmissions, the resulting distribution of power levels would be truncated, resulting in a selection bias. This selection bias can be mitigated by investigating different thresholds in post-processing.
- Time-correlations in the measurements could bias uncertainty estimates for the empirical CDFs. This issue will be mitigated by estimating empirical CDFs with varying amounts of down-sampling.

9 Data Management

Data will be collected from the UTG, UE monitoring software, VSA, and LTE protocol analyzer. The data format and size will depend on the make of the adopted instrument, bandwidth, time over which data is collected, the number of measurements, and storage format. The experimental test factors will be determined for Phase 1 within the proposed test (see Sections 8.1 and 8.3 above). Once these parameters are known and specific instruments are targeted for use, the approximate size of the data can be found if the data generation rate is known, *e.g.*, as in Table 2. For example, if 1024 measurement scenarios are implemented with 100 measurement locations, each with acquisition over 90 seconds, the data storage requirement for Phase 1 would be approximately 450 TB, requiring over 100 days of non-stop measurements. Clearly, the data storage requirements are determined by the VSA, which generates the most data per unit time. A real-time spectrum analyzer with data of 15 kHz subcarrier and 66.7 μs resolution could reduce these requirements by roughly a factor of 2 to 3.

Table 2 Examples of data generation in one minute for some possible instruments to be used in this test

Instrument	Approximate Acquisition Rate, 5 MHz Band
UE monitoring software	27 MB
UTG	35 kB
VSA	2.9 GB
LTE protocol analyzer	240 MB

The data will be stored and backed up for the duration of the subsequent phase(s) of the project and for three years later for possible follow-on NIST research. The data will only be accessible to the NASCTN test team and authorized NIST personnel.

Various instruments, software, manuals, etc. used in the test may be proprietary in nature. NASCTN is prepared to protect such proprietary information by drafting contracts such as non-disclosure agreements (NDAs) or cooperative research and development agreements (CRADA).

10 Coordination and outreach

A NASCTN test brings science, outreach and information handling components to its tests. The coordination and outreach plan for this test began during the test plan drafting stages. This plan was reviewed by peers at NIST and the larger spectrum stakeholder community including the sponsor. To expand the reach for community comment solicitation, this test plan will be posted on the NASCTN website (https://www.nist.gov/communications-technology-laboratory-ctl/nasctn/projects/) and emailed to known stakeholders and interested organizations. We encourage further distribution to their membership. Comments will be requested via a form and subsequently adjudicated. The comment period will be one month with a briefing for a face-to-face opportunity to learn about the test's objectives and plans. After the comment period ends, the draft will be updated if needed. Test execution will then begin.

The NASCTN test team is interested in cell site specific parameters the WNOs can specifically help to answer. These parameters may be controlled information that a WNO may not wish to share outside of NASCTN. In the case of working with controlled information, NASCTN is prepared to protect information by drafting contracts such as NDAs or CRADAs. Contact the NASCTN Program Manager, Dr. Sheryl Genco (sheryl.genco@nist.gov, 303.497-3591) to discuss implementing agreements. Controlled experimental parameters that the test team would like assistance in choosing to better mimic reality are given in Table 3 [13].

Table 3 Desired Feedback from Wireless Network Operators

Settings	Suggested settings (from Wireless Network Operators)
Range of eNB power control parameters (such as P_0 *and* α)	
Other eNB settings that might impact UL traffic (such as scheduler and number of simultaneous UEs)	
Range of geographic cell sizes (rural, suburban, urban) and corresponding user density	
Cell morphologies (user density, site topography, man-made structure, etc.)	

To maintain impartiality, NASCTN will manage the test execution and data analysis to obtain the highest degree of trust amongst all stakeholders. The final test report will be peer reviewed and published as a NIST Technical Note. The report will be provided to the sponsor of the test upon completion of the Editorial Review Board process. NASCTN will also provide an out-brief, describing test execution and results made at a time agreeable to the sponsor and key stakeholders.

11 Schedule

The following are the major tasks of the project.

- Brief plan to DSO & NASCTN Steering Committee for execution decision
- Project resource identification, negotiation, procurement and scheduling.
- Conduct laboratory measurements
- Report preparation
- Editorial review
- Issue report and links to downloadable files

12 Safety

Electrical safety training, fall training, reverberation chamber training, and/or anechoic chamber training may be applicable.

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Appendix A. Baseline LTE Uplink Characteristics from [A.1][12]

A.1. UE Transmit Characteristics

Assumptions for generation of CDF data (shown in Fig. A.1)

- LTE Frequency Division Duplex (FDD) system
- 10 MHz LTE Bandwidth
- 100% system loading at LTE Base Station (eNodeB)
    - All Physical Resource Blocks (PRB) are occupied at all times
- 100% outdoor UE distribution
- P_0 = -90 dBm and α = 0.8 for UL Power Control (urban/suburban/rural)
- Proportional fair algorithm for LTE Scheduler
- Full-buffer traffic model (i.e. All UEs have data in their Radio Link Control (RLC) layer buffer at all times)

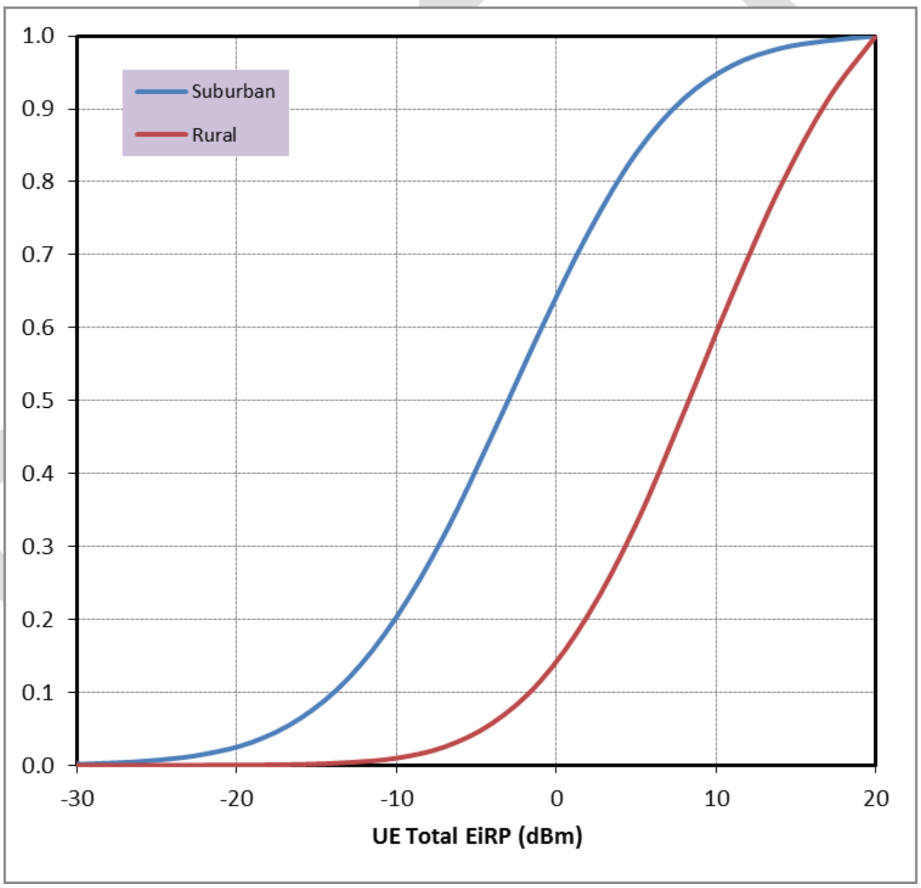

Figure A.1 Cumulative distribution function (CDF) of total EIRP per scheduled UE.

[12] We note that listing these assumptions here does not endorse or question the CSMAC model. Other assumptions and/or models may work as well or better.

Assumed Number of Scheduled (transmitting) UE per Sector

- Assume Physical Downlink Control Channel (PDCCH) = 6 is typical for a 10 MHz LTE Channel
  - PDCCH contains Downlink Control Information (DCI) blocks, which provide downlink and uplink resource allocations, and power control commands for UEs
  - Use UEs per sector (i.e. the number of simultaneously transmitting UEs is 6 per sector or 18 per eNodeB, for a 10 MHz Channel)
  - 100 % of uplink resources (PRBs) are equally distributed among transmitting UEs in each sector
- Randomly assign power in accordance with UE power CDF for each independent Monte-Carlo analysis trial
- The PDCCH value and corresponding number of UE should be adjusted based on the LTE channel bandwidth as in Table A.1.

Table A.1. Physical Downlink Control Channel Simultaneous emitters (from [A.1])

PDCCH Value / Channel Bandwidth			
5 MHz	**10 MHz**	**15 MHz**	**20 MHz**
PDCCH = 3	PDCCH = 6	PDCCH = 9	PDCCH = 12

Assumed Inter-Site Distance (ISD) for Generic LTE eNodeB Deployment

- Use concentric circles centered around metropolitan area unless other site specific assumptions are agreed upon.
- Urban/suburban area assumed to be 30 km radius with rural area covering outer circle up to 100 km, unless other site specific assumptions are mutually agreed upon.
- Surrounding rural deployment may be adjusted by mutual agreement if and when there is more than one urban/suburban area within 100km of the site being analyzed.

Table A.2. LTE Network laydown details (from [A.1])

Deployment	**ISD**	**eNodeB Antenna Height**	**UE Antenna Height**
Urban/Suburban (r <= 30 km)	1.732 km	30 m	1.5 m
Rural (U/S Edge < r <= 100 km)	7 km	45 m	1.5 m

Base Stations

- Antenna heights – 30 m urban, 15 m to 60 m rural
- Sector coverage – pattern as described in ITU-R F.1336-3[A.2]
- Down tilt – 3 degrees from the horizontal

After CSMAC completed their work in 2013, a Joint (FCC and NTIA) Public Notice [A.3] was released in July, 2014 which updated the CSMAC assumptions. The changes were:

- Reduced the terrain data resolution from 30 arc second to 3 arc second resolution
- Changed network loading parameters to 40 % for rural and 60 % for urban/suburban LTE deployments
- A term for clutter was added to the ground-to-ground and ground-to-air propagation models

A.2. References

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Appendix B. Example Factor Prioritization

An example factor prioritization for the experimental design is given below. Further details on the proposed experimental design plan are given in Section 8.3. Note that this prioritization is done assuming the parameters are independent. That is, only the impact of the listed parameter is categorized into a tier. Combinations of factors may yield scenarios which are not part of this categorization.

Tier 1

Changes in the value of these parameters are likely to have a meaningful impact on the Phase 1 measurement results. Factors in Tier 1 should be extensively investigated in the factor selection process, and are likely to be the subject of many measurements.

Parameter	**Hardware**	**Deliverables Impacted**
Simulated DUT UE position, relative to serving eNB	Channel emulator	1,2
Channel type (urban, rural, etc.)	Channel emulator	1,2
Spatial size of cell	UTG	1,2,3
Number of loading UEs in serving cell	UTG	1,3
Closed-loop power control parameters (P0, alpha)	eNB	1,2
eNB scheduling algorithm type	eNB	3

Tier 2

Changes in the value of these parameters are likely to have a measurable, but not necessarily meaningful impact on the Phase 1 measurement results. Factors in this tier should be investigated during the factor selection process and be included during the measurement campaign.

Parameter	**Hardware**	**Deliverables Impacted**
UE cell-cell handover	DUT UE	1,2
UE Attaching to eNB	DUT UE	1,2
Channel model of loading UEs	UTG	1,2,3
Number of loading UEs in adjacent cell	UTG	1
Spatial distribution of UEs	UTG	1,2,3
Method for UL power control[13]	eNB	1,2

Tier 3

Changes in the value of these parameters are likely to cause changes in the Phase 1 measurements that could be considered insignificant. Factors in this tier may be considered “optional”. Individual experiments may be done to confirm their placement in Tier 3.

Parameter	**Hardware**	**Deliverables Impacted**
UE Make/Model	DUT UE	1,2
UE Type (handset, dongle, etc.)	DUT UE	1,2
eNB Make/Model	eNB	3
Max. number of UEs allowed to transmit in single frame	eNB	3
UL improved latency timer reaction	eNB	3
Method for UL power control[11]	eNB	1,2
Initial maximum amount of RBs	eNB	3
Extended UL link adaptation low PRB threshold	eNB	1,3

[13] For measurement scenario #1 and #3, tier 3; for scenarios #2, tier 2.