SMALL SATELLITE LICENSE

UHF Interference Mitigation Analysis

LYNK GLOBAL, INC.

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Acronyms and Glossary

ADC	Attitude Determination and Control system
BS	Base Station
BW	Band-Width
CGSA	Cellular Geographic Service Area
CQI	Channel Quality Indicator
EIRP	Effective Isotropic Radiated Power
eNB	eNodeB or Evolved Node B
EPC	Evolved Packet Core
E-UTRA	Evolved UMTS Terrestrial Radio Access
EARFCN	E-UTRA Absolute Radio Frequency Channel Number
FDD	Frequency Division Duplex
FOR	Field Of Regard
gNB	Next Generation NodeB
H-ARQ	Or HARQ, Hybrid Automatic Repeat reQuest
I/C	Interference to Carrier Ratio
MCS	Modulation and Coding Scheme
MIMO	Multiple-Input Multiple-Output (antenna scheme)
MNO	Mobile Network Operator
OOB	Out-of-Band
PFD	Power Flux Density
RAN	Radio Access Network
RRC	Radio Resource Control
SDN	Software Defined Networking
SINR	Signal to Interference plus Noise Ratio
SNR	Signal-to-Noise Ratio
UMTS	Universal Mobile Telecommunications System
UTRA	UMTS Terrestrial Radio Access
3GPP	3rd Generation Partnership Project standards organization
c	Speed of light in vacuum
λ	Wavelength at center frequency
$BW_{Channel}$	Channel bandwidth
N_{DL}	Downlink EARFCN

I. Introduction

Lynk is a pioneer in solving the challenges associated with satellite-direct-to-phone connectivity. Radio engineers have long understood the challenges of mobile satellites such as the frequency scaling due to the high velocities of satellites (i.e., Doppler shift) and propagation delay limitations associated with protocols such as GSM and LTE. Indeed, standards for 3GPP compliant networks are predicated on stationary base stations and mobile handsets. Mobility management of handsets can be challenging in terrestrial networks due to the simple fact that handset mobility about the radio access network is difficult to predict. However, Lynk's network flips this concept on its head, providing service with mobile base stations and relatively stationary handsets. Lynk developed proprietary software modifications to standard BTS, eNB, and gNB software stacks that enable modified base stations in orbit to communicate with standard 3GPP compliant mobile devices capable of meeting 2G GSM, 4G LTE, and 5G NR standards.

The interference analysis contained herein is relevant to the initial ten (10) satellites of Lynk's constellation—also known as the Lynk Smallsat System—for which Lynk submits this application. Although Lynk only seeks to operate a small number of satellites and is not currently seeking authority to operate on UHF frequencies in the United States, the same interference analysis would apply to Lynk's fully realized satellite constellation for operations anywhere in the world.

II. Lynk's Network Architecture

Lynk's satellite network will act as a layer of connectivity that fills in all the geographical coverage gaps left by the terrestrial-based mobile cells deployed by MNOs in their licensed geographies. While the space segment of Lynk's network is a virtual implementation of standard 3GPP and proprietary network functions, Lynk's network maintains compatibility with existing terrestrial networks on the ground via standard roaming arrangements. Thus, Lynk's satellites will operate as cellular networks-in-a-box.

The locations of Lynk's satellite base stations are highly predictable, offering opportunities for Lynk's satellite network to accurately predict the availability of service links (and other links, including feeder links). This predictability can be coupled with supplementary databases and other techniques (e.g., compliance with specific boundaries via "super macro cells" to serve specific licensed areas, with country boundaries, with signal threshold requirements) to allow the satellite's SDN flight software to dynamically manage the space segment configurations for Core Network and RAN deployments around the globe.

<u>Figure 1</u> depicts a high-level snapshot of Lynk's network architecture. The network will operate in a store-and-forward fashion except for times when a servicing satellite has access to a gateway earth station, when the servicing satellite can provide mobile phones in a service beam a near real-time IP data connection to the internet. With the EPC located in the satellite, peer-

to-peer communications between user equipment within the satellite's coverage area can occur without backhaul delays.

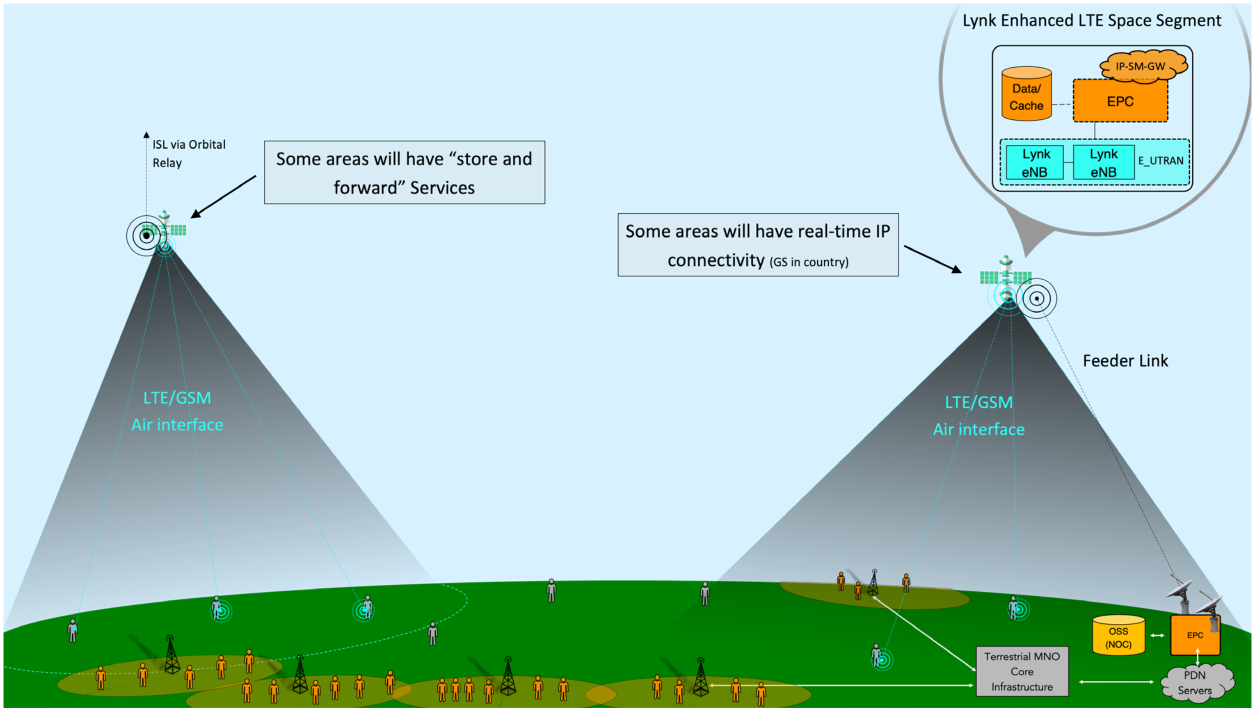

Figure 1 - Illustration of the Lynk Smallsat System space segment architecture

The satellites will deploy spectrum into rural and remote areas over the existing terrestrial cellular fabric predominantly using spectral orthogonality, exactly like existing terrestrial heterogenous networks. Today the existing cellular RAN fabric is comprised of macro cells which are deployed for widespread coverage in rural and suburban areas, often overlapping with smaller cells—e.g.: small, mini, pico, femto, etc.—used for densification and higher frequency reuse in more populous areas. Lynk's satellites can be thought of as "super macro cells," offering wide-spread coverage in even less dense geographies where existing macro cell infrastructure is too expensive to be profitable. Figure 2 illustrates the Lynk "super macro cell" as just another layer in the existing heterogenous network architecture.

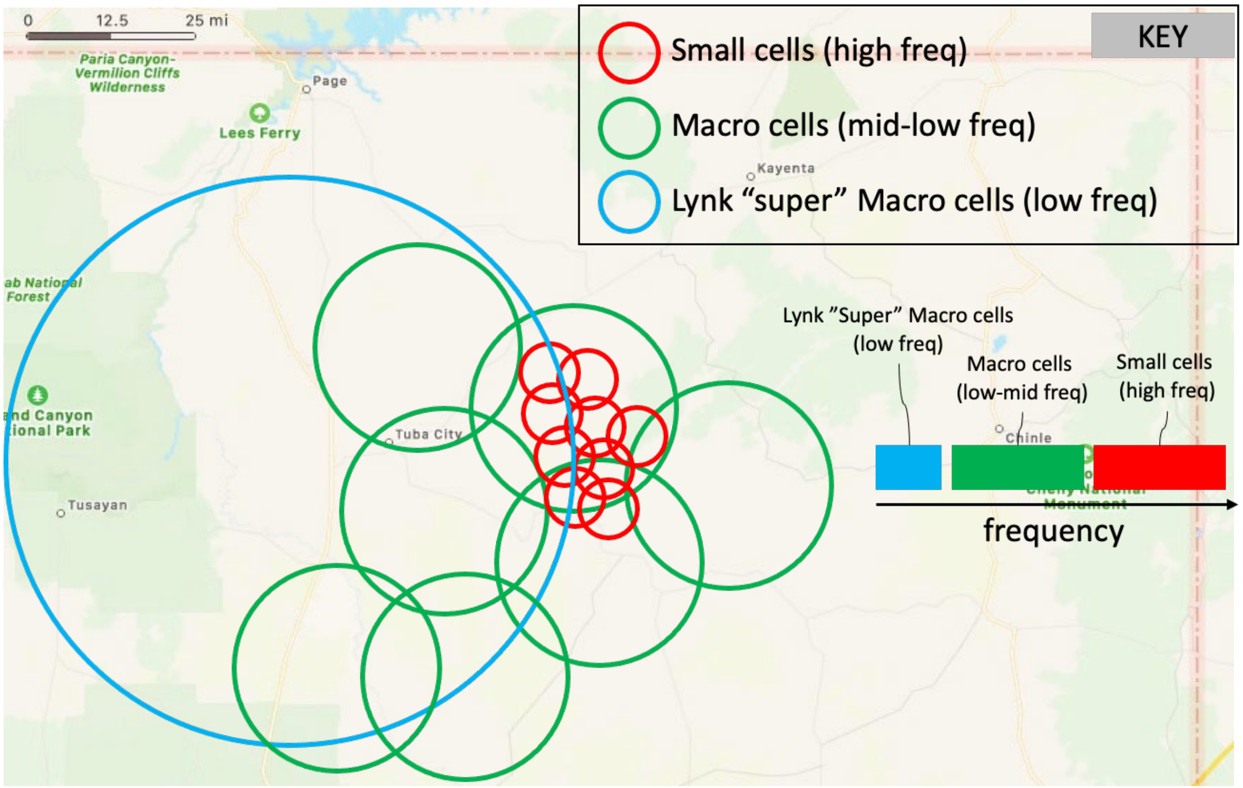

Figure 2 - Illustration of the hypothetical geospatial overlap and spectral orthogonality of terrestrial small cells, terrestrial macro cells, and Lynk "super macro cells" (not to scale).

The Lynk "super macro cell" locations can be programmed into the satellite constellation as a latitude, longitude coordinate, which is used to compute target pointing vectors for the spacecraft beam. With a combination of attitude control and steerable phased array beams, signal energy can be focused on specific, static locations on the Earth such that Lynk can place the beams in locations that prevent unnecessary overlap between the terrestrial cellular network and the Lynk space network. Figure 3 illustrates the mode of operation of Lynk's spot beams.

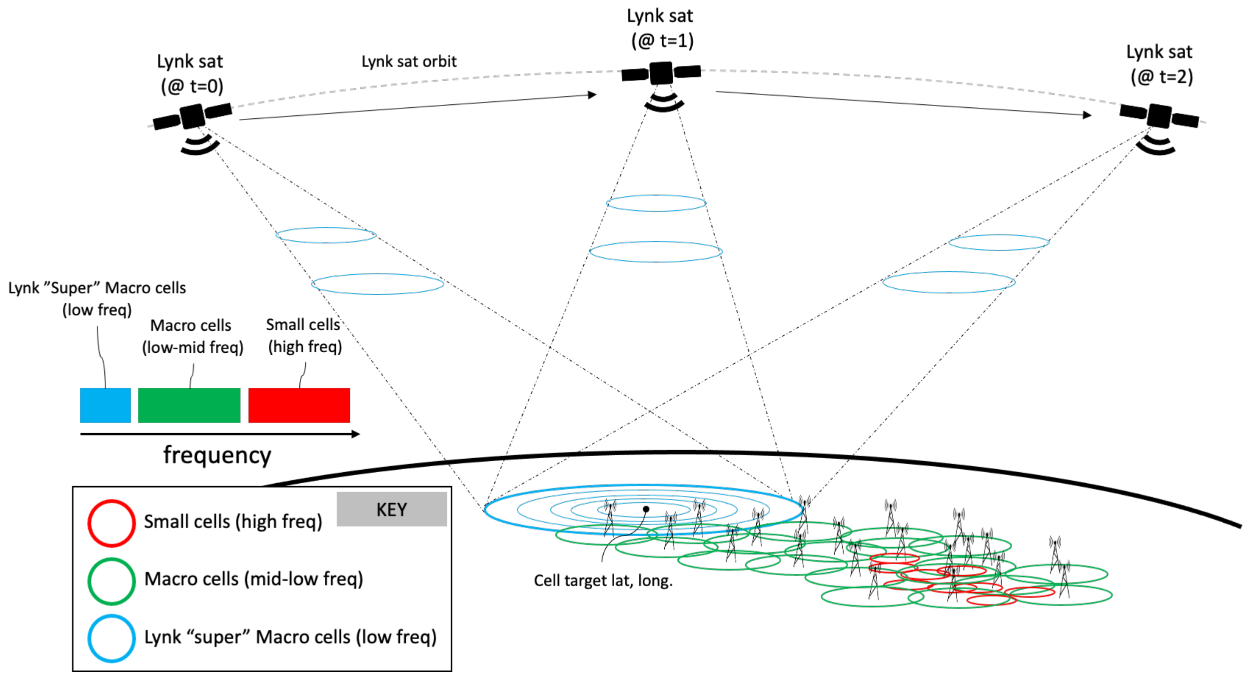

Figure 3 - Illustration of Lynk space-based cellular network deployment architecture

A. Lynk's Spectrum Deployment for Service Links

Lynk is collaborating with MNOs to identify their preferred spectrum deployment strategy using Lynk's satellite network. Lynk is pursuing a spectrum deployment strategy that will employ two techniques:

1. **Spectral orthogonality:**
   Deploy beams using "latent" spectrum in an MNO's portfolio—e.g., utilize spectrum not already deployed by the terrestrial network.

2. **Geospatial orthogonality:**
   Deploy beams using spectrum in MNO portfolios that is not widely deployed in their current license areas—e.g., place satellite spot beams in areas where that spectrum is not currently utilized.

By using one or both of the techniques listed above, Lynk can ensure seamless operations between the terrestrial networks of MNOs and Lynk's satellite network in the same manner as existing terrestrial heterogenous network deployments. Lynk will not create any harmful interference to existing or future extensions of these terrestrial cellular deployments. Lynk is aware that this collaboration with terrestrial MNO partners will require coordinating spectrum selection for the satellites based on the size of the radiated beam from the satellite on the Earth and ensuring that this conforms to any geographic boundary conditions for their current licenses, whether they be intranational (e.g.: state, county, Cellular Market Area, etc.) or international boundary conditions. Lynk provides a real-world example where both spectral orthogonality and geospatial orthogonality can be achieved by the Lynk network with respect to a customer terrestrial MNO network.[1]

Analysis of a third spectrum deployment technique is also included below:

3. **Overlapping Co-Channel Cells:**
   Deploy beams with neither spectral nor geospatial orthogonality.

While this is not a technique Lynk intends to use, Lynk provides the Commission with a detailed co-channel interference analysis herein, consistent with previous Commission requests for this information.[2] This analysis considers the scenario in which Lynk satellites place spot beams on the Earth that both overlap and share co-channel spectrum with a terrestrial mobile network on the Earth.

B. Lynk Evidencing No Harmful Interference

As the Commission is aware, Lynk has been conducting trials of its orbiting cell tower technology around the world, including in the United States.[3] MNOs actively participated in these trials by agreeing to specific spectrum/channels for use during the tests and sent technical personnel to attend field trials as well. Lynk provided the MNOs with information about the timing and location of transmissions so that local RAN engineers/operators could monitor for potential indications of harmful interference. Many of these initial trials were conducted when the terrestrial network had simultaneously deployed the same spectrum on terrestrial towers. During all trials conducted to date, the participating MNOs have reported that there has been no evidence of harmful interference in their terrestrial network.

These experimental trials are the beginning of Lynk's process of working with MNOs to test and deploy Lynk's network safely and incrementally. Lynk measures, mitigates, and eliminates risk of interference to terrestrial mobile networks with a planned stepwise build out of its constellation from initial intermittent use to future continuous service. While the initial trials have been with one satellite on orbit at a time, the analysis presented herein demonstrates that the incremental increase in interference risk with a fully deployed constellation providing continuous service is inconsequential. This includes the first ten (10) satellites providing intermittent service known as the Lynk Smallsat System for which Lynk submits this application.

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[1] *See, infra,* Section VI.

[2] The interference mitigation analysis presented herein is like prior analyses presented by Lynk to the Commission for the experimental authorization of Lynk's prototype satellites. *See* Legal Narrative, Section V, B, for a list of Lynk's experimental authorizations.

[3] *See id.*

III. Terrestrial Network Interference Considerations

The following sections present analyses that support Lynk's conclusion that its constellation—including this application for initial, intermittent commercial service with ten (10) satellites—will protect existing terrestrial services from harmful interference while providing Lynk's MNO partners with important new capabilities and greatly improving public safety and convenience.

In the interference analysis, Lynk considers the traditional radio interference issues in terms of SINR, which considers both noise and interference. Lynk also considers that modern mobile networks are not *noise* limited but rather *interference* limited due to the fundamental design of the inter-cellular interference levels that raise interference above the thermal noise limits while also using signal processing and coding to provide a low error rate signal. The dynamic interference level that arises from moving terminals in a mobile environment in a cellular network that reuses spectrum throughout the network is addressed via changing MCS that compensate for the time varying SINR levels. Modern networks perform measurements at the millisecond level, of signal quality ("CQI index") as moving vehicles, changing multipath and shadowing obstructions such as trees, vehicles, and buildings impacting the signal strength and as other base stations inject changing levels of interference from those same physical channel effects, often prompting near continuous antenna reselection, polarization changes, and beam reforming. Thermal noise, or even the weak interference from distant Lynk satellites, is a small contributor to the radio performance in such networks.

Table 1, below, summarizes the CQI indexes and corresponding modulation, coding, efficiency, and SINR requirements for the LTE protocol. The SINR values in the last column of the table are generally rough estimates and are not quantified in the 3GPP specification. As such, these values are denoted with tildes; however, the SINR requirement of -5 dB at CQI index of 1 is generally accepted within the industry and is not denoted with a tilde. This particular threshold is referenced later.

CQI index	Modulation	Code rate x 1024	Efficiency (bps/Hz)	SINR estimate[4,5]
0	Out of Range			
1	QPSK	78	0.1523	**-5.0**
2	QPSK	193	0.3770	~ -3.0
3	QPSK	449	0.8770	~ 1.0
4	16QAM	378	1.4766	~ 5.0
5	16QAM	490	1.9141	~ 8.1
6	16QAM	616	2.4063	~ 9.6
7	64QAM	466	2.7305	~ 11.0
8	64QAM	567	3.3223	~ 13.0
9	64QAM	666	3.9023	~ 15.1
10	64QAM	772	4.5234	~ 16.9
11	64QAM	873	5.1152	~ 18.9
12	256QAM	711	5.5547	~ 20.0
13	256QAM	797	6.2266	~ 22.0
14	256QAM	885	6.9141	~ 24.0
15	256QAM	948	7.4063	~ 27.0

Table 1 - MCS Table for LTE per 3GPP TS 36.213 version 12.3.0 Release 12, Table 7.2.3-2.

Moreover, there is a difference between radio interference and packet losses. Mature networks typically employ many base stations densely deployed in congested areas and make multiple frequency blocks and bands available to the serviced mobile devices. As a result, these networks provide channel diversity which enables handover to other frequency channels or handoffs to other base stations entirely to avoid packet loss in the event of radio interference. For example, in the United States the four nationwide MNOs all have many licensed blocks of spectrum in a variety of frequency bands, typically used with Carrier Aggregation to transport downlink data streams simultaneously through multiple frequency bands. An error on one frame's transmission on one carrier will, through H-ARQ, be retransmitted, typically on diverse alternative channels via Intra-band and Inter-band aggregation. According to the Commission's annual Communications Marketplace Report, the big four nationwide wireless carriers each

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[4] *See* Kalil, et.al., "QoS-Aware Power-Efficient Scheduler for LTE Uplink," IEEE Transactions on Mobile Computing, Vol. 14, No. 8 (Aug. 2015), *available at* https://www.researchgate.net/figure/List-of-MCS-Indices-21_tbl2_279633864.

[5] *See* Iwakuni, et. al., "Experimental Verification of Null-Space Expansion for Multiuser Massive MIMO via Channel State Information Measurement," IEICE Trans. Commun., Vol. E101-B, No. 3 (Mar. 2018), *available at* https://www.researchgate.net/figure/Modulation-and-coding-scheme-parameters_tbl2_319324923.

have over 93 MHz of spectrum licenses in at least 5 of 12 low frequency bands.[6] Notably, results from the recent CBRS and C-Band Auctions indicate that the 4 nationwide MNOs all have at least 114 MHz in population weighted spectrum licenses that are currently being deployed. Such diversity of spectrum resources allows for the robust performance of modern mobile networks even in the presence of various types of radio interference.

	600 MHz	700 MHz	Cell.	SMR	PCS	H Block	AWS-1	AWS-3	AWS-4	WCS	BRS	EBS	CBRS *	C-Band*	Total
Spectrum Counted	**70**	**70**	**50**	**14**	**130**	**10**	**90**	**65**	**40**	**20**	**67.5**	**116.5**	**70.0**	**280.0**	**1,093.0**
AT&T	0.0	29.7	23.6	0.0	38.3	0.0	14.9	20.3	0.0	20.0	0.0	0.0		79.8	196.9
T-Mobile	30.8	10.4	0.0	13.8	66.5	0.0	37.0	3.3	0.0	0.0	62.9	92.2	0.14	27.0	344.0
VZW	0.0	21.7	25.2	0.0	22.0	0.0	36.1	11.8	0.0	0.0	0.0	0.0	15.66	161.0	293.5
USCC	1.8	2.4	2.1	0.0	1.4	0.0	0.7	1.2	0.0	0.0	0.0	0.0	0.27	5.1	10.8
DISH	17.8	4.6	0.0	0.0	0.0	10.0	0.0	21.1	40.0	0.0	0.0	0.0	19.37	1.4	114.3
Other	17.5	1.2	2.0	0.5	2.1	0.0	1.3	3.1	0.0	0.0	4.6	24.3		5.7	43.6

From FCC 20-188 2020 COMMUNICATIONS MARKETPLACE REPORT
Adopted: December 31, 2020 Released: December 31, 2020
*** Added Feb. 26, 2021 upon completion of Auctions 105 and 107 by Spectrum Financial Consulting.**

Table 2 - Spectrum License Holdings of Major MNOs showing population weighted national bandwidth holdings.

Terrestrial mobile network operators address the growing demand for increasing wireless traffic by monitoring each base station's traffic at busy hours and forecast when that traffic will exceed 80% of the base station's capacity. MNOs plan to increase that capacity by the forecasted date by using one of three methods: (1) cell site splitting, (2) increased spectral efficiency through technology upgrades, and (3) acquiring and deploying new radio spectrum.[7] The third approach tends to be the least costly and expeditious resulting in typical base stations with an over 20% excess spectrum capacity during busy hour, in order to maintain calls and keep dropped call rates below a KPI level of approximately 0.1% or better.

These maintenance practices provide great assurance that intermittent radio interference on a particular narrowband channel, such as from a satellite like Lynk's, will not block IP packets destined for the handset or user equipment, even if some lower-level datagrams are recoded and retransmitted in the following frame on alternative frequency channels, a protective measure that regularly takes place in a sizeable portion of existing low-level datagram packets.[8]

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[6] *See 2020 Communications Marketplace Report*, GN Docket No. 20-60, FCC 20-188, ¶ 33, Figure II.A.14 (rel. Dec. 31, 2020). Note that this report was prepared prior to the granting of licenses through Auctions 105 (CBRS) and 107 (C-Band).

[7] *See* Richard N. Clarke, "Expanding mobile wireless capacity: The challenges presented by technology and economics," Telecommunications Policy, Volume 38, Issues 8–9, Pages 693-708, ISSN 0308-5961 (Sept. 2014), *available at* https://doi.org/10.1016/j.telpol.2013.11.006.

[8] *See* Matías Toril, Rocío Acedo-Hernández, Almudena Sánchez, Salvador Luna-Ramírez, Carlos Úbeda, "Estimating Spectral Efficiency Curves from Connection Traces in a Live LTE Network,"

In the following sections, Lynk shows very low probability for low-level datagram packet errors from satellite radio interference, which occurs only in remote circumstances when connectivity is already problematic and in most need of Lynk's satellite services. Even in these rare cases, the packet loss controls of modern networks greatly mitigate these radio channel problems.

A. Power Flux Density of Lynk's Service Link

Lynk's satellites will be equipped with a phased array antenna which can be steered electronically and mechanically using the spacecraft ADC system. The spacecraft antennas will have a peak gain of 24.5 dBi at boresight (23.5 dBi after antenna feed losses), and depending on the protocol, the EIRP as a function of bandwidth may vary. GSM carriers each deploy 200 kHz of spectrum. LTE carriers can be deployed in varying bandwidths of either 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, or 20 MHz. All LTE deployment scenarios will utilize 180 kHz resource blocks. Each satellite beam is capable of up to 50 W transmit power from the antenna for a max EIRP of 70.5 dBm, which would create the maximum possible power flux density at the Earth's surface for the service links.

Based on link budget analysis and losses presented in the Technical Appendix to this document, the resulting maximum RSSI of the Lynk service beams at the surface of the Earth is approximately -81 dBm.

Figure 4 illustrates the radiation pattern of the phased array antenna for both transmit and receive, at two different cross sections with the zero-degree angle held constant and the slices taken at zero degrees and ninety degrees in the azimuth direction.

Mobile Information Systems, vol. 2017, Article ID 7969102 (Jun. 2017), *available at* https://doi.org/10.1155/2017/7969102.

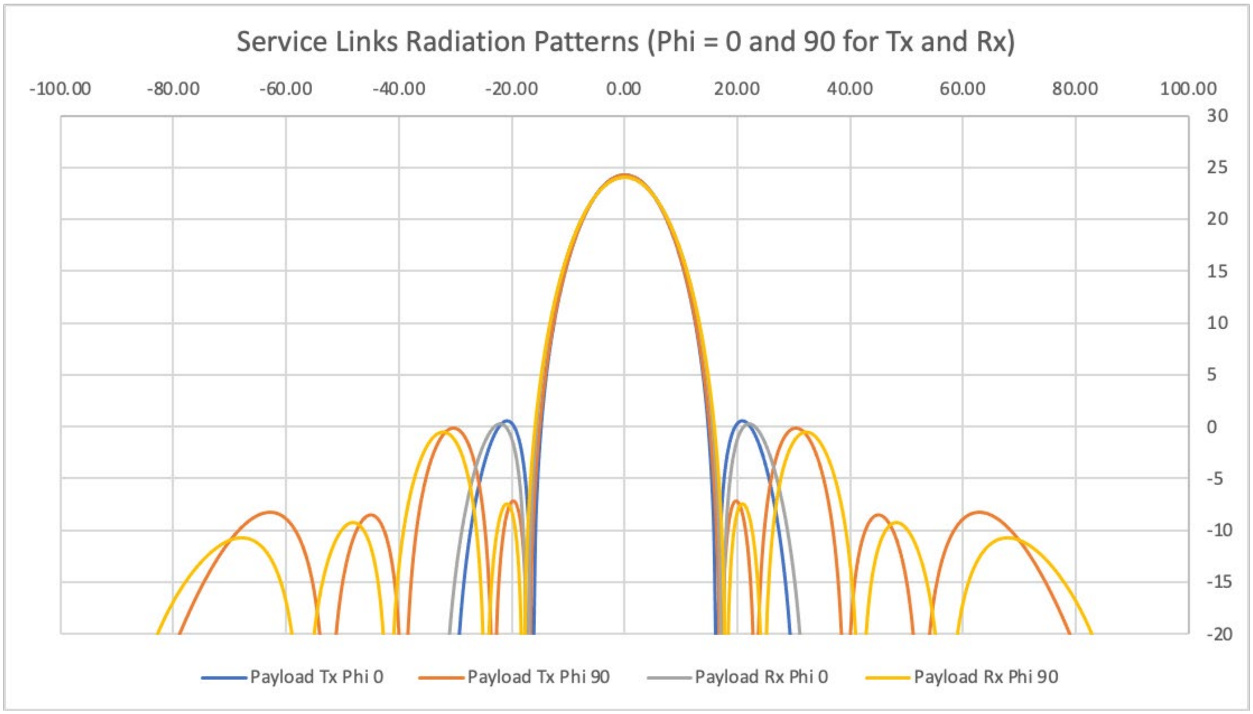

Figure 4 - Boresight Radiation pattern of the Lynk phased array with Chebychev taper. Phi indicates the "azimuth" direction relative to the boresight of the antenna.

Current FCC rules for Median field strength at the edge of coverage with neighboring CGSAs for any given CGSA is 40 dBμV/m.[9] This signal energy threshold corresponds to a PFD of -75.7 dBm/m^2, corresponding to about -96 dBm of signal energy at the surface for mobile devices with antennas with 0 dBi of gain.[10] Table 3 provides the conversion from dBuV/m to dBm.

Parameter	Value	Units
Field Strength Limit at CGSA Edge (dB)	40	dBμV/m
Field Strength Limit at CGSA Edge (base)	0.0001	V/m
Characteristic Impedance of Air	376.99	Ohms
Power flux Density (base)	2.65 E-11	W/m^2
Power flux Density (dBm/m^2)	-75.76	dBm/m^2
Wavelength, λ, of 856.5 MHz signal	35	cm
Effective 0 dBi antenna area ($\lambda^2/4\pi$)	0.0097	m^2
Corresponding signal power at cell phone	**-95.87**	dBm

Table 3 – Median CGSA Field Strength Limit and Received Power at Handsets.

[9] 47 CFR § 22.983(a).

[10] Terminal equipment antennas inevitably have losses that subtract from the isotropic gain, particularly when held next to hands or heads, but LTE handsets also include at least two antennas for diversity and MIMO operation effectively raises the gain close to 0 dBi, so Lynk uses 0 dBi as a value that is easily accounted for when applied to a specific mobile device.

Since this signal energy level is agreed upon by MNOs today, Lynk believes it would be a suitable metric for Lynk's "super macro cell" edge signal thresholds presented in this analysis. Furthermore, it avoids the variability of mobile devices with respect to their performance and sensitivity.

B. Cell Size Adjusted via Satellite Transmit Power

Phased array antennas experience reduced directivity of the main lobe when digitally steering off boresight by larger angles (the effective aperture is decreased by Cos(θ)), and as a result, the beamwidth of the main lobe increases. This effect will not occur, however, if the satellite attitude control system is used to steer the boresight of the antenna toward a target cell. In either event, steering a beam of any beamwidth off boresight combined with the increase gradient of slant range associated with off nadir beam angles, results in elongation of the beam footprint on the earth's surface when compared to beams that are steered toward nadir (both digitally or mechanically).

The size of the beam coverage contour can be regulated based on the downlink transmit power for each beam. Consequently, reduced transmit power can reduce the cell size for that particular beam angle. The reduction in cell size also results in a reduction of peak SNR for the center of the cell. However, in most cases, the service is uplink power limited, and so the loss of coverage by this downlink reduction is somewhat mitigated. Lynk would work with MNO partners to identify a cell center and cell radius for service and would conform to signal energy levels at the cell edge of some signal level better than or equal to the existing regulation for cellular license area cell edges. Lynk demonstrates this technique with a series of spot beam simulations of a satellite overpass for a hypothetical U.S. location in Figure 6 through Figure 12.

While the cell edge power where neighboring CGSAs meet is to have a signal level at -96 dBm, the signal may fall off more quickly than the Lynk space-based tower. In fact, the cell edge will be the hardest location to contend with interference, and at the border between license areas, each licensee may be contending with largest path loss scenarios for their given service. Even though Lynk's satellite beams may be more uniformly consistent over larger swaths of area, meeting the -96 dBm signal limit at the edge is most important, since signals at -96 dBm closer to the center of an existing license area will be easier to mitigate because licensee base stations will be closer to those locations. In other words, if -96 dBm of interference can be mitigated at the edge of a license geography, it is easier to mitigate the same -96 dBm signal at the center of the license geography. Figure 5 illustrates that the "super macro cell" radius could be incrementally increased or decreased as needed.

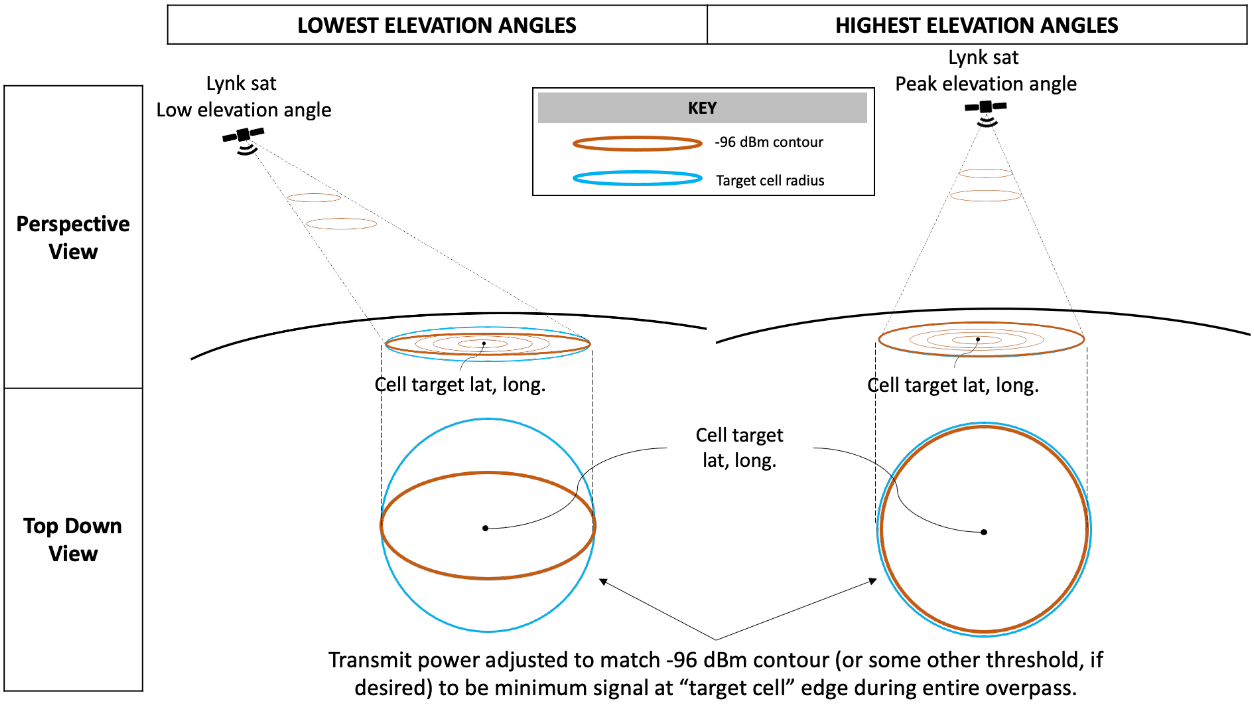

Figure 5 - Illustration for how transmit power can be adjusted during a target cell overpass to match -96 dBm signal contour to the target cell edge (e.g., ensuring that the maximum cell edge signal does not exceed -96 dBm or 40 dBμV/m regulation).

C. Example Spot Beam Simulation

In a deployment scenario, the Lynk network will define a cell at a central latitude and longitude with a polygon of points that describe some approximately circular radius about the central point. The Lynk network may track meta-data such as a signal energy threshold (among other things) for the polygon of points that describe that cell.

Figure 6 through Figure 12 simulate this by showing seven snapshots in time (each 30 seconds apart) of a hypothetical satellite overpass (orbiting at 500 km) over the Navajo Nation in Northeast Arizona. At each snapshot, the simulation software computes the transmit power required by the satellite to conform a signal energy threshold to a physically steered beam toward a 100 km radius cell about a center location over the hypothetical location. The 100 km radius is only an example and so can be larger or smaller as noted in the previous section.

The following figures are color coded with the highest signal level as yellow, and the lowest signal level as deep blue. The contours are programmed to plot all signal energy above -96 dBm to demonstrate how the beams can keep signal energy focused on the target cell and limit spillover.

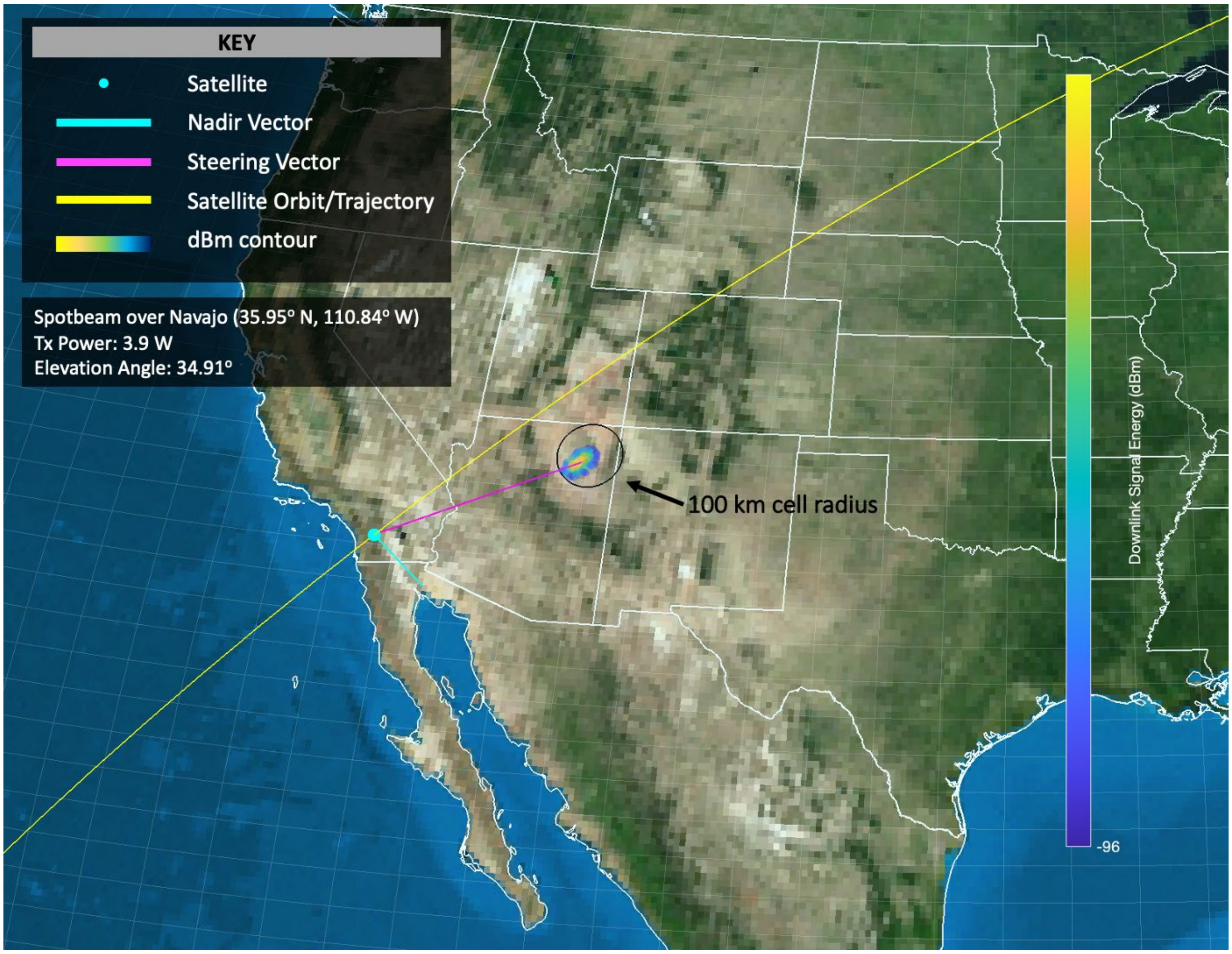

Figure 6 - Snapshot of satellite overpass of Navajo at 34.91 deg elevation angle.

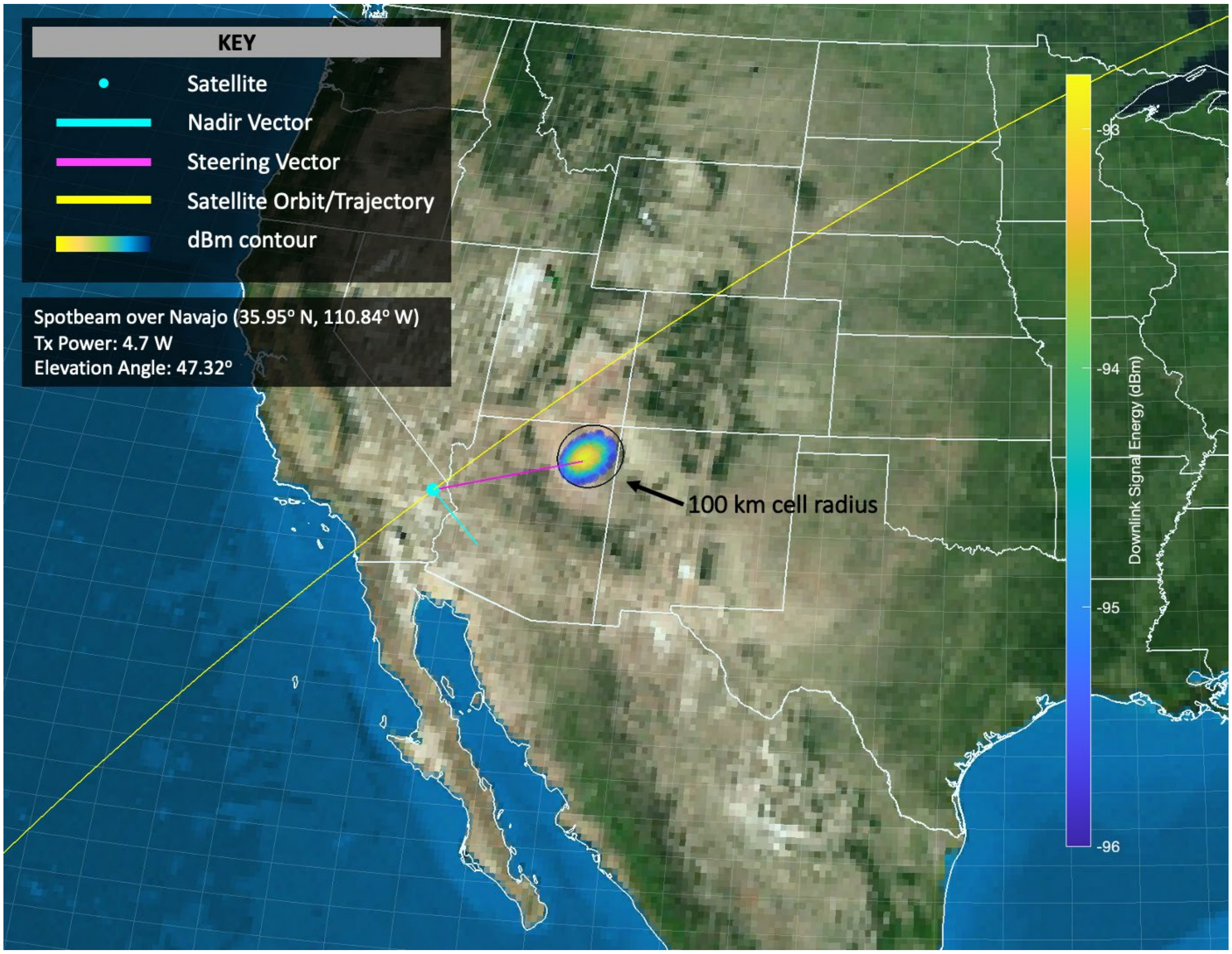

Figure 7 - Snapshot of satellite overpass of Navajo at 47.52 deg elevation angle.

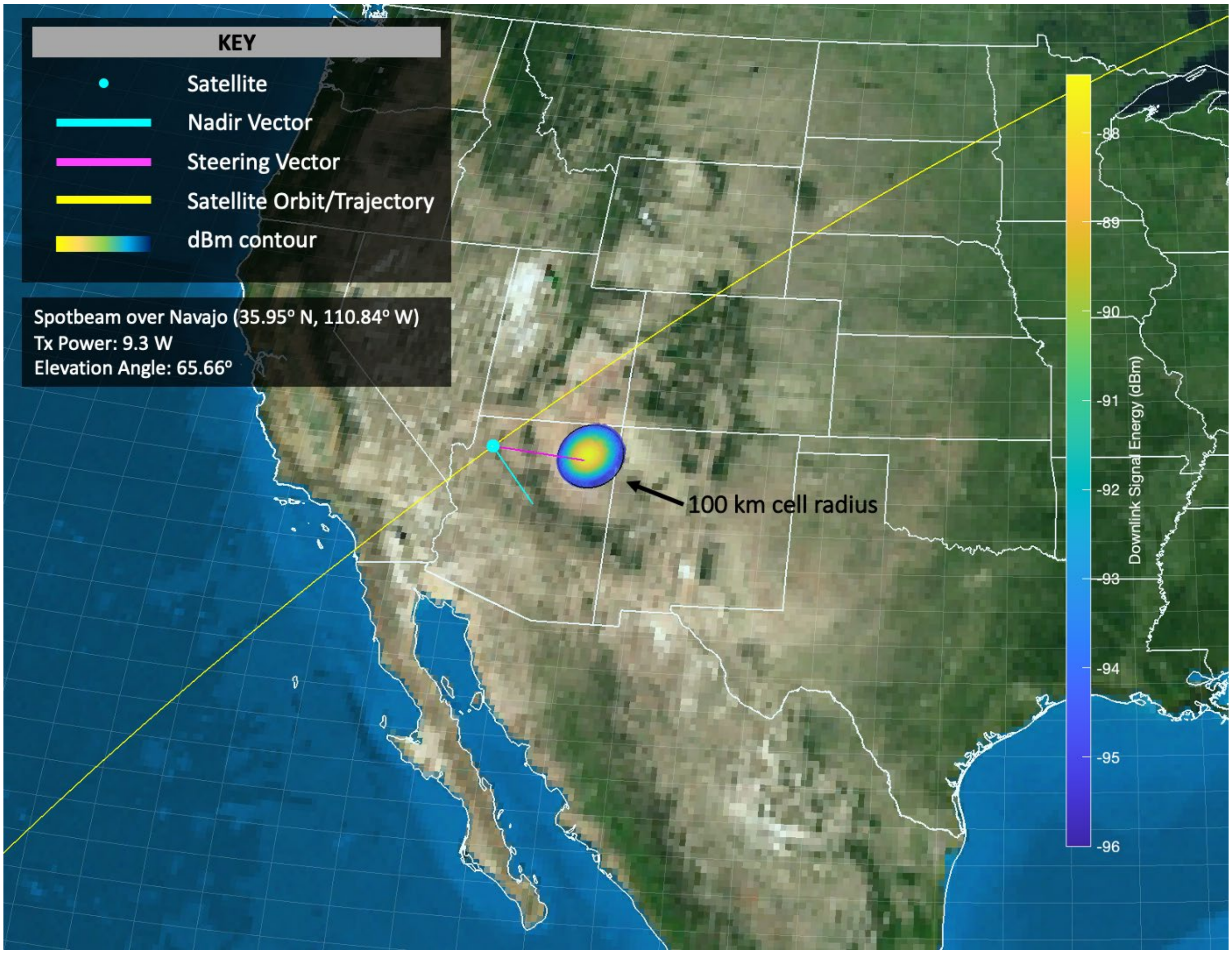

Figure 8 - Snapshot of satellite overpass of Navajo at 65.66 deg elevation angle.

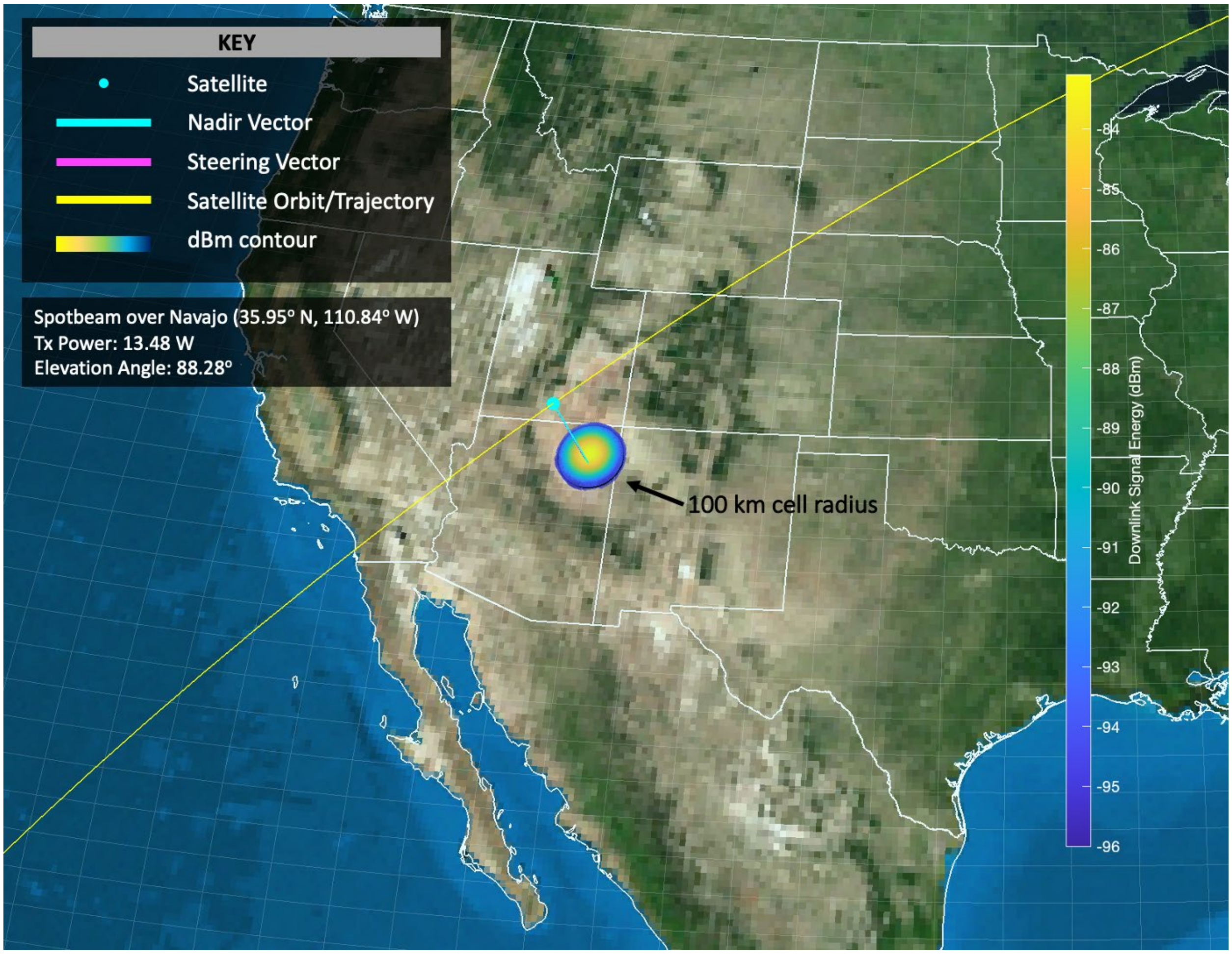

Figure 9 - Snapshot of satellite overpass of Navajo at 88.28 deg elevation angle.

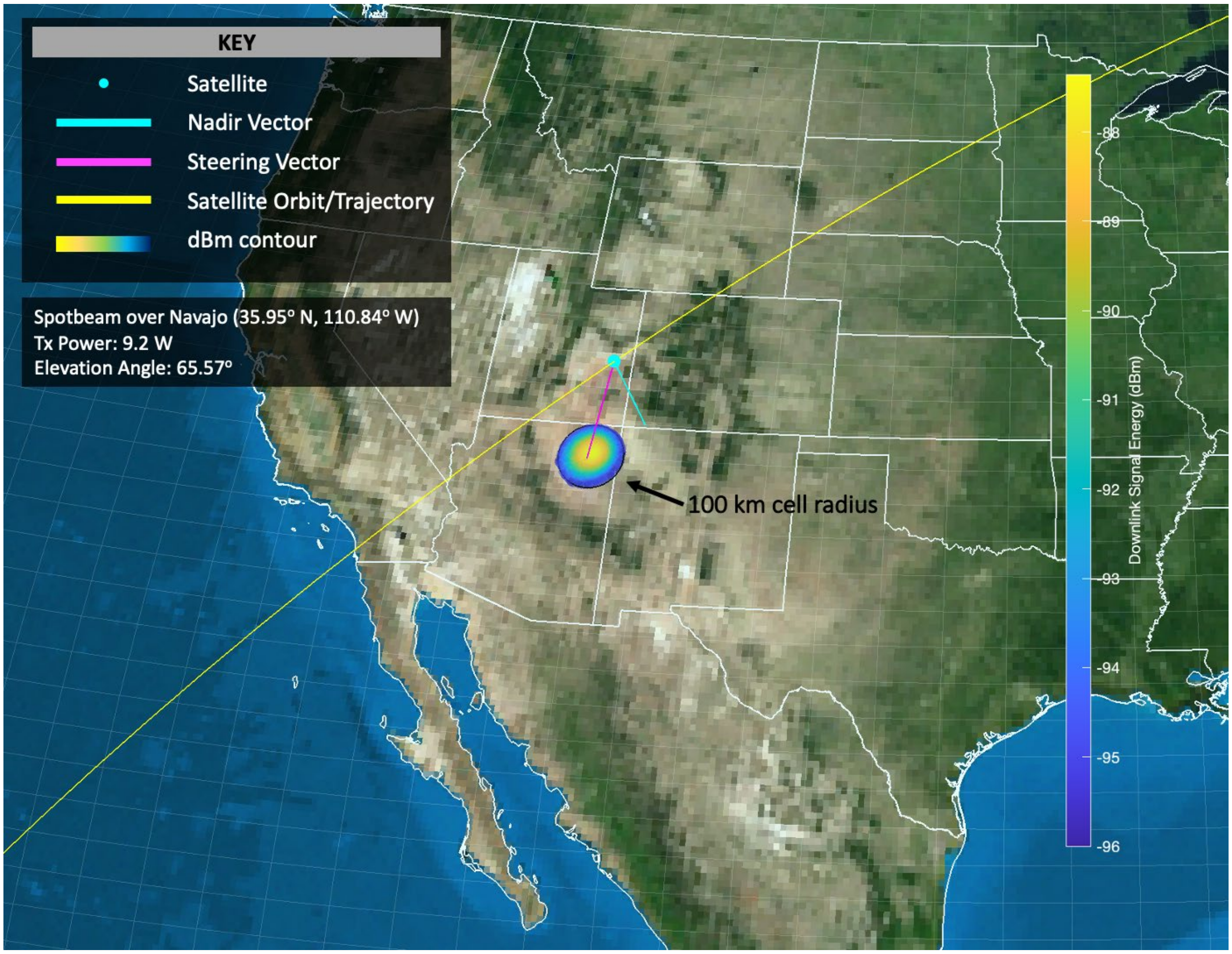

Figure 10 - Snapshot of satellite overpass of Navajo at 65.57 deg elevation angle.

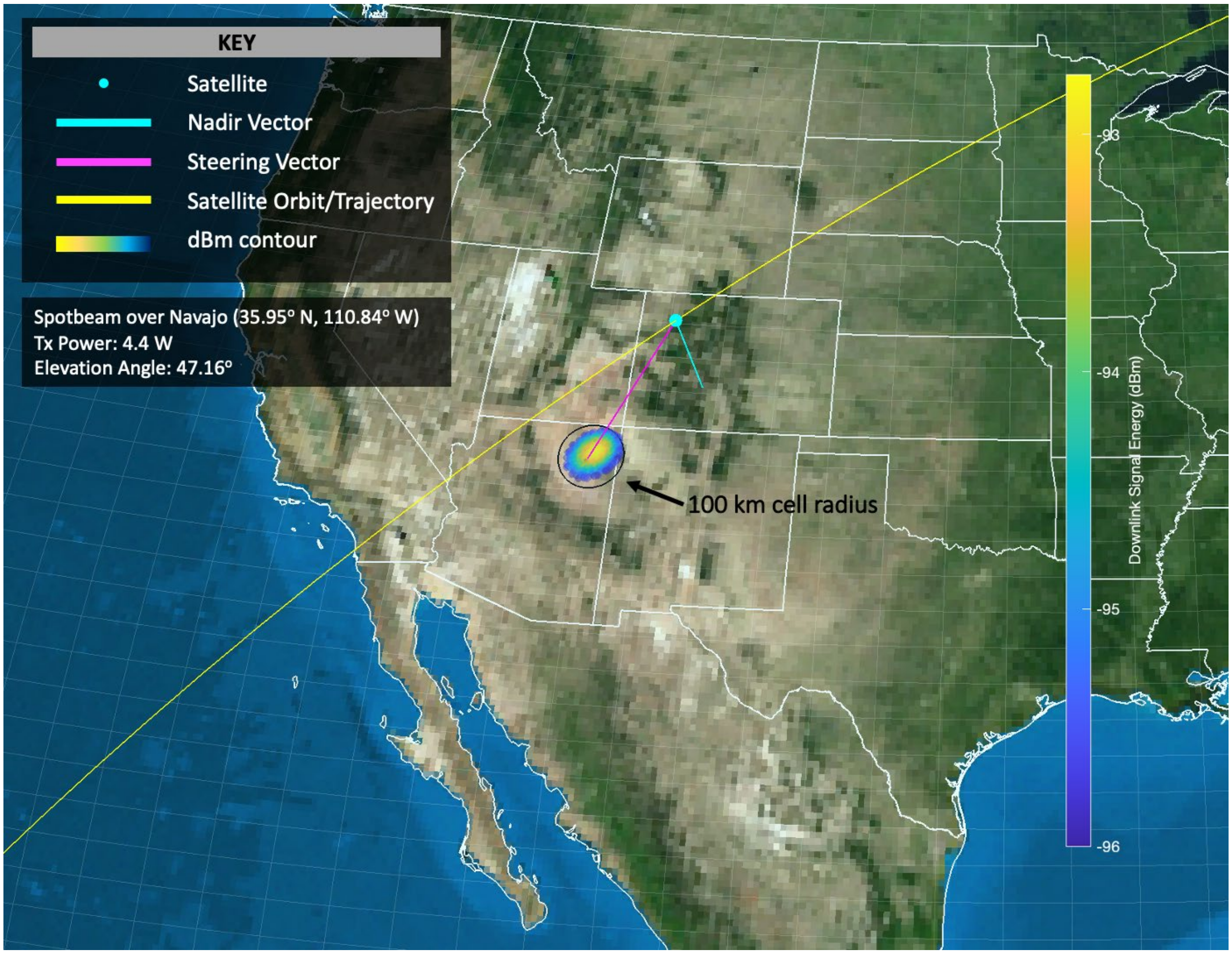

Figure 11 - Snapshot of satellite overpass of Navajo at 47.16 deg elevation angle.

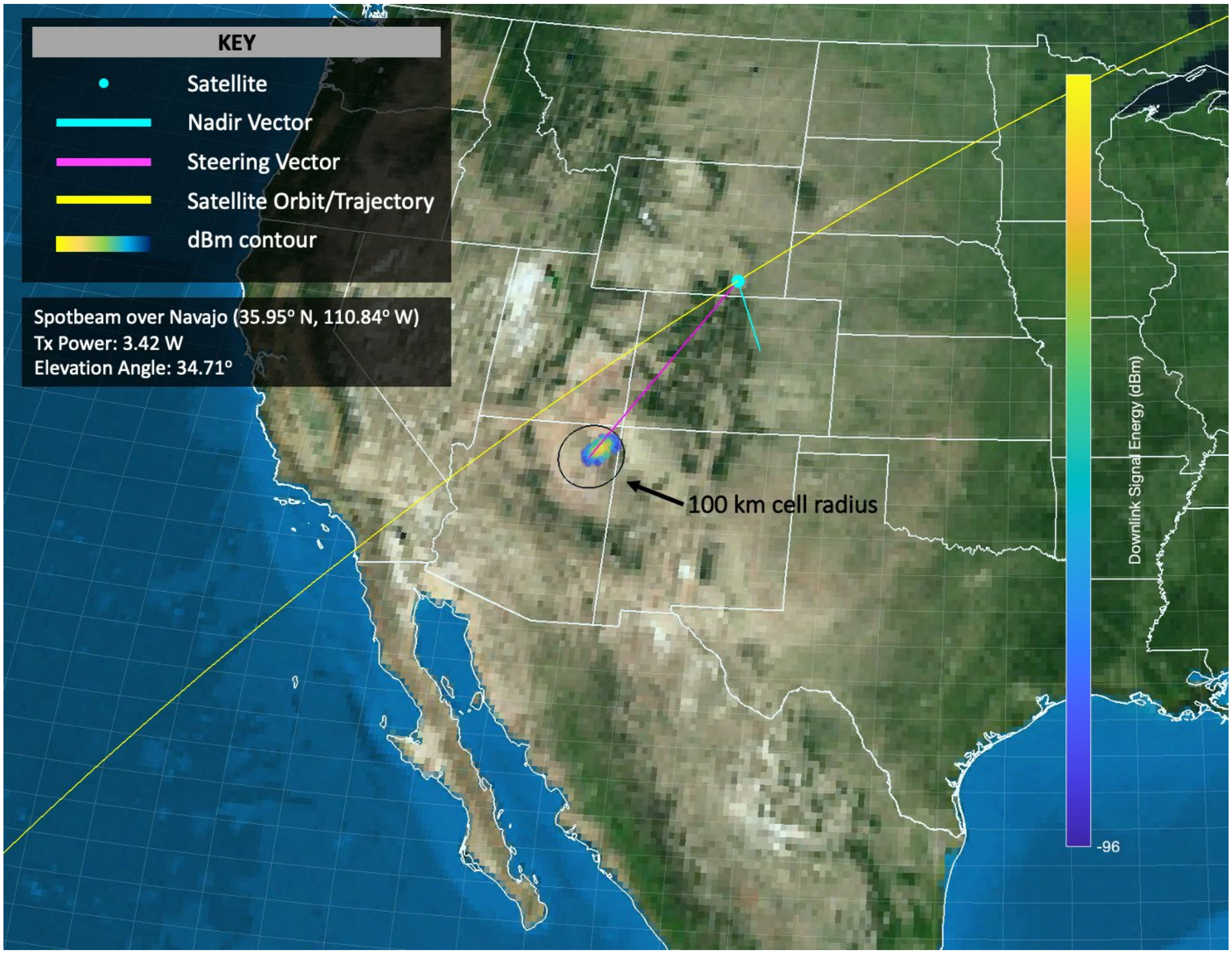

Figure 12 - Snapshot of satellite overpass of Navajo at 34.7 deg elevation angle.

These simulations demonstrate that Lynk can deliver services to prescribed geographic areas and conform to signal energy levels at the "super macro cell" edge. This capability supports coordination of service deployment in rural and remote areas by limiting overlap with the existing terrestrial cellular fabric.

IV. Introduction to Interference Analysis

The Co-Channel Interference Analysis and Monte Carlo Interference Analysis presented below are updated, higher fidelity interference mitigation analyses, similar to those submitted with Lynk's previous experimental applications. In Lynk's experimental applications, Lynk's engineering and spectrum teams computed that the probability of harmful interference is practically non-existent for use of the same frequencies requested in this license request.[11] The same holds true for the analyses provided with this application.

The following analyses address GSM and LTE use cases as separate, unique scenarios. The Lynk satellites will utilize specific GSM or LTE channels licensed to a specific MNO in a given service area. Generally, the satellite downlink signal that reaches the Earth is relatively low power compared to those produced by terrestrial towers, resulting in Lynk's satellites serving as the "towers of last resort." Consequently, the satellite's transmission will not harmfully compete or interfere with terrestrial communications because this low signal power level in combination with the geospatial, temporal, and protocol factors (outlined in detail later in this document)[12] will preclude harmful interference in all instances. Notably, both GSM and LTE analyses result in the same conclusion of no harmful interference.

While the methodology presented in this document is applied to a specific international use case (i.e., the Bahamas), the methodology and conclusions are valid for any location in the world. A similar analysis could be conducted on other geographies if the relevant data for the analysis were made available (e.g., tower data, etc.). NOTE: the analyses presented herein do not utilize U.S. data as the service links associated with this application *will not* be deployed within U.S. borders but will instead be deployed only in locations outside of the United States in partnership with MNOs and pursuant to authorizations issued by the relevant regulatory body.

Lynk will work with MNO partners to select service areas that generally include areas where there is little to no MNO coverage at the same carrier frequency. The satellites will be programmed to produce beams on the Earth that predominantly cover geographies outside cell tower coverage and minimize beam overlap with terrestrial cells as much as possible. Furthermore, Lynk is conducting tests with the express cooperation and participation of the terrestrial licensee to prove both the system's functionality and compatibility with existing terrestrial deployments. As in its experimental applications, Lynk will continue to accumulate data to validate its assumptions and provide a design baseline for enhancements to the Lynk network for delivering and improving cellular service for the public good.

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[11] *See* Legal Narrative, Section V, B, for a list of Lynk's experimental authorizations.

[12] *See, infra,* Section VI.

V. Co-Channel Interference Analysis

This Co-Channel Interference Analysis makes a qualitative consideration of any co-channel radio interference with terrestrial towers in three separate cases with respect to the area illuminated by the satellite—i.e., Urban, Suburban/Rural, and Remote. Then, the analysis takes a quantitative approach to compute the risk of harmful radio interference as a result of co-channel use between the terrestrial network and the Lynk network. The analysis considers geospatial, frequency, time, and protocol aspects to harmful interference and applies these processes sequentially. In conclusion, no matter which case is considered, there is no measurable chance of harmful interference.

Figure 13 below summarizes the interference analysis in a process flowchart in which each subsequent individual process further reduces the chance for harmful interference. The numerical probability of radio interference at each step in the process flow is numerically derived in the various sections of this Interference Analysis. The flowchart reads from top left to bottom right, and it uses color-coded columns to indicate the dimension being analyzed along that point in the process flow line.

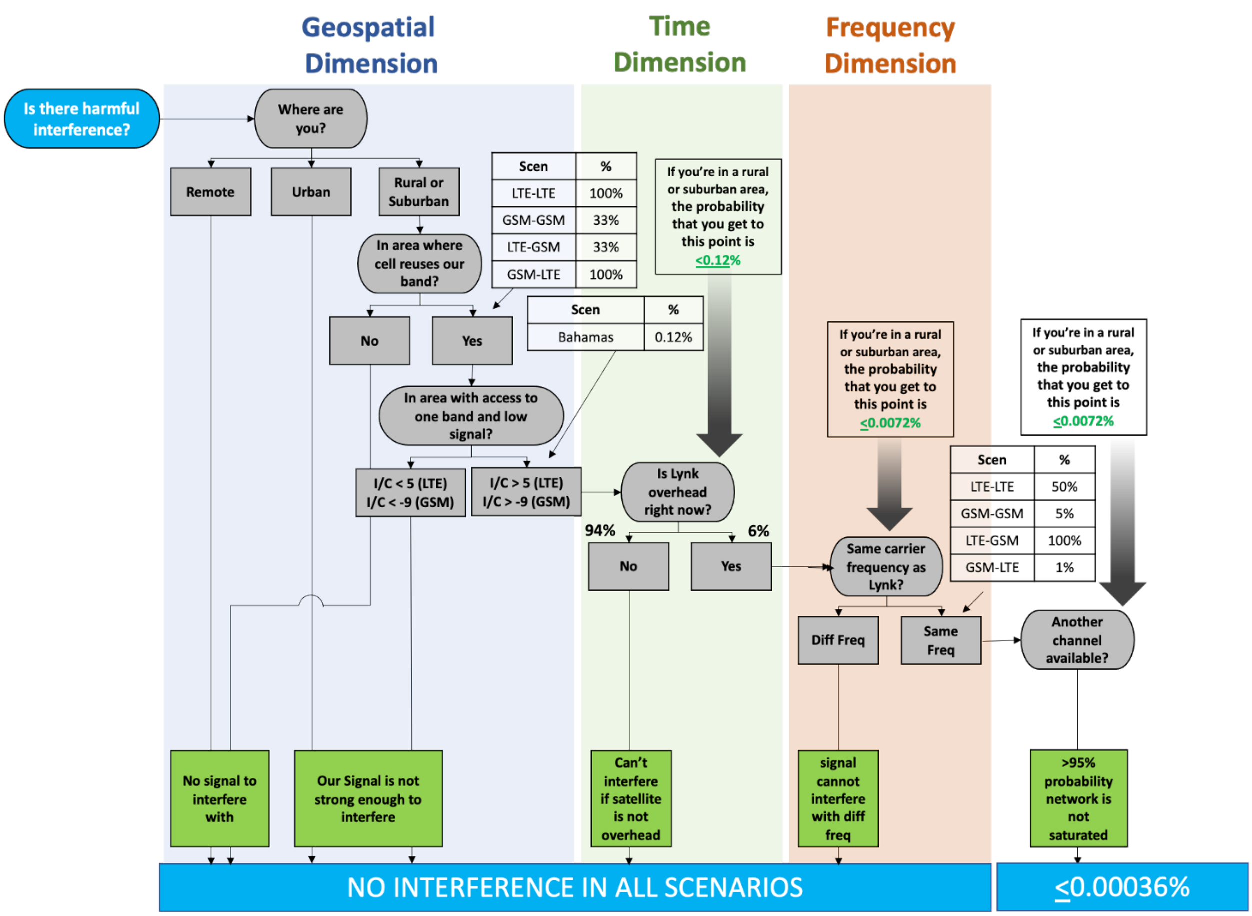

Figure 13 - Flowchart illustrating the risk of interference of the Lynk Smallsat System.

A. Qualitative Analysis

1. Remote User Interference Potential

There is no potential of Lynk causing harmful interference in remote areas with the proposed Lynk service architecture. Remote users, by definition, are those who reside in regions in which there are no towers sufficiently close to provide service. Even in cases where remote users have a signal from a terrestrial tower, the maximum timing advance employed by the local servicing tower may consider such users too far away to provide service. Because remote users have no access to an existing terrestrial mobile service, such users will not suffer impeded service due to the presence of a signal from Lynk's satellites. Indeed, such remote users with either no or unusable terrestrial connectivity are one of the primary use cases for Lynk's satellite network.

2. Urban User Interference Potential

Urban environments contain many closely spaced towers to provide ample performance in the presence of significant multipath, shadowing, and attenuation. Additionally, towers are spaced closely to leverage many instances of frequency reuse as well as to support numerous subscribers and substantial bandwidth demands. Furthermore, urban deployments of cells are often heterogenous in nature, where cell coverage often involves substantial geographic overlap and where interference is avoided using spectral orthogonality among overlapping cells, and increasingly by using active antennas to direct beams toward specific users, via MIMO and selective polarization. Typically, there is overlap of various frequency bands (often as numerous as five (5) or six (6) frequency bands) with higher frequencies deployed on smaller cells, making frequency reuse even more substantial.

Frequency orthogonality refers to the use of different or even adjacent frequency blocks in cells that are geographically adjacent. Mobile users operating in adjacent blocks of spectrum are also intrinsically safe from interference for the same reason that terrestrial networks are safe from interference. The digital and RF filters in the base station transmit chains that ensure the adjacent channels and blocks as well as OOB transmissions are reduced to the required levels—for example the factor of at least 43+10 log(P) dB as appropriate to the Broadband PCS band[13]— or other standard levels, whichever are more stringent.[14] The signal produced by

[13] As required in various bands, such as in the PCS band, by 47 CFR § 24.238(a).

[14] *See* 3GPP TS 36.104 V 16, "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception," Section 6.6, *available at* https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=2412.

Lynk's satellites is simply too weak to impact the C/I ratio since the satellite users are essentially operating at signal strengths comparable to those experienced close to the cell edge.

The only locations in urban geographies where cellular signals drop to levels comparable to those from Lynk's satellites are when attenuation from obstructions, multipath, building penetration, etc. occur. Even still, at these urban locations, any attenuation creating terrestrial signal loses will similarly impact the signal from Lynk's satellite payload such that it will be reduced to well below the thermal noise limit. Regarding the urban locations shielded from terrestrial base station transmissions by large obstructions (e.g., mountains), these areas may not be shielded from Lynk's satellite beams, but these locations may be treated like the remote areas discussed in the previous section, and so Lynk would be providing service where there otherwise was none.

Thus, there is no material case in which a customer in an urban location will suffer impeded service due to the presence of a signal from Lynk's satellites.

3. Suburban/Rural User Interference Potential

The only locations where the Lynk network could reasonably pose a risk of harmful interference is in suburban/rural areas, where the same frequency band is used and where there are only a few overlapping cells in the existing heterogenous terrestrial network.

The terrestrial cellular network is designed to deploy the use of its spectrum to users across three dimensions for maximum throughput: space, time, and frequency. In other words, the spectrum is deployed geographically via expansive frequency reuse and then each cell channelizes communications across the domains of frequency and time using multiple access schemes. Consequently, harmful interference may only occur at a particular place and time as well as on a particular carrier frequency, which will only be possible if the terrestrial cellular network cannot automatically reallocate the communications to another available channel.

A satellite payload poses the greatest risk of impacting the service of suburban and rural users because cellular base station coverage areas in these places are generally larger and more spread out with fewer transmitting towers, creating more opportunities for these users to operate at the edges of cellular service. Fortunately, at these edges there are usually very few, if any, mobile devices, and thus ample excess capacity. This is the case because economics drive the MNOs to expand their coverage capability until the population density of coverage areas is too limited to merit the investment. In other words, the edge of cellular coverage is intentionally designed to occur in geographies with limited population density, and these are the only geographies where the Lynk's satellites could ever present potential interreference.

Nevertheless, the quantitative analysis presented in the next section shows that the probability of harmful interference in even these geographies is so negligible as to be essentially zero.

B. Quantitative Analysis

By investigating the three dimensions of space, time, and frequency, this quantitative analysis evaluates the probability of harmful interference to a terrestrial network due to Lynk satellites operating on a co-channel frequency. For there to be a possibility of harmful interference, all three dimensions must be invoked—see Figure 13 above. This means that harmful interference is only possible if a user is in a location (space) where the signal from the Lynk network is present and measurable (time), and that signal happens to be on the same, and only, band (frequency) being utilized by the mobile user.

This analysis will detail the quantification of the probability of interference, taking conservative assumptions and models that generously (and intentionally) overestimate the risk of harmful interference. As shown in the Figure 13 above, there is approximately 0.00036% probability (the worst case) that the Lynk Smallsat System has a potential to create harmful interference to a terrestrial network using the same carrier frequency in the same band; and even then, the mobile device would use a protocol to automatically select another carrier if this extremely unlikely event were to occur.

Accordingly, the following four-pronged analysis shows the final likelihood of actual harmful interference impacting service in suburban and rural geographies being so nominal as to be practically zero.

1. Spatial/Geospatial Impact on Potential Interference

Across terrestrial networks, Lynk's analysis finds approximately 0.12% chance of any interference regarding the dimension of space.[15]

The structure of the terrestrial mobile network relies on frequency reuse patterns and protocol level features to avoid inter-cell interference. The strategies for this are technology dependent. GSM networks will deploy spectrum in a manner that only reuses the frequency every "n" cell sites, where "n" is the frequency reuse factor of 3, 5, 7, etc. As a result, spectral orthogonality exists in locations where cells overlap. LTE networks, in contrast, can deploy spectrum using a frequency reuse pattern of 1—i.e., every tower can use all frequencies. To avoid inter-cell interference, the cells use fractional frequency reuse for cells with overlapping coverage areas. This technique allocates certain portions of the bandwidth for mobile devices at the cell edge and the rest of the bandwidth for mobile devices closer to the center of the cell. Neighboring cells will allocate opposite portions of the bandwidth for mobile devices within their overlapping coverage areas to create frequency orthogonality in these locations. In some cases, MNOs may not use fractional frequency reuse at cell edges and may simply rely on the significant levels of coding at the low CQIs/MCSs to keep all the mobile devices connected. This scenario further demonstrates that existing deployments can operate commercially even in the

[15] *See, infra,* Section VI, for the computation of this probability in the Monte Carlo Interference Analysis.

event of intentional co-channel interference by leveraging the air interface capabilities baked into the LTE protocol.

The following figures illustrate frequency reuse strategies for managing inter-cell interference.

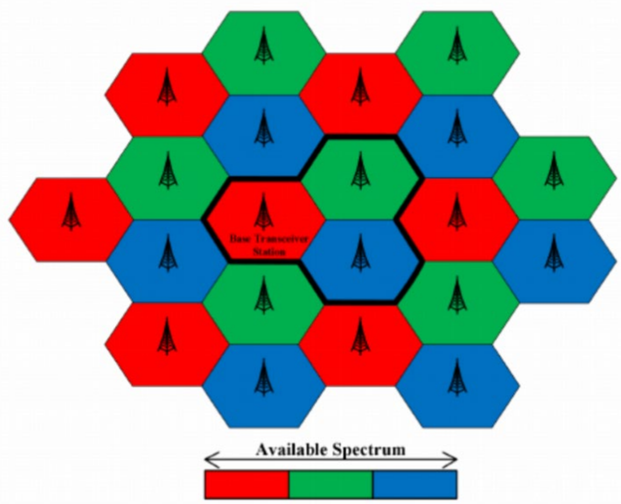

Figure 14 – GSM frequency reuse strategy for inter-cell interference illustrating 1/3 reuse, though reuse of 1/7 is more commonly used.

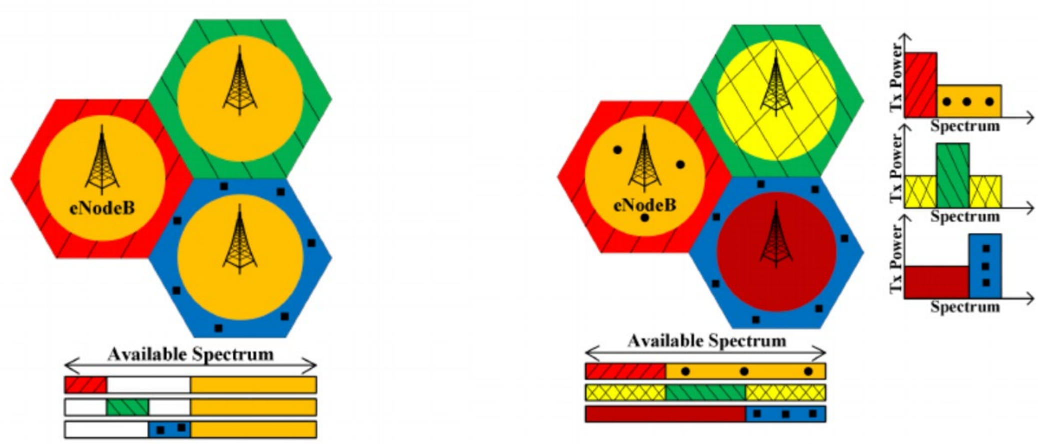

Figure 15 - LTE fractional frequency reuse strategies for inter-cell interference. The cross hatching in the image indicates the use of fractional frequency reuse in LTE adjacent cell deployments on co-channels.

Notably, locations that have a working signal from more than one tower have access to each of the nearby towers using orthogonal frequency sets. This is important for the interference risk assessment in the geospatial domain because it implies that the risk of interference can fundamentally only exist at the edge of cellular coverage in these geographies when only one base station can provide coverage on one band or when all towers are fully saturated.

The risk of interference in the geospatial domain can be computed based on the numerical coincidence of two criteria. The first is the percentage of cells on the ground that happen to exclusively reuse the frequencies deployed by the Lynk satellite network. The second is the percentage of geography that only has access to a working signal from one cellular band. Furthermore, these geographies must have a weak enough signal such that a co-channel signal from a satellite is strong enough to create harmful interference and eliminate that band's coverage in that geography.

Table 4 computes the risk of interference based solely on the frequency reuse strategy.

Frequency Reuse Strategy		Risk of common frequency use with terrestrial cells
GSM	Frequency reuse 3	33%
	Frequency reuse 5	20%
	Frequency reuse 7	14%
LTE	Frequency reuse 1	100%

Table 4 - Risk of Coincident use of Spectrum with different Reuse Strategies.

The Monte Carlo Interference Analysis presented in Section VI of this illustrates where exactly in the existing coverage of a terrestrial network there is any risk of interference. In summary, the only geographies that can experience harmful interference are those with access to only one frequency band, and if a user happens to be in one of these geographies, harmful interference is only possible when the I/C of the Lynk transmitter relative to the signal level of the serving terrestrial tower is higher. Assuming $I \gg N$, there can only be potential interference when:

(A) GSM I/C exceeds -9 dB (GSM requires minimum SINR of 9 dB) or
(B) LTE I/C exceeds 5 dB (LTE requires minimum SINR of -5 dB).

For geographies where the signal from the serving terrestrial tower is already below 9 dB for GSM, or -5 dB for LTE, interference from Lynk's satellites is not possible because the terrestrial towers are not capable of providing existing mobile coverage with which to interfere. The Monte Carlo Interference Analysis computes the potential geospatial interference factors described here; the results of which provide the risk of interference in the geospatial domain for one real-world network deployment.

Country	Max percent of geography at risk of interference
Bahamas	0.12 %

Table 5 - Risk of Geographic Interference based on network deployment in the Bahamas.

The risk of interference in the spatial domain based on technology can be computed based on combining the factors of frequency reuse and at-risk geography. Table 6 below summarizes this computation by assuming the more conservative results provided in Table 4 above.

Technology	Risk of interference in spatial domain
GSM	0.0396 % (0.12 % x 33%)
LTE	0.12 % (0.12 % x 100%)

Table 6 - Risk of Interference in Spatial Domain by Technology.

NOTE: the risk of interference calculated in this portion of the analysis is not weighted to account for the number of users who experience interference in any given location. The potential victims of harmful interference are people themselves who use mobile devices. As such, the impact of interference is more significant in urban areas where there are higher population densities, and less significant in areas where there are lower population densities. If reflected as a percentage of the population who reside in, or may travel to, geographies that have risk of interference, the analysis would produce a significantly lower result. The present analysis is, therefore, conservative with respect to the subject of interference as it considers harmful interference of one device to be equal in impact to interference of thousands of devices.

2. Time Impact on Potential Interference:

Lynk will initially provide intermittent cellular services in remote and rural areas that do not currently have terrestrial service. The intermittency of the cellular service is driven by the FOR of the beam steered antenna as well as the number of satellites in the network. By design, each satellite will have a FOR with relatively high elevation angles so the presence of a beam from a particular satellite in any given location is limited to about three (3) minutes per satellite overpass. Based on the satellite orbit, the number of overpasses per day per satellite, for any given location, can vary between one (1) and three (3) based on the latitude of the geography.

Table 7 below computes the risk of interference as a function of satellites in the network. The minimum risk of interference occurs at the equator, while the maximum risk of interference would occur at approximately the latitude that is equal to the orbit inclination angle for most of the satellites. In this case that is 53 degrees N/S latitude. The computations below assume satellite overpasses do not coincide in time, which presents a somewhat conservative estimate for the risk of interference in the temporal domain.

Number of Satellites	Min risk of interference (at equator)		Max risk of interference (around 53 degrees N/S latitude)	
1	0.2%	3 min/day	0.6%	9 min/day
10	2%	30 min/day	6%	90 min/day
100	20%	300 min/day	60%	900 min/day

Table 7 – Risk of Interference by # of Satellites.

Note that this analysis does not consider the temporality of the actual user time (diurnal effects) or RRC connected time that a mobile device spends on a network each day. The analysis conservatively assumes that all mobile devices within the satellite beam are attempting communications with their servicing terrestrial towers. While it is difficult to estimate the exact percentage of time the average mobile device is exchanging bursts with the terrestrial network, reasonably practical percentages might fall in the 10% to 20% range. Furthermore, the analysis does not consider channelization of time slots either. As such, the present analysis assumes that the Lynk satellite is occupying all timeslots across the entirety of the analyzed bandwidth which is unlikely and highly conservative. Consequently, the risk of interference in the time domain is overestimated by at least a factor of ten (10) in this analysis.

3. Frequency Impact on Potential Interference:

The probability of potential interference in the spectral dimension is predicated on the technology, bandwidth, and frequencies deployed by the Lynk satellite network. These parameters will be highly dynamic being based on agreements with MNOs. This portion of the analysis assumes that Lynk's satellite shares a portion of the spectral bandwidth for a given cell on the Earth and that cell on the earth utilizes twenty (20) MHz of reverse link and twenty (20) MHz of forward link FDD bandwidth. Note that this, too, is a very conservative case as it assumes one frequency block in one given band. For instance, the four U.S. nationwide spectrum holders all have over 114 MHz of spectrum holdings, as shown in Table 2.

As noted before, the risk of interference is computed as a function of the bandwidth and technology deployed by Lynk. If a known co-channel deployment between Lynk and a terrestrial network is known, Lynk would utilize only a fraction of the co-channel deployment on the terrestrial network to prevent full co-channel overlap. As such, with a twenty (20) MHz co-channel deployment on the terrestrial network, Lynk's bandwidth would be limited to ten (10) MHz forward link and ten (10) MHz reverse link of LTE per beam. In case of co-channel interference, preventing complete co-channel overlap of a contiguous block would be prudent. Larger bandwidths are deployable if spectral or geographic orthogonality are achieved.

Lynk Satellite Bandwidth		Risk of interference with terrestrial cell sharing bandwidth over a 20 MHz downlink
GSM	200 kHz	1%
LTE	1.4 MHz	7%
	3 MHz	15%
	5 MHz	25%
	10 MHz	50%

Table 8 – Risk of Interference by Lynk Satellite Bandwidth.

The best scenario for Lynk and its MNO partners is for Lynk to deploy spectrum that will not be used by the terrestrial network, especially near edge boundaries. However, even if Lynk were not to deploy in unused spectrum, the deployments could be made with spectrum bandwidth that do not completely overlap with adjacent cells. In either case, since there is never a complete overlap of the spectral bandwidth from the Lynk satellite and the terrestrial cells, there is always an opportunity for channel reassignment in the event that RF energy from the satellite converges in the same resource block and time slot as one being used by a mobile device. The only time when there may not be an opportunity for channel reassignment is when the network is too congested to reallocate channels (since the Lynk network could easily be designed to not use all channels on a given block). The probability for a scenario like this in an urban setting is higher, but much less so in a suburban or rural setting. An assumption is made in the analysis that there is a 95% chance that mobile devices being interfered with can be reallocated to a channel serving their terrestrial cell.

It is worth noting that the probability of another available channel is not static. Indeed, the probability of there being another available channel would ultimately be a function of the overlap of the Lynk spectrum with respect to terrestrially deployed spectrum. As the percentage of overlap is reduced, there is more available bandwidth for potential reallocation, increasing the probability that there is an available channel in the presence of typical, or peak, traffic patterns. In the absence of rigorous empirical data, however, it is difficult to model the non-linearity described by this relationship. As such, the linear model provided for risk of interference with respect to the frequency domain is highly conservative.

The typical terrestrial networks conduct capacity planning, mostly in a heuristic manner. Capacity planning is often conducted based on demand variations between peak and low demand scenarios (e.g., busy hour, day/night, weekends, events, etc.). The most loaded cells on the macro grid are in areas with the highest population densities, while the least loaded cells are in areas with the lowest population densities.

Some public data suggests the approximate percent utilization of network capacity in the terrestrial mobile macro grid for various operators around the globe does not exceed 60% utilization on average for the most loaded cells, while the 50% least loaded cells (half of the network) on the macro grid often do not exceed 5% utilization on average.[16] Typically, most MNOs monitor cellular traffic demanded by each base station, and when the traffic at busy hour approaches 80% of full capacity of the site, then the MNO either splits the cell, adds additional carriers, or upgrades to MIMO or other more efficient air interface capabilities.[17] Consequently, most networks that have been well maintained have 20% or more excess capacity at all times (often significantly more).

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[16] *See Capacity utilization and fixed-to-mobile broadband substitution potential with existing macro site grids – 2017*, Rewheel research PRO-study (Sept. 2018), *available at* http://research.rewheel.fi/downloads/Capacity_utilization_fixed_mobile_broadband_substitution_potential_2017_PUBLIC.pdf.

[17] *See* Clarke, *supra* at 693-708.

The Lynk network is designed to provide service in areas that mostly overlap with low population geospatial locations where sub-1 GHz band spectrum is deployed. As such, most of the locations that have a risk of interference will be operating at 5% utilization of existing terrestrial infrastructure on average. This suggests almost a guarantee that there is available bandwidth on the serving terrestrial cell to which mobile devices can be reallocated to avoid harmful interference; in the least loaded cells there is, on average, twenty (20)x more excess capacity than what is utilized. There is limited publicly available data on the standard deviation of the percent utilization away from the average, but it is unlikely that three (3)-sigma for percent utilization on the least loaded cells to be substantial enough to ever result in a scenario where there is not any more usable bandwidth on a given, remote macro cell. Nevertheless, Lynk takes the conservative assumption that there is a 95% chance that there is available bandwidth on any cell with a risk of interference.

4. All 3 Dimensions Impact on Potential Interference

There is an infinitesimal chance that Lynk's service will interfere with existing terrestrial deployments. This is based on the aggregate probability of a mobile device simultaneously meeting all of the following criteria**:**

- (A) operating in a geography where only one frequency band is available, and at a signal energy that cannot achieve a high enough SINR for usable service when an interfering signal is present from a satellite,
- (B) operating at the exact time that Lynk's satellite is overhead,
- (C) operating on the exact frequency block Lynk is using for service, and
- (D) operating when no alternative channel on the frequency block is available for mobile device reassignment.

Table 9 below shows the numerical computation of the probability of interference and the probability of harmful interference for four different scenarios. The first two (2) scenarios are for common protocol scenarios, where the cellular deployments on the ground and those used by Lynk employ the same technology (e.g., LTE on LTE, and GSM on GSM). The second two (2) scenarios are for cross protocol scenarios, where the cellular deployments on the ground and those used by Lynk employ different technologies (e.g., GSM on LTE, and LTE on GSM). In all four (4) scenarios, the probability of interference is very small, and the probability of harmful interference is negligible (i.e., less than 0.00036% in all cases). Because of the conservative assumptions Lynk made in this analysis, these estimates are likely much higher than reality by an order of magnitude or more. Notably, some probability factors (as described previously in this document) further reduce the probability of interference, but they have not been included in the calculation. It is also worth noting that even in the event that a full Lynk constellation (providing constant coverage, not intermittent) is considered by the analysis, the risk of radio interference for each scenario would increase by a factor of 16.6, still resulting in a negligible risk of harmful interference.

Scenario	Description	Risk of Interference (10 satellites)	Risk of Harmful Interference (10 satellites)
1	LTE on LTE	0.003600 %	**0.00018000 % (1.8 x 10^{-4} %)**
2	GSM on GSM	0.000480 %	**0.0000240 % (2.4 x 10^{-5} %)**
3	LTE on GSM	0.007200 %	**0.0003600 % (3.6 x 10^{-4} %)**
4	GSM on LTE	0.000024 %	**0.0000012 % (1.2 x 10^{-6} %)**

Table 9 - Risk of Harmful Interference by Technology Combination.

The summary of the probabilities used to compute the results in the Table 9 above are given in more detail in the following tables.

Statistical Co-channel Interference Analysis of Lynk Satellites on Terrestrial Cells - Common Protocol		
	LTE - LTE	GSM - GSM
Probability that user is in a location that only has access to one band, which is the same as that used by Lynk *Analysis: From Monte Carlo Simulations*	0.12%	0.12%
Probability user is in an area with the same carrier frequency as Lynk (considering re-use factor in band) *Analysis: Frequency re-use for LTE = 1, Frequency re-use for GSM = 3*	100%	33%
Percent of available licensed bandwidth utilized by Lynk network *Analysis: LTE assumes 10 MHz deployed with 20 MHz on tower, GSM assumes 1 carrier with 5 on tower*	50%	20%
Probability that a Lynk satellite is overhead *Analysis: Percent of time area is covered by Lynk satellite*	6%	6%
Probability of Interference	0.003600%	0.000480%
Probability there is available bandwidth on other carriers served by the terrestrial tower *Analysis: Percent of time that non urban cell towers are NOT at capacity/saturation.*	95%	95%
Probability of Harmful Interference	**0.0001800%**	**0.0000240%**

Table 10 - Analysis of the risk of interference assuming common protocol.

Statistical Co-channel Interference Analysis of Lynk Satellites on Terrestrial Cells - Cross Protocol		
	LTE-GSM	GSM-LTE
Probability that user is in a location that only has access to one band, which is the same as that used by Lynk *Analysis: From Monte Carlo Simulations*	0.12%	0.12%
Probability user is in an area with the same carrier frequency as Lynk (considering re-use factor in band) *Analysis: Frequency re-use for LTE = 1, Frequency re-use for GSM = 3*	100%	33%
Percent of available licensed bandwidth utilized by Lynk network *Analysis: LTE assumes 5 MHz deployed with 5 carriers on GSM tower, GSM assumes 1 carrier with 20 MHz LTE on tower*	100%	1%
Probability that a Lynk satellite is overhead *Analysis: Percent of time area is covered by Lynk satellite*	6%	6%
Probability of Interference	0.007200%	0.000024%
Probability there is available bandwidth on other carriers served by the terrestrial tower *Analysis: Percent of time that non urban cell towers are NOT at capacity/saturation.*	95%	95%
Probability of Harmful Interference	**0.0003600%**	**0.0000012%**

Table 11 - Analysis of the risk of interference assuming cross protocol.

VI. Monte Carlo Co-Channel Interference Analysis

The following is an analysis of coverage statistics of existing terrestrial mobile networks using Monte Carlo methods. The results of the analysis are used to numerically compute the probability that co-channel interference from Lynk satellites can create harmful interference into an existing terrestrial network. In short, Lynk confirms that this probability is negligible.

There is little to no publicly available data that comprehensively describes the RAN configuration of MNOs around the globe. There are some available data sources with RAN information—e.g.: cellmapper.com, openCellID, FCC ASR Database, FCC Cellular Tower Database, etc.—however, these data sources are either dated or lacking the totality of information required for an analysis. As such, the use of these data sources in the analysis would come with a number of assumptions that may reduce the merit of the analysis. Fortunately, Lynk was able to obtain substantial and actual details on the RAN information of an MNO partner in the Bahamas. The MNO partner provided a database of the locations, directions, patterns, and frequencies of all transmitter antennas for all deployed frequency bands in the MNO's geography. The results of following Monte Carlo analysis employing these details will be used to compute the probability of harmful interference in the event of co-channel use between the Lynk network and the terrestrial MNO network—see Figure 13.

Notably, the partner MNO already identified latent spectrum in its portfolio—i.e., spectrum not deployed anywhere in the network's licensed geography. The MNO identified a portion of Band 5 (i.e., 850 MHz Band) as currently latent in its terrestrial network that could be used by Lynk satellites to fill in gaps and extend the MNO's existing coverage. If the Lynk space network utilized this latent spectrum in the Bahamas, this spectrum use would be perfectly orthogonal to the terrestrial network in the frequency domain, preventing the possibility of co-channel interference, making harmful interference impossible.

In addition to latent spectrum, there are latent geographies in the network license area as well. Specifically, these are areas within the MNO's licensed geography that are not provided with coverage by certain portions of the licensed spectrum. These latent geographies represent opportunities to orthogonally deploy spectrum that is already deployed by the terrestrial network. Specifically, there is five (5) MHz of bandwidth in Band 5 that is deployed in smaller portions of the nationwide licensed geography. This leaves large swaths of geography and ocean that are not provided coverage by that carrier on that band. Lynk's use of this five (5) MHz of bandwidth in beams deployed in areas adjacent to or away from existing coverage using the same spectrum would also result in a scenario where co-channel interference and harmful interference are both impossible.

Lynk also prepared this co-channel interference analysis to investigate the impact of overlapping co-channel cells between the terrestrial MNO network and the Lynk satellite network. The results of this analysis show that the harmful impact of co-channel interference on Band 5 from the Lynk network is in and of itself infinitesimally small.

A. Bahamas Network Use-Case

Table 12 outlines the partner MNO spectrum deployment and nationwide license portfolio in the Bahamas.

Band	LTE Deployment Bandwidth	UMTS Deployment Bandwidth	Total Licensed Bandwidth
Band 2 (1900 MHz)	15 + 15 MHz LTE (1 carrier)	N/A	15 + 15 MHz
Band 4 (2100 MHz)	20 + 20 MHz LTE (1 carrier)	N/A	20 + 20 MHz
Band 5 (850 MHz)	5 + 5 MHz LTE (1 carrier)	5 + 5 MHz LTE (1 carrier)	11 + 11 MHz
Band 13 (700 MHz)	10 + 10 MHz LTE (1 carrier)	N/A	10 + 10 MHz

Table 12 - Deployed and Licensed Bands for this MNO in the Bahamas.

There is one (1) MHz of latent spectrum in Band 5, which the MNO does not currently deploy and is licensed nationwide in the Bahamas. The MNO would like to work with Lynk to deploy this spectrum for wide-spread GSM coverage around the islands of the Bahamas. This demonstrates a real-world example of how the Lynk network can deploy services with spectral orthogonality.

The five (5) MHz of LTE deployed in Band 5 is not widely deployed around the islands. This is illustrated with more detail later in this analysis, but there are opportunities to place beams from Lynk satellites on this same five (5) MHz in areas around the islands where the current Band 5 LTE deployments do not overlap. The MNO would like to work with Lynk to deploy this spectrum for wide-spread LTE coverage around the islands of the Bahamas. This demonstrates a real-world example of how the Lynk network can deploy services with geospatial orthogonality.

The analysis presented herein will evaluate the coverage reach of each band in the network. The analysis will focus on a scenario where a there is a co-channel interferer from a Lynk satellite overlapping the existing Band 5 LTE deployments from the terrestrial network.

1. Transmitter Data

The coverage analysis leverages RAN configuration data, which is outlined and described below.

Radio Access Network Deployment		
No	Variable	Description
1	Site ID	Each transmitter has a Site ID—an identifier for the tower/mast.
2	Cell ID	Each transmitter has a unique Cell ID—an identifier for the unique cell.
3	Band	The frequency band used by the cell (e.g.: B2, B4, B5, B14, etc.).
4	Carrier	The carrier block used within the band used by the cell (e.g.: F1, F2, etc.).
5	Longitude	The longitude of the site in degrees.
6	Latitude	The latitude of the site in degrees.
7	Height	The height of the transmitter on the site in meters.
8	Azimuth	The azimuth angle of the antenna boresight—degrees from due North.
9	Mechanical Downtilt	The angle formed by mechanically tilting an antenna downwards.
10	Electrical Downtilt	The angle formed by electronically tilting an antenna downwards.
11	Downlink EARFCN	The EARFCN of the downlink carrier.
12	Center Downlink Frequency	The center frequency corresponding to the EARFCN of the downlink carrier.
13	Uplink EARFCN	The EARFCN of the uplink carrier.
14	Center Uplink Frequency	The center frequency corresponding to the EARFCN of the uplink carrier.
15	Cell Radius	The maximum cell radius for service coverage.
16	Cell Bandwidth	The bandwidth deployed by the cell (e.g.: 5 MHz, 10 MHz, 20 MHz, etc.)
17	Max Cell Power per RB	The max cell transmit power per resource block (e.g., 180 kHz) in dBm/RB.
18	Antenna Gain	The gain of the antenna for the cell (accounting for electrical tilt) in dBi.
19	Antenna VBW	The full-cone half power vertical beamwidth of the cell antenna.
20	Antenna HBW	The full-cone half power horizontal beamwidth of the cell antenna.

Table 13 - This table contains a summary of the cell level information provided for the radio access network deployment of all bands in the Bahamas.

Fundamentally, this dataset provides the elements needed, in combination with a propagation model, to generate a coverage map of signal energy values from each of the transmitters in their corresponding frequency bands, on the uniquely deployed carrier frequencies. Based on the signal energy values from each of the transmitters, and the noise power in the analyzed bandwidth, a SINR map can be computed.

The figure below illustrates the locations of all the sites in the dataset, with a magnification of one site illustrating some of the sector level/cell level data in the data set. Included in the dataset is 2,450 unique cells (1,812 LTE cells and 638 UMTS cells).

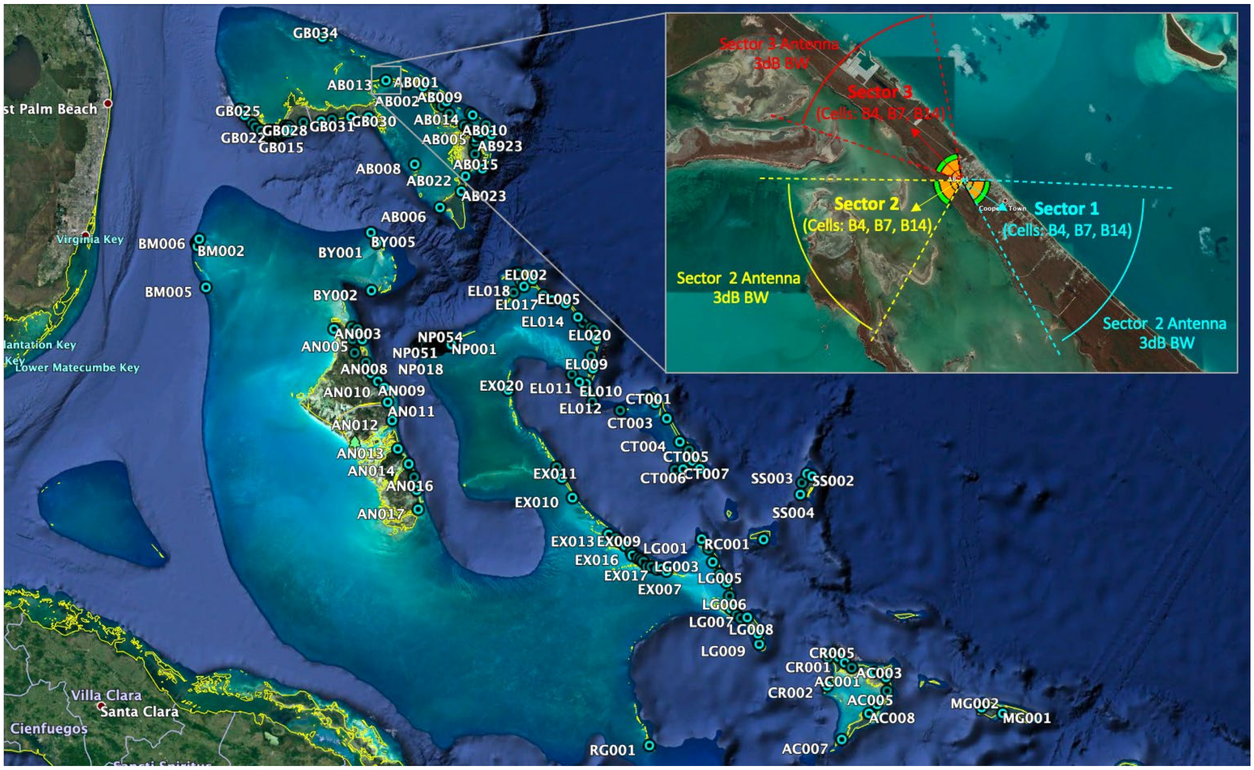

Figure 16 - Illustration of the MNO network sites across the Bahamas. Each of these sites contains multiple transmitters in multiple bands. Shown at the top right is a magnification of site AB001, which is home to a trisector deployment of 3 bands using directional antennas. Note: not all cell sites are labeled in the figure.

2. Propagation Model

The analysis uses the Longley Rice propagation model. Given that the analysis is conducted in the Caribbean region, the Longley Rice model is configured with the following properties.

Parameter	Propagation Model Value
Antenna Polarization	vertical
Ground Conductivity	0.0694[18]
Ground Permittivity	15
Atmospheric Refractivity	301
Climate Zone	'maritime-over-land'
Time Variability Tolerance	50%
Situation Variability Tolerance	50%

Table 14 - Outlines parameters used for the Longley Rice propagation model in the Bahamas.

Figure 17 is the result of the coverage analysis for an individual tri-sector tower on one of the bands that it supports by using a combination of the antenna transmitter data and the propagation model described above in Figure 16.

[18] The Ground Conductivity for the Bahamas is about 0.0694 Siemens per meter (S/m). *See* “Soil Test Procedures for Calcareous Rockland Soils of the Bahamas,” Florida A&M University International Soils Bulletin #1– Rev. 2, *available at* https://www.umes.edu/uploadedFiles/_WEBSITES/ARD/Content/bahamian%20soil%20test%20bulletin.pdf.

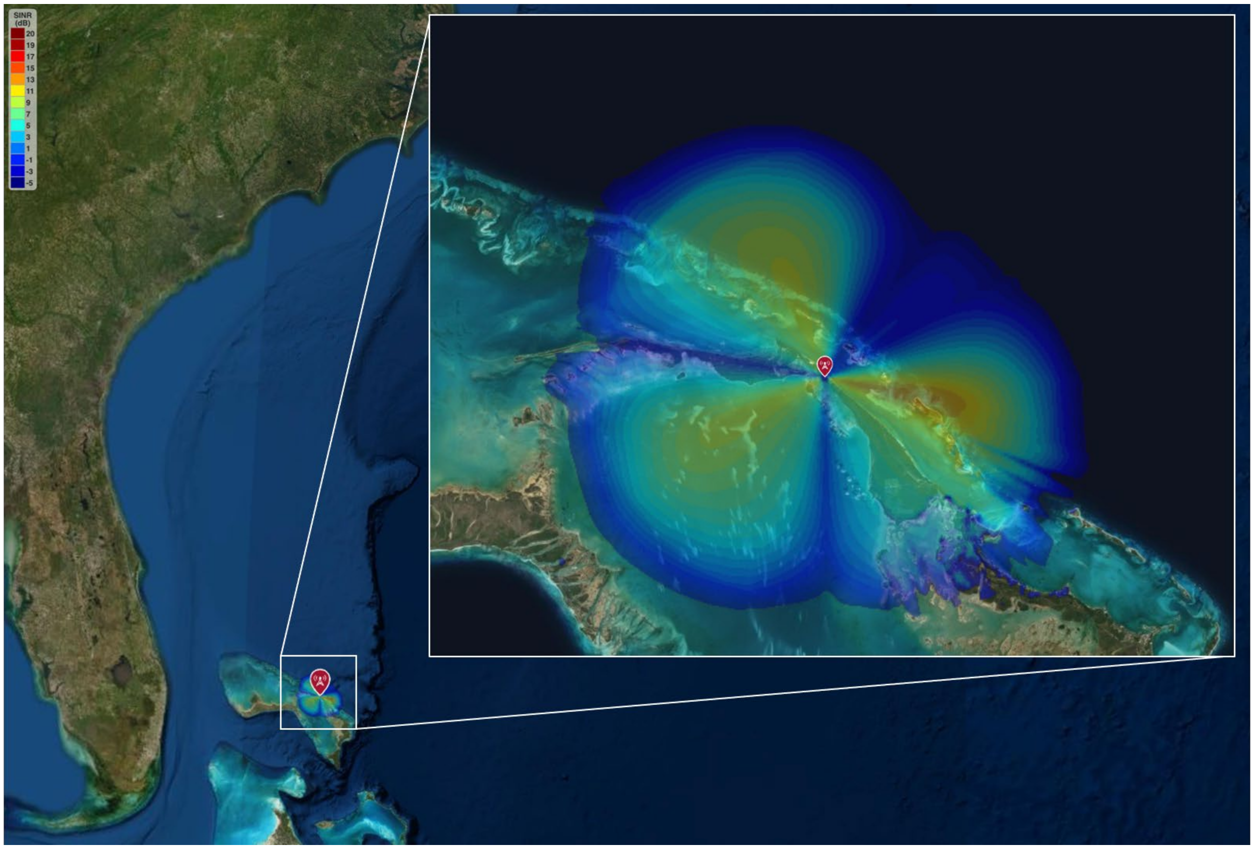

Figure 17 - Demonstration of the results of the Longley Rice coverage analysis utilizing one tri-sector antenna for one of the bands it deploys. In this case, Lynk analyzed site AB001 on Band 4, simply by way of demonstration and example of the analysis results.

3. Analyzing the Data

The analysis leverages a discrete mesh of 50,000 points randomly spread across the latitude and longitude frame of reference to fully occupy the country of the Bahamas and the surrounding water. After the mesh is created, the analysis evaluates the signal energy at each point resulting from each transmitter. The highest signal value from a transmitter at a given point indicates the signal from the serving cell. All other signals at the same point in the mesh resulting from other transmitters on the same band and carrier frequency are assumed to be interfering signals. Unique band and carrier frequencies in the analysis do not have any spectral overlap. The figure below illustrates this mesh.

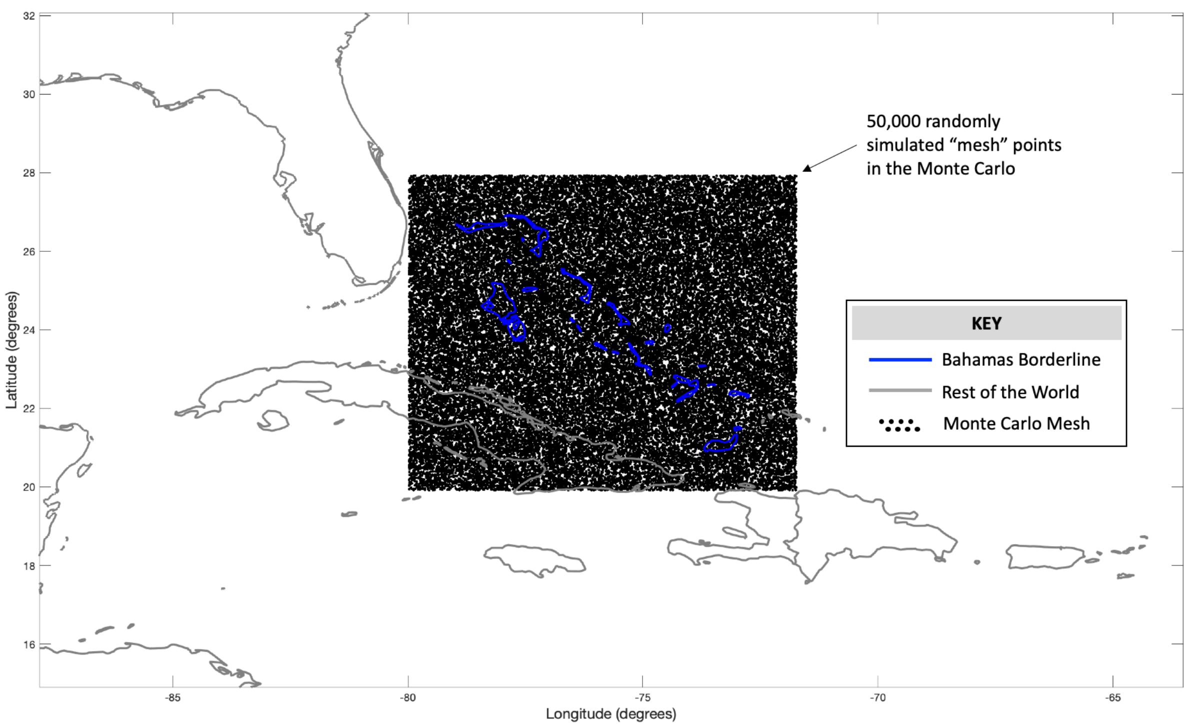

Figure 18 - Illustration of the 50,000 mesh points in the Monte Carlo simulation that generates the coverage maps for each frequency band.

Once the signal energy from the serving cell and the signal energy from all interferers are known, the SNIR can be computed. The coverage maps for each unique band and carrier frequency combination are generated based on the SINR computed for each band across the mesh. The following figures illustrate the coverage maps for each deployed band and carrier frequency combination.

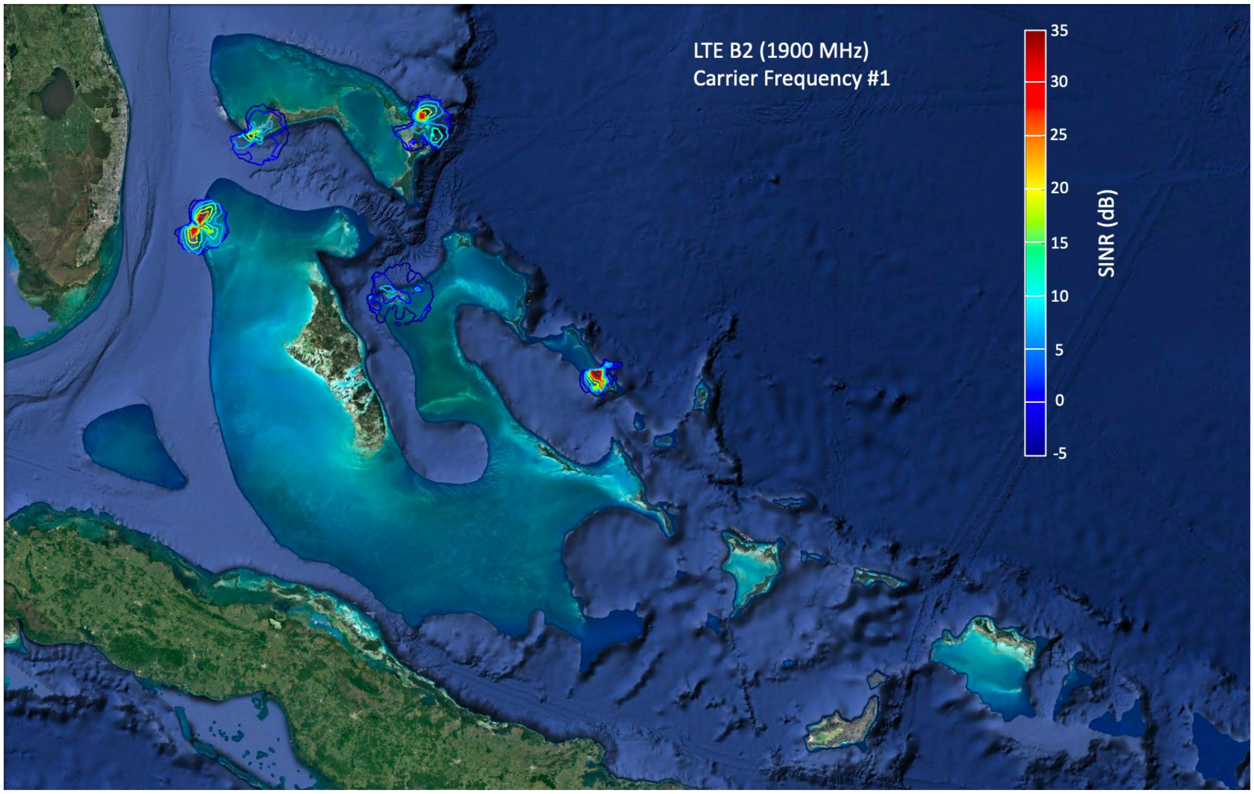

Figure 19 - Band 2 (1900 MHz) SINR coverage using Carrier Frequency #1.

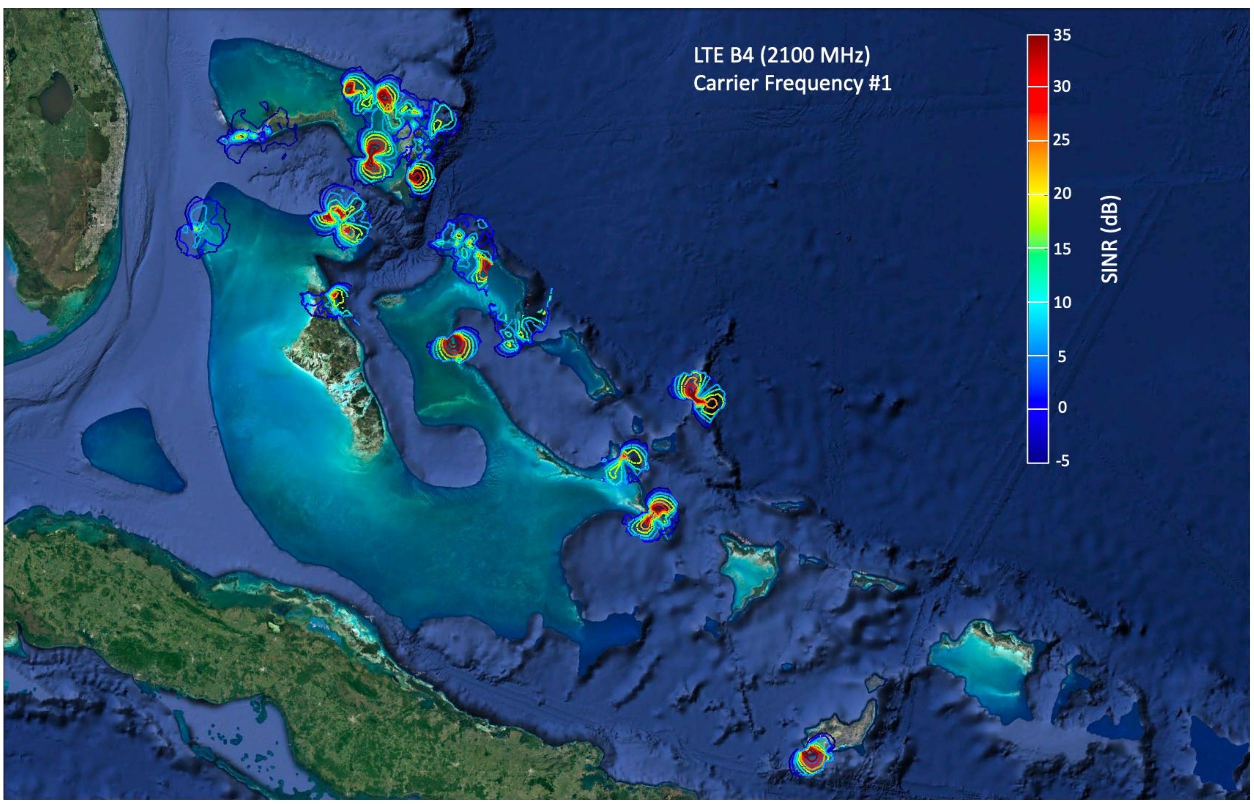

Figure 20 - Band 4 (2100 MHz) SINR Coverage using Carrier Frequency #1.

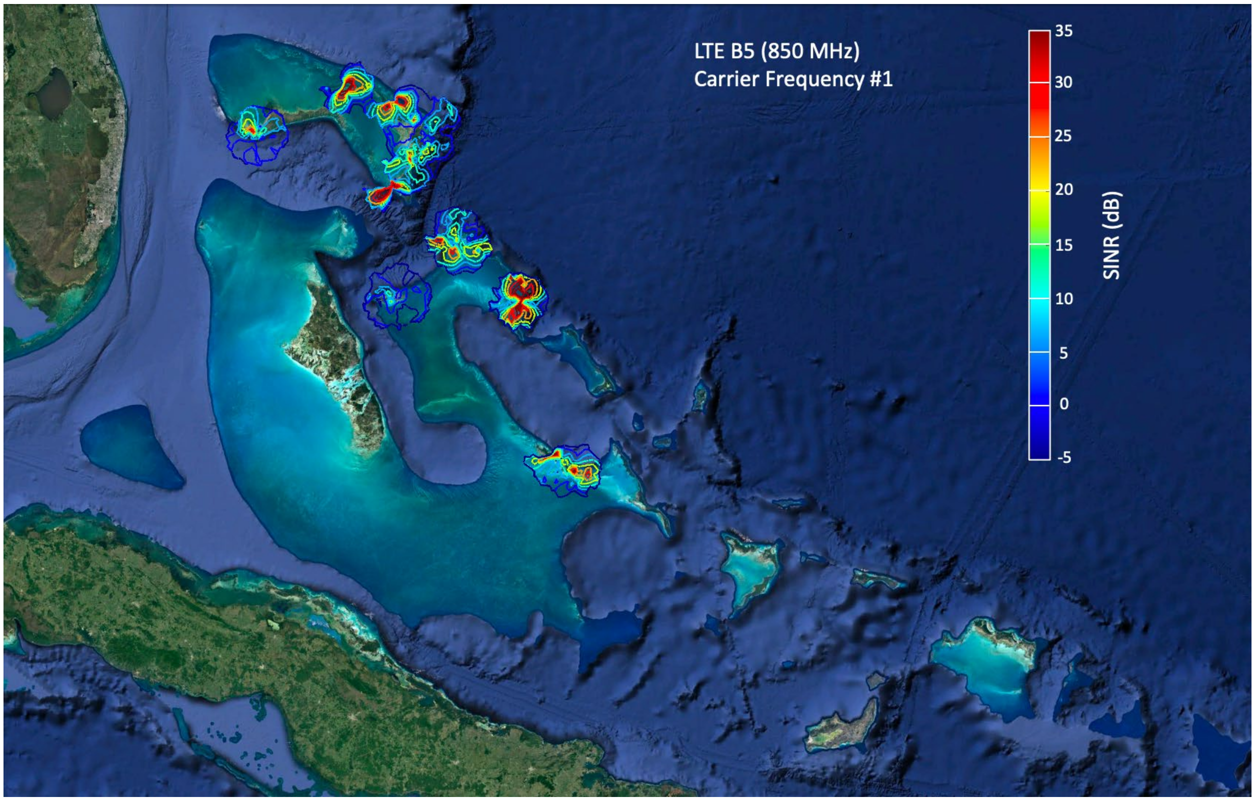

Figure 21 - Band 5 (850 MHz) SINR Coverage using Carrier Frequency # 1

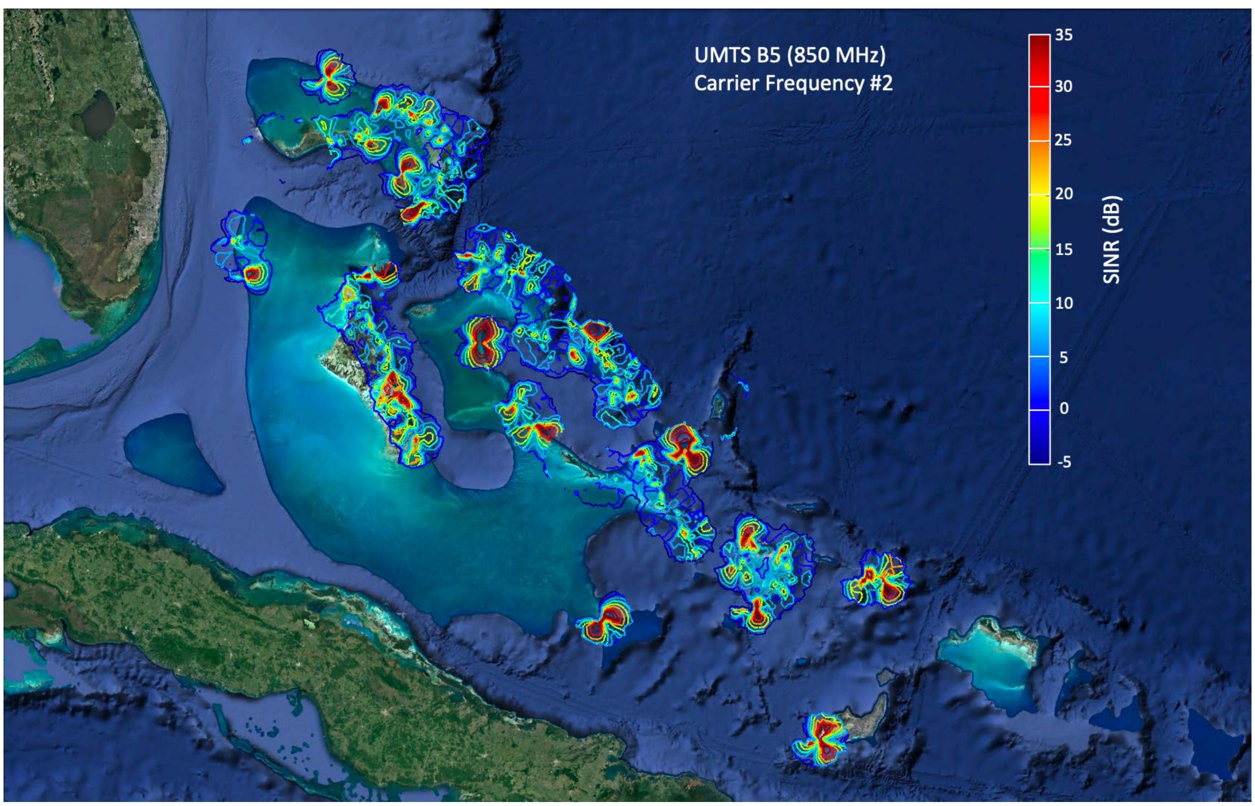

Figure 22 - Band 5 (850 MHz) SINR Coverage using Carrier Frequency #2

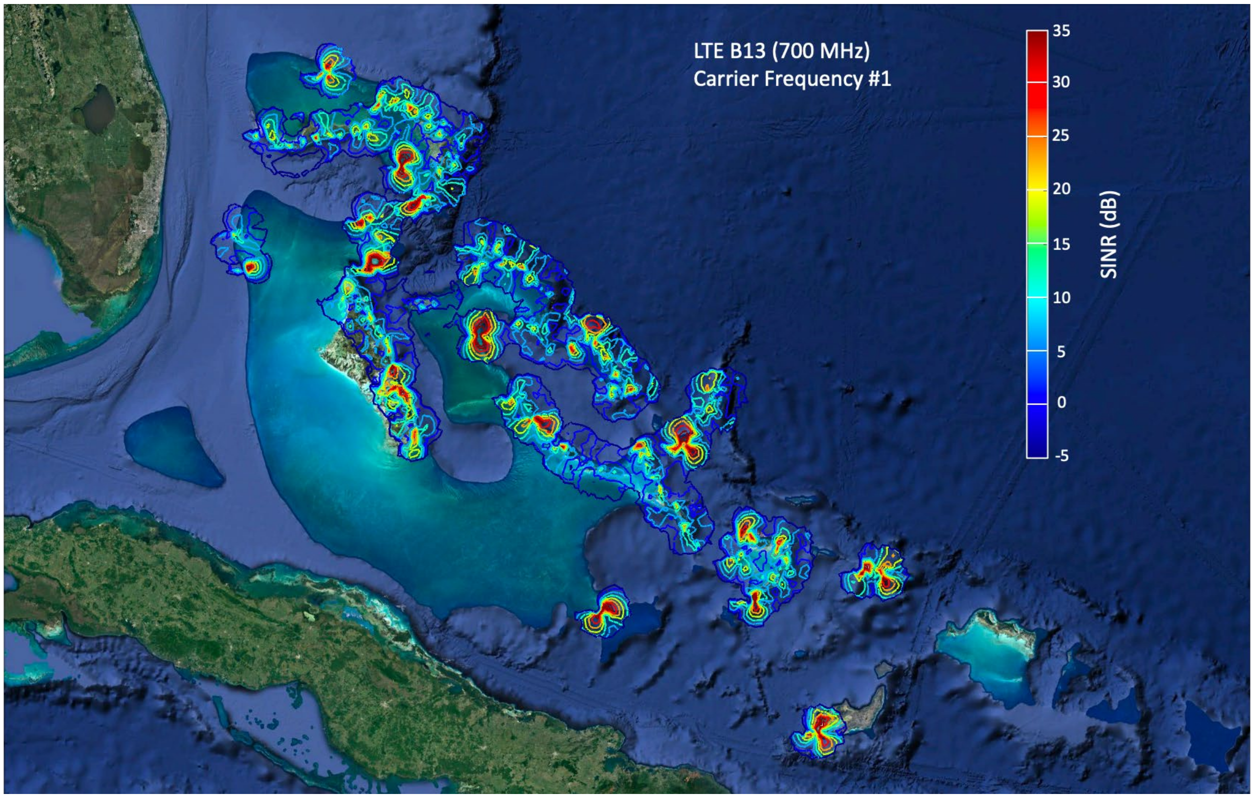

Figure 23 - Band 13 (700 MHz) SINR Coverage using Carrier Frequency #1.

Figure 24 below demonstrates the feasibility of deploying co-channel Band 5 beams from the Lynk satellites by illustrating a hypothetical deployment of 100 km radius cells around the Bahamas that do not overlap with the existing deployment of Band 5 from the terrestrial network. The current network deployment on the terrestrial cells is optimized for capacity requirements. As such, some of the country's islands do not merit deployment of all available spectrum to meet the demand for services. As a result, these bands are ideal candidates for Lynk satellite service.

Figure 24 in and of itself demonstrates the viability of the Lynk system to deploy terrestrial spectrum without concern of co-channel interference with existing deployments.

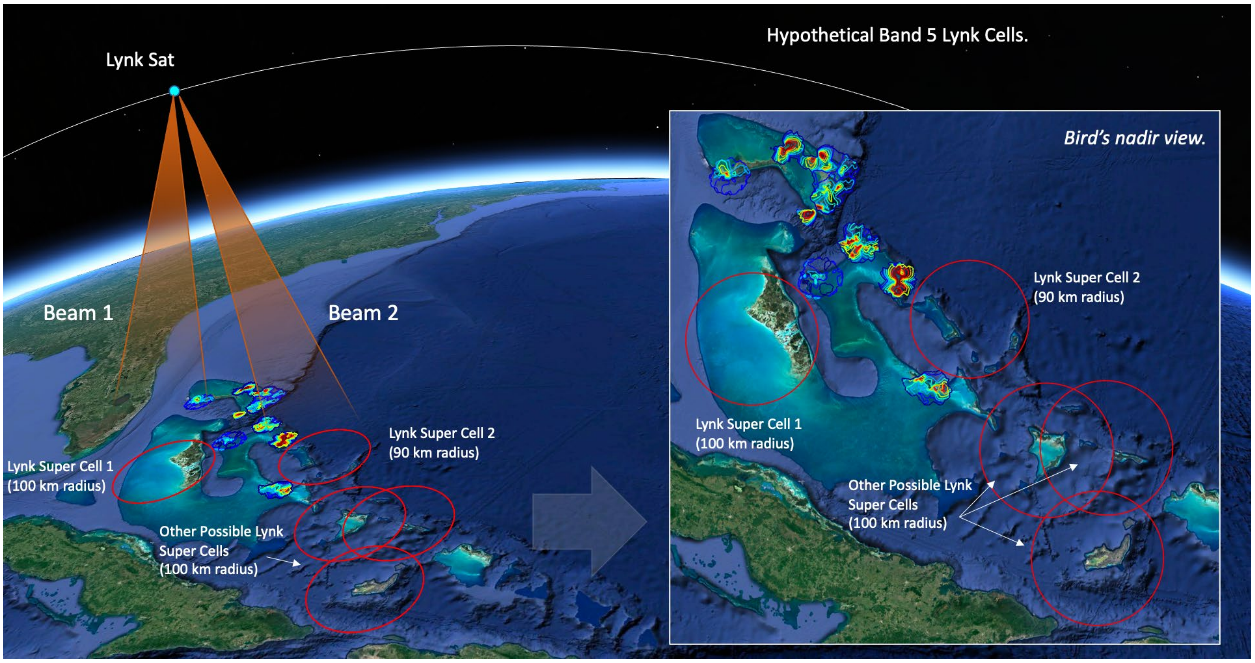

Figure 24 - Illustration of a hypothetical deployment of 100 km and 90 km radius Lynk Super Macro Cells in Band 5 (850 MHz Band) Carrier Frequency #1. The contours show the existing terrestrial coverage which does not have any geographical overlap with the 100 km radius Lynk Super Macro Cells drawn in the figure.

Based on the coverage map evaluation across the same mesh, the number of points in the mesh that have coverage from a given band can be computed. The totality of coverage from each band overlaid on themselves is plotted below.

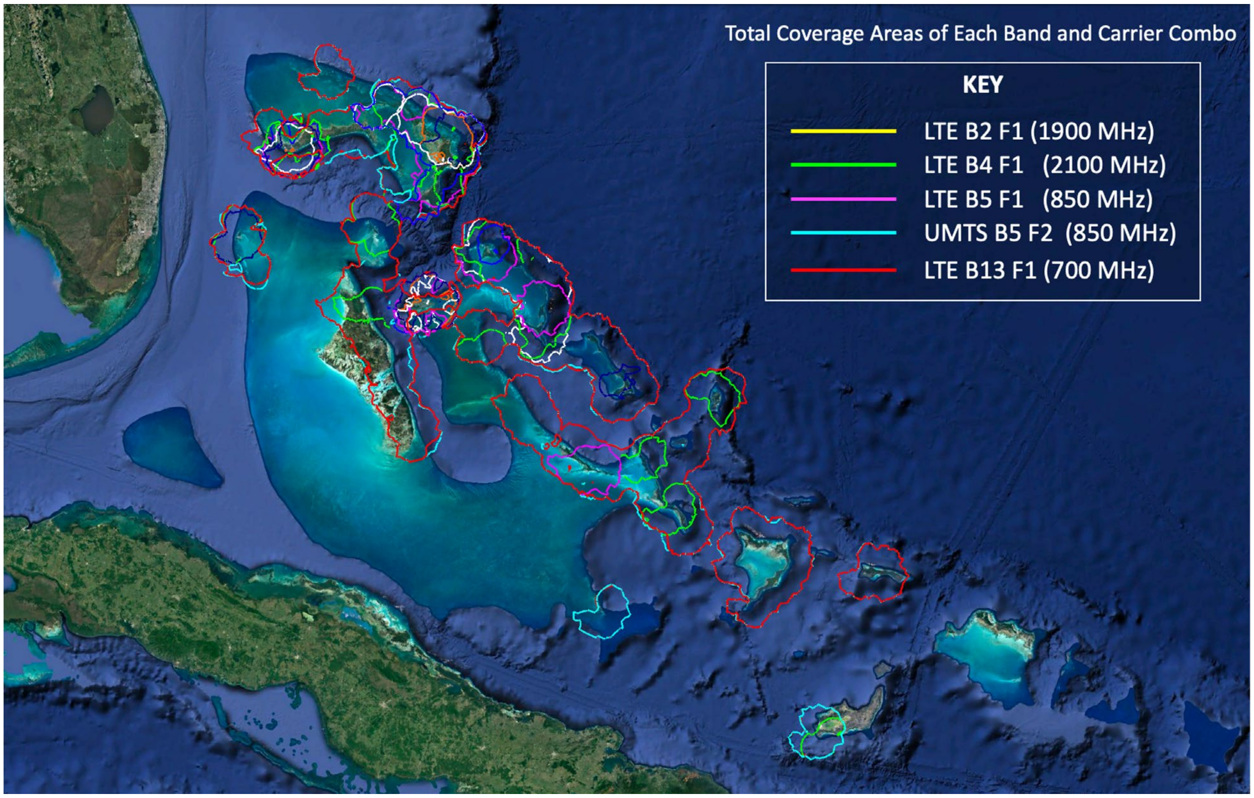

Figure 25 - Coverage Areas of each band (Yellow, B2, F1; Green, B4, F1; Magenta, B5, F1; Cyan, B5, F2; Red, B13).

Based on the totality of coverage for each band across the same mesh, the locations within the mesh that have access to only one individual band can be computed. The table below shows the percentage of all network coverage with access to only the one band. It is worth noting that the order of operations for priority in the terrestrial network is as follows: Band 4 (LTE); Band 2 (LTE); Band 13 (LTE); Band 5, F1 (LTE); and Band 5, F2 (UMTS). In other words, Band 5 is the last priority band allocated for use in the network today.

Band	Percent of coverage with access to single band and carrier frequency combination
Band 2, F1 (1900 MHz)	0.0035 %
Band 4, F1 (2100 MHz)	0.0044 %
Band 5, F1 (850 MHz)	0.1204 %
Band 5, F2 (850 MHz)	1.3185 %
Band 13, F1 (700 MHz)	4.5036 %
Total	**5.9504 %**

Table 15 - Percent of existing coverage with access to a single band and carrier frequency combination.

So, in total, 5.95% of the network coverage is provided by only one band. Unsurprisingly, this is the lowest frequency and naturally has the largest coverage area. The large majority of the time it is Band 13 and Band 5, F2, which serve as the coverage layers for the network. As a result, these coverage layers are least ideal for co-channel deployment from Lynk's satellite and would not be the focus of Lynk's augmentation of the existing terrestrial network deployment.

The figure below shows the locations in the model that only have access to each band and carrier frequency individually (Band 13 not plotted).

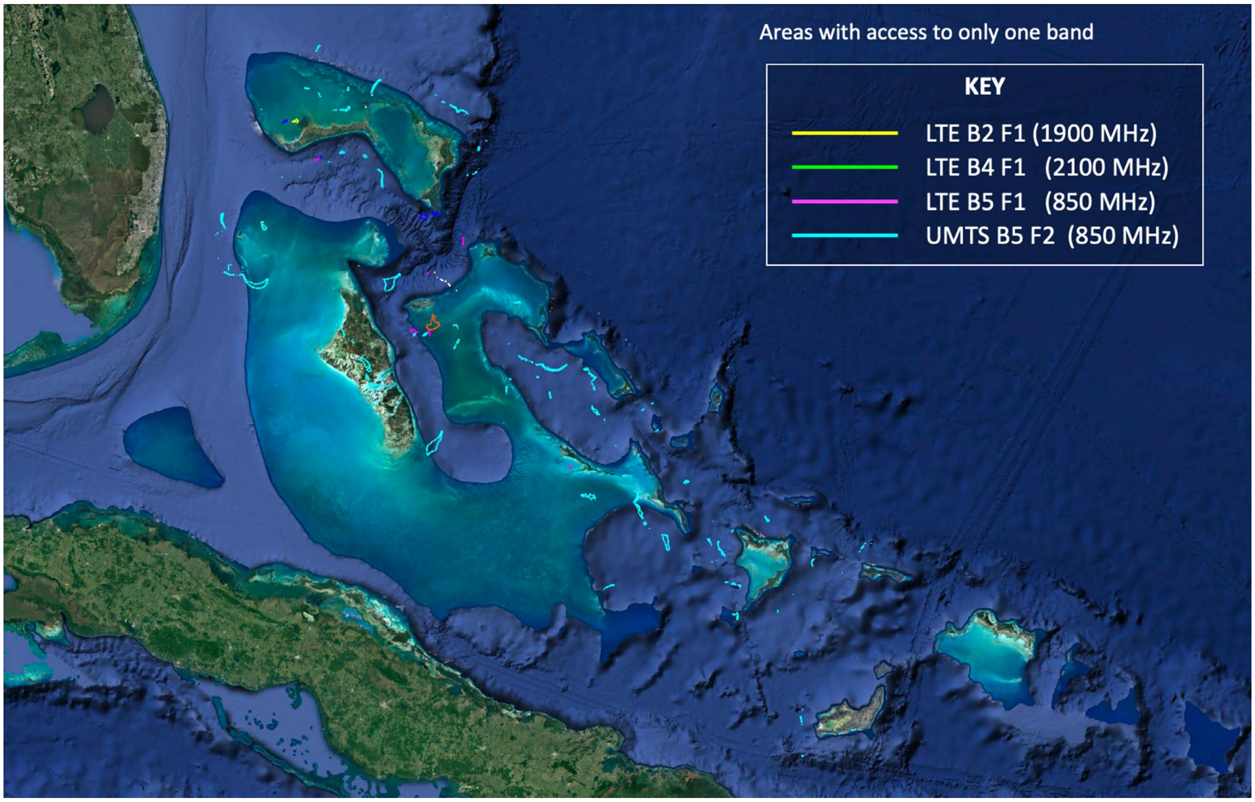

Figure 26 - Shown are all location in the coverage model that only have access to one individual band. In this figure each band is plotted in a different color (Yellow, B2, F1; Green, B4, F1; Magenta, B5, F1; Cyan, B5, F2).

To evaluate the impact of co-channel interference, a scenario is evaluated where the Lynk satellite places a co-channel B5, F1 spot beam directly overtop the existing Band 5 terrestrial coverage. To make the analysis as conservative as possible, Lynk assumes that the peak signal energy per unit bandwidth from the satellite spot beam is applied everywhere where there is existing B5, F1 coverage provided by the terrestrial network. The peak signal energy from the satellite across 5 MHz block (4.5 MHz bandwidth) would be -81 dBm RSSI. This corresponds to -87.5 dBm/MHz, or -105.7 dBm, RSRP for this bandwidth and power. If it is assumed that there is an additional -81 dBm interferer on the existing B5, F1 coverage, then the coverage area is reduced by about 29%, which is illustrated in the following figure.

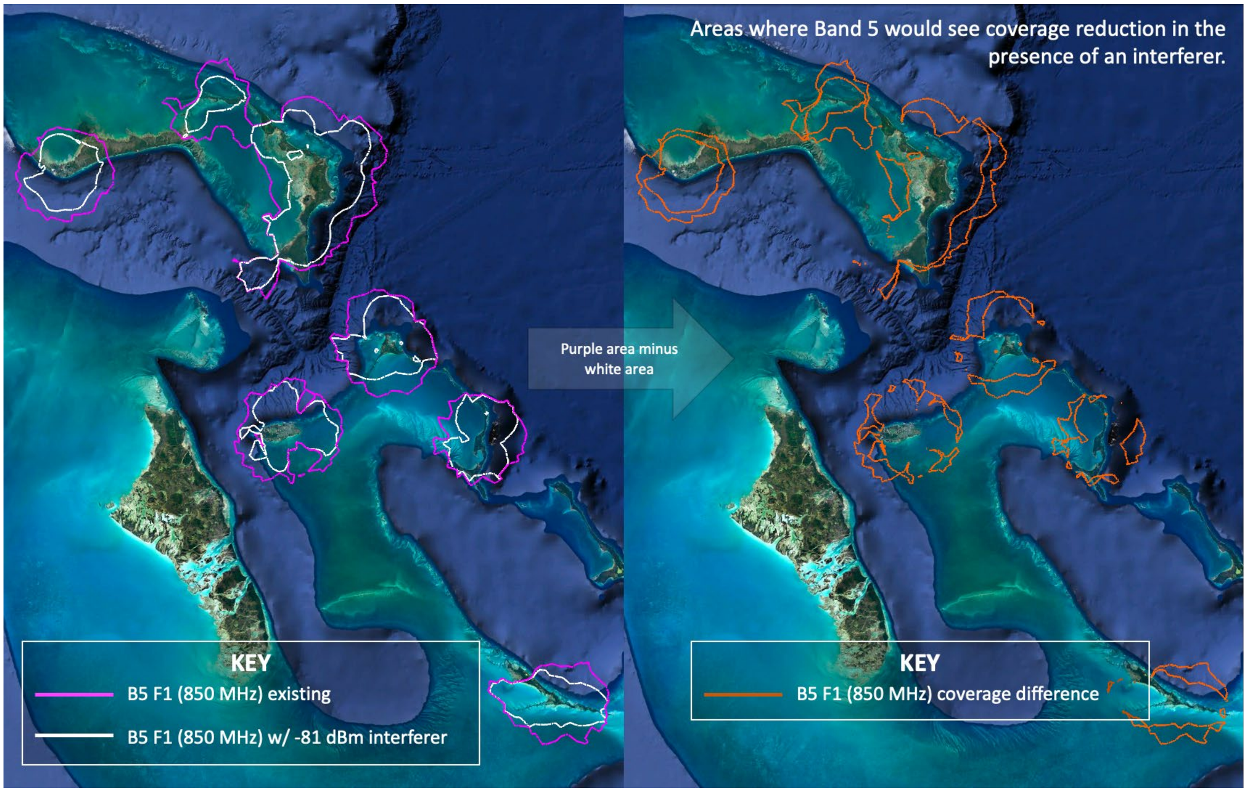

Figure 27 - [Left Image] The magenta line illustrates the existing B5, F1 coverage from the terrestrial network. [Left Image] The white line shows when the entire B5, F1 deployment is interfered with a -81 dBm co-channel signal. [Right Image] The orange line illustrates which areas would see a reduction of B5, F1 coverage in the presence of the -81 dBm co-channel interferer.

Although the interfering signal could generate a worst case of 29% reduction in Band 5 coverage, the substantial majority of the affected areas are in highly coverage-limited geographies—e.g.: out on the ocean, island edges, and away from major population centers. Furthermore, this reduction in coverage only creates harmful interference to the network if the areas that lose coverage from B5, F1 do not have access to a cell on another frequency band. Thus, as long as the coverage limited areas that lose access to B5, F1 as a result of an interferer have access to another band, the interference is not harmful. Based on the analysis, there is approximately 0.5% of existing B5, F1 coverage (and 0.12% of existing coverage from all bands) that would see harmful interference in the presence of a -81 dBm RSSI interferer, thanks to handovers to other bands.

As an additional note, even in the event of co-channel interference where coverage does in fact become reduced, operational remedies may be possible, where the transmitters for these bands in the terrestrial deployment might be increased slightly to further mitigate the impact of coverage reduction from co-channel interference.

Illustrated below are the areas where coverage is reduced and before any interference had access to Band 5.

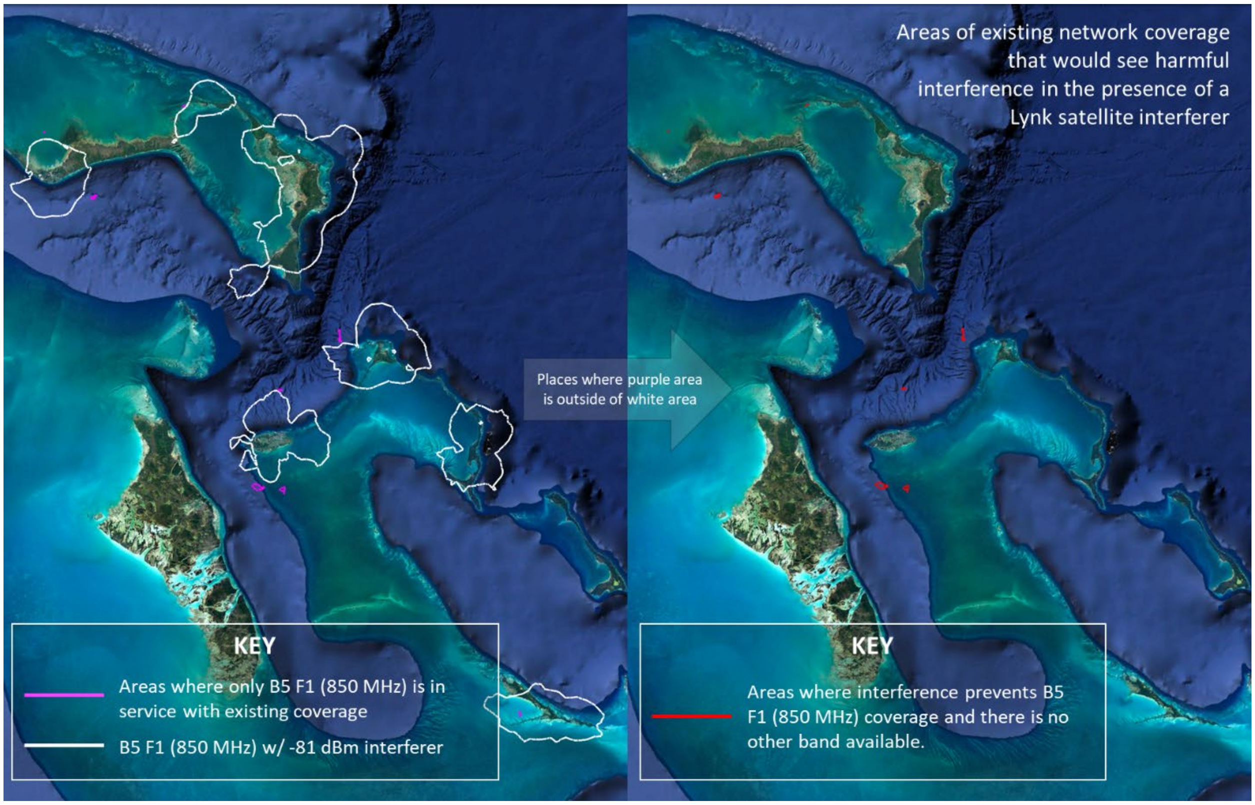

Figure 28 - [Left Image] White areas contain B5, F1 coverage in the presence of a -81 dBm interferer. [Left Image] Purple areas contain B5, F1 coverage without an interferer that only have access to B5, F1 and no other bands. [Right Image] Red areas are where the interferer prevents existing B5, F1 coverage and only B5, F1 is available in those areas from existing coverage.

The probability of harmful interference resulting from co-channel interference can be evaluated as the ratio of the area of the red contour in the Figure 28 above and the totality of existing coverage from all bands. In the case of B5, F1 that would be 0.12% probability of interference, as shown above.

To further illustrate this, the entirety of existing coverage from all bands is shown in Figure 29 relative to the areas that would see harmful interference from a co-channel interferer in the Lynk satellite network (at a level of -81 dBm across the entire 5 MHz) for those few minutes per day when the satellite is providing service to the region.

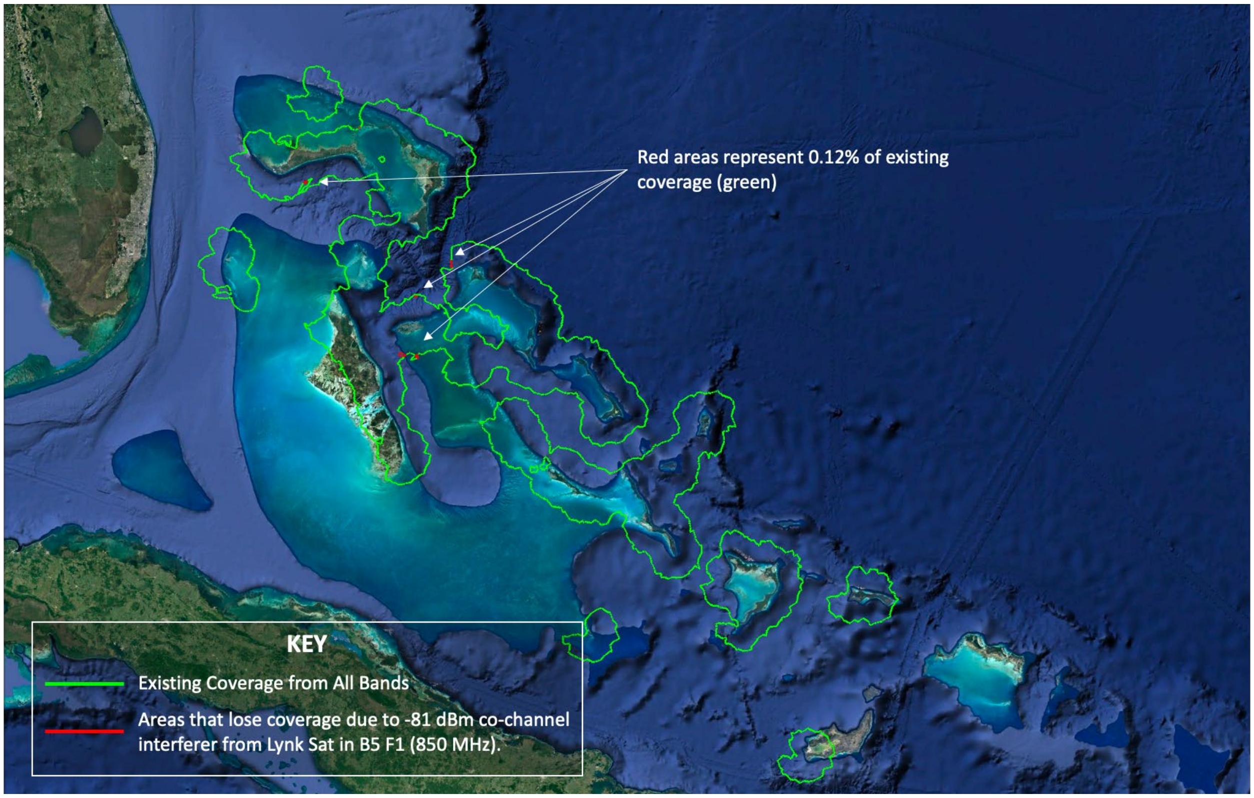

Figure 29 - Illustration of the 0.12% of existing coverage that would experience harmful interference (loss of coverage) in the presence of a -81 dBm, 5 MHz wide, Band 5 co-channel interferer from the Lynk satellite system.

In summary, the probability of harmful interference resulting from a Lynk satellite operating on a co-channel bandwidth overlapping with terrestrial deployments is effectively non-existent at 0.12%.

B. Conclusion

The above Monte Carlo analysis demonstrates that it is highly unlikely that Lynk's operations would create harmful interference into existing terrestrial deployments in the geospatial domain. Even if a Lynk satellite operates on a co-channel bandwidth that overlaps with the existing terrestrial deployments both spectrally and geospatially, as evaluated in the detailed analysis above, the probability of harmful interference in the geospatial domain is effectively zero (i.e., 0.12%) because the spatial overlap is limited to tiny areas out in the ocean, where existing coverage is already likely to fluctuate based on weather and other environmental temporalities.

Furthermore, the probability of Lynk's system causing harmful interference is shown to be even more so of an impossibility by employing spectral orthogonality followed by geospatial orthogonality when using co-channels. As calculated in this Monte Carlo analysis, the numerical probability of harmful interference solely in the geospatial domain is 0.12%. This probability is then fed back into the overall interference analysis illustrated in Figure 13 above, resulting in the probability of harmful interference being ≤ 0.00036% for frequency use in the same location at the same time with no other band or channel to utilize. As stated earlier, Lynk intends to employ spectral and geospatial orthogonality, and therefore, the probability of Lynk's system causing harmful interference is nearly impossible.

Nevertheless, in the event of co-channel deployments between Lynk and terrestrial networks, Lynk and its MNO partners would negotiate how best to mitigate or eliminate potential harmful interference. The MNOs would actively decide to use Lynk in providing vast regions of additional coverage in exchange for the occasional few minutes of the very unlikely potential for blocked calls or slightly reduced service data rates in very small regions of existing terrestrial-only coverage. This is a tradeoff many MNO partners are willing to make to improve overall customer service and coverage. In cases where Lynk's MNO partners do not wish to allow Lynk to operate with co-channel deployments, such partners can elect deployment techniques that utilize spectral and/or geospatial orthogonality.

VII. Technical Appendix

A. LTE Link Budgets

1. Downlink LTE Budget (Nadir)

Frequency	Standard		Decibels	
Frequency of Signal, f	859.00	MHz		
Wavelength of Signal, λ	0.349	m		

Orbit				
Altitude, h	500.00	km		
Elevation Angle	90.00	deg		
Line of Sight Range, S	500.00	km		
Earth Central Angle, lambda	0.00	deg		
Angle from nadir, rho	0.00	deg		

Path Losses				
Link Loss (or free-space loss), Ls	3.09E-15		-145.12	dB
Atmospheric Attenuation, La	0.98		-0.10	dB

Transmitter	Satellite eNB			
Estimated Peak Transmitter Antenna Gain, Gpt	281.84		24.50	dB
Transmitter Line Loss, Ll	0.79	-	-1.00	dB
Transmitter Power, P	50.00	W	16.99	dbW (46.99 dBm)
Equivalent Isotropic Radiated Power (EIRP), W	11193.61	W	40.49	dbW (70.49 dBm)

Receive	UE			
Estimated Peak Receiving Antenna Gain (net), Grp	0.50	-	-3.00	dB
Polarization Losses, Lp	0.50		-3.00	dB
Signal Bandwidth, B	4500.00	kHz	66.53	dBHz

System Noise				
Receiver Antenna Temperature	300.00	K		
Receiver Noise Figure	7.94		9.00	dB
Receiver Noise Temperature	2013.55	K		
System Noise Temperature, Ts	2313.55	K	33.64	dBK
System Noise, N	1.44E-13	W	-128.42	dbW (-98.42 dBm)

Link Quality				
Received Power, Carrier Power, C	8.45E-12	W	-110.73	dbW (-80.73 dBm)
Carrier to Noise, C/N	58.76		17.69	dB
Peak Modulation and Coding Scheme (MCS)			64 QAM (0.6504)	Modulation (Encoding)
Peak Cell Thoughput (5 MHz BW)	17.56	Mbps		
Carrier to Noise spectral density, C/N0	264436950.00		84.22	dB-Hz

2. Downlink LTE Budget (Footprint Edge, 35 deg elevation angle)

Frequency	Standard		Decibels	
Frequency of Signal, f	859.00	MHz		
Wavelength of Signal, λ	0.35	m		

Orbit				
Altitude, h	500.00	km		
Elevation Angle	35.00	deg		
Line of Sight Range, S	815.09	km		
Earth Central Angle, lambda	5.57	deg		
Angle from nadir, rho	49.43	deg		

Path Losses				
Link Loss (or free-space loss), Ls	1.16E-15		-149.37	dB
Atmospheric Attenuation, La	0.94		-0.25	dB

Transmitter	Satellite eNB			
Estimated Peak Transmitter Antenna Gain, Gpt	183.30		22.63	dB
Transmitter Line Loss, Ll	0.79	-	-1.00	dB
Transmitter Power, P	50.00	W	16.99	dbW (46.99 dBm)
Equivalent Isotropic Radiated Power (EIRP), W	7280.16	W	38.62	dbW (68.62 dBm)

Receive	UE			
Estimated Peak Receiving Antenna Gain (net), Grp	0.50	-	-3.00	dB
Polarization Losses, Lp	0.50		-3.00	dB
Signal Bandwidth, B	4500.00	kHz	66.53	dBHz

System Noise				
Receiver Antenna Temperature	300.00	K		
Receiver Noise Figure	7.94		9.00	dB
Receiver Noise Temperature	2013.55	K		
System Noise Temperature, Ts	2313.55	K	33.64	dBK
System Noise, N	1.44E-13	W	-128.42	dbW (-98.42 dBm)

Link Quality				
Received Power, Carrier Power, C	2.00E-12	W	-117.00	dbW (-87 dBm)
Carrier to Noise, C/N	13.89		11.43	dB
Peak Modulation and Coding Scheme (MCS)			16 QAM (0.6016)	Modulation (Encoding)
Peak Cell Thoughput (5 MHz BW)	10.83	Mbps		
Carrier to Noise spectral density, C/N0	62520425.13		77.96	dB-Hz

3. Uplink LTE Budget (Nadir)

Frequency	Standard		Decibels	
Frequency of Signal, f	814.00	MHz		
Wavelength of Signal, λ	0.368	m		

Orbit				
Altitude, h	500.00	km		
Elevation Angle	90.00	deg		
Line of Sight Range, S	500.00	km		
Earth Central Angle, lambda	0.00	deg		
Angle from nadir, rho	0.00	deg		

Path Losses				
Link Loss (or free-space loss), Ls	3.44E-15		-144.66	dB
Atmospheric Attenuation, La	0.98		-0.10	dB

Transmitter	UE			
Estimated Peak Transmitter Antenna Gain, Gpt	0.50		-3.00	dB
Transmitter Line Loss, Ll	0.79	-	-1.00	dB
Transmitter Power, P	0.20	W	-6.99	dbW (23.01 dBm)
Equivalent Isotropic Radiated Power (EIRP), W	0.08	W	-10.99	dbW (19.01 dBm)

Receive	Satellite eNB			
Estimated Peak Receiving Antenna Gain (net), Grp	281.84	-	24.50	dB
Polarization Losses, Lp	0.50		-3.00	dB
Signal Bandwidth, B	180.00	kHz	52.55	dBHz

System Noise				
Receiver Antenna Temperature	300.00	K		
Receiver Noise Figure	1.41		1.50	dB
Receiver Noise Temperature	119.64	K		
System Noise Temperature, Ts	419.64	K	26.23	dBK
System Noise, N	1.04E-15	W	-149.82	dbW (-119.82 dBm)

Link Quality				
Received Power, Carrier Power, C	3.76E-14	W	-134.25	dbW (-104.25 dBm)
Carrier to Noise, C/N	36.08		15.57	dB
Peak Modulation and Coding Scheme (MCS)			64 QAM (0.5537)	Modulation (Encoding)
Peak Cell Thoughput (5 MHz BW)	14.95	Mbps		
Carrier to Noise spectral density, C/N0	6494209.11		68.13	dB-Hz

4. Uplink LTE Budget (Footprint edge, 35 deg elevation angle)

Frequency	Standard		Decibels	
Frequency of Signal, f	814.00	MHz		
Wavelength of Signal, λ	0.37	m		

Orbit				
Altitude, h	500.00	km		
Elevation Angle	35.00	deg		
Line of Sight Range, S	815.09	km		
Earth Central Angle, lambda	5.57	deg		
Angle from nadir, rho	49.43	deg		

Path Losses				
Link Loss (or free-space loss), Ls	1.29E-15		-148.90	dB
Atmospheric Attenuation, La	0.94		-0.25	dB

Transmitter	UE			
Estimated Peak Transmitter Antenna Gain, Gpt	0.50		-3.00	dB
Transmitter Line Loss, Ll	0.79	-	-1.00	dB
Transmitter Power, P	0.20	W	-6.99	dbW (23.01 dBm)
Equivalent Isotropic Radiated Power (EIRP), W	0.08	W	-10.99	dbW (19.01 dBm)

Receive	Satellite eNB			
Estimated Peak Receiving Antenna Gain (net), Grp	183.30	-	22.63	dB
Polarization Losses, Lp	0.50		-3.00	dB
Signal Bandwidth, B	180.00	kHz	52.55	dBHz

System Noise				
Receiver Antenna Temperature	300.00	K		
Receiver Noise Figure	1.41		1.50	dB
Receiver Noise Temperature	119.64	K		
System Noise Temperature, Ts	419.64	K	26.23	dBK
System Noise, N	1.04E-15	W	-149.82	dbW (-119.82 dBm)

Link Quality				
Received Power, Carrier Power, C	8.90E-15	W	-140.51	dbW (-110.51 dBm)
Carrier to Noise, C/N	8.53		9.31	dB
Peak Modulation and Coding Scheme (MCS)			16 QAM (0.4785)	Modulation (Encoding)
Peak Cell Thoughput (5 MHz BW)	8.61	Mbps		
Carrier to Noise spectral density, C/N0	1535415.96		61.86	dB-Hz

B. GSM Link Budgets

1. Downlink GSM Budget (Nadir)

Frequency	Standard		Decibels	
Frequency of Signal, f	859.00	MHz		
Wavelength of Signal, λ	0.349	m		

Orbit				
Altitude, h	500.00	km		
Elevation Angle	90.00	deg		
Line of Sight Range, S	500.00	km		
Earth Central Angle, lambda	0.00	deg		
Angle from nadir, rho	0.00	deg		

Path Losses				
Link Loss (or free-space loss), Ls	3.09E-15		-145.12	dB
Atmospheric Attenuation, La	0.98		-0.10	dB

Transmitter	Satellite BTS			
Estimated Peak Transmitter Antenna Gain, Gpt	281.84		24.50	dB
Transmitter Line Loss, Ll	0.79	-	-1.00	dB
Transmitter Power, P	15.00	W	11.76	dbW (41.76 dBm)
Equivalent Isotropic Radiated Power (EIRP), W	3358.08	W	35.26	dbW (65.26 dBm)

Receive	UE			
Estimated Peak Receiving Antenna Gain (net), Grp	0.50	-	-3.00	dB
Polarization Losses, Lp	0.50		-3.00	dB
Signal Bandwidth, B	200.00	kHz	53.01	dB-Hz

System Noise				
Receiver Antenna Temperature	300.00	K		
Receiver Noise Figure	7.94		9.00	dB
Receiver Noise Temperature	2013.55	K		
System Noise Temperature, Ts	2313.55	K	33.64	dBK
System Noise, N	6.39E-15	W	-141.95	dbW (-111.95 dBm)

Link Quality				
Received Power, Carrier Power, C	2.53E-12	W	-115.96	dbW (-85.96 dBm)
Received Power Flux Density, phi	4.77E-06	W/m^2	-53.21	dbW/m^2 (-23.21 dBm/m^2)
Carrier to Noise, C/N	396.66		25.98	dB
Carrier to Noise spectral density, C/N0	79331085.00		78.99	dB-Hz

2. Downlink GSM Budget (Footprint Edge, 35 deg elevation angle)

Frequency	Standard		Decibels	
Frequency of Signal, f	859.00	MHz		
Wavelength of Signal, λ	0.35	m		

Orbit				
Altitude, h	500.00	km		
Elevation Angle	32.00	deg		
Line of Sight Range, S	868.85	km		
Earth Central Angle, lambda	6.15	deg		
Angle from nadir, rho	51.85	deg		

Path Losses				
Link Loss (or free-space loss), Ls	1.02E-15		-149.92	dB
Atmospheric Attenuation, La	0.94		-0.25	dB

Transmitter	Satellite BTS			
Estimated Peak Transmitter Antenna Gain, Gpt	174.10		22.41	dB
Transmitter Line Loss, Ll	0.79	-	-1.00	dB
Transmitter Power, P	15.00	W	11.76	dbW (41.76 dBm)
Equivalent Isotropic Radiated Power (EIRP), W	2074.35	W	33.17	dbW (63.17 dBm)

Receive	UE			
Estimated Peak Receiving Antenna Gain (net), Grp	0.50	-	-3.00	dB
Polarization Losses, Lp	0.50		-3.00	dB
Signal Bandwidth, B	200.00	kHz	53.01	dB-Hz

System Noise				
Receiver Antenna Temperature	300.00	K		
Receiver Noise Figure	7.94		9.00	dB
Receiver Noise Temperature	2013.55	K		
System Noise Temperature, Ts	2313.55	K	33.64	dBK
System Noise, N	6.39E-15	W	-141.95	dbW (-111.95 dBm)

Link Quality				
Received Power, Carrier Power, C	5.01E-13	W	-123.00	dbW (-93 dBm)
Received Power Flux Density, phi	1.58E-06	W/m^2	-58.01	dbW/m^2 (-28.01 dBm/m^2)
Carrier to Noise, C/N	78.39		18.94	dB
Carrier to Noise spectral density, C/N0	15677798.24		71.95	dB-Hz

3. Uplink GSM Budget (Nadir)

Frequency	Standard		Decibels	
Frequency of Signal, f	814.00	MHz		
Wavelength of Signal, λ	0.368	m		

Orbit				
Altitude, h	500.00	km		
Elevation Angle	90.00	deg		
Line of Sight Range, S	500.00	km		
Earth Central Angle, lambda	0.00	deg		
Angle from nadir, rho	0.00	deg		

Path Losses				
Link Loss (or free-space loss), Ls	3.44E-15		-144.66	dB
Atmospheric Attenuation, La	0.98		-0.10	dB

Transmitter	UE			
Estimated Peak Transmitter Antenna Gain, Gpt	0.50		-3.00	dB
Transmitter Line Loss, Ll	0.79	_	-1.00	dB
Transmitter Power, P	2.00	W	3.01	dbW (33.01 dBm)
Equivalent Isotropic Radiated Power (EIRP), W	0.80	W	-0.99	dbW (29.01 dBm)

Receive	Satellite BTS			
Estimated Peak Receiving Antenna Gain (net), Grp	281.84	_	24.50	dB
Polarization Losses, Lp	0.50		-3.00	dB
Signal Bandwidth, B	200.00	kHz	53.01	dB-Hz

System Noise				
Receiver Antenna Temperature	300.00	K		
Receiver Noise Figure	1.41		1.50	dB
Receiver Noise Temperature	119.64	K		
System Noise Temperature, Ts	419.64	K	26.23	dBK
System Noise, N	1.16E-15	W	-149.36	dbW (-119.36 dBm)

Link Quality				
Received Power, Carrier Power, C	3.76E-13	W	-124.25	dbW (-94.25 dBm)
Received Power Flux Density, phi	6.37E-07	W/m^2	-61.96	dbW/m^2 (-31.96 dBm/m^2)
Carrier to Noise, C/N	324.71		25.11	dB
Carrier to Noise spectral density, C/N0	64942091.13		78.13	dB-Hz

4. Uplink GSM Budget (Footprint Edge, 35 deg elevation angle)

Frequency	Standard		Decibels	
Frequency of Signal, f	814.00	MHz		
Wavelength of Signal, λ	0.37	m		

Orbit				
Altitude, h	500.00	km		
Elevation Angle	35.00	deg		
Line of Sight Range, S	815.09	km		
Earth Central Angle, lambda	5.57	deg		
Angle from nadir, rho	49.43	deg		

Path Losses				
Link Loss (or free-space loss), Ls	1.29E-15		-148.90	dB
Atmospheric Attenuation, La	0.94		-0.25	dB

Transmitter	UE			
Estimated Peak Transmitter Antenna Gain, Gpt	0.50		-3.00	dB
Transmitter Line Loss, Ll	0.79	-	-1.00	dB
Transmitter Power, P	2.00	W	3.01	dbW (33.01 dBm)
Equivalent Isotropic Radiated Power (EIRP), W	0.80	W	-0.99	dbW (29.01 dBm)

Receive	Satellite BTS			
Estimated Peak Receiving Antenna Gain (net), Grp	183.30	-	22.63	dB
Polarization Losses, Lp	0.50		-3.00	dB
Signal Bandwidth, B	200.00	kHz	53.01	dBHz

System Noise				
Receiver Antenna Temperature	300.00	K		
Receiver Noise Figure	1.41		1.50	dB
Receiver Noise Temperature	119.64	K		
System Noise Temperature, Ts	419.64	K	26.23	dBK
System Noise, N	1.16E-15	W	-149.36	dbW (-119.36 dBm)

Link Quality				
Received Power, Carrier Power, C	8.90E-14	W	-130.51	dbW (-100.51 dBm)
Received Power Flux Density, phi	2.40E-07	W/m^2	-66.21	dbW/m^2 (-36.21 dBm/m^2)
Carrier to Noise, C/N	76.77		18.85	dB
Carrier to Noise spectral density, C/N0	15354159.65		71.86	dB-Hz