

Direct to Cell Handbook for Telecommunications Partners

Revised: September 16, 2022

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Direct to Cell System Overview

Concept

SpaceX is deploying a Direct to Cell satellite system in low Earth orbit that will support ubiquitous voice, text, and low-data-rate web browsing directly to all modern phones using 4G LTE standards. This Direct to Cell system will complement existing terrestrial LTE networks by eliminating dead zones, by allowing users to seamlessly connect to the SpaceX satellite network when they leave terrestrial coverage from most places on Earth (pending regulatory approvals). This system will leverage SpaceX's existing and planned infrastructure, including rocket launch, satellite development and operation, inter-satellite laser links, ground stations, networking, and backhaul capabilities to connect billions of cellular devices worldwide. The service supports consumers, businesses, and governments, to enable remote connectivity for rural, emergency, and off-the-grid communications. SpaceX anticipates that this network will connect people and devices outside of terrestrial network coverage at a fraction of the current cost in these regions today.

Timeline

The first Direct to Cell satellite launch is scheduled for mid-2023, and SpaceX will fully deploy the network after approximately one year of Starship launches. The deployment process is marked by three distinct coverage milestones, each unlocking continuous service capability within two widening bands of latitudes, mirrored across the equator. The earliest coverage milestone occurs in late 2023 after the first 7 orbital planes have been established, and enables service between 49° and 55° latitudes (much of Germany, Canada, and the UK). By early 2024, the first 14 orbital planes will be established, enabling coverage from 41° to 56° (Northern US, all of Germany, and most of Western, Central, and Eastern Europe). The constellation is expected to reach full deployment (28 planes) by mid 2024, enabling continuous coverage from +/- 58° to the equator. The system will become commercially operational in countries upon finalizing partnerships with telco partners and obtaining regulatory approvals.

Telco Partners

The Direct to Cell program will require strategic partnerships with terrestrial telecom providers who control exclusive and nationwide spectrum to reduce regulatory barriers and ensure rapid introduction of the service. This system is designed to be fully compatible with all modern 4G LTE-capable mobile devices including iOS and Android, and possibly supporting 5G in the future, as described in the Spectrum section below. SpaceX announced our first telco partnership with T-Mobile in the US on August 25, 2022 at Starbase.

Applications

The Direct to Cell system will provide the convenience and safety of being able to make a voice call or send text messages when everyday cell phone users travel out of range of terrestrial networks. It also will provide new connectivity that otherwise would not exist for subscribers that lack coverage at home, work, school, or at off-grid facilities that they visit. For all consumers, the service will provide peace of mind in situations where real-time communications are critical, and may even be lifesaving.

Hikers in remote areas will get weather updates and rural communities will stay connected with family. Likewise, firefighters battling dangerous and unpredictable forest fires will be able to maintain situational

awareness even if terrestrial base stations were destroyed in the blaze. Citizens and first responders would be able to communicate during an earthquake, flood or other disaster, natural or manmade, even when the electrical grid fails. Perhaps most importantly, they would be able to access these capabilities using the same mobile handset, with no modifications to hardware, firmware, software, or any new apps, that virtually every consumer has in their pocket today, as well as with tablets and other off-the-shelf cellular-enabled mobile devices.

The Direct to Cell system also presents significant opportunities for connecting assets, sensors, and devices (e.g. IoT applications). With enhanced space-based coverage, users will be able to deploy low-cost, commercially available IoT devices equipped with terrestrial, commercial off the shelf LTE modems and SIM cards to monitor critical infrastructure, track vehicles, deploy smart agriculture solutions, detect wildfire activity in remote locations, and other applications, as the current Swarm network (completely different system from Direct to Cell) provides today.

Satellite Constellation

The payload will be added to 2,016 Starlink satellites planned as part of the broadband network deployment, as depicted in the figure below. The Direct to Cell system leverages the capabilities of SpaceX's Starlink Ku/Ka network for backhaul and uses a new phased array for service links to cellular devices. With this design, the constellation will provide continuous coverage for Direct to Cell connectivity between +58° and -58° latitudes, covering more than 99% of the global population and cellular devices. The network will provide continuous coverage at the equatorial regions, which in turn results in significant redundancy in satellite coverage at higher latitudes. For instance, the use of 53° inclination orbits produces a peak in satellite availability near +/- 50° latitude. In this region, an average of 14 satellites are capable of providing service to each user. Even in the Southern US (25° N), between 4 and 5 redundant satellites is typical.

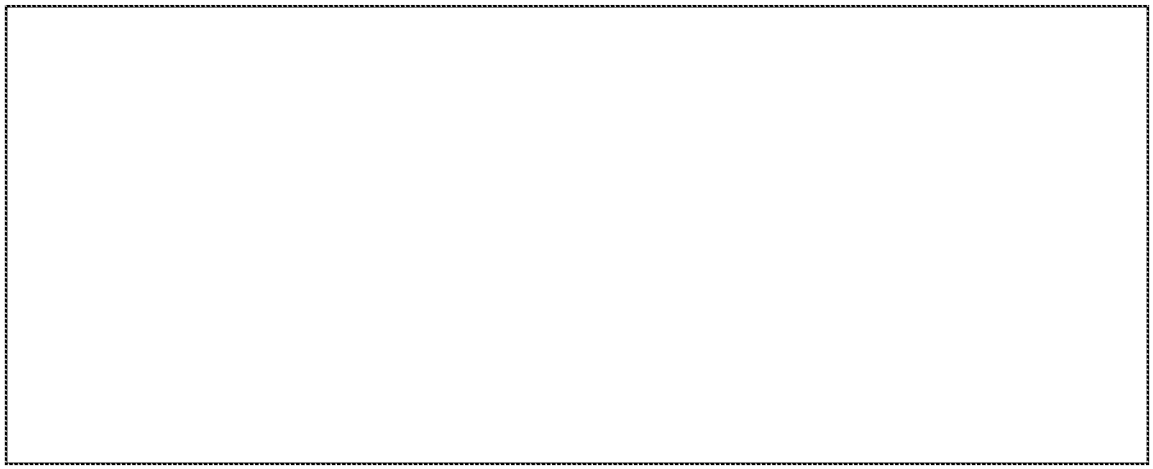


Figure 1 :Direct to Cell payload (bottom gray antennae) on Starlink satellite

Technical Parameters

Key System Parameters

The key parameters of the SpaceX Direct to Cell system are summarized in the table below.

Network Hardware	Direct to Cell Payload on V2.0 Starlink Satellites
Number of Satellites	2,016
Altitude	525 km in Low Earth Orbit
Orbital Inclination	53°
Coverage	Continuous coverage within +58° to -58° latitude, by mid-2024
Antenna Size	Tx: 2.1x1.8m, Rx: 2.1x1.8m
Supported Frequency Range	1429 MHz to 2690 MHz (excluding safety of life, protected frequencies, and GNSS)
Beams	256 beams (~50 km dia per beam, as shown in Topology Strategy section)
Channels	5 MHz uplink + 5 MHz downlink from partnering telcos: Uplink (Earth-to-space): 5 MHz with 4x 1.08 MHz channels Downlink (space-to-Earth): 5 MHz with 4x 1.08 MHz channels Can support 4x 5 MHz channels if more spectrum is available.
Technology	4G LTE, FDD only 5G may be possible in the future with more spectrum or a new system. Currently limited by link budget.

Key System Targets

The key system targets are summarized in the table below. Note these are not guaranteed, but rather system targets in the design and build of the system, and we may exceed these parameters in the final system.

Network Availability (when covered)	>99% of time outdoors (possibly under light foliage, in vehicles, to be tested)
Dropped call reliability	>99%
Handover reliability	>99%
Data Rates per beam (5 MHz UL/5 MHz DL)	Download: 1 Mbps max, 0.5 Mbps avg Upload: 500 kbps max, 100 kbps avg
Simultaneous users/beam (text/voice)	50 simultaneous voice users per beam (only VoLTE) 350 simultaneous SMS users per beam (only SMS)

Texting only (start mid-2024)	Latency: <100 ms round-trip SMS: unlimited* MMS: unlimited*
Text, Talk, Data (start 2025)	VoLTE + SMS/MMS + Web browsing Latency: <100 ms round-trip SMS: unlimited* MMS: unlimited* Voice: unlimited* Data: TBD

*The estimated number of SMS, MMS, and supportable voice time exceeds what the typical American uses in a month (>2000 SMS, >500 MMS, >500 mins voice airtime all per month) when in terrestrial cell coverage, so we are categorizing as "unlimited". If excessive data is used, usage may be throttled. Data caps will apply. Results depend on customer user behavior and geographic distribution.

Spectrum

The Direct to Cell satellite system is designed to operate across a frequency range of 1429 MHz to 2690 MHz, with some expandability if there is supportable spectrum beyond these ranges. Within each region or country, we require a minimum bandwidth of 5+5 MHz (uplink+downlink), and ideally 10+10 MHz (uplink+downlink) that is within 3GPP-defined FDD LTE bands from a telco partner. The spectrum should be exclusive to the telco alone, not leased to others, and ideally nationwide (or nearly nationwide), meaning the partner telco has exclusive rights to the spectrum and the spectrum is licensed through the entire region or country. The SpaceX system can dynamically tune beams to any frequency in this range. Satellites can simultaneously support different spectrum within the same band, and different satellites can support different LTE bands. This means we can tune the spectrum depending on availability specific to the region/country.

SpaceX plans to implement a frequency reuse factor of four, meaning neighboring beams use four different center frequencies (each with the default 1.08 MHz bandwidth) to minimize interference and provide a high-performance experience to the user. We are also studying the use of one 5 MHz channel on the downlink so that we can make 5G possible, however additional spectrum may be required and the link budget is challenging. We have studied self-interference between the adjacent beams with appropriate topology beam placement solutions, and the results demonstrate that the desense is acceptable for a sufficiently performant system to support the proposed services. If 10 MHz uplink and 10 MHz downlink or more spectrum is available in a given region or country, this will enable us to deliver even greater data rates and capacity.

Regulatory

ITU Filing

SpaceX's Direct to Cell system will require regulatory approval in each country and partnerships with local telcos to extend conventional terrestrial spectrum for use with our satellites in low Earth orbit (LEO). The regulatory approach for Direct to Cell operations worldwide will maintain compliance with regulators and partners globally.

Underpinning the Direct to Cell system is a SpaceX filing at the International Telecommunications Union (ITU) through the German Administration. The filings, both with a date of receipt of 23 August 2022,

include a request for coordination (CR/C) under the name MARS-VLS and an advanced publication information (API) on a non-interference, non-protection basis under the name MARS-ULS. The goal of the SpaceX ITU filing is to maintain frequency flexibility while supporting a wide-range of frequencies across 1429 MHz to 2690 MHz while omitting sensitive bands that support safety of life. These ITU filings will also enable SpaceX to provide Direct to Cell service in international waters in spectrum bands covered under SpaceX's ITU license. SpaceX will work with all partners to leverage the SpaceX ITU filings to facilitate and authorize Direct to Cell on the relevant spectrum and under the appropriate allocations.

Regulatory Compliance

Once SpaceX and a telco partner jointly identify a specific spectrum band of interest for Direct to Cell in a given region or country, then SpaceX will configure the system to comply with all relevant in-band and out-of-band regulations that would apply as if the Direct to Cell system were simply part of the existing ground-based terrestrial network. For example, the downlink (space-to-Earth) Direct to Cell power-flux density at the surface of the Earth and at cell and country borders will be only as powerful as permitted for a ground-based base station. This means that no additional in-band interference occurs to telcos and operators in adjacent bands. Additionally, out-of-band limits and restrictions are taken into account, with appropriate out-of-band filters and guard bands in place so that neighboring operations on adjacent spectrum remain protected from harmful interference with the same confidence of the existing ground-based systems. Downlink beams can be placed with precision, as explained in the Topology Strategy section.

Like the downlink, uplink (Earth-to-space) operations will adhere to all of the same terrestrial regulations in effect for mobile handsets and LTE modems, including power, bandwidth, and duty cycles. Since these already-certified handsets and LTE modems will require no hardware, software, or firmware changes, SpaceX anticipates that no additional type certification will be necessary. Users will be able to connect their existing devices to the Direct to Cell network without changes or causing increased interference.

Emergency Services

Where possible and as required, the Direct to Cell system will connect users with emergency text and voice services should they need emergency assistance. These requirements vary by country, depending on local regulations, and will be implemented on a case-by-case basis.

Lawful Interception

Depending on the county-specific requirements, lawful interception strategies, policies, and procedures will need to be implemented, coordinated, and executed. Additionally, lawful interception requirements may vary based on the spectrum, type of service offered (text or data versus voice), and where the data is stored and/or routed. SpaceX will make every effort to comply with all lawful interception requirements and work with regulators and partners to do so.

Network

Radio Access Network

The Direct to Cell system will implement a 4G LTE Radio Access Network (RAN) based on 3GPP LTE standards for terrestrial networks. Each satellite hosts a single eNodeB with up to 256 sectors/beams. Starlink backhaul carries the encrypted S1 connection between the eNodeB and the SpaceX ground

network. Intra-satellite (inter-beam) handovers function like X2 handovers and inter-satellite handovers function like S1 handovers.

The fundamental differences between terrestrial cellular networks and the Direct to Cell RAN are:

1. eNodeBs hosted on satellites are moving at high speed relative to devices on the ground, causing doppler shift.
2. The propagation delay between the user equipment (UE) and eNodeB is large due to the satellite's altitude (~525 km).

The primary challenges associated with these aspects are increased doppler, increased airtime delay, and variation of these parameters within each cell (for different UE) and over time. The SpaceX Direct to Cell network accommodates these factors so that commercial off-the-shelf LTE devices can connect to the Direct to Cell network without modification to the standard. Therefore, no modifications to LTE devices are required, including hardware, software, firmware, or the use of specific apps.

Doppler

Pre and post compensation to overcome doppler shift at the cell center is achieved by continuously adjusting the frequency over time as the doppler changes throughout the course of a satellite pass, shown in the figure below. The doppler that remains after pre/post compensation (because a user is moving or is not at cell center) is handled by the UE on downlink (imposing a limit on maximum cell size) and by eNodeB on uplink.

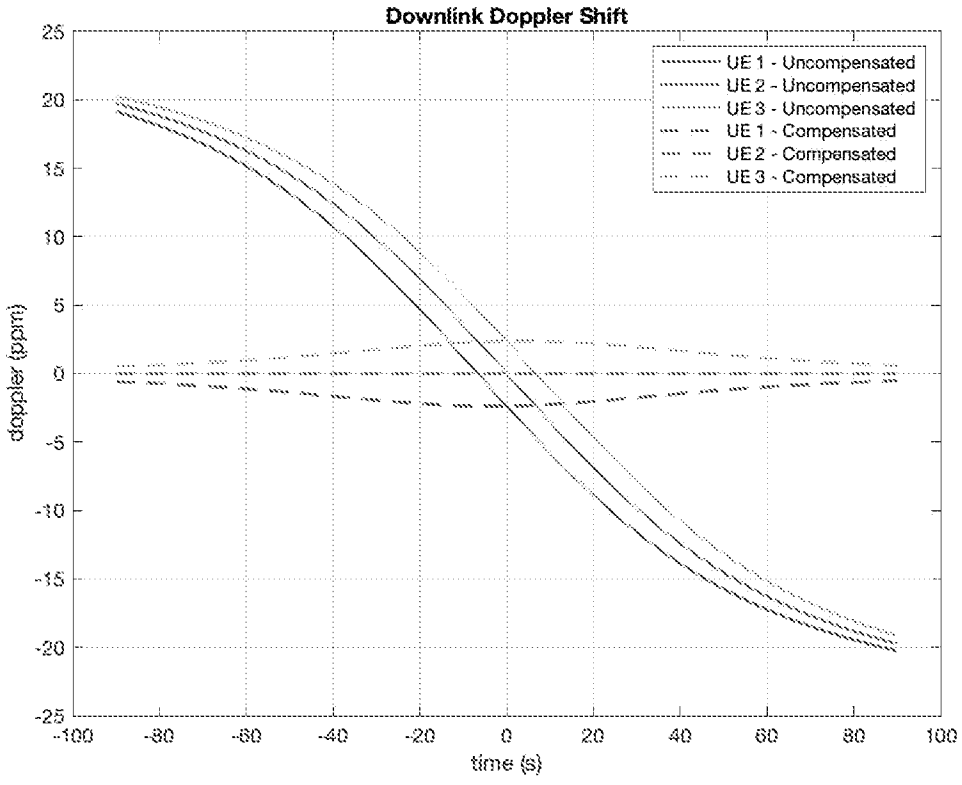


Figure 2: Compensation for downlink downlink doppler shift

Large Delay and Delay Variation

One-way airtime delay for the satellite to ground links used in the Direct to Cell network can be close to 3 ms, which is far more than encountered in terrestrial LTE networks. The larger airtime delay poses challenges for both initial access (RACH) and on-going operation (timing advance and HARQ).

To overcome this challenge for initial network access, the random access response window (RAR) is configured sufficiently large (10 ms) to allow the standard LTE RACH procedure to complete without modification. PRACH preamble formats 1 and 3 are used to accommodate larger timing uncertainty seen in the Direct to Cell network. These were designed to support the largest LTE cell radius possible (~25 km) and are sufficient to support random access in Direct to Cell without modifications to the standards or UEs.

After initial access all UEs within a cell are kept time-aligned using the same timing advance procedure used in terrestrial LTE networks. The standard 8 ms HARQ Round Trip Time (RTT) cannot be met, but more conservative link adaptation is used to reduce the rate of HARQ retransmissions and HARQ can still be used but with a higher RTT.

Network Identity

The Direct to Cell network will operate with local Public Land Mobile Network IDs (PLMN IDs) for each partner network or geographical region. This keeps users on telco partners' spectrum that is allocated for Direct to Cell and prevents users from using spectrum that is licensed to other geographical areas or mobile operators.

The user's device will only switch to the Direct to Cell network if no higher priority terrestrial network is available. The prioritization is based on PLMN ID and signal strength, and uses standard 3GPP-based network selection procedures. To prevent rapidly switching between terrestrial and space networks, access control customizations can be put in place to either detect the condition or to prevent UE from connecting to the Direct to Cell network if they were recently connected to a terrestrial network in a specific geographic location (e.g. connected to terrestrial macro-cell in a metropolitan area one minute ago).

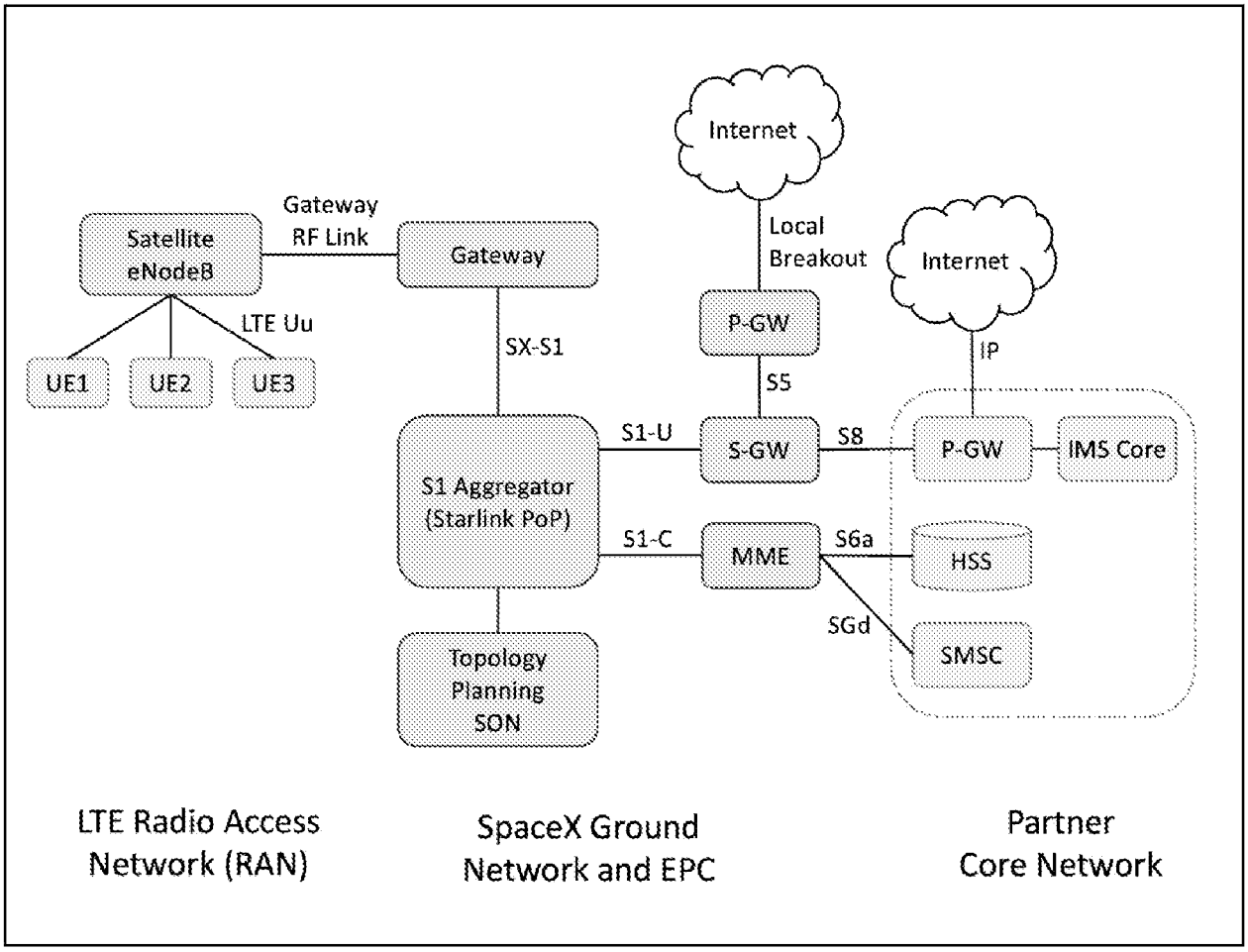


Figure 3: Example Direct to Cell LTE network architecture showing LTE devices (orange), the Direct to Cell system (blue), and the telco partner's core network (green)

Core Network

SpaceX will operate its own core network for the Direct to Cell system with interfaces into partner networks, as shown in the figure above. In this way SpaceX has no native users and is not operating as an independent MNO or MVNO, but users will connect to the Direct to Cell network via a roaming partnership.

Services

The Direct to Cell network will provide SMS/MMS messaging, low-data-rate web browsing, and voice services. At the beginning the Direct to Cell core network will have no IMS or SMSC nodes. The partner network will provide the IP address, APN, etc. Data and voice traffic will be routed from SpaceX's S-GW to the partner network's P-GW via the S8 interface. These services will be established over 3GPP-supported data and voice bearers. SMS messaging will be routed to the partner network's SMSC via the SGd interface.

Limitations

Currently hand-ins and hand-outs from the Direct to Cell network to the partner operator network are not supported. Since IP sessions are ending in the partner network, they will need to be reestablished. Due to beam size, there may be limitations to admission control such as those based on Tracking Area Code (TAC) planning and others.

There may also be limitations on services which would require local breakouts for regulatory reasons. These will be examined on a case-by-case basis and solutions will be crafted accordingly.

Topology Strategy

Each satellite footprint has an area of 1.1M km^2 at all latitudes. The satellites will communicate with users on the ground when the satellite is mostly overhead, down to a minimum elevation angle of 37° above the user's horizon (as shown in the figure below), switching seamlessly to the next beam as it comes over the horizon. Each satellite has 256 total available beams with 5 dB contours (nominal design). However, the actual number of beams required to provide continuous coverage decreases (and the beams get smaller) at more northern latitudes, as there is more satellite overlap.

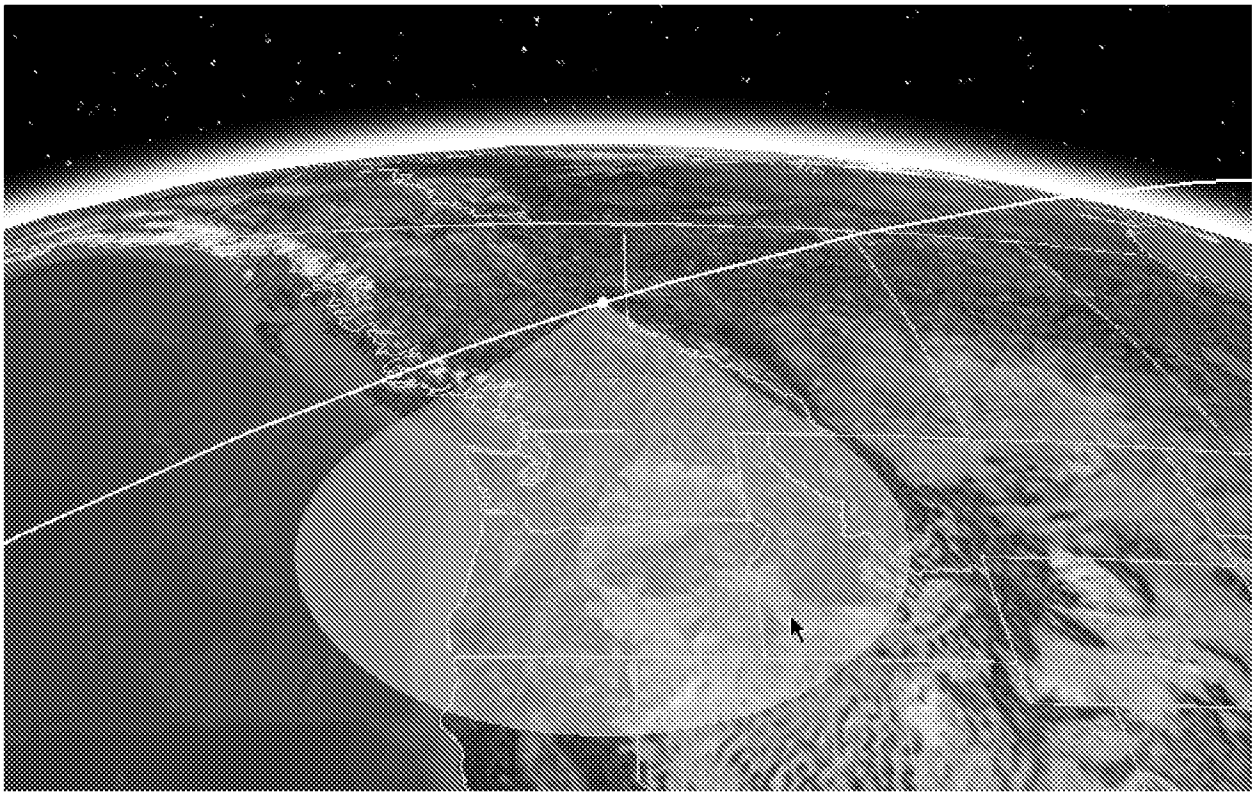


Figure 4: Each satellite can place beams within a 1.1M km^2 circular footprint.

The system transmission parameters are in the table below:

Modulation Type	4G LTE to support voice (VoLTE/OTT), text (SMS/MMS), web browsing, IoT
Transmit power	Satellite: ≤ -80 dBW/m^2/MHz aggregate power flux density (proposed)

	Mobile handset:	≤ 0.2 W (as certified, no modifications)
Antenna gain	Satellite: Mobile handset:	≤ 32 dBic, RHCP ≤ -8 dBi, Vertical (linear) (as certified, no modifications)

With satellites constantly moving relative to users on the ground and orbiting the earth every 94 minutes, the network topology must be constantly re-designed in real-time. We call this software problem the network topology service, and it plans how satellites assign beams to locations on the ground as well as how frequency reuse happens throughout the system.

The network topology operates by calculating the possible links between satellites and locations on the ground and allocating these links to ensure high signal-to-noise ratio (SNR) and avoid interference. This beam allocation system builds on the strong foundation of the Starlink system currently in operation worldwide. The topology also handles deconflicting other constraints, such as ensuring beams are placed around keep-out zones to meet spectrum usage requirements and managing the vehicle's power budget. This is achieved by calculating the power flux density of the beam and ensuring that the beam is placed such that the power flux density at a border is below country specific thresholds at all times.

National Borders

The network topology enables precision beam placement around national borders to respect regulatory limits for power flux density (PFD) spillover. The figure below shows the typical power flux density for a service beam (blue, -5 dB from beam center power flux density), and the keep-out zone for country borders (red, -9.5 dB in the case of the US/Canada/Mexico borders). This example shows a service beam near the US/Canada border in Washington State. User service is still possible between the blue and red contours, but at a slower data rate.

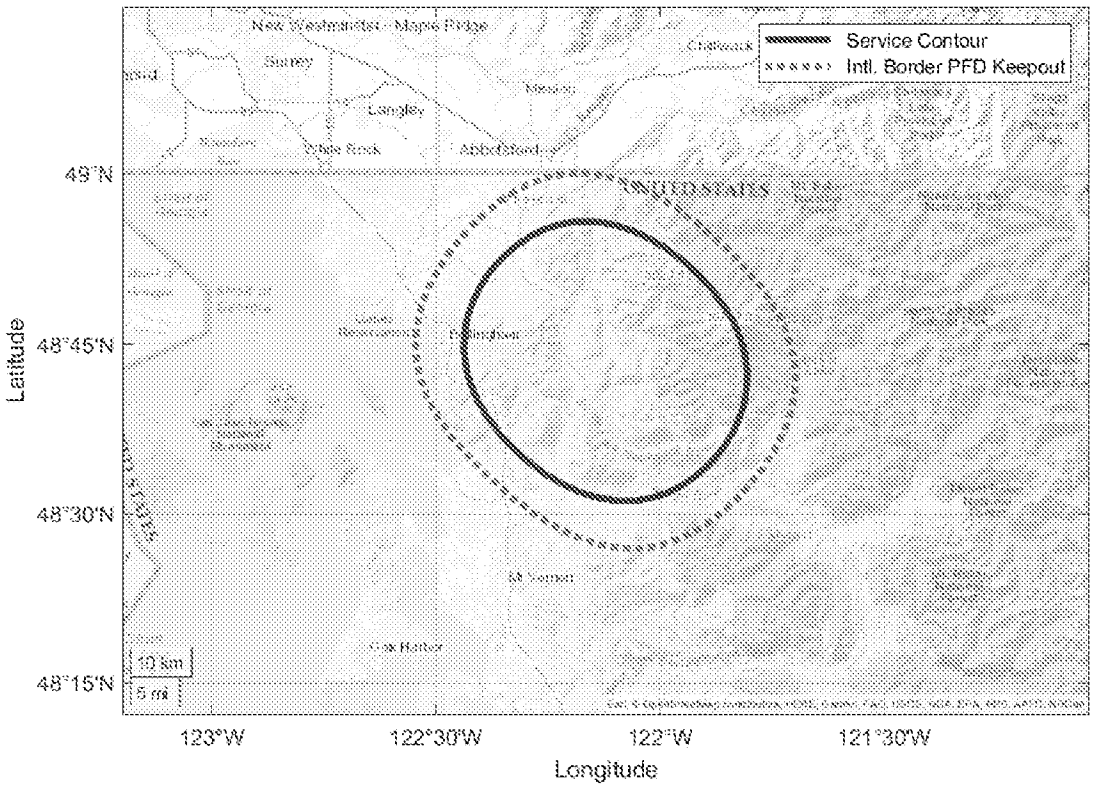


Figure 5: Example coverage setback between a beam's primary service area and international border, ensuring PFD spillover remains below regulatory limits of neighboring countries.

Frequently Asked Questions

Will Direct to Cell or Starlink eventually replace terrestrial mobile networks?

No, Starlink or Direct to Cell are neither intended to replace terrestrial mobile networks, nor can they, given spectrum, throughput, and capacity constraints. The goal is to complement terrestrial networks by eliminating cell phone dead zones and connecting people and devices outside of terrestrial network coverage at a fraction of the current cost compared to dedicated legacy satellite phones with expensive hardware and data. Direct to Cell would provide service in areas where it is cost prohibitive to connect users via terrestrial networks.

How does billing work?

Users will be billed as usual by their mobile network operator. SpaceX and the partner network operator will sign a commercial agreement establishing terms and conditions for the service.

Can we share spectrum so we don't need to provide it exclusively?

Unfortunately the Direct to Cell system will not work if uplink spectrum is shared with the terrestrial network. In addition, current analysis shows that the Direct to Cell service would cause meaningful desense to terrestrial services if downlink spectrum is shared, and therefore may result in outages 50-100km outside of cities, depending on the allowable desense and geometry, which we believe will

result in a poor customer experience. In an effort to preserve an acceptable user experience for both terrestrial and Direct to Cell users, we require 5 MHz uplink exclusively, and strongly recommend 5 MHz downlink spectrum exclusively as well, although we can consider solutions for individual operator requirements.

Why can't SpaceX apply for their own spectrum to provide this service?
Partnering with terrestrial telecom providers that control exclusive and nationwide spectrum is ideal to reduce regulatory barriers and ensure rapid introduction and adoption of the service.

Is it possible to use just 1.4 MHz UL + 1.4 MHz DL?
Our topology strategy is based on a frequency reuse factor of four, with individual channels of 1.4 MHz (or 1.08 MHz without guard bands). To avoid interference and performance degradation, 5 MHz is the minimum required bandwidth.

Is it possible to use TDD LTE?
No, as the round-trip propagation time for Direct to Cell satellites is up to 6 ms. An LTE FDD system can accommodate this delay without changes to the standard, whereas LTE TDD guard times were not designed to support such a large delay.

Will Direct to Cell support 5G?
We are studying the possible future support of 5G, but additional spectrum may be required, and additional 5G NTN implementations may be needed to accommodate the uplink budget for 5G's wider bandwidth requirements.

Why not use the NTN (Non-Terrestrial Networks) standard?
3GPP Release 17 includes NTN standards for satellite backhaul and low-data-rate services for mobile devices and IoT. While Release 17 sets the standards for these technologies, MNOs will have to first get on board to generate momentum. It is expected to be several more years before chipsets are available and widespread. By adapting existing 4G/5G standards, we are able to connect with billions of existing handsets worldwide with no upgrades required.

How does this relate to Starlink?
The Direct to Cell system described in this document is completely separate from a customer experience perspective. The Direct to Cell system is designed to support current, unmodified mobile cellular devices, and is intended to eliminate cell phone dead zones with voice, text and internet browsing. The Starlink system provides broadband internet, and requires the purchase of a dedicated user terminal and data plan. The Direct to Cell system is an attached payload to the Starlink satellites, enabling its rapid deployment and leveraging its platform, power, and backhaul capability, however this is transparent to the end user.

Will Direct to Cell support backhaul for remote cell sites?
The Direct to Cell system is not designed to support backhaul for terrestrial networks, but Starlink is well suited for this. If you are interested in using Starlink for backhaul to cell sites please let us know.

Will the Direct to Cell network add polar coverage?
Higher and lower latitude >58° and <-58° and polar coverage is being considered, but there is no fixed timeline for this addition yet.

Can additional capacity be added by adding more satellites?

Although increasing constellation size does help to modestly increase capacity, the primary limitation is the availability of spectrum.

Can additional capacity be added with more spectrum?
Yes, if spectrum can be provided that is exclusive for Direct to Cell service, system capacity can be increased. If additional spectrum is available in a given region or country, this will enable us to deliver even higher user data rates and network capacity.

When/how does the cell switch to SpaceX network but avoid rapid switching between networks?
A cell phone will only switch to the direct to cell network if no higher priority terrestrial network is available. The prioritization is based on PLMN and signal strength and uses standard 3GPP based network selection procedures. To prevent ping-ponging between networks, access control customizations can be put in place to either detect the condition or to prevent UE from connecting to the direct to cell network if they were recently connected to a terrestrial network in a specific geographic location (e.g. connected to terrestrial macro in the middle of a metropolitan area one minute ago).

Will global roaming via Direct to Cell be supported?
T-Mobile has expressed support for reciprocal roaming agreements with overseas mobile operators so they can connect to Direct to Cell when outside of terrestrial network coverage in the US. Under this agreement, users roaming in your region will be able to connect to Direct to Cell on your network's allocated spectrum in exchange for your customers being able to roam on other Direct to Cell networks in other regions. There are many details to work out, but eventually all Direct to Cell customers will have a truly global experience, being able to connect to Direct to Dell in any country or ocean they may travel! This is not a standard roaming agreement, and therefore new telcos don't need to have a relationship with T-Mobile, they only need to have a relationship with SpaceX.

How does this compare to what other competitors are proposing?
Other companies have proposed similar services in recent years, however, SpaceX's Direct to Cell has several advantages compared to other systems. First, the SpaceX Direct to Cell service leverages the existing Starlink satellite technology to host the payload and inter-satellite laser communications for data backhaul. This system is currently operational, whereas other systems require development, build, launch, testing, and regulatory approval. Additionally, the SpaceX Direct to Cell system leverages the rapid production capabilities already used for Starlink, providing us with the ability to quickly and efficiently integrate Direct to Cell as a hosted payload on satellites already being manufactured on our production lines today. Last, SpaceX uniquely possesses the ability to rapidly and affordably deploy a constellation to provide this service using our own launch capabilities. We have successfully demonstrated this capability with over 50 dedicated Starlink launches successfully carrying over 2,800 Starlink satellites to orbit over the last 3 years, which is nearly 10 times larger than the next largest satellite constellation

Are LTE-based IoT standards such as NB-IOT and CAT-M supported?
IoT devices using standard LTE modems will be able to connect to the Direct to Cell network without any additional modifications. However, support for specific LTE-based IoT standards such as NB-IOT and CAT-M1 will depend on deployment modes, available spectrum and existing IoT network parameters. Please share your network requirements with us and we will address these on a case-by-case basis.

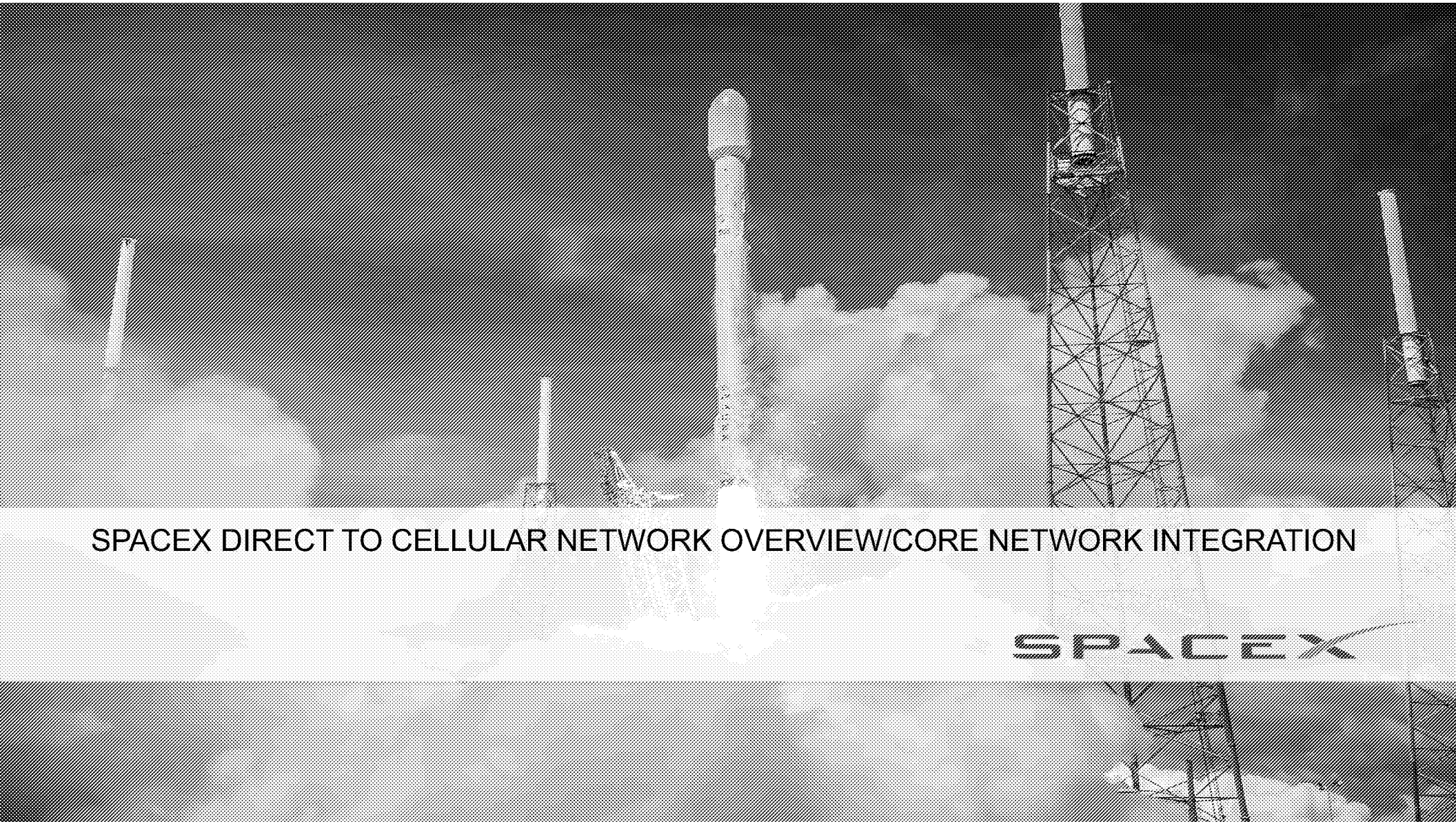
How long do the satellites stay up in low earth orbit?
SpaceX elects to launch its satellites into an orbital altitude below 610 km. At this altitude, unless active propulsion is used, all satellites will passively de-orbit and burn up in the atmosphere within approximately 4 to 5 years. These are what are referred to as "self-cleaning orbits", and are part of the overall solution to

mitigate orbital debris, which SpaceX takes very seriously (see our Feb 10, 2022 update). Most of SpaceX's satellites stay up for their designed mission lifetime of 5 years. SpaceX has a steady launch and replacement cadence and is therefore able to update the satellites with the latest technology.

What about space debris?

SpaceX is very serious and proactive in protecting the space environment for a safe and sustainable space future, as described in detail in our Feb 10, 2022 update.

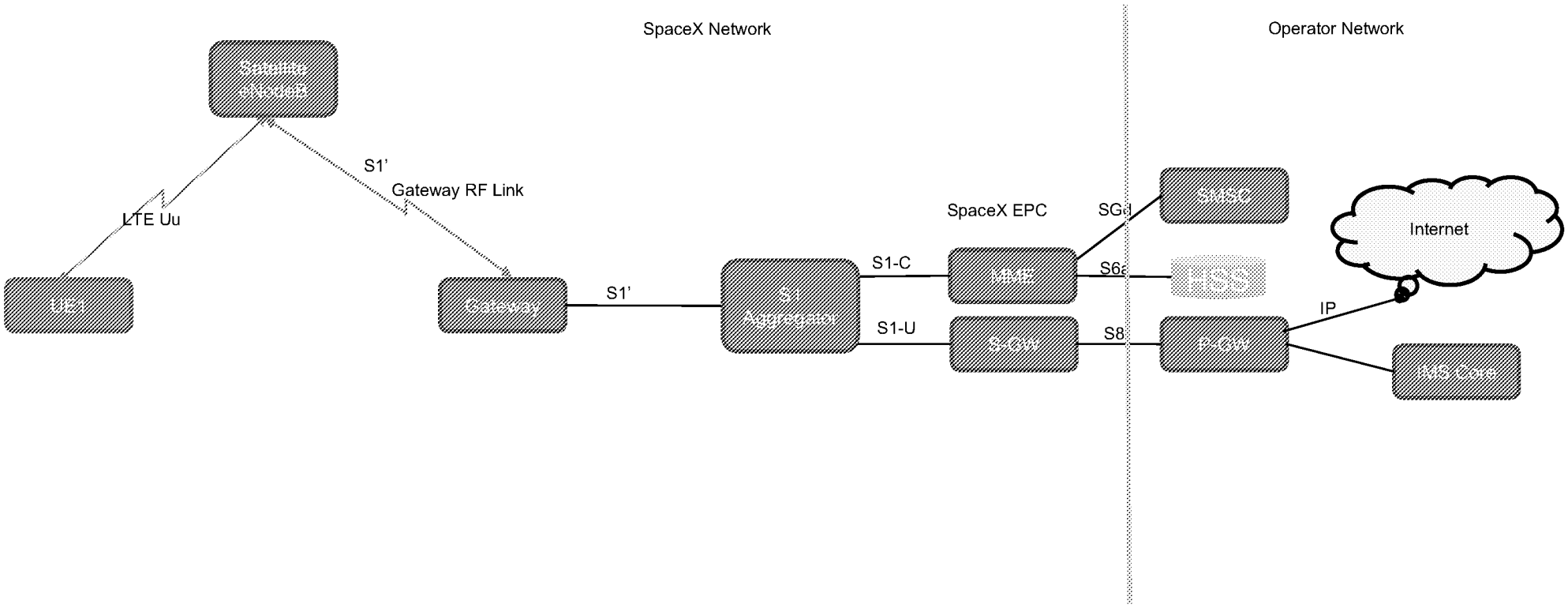
Please contact us with any additional questions or concerns.



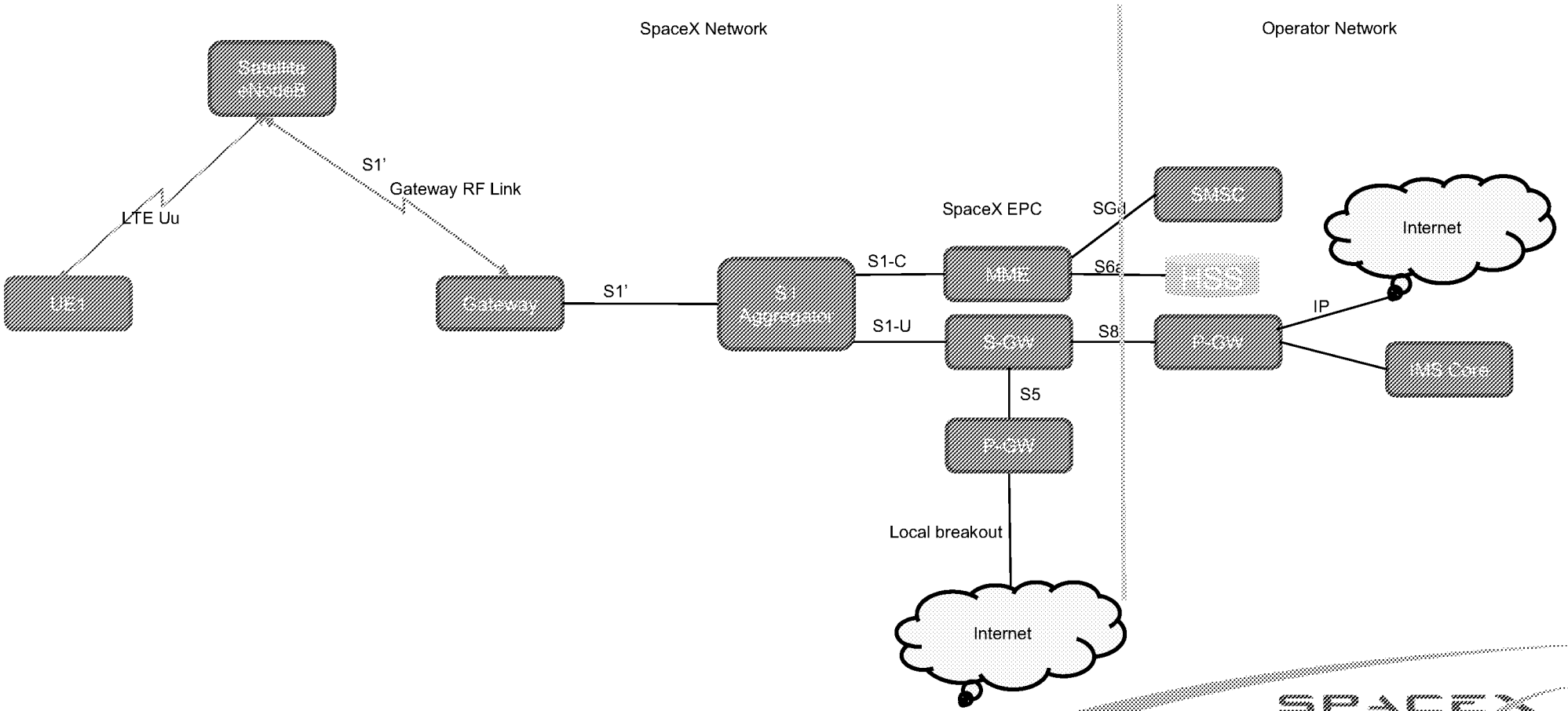
SPACEX DIRECT TO CELLULAR NETWORK OVERVIEW/CORE NETWORK INTEGRATION

SPACEX

SpaceX Direct-To-Cell LTE Network Architecture



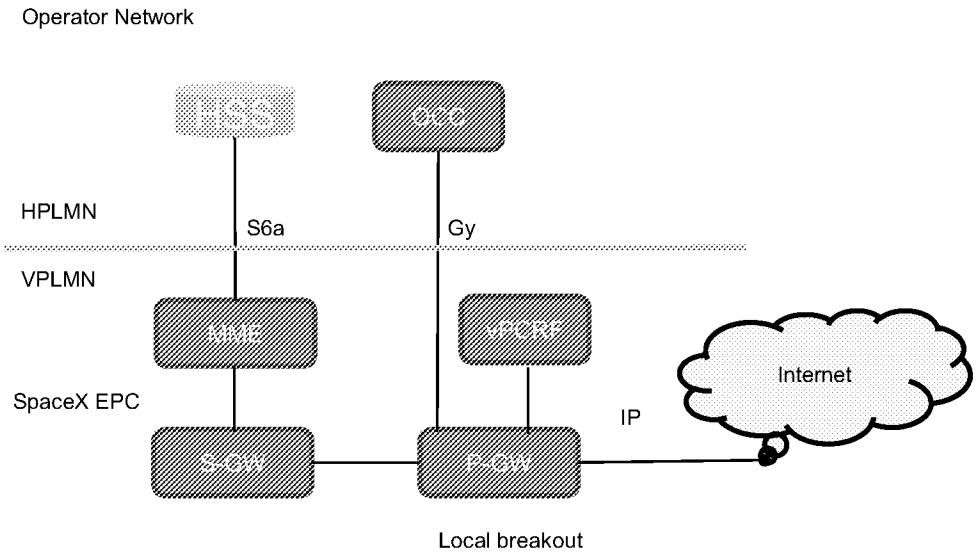
SpaceX Direct-To-Cell LTE Network Architecture



SpaceX Direct-To-Cell Network

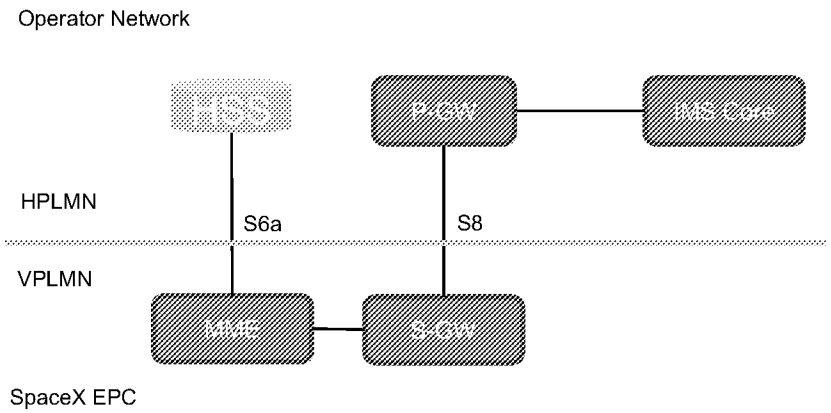
- SpaceX Direct-To-Cell Satellite/eNodeB
  - SpaceX eNodeB built using Intel FlexRAN architecture, SpaceX phased array antenna hardware
- SpaceX Gateways
  - Existing Starlink gateways that allow reachability between SpaceX ground network and satellites
- S1 Aggregator
  - Tracks satellites to route S1 traffic, encapsulate in SpaceX tunnel for routing to satellite
- SpaceX EPC
  - Leverage existing Starlink Point-of-Presence infrastructure and software to build EPC
  - EPC to be deployed on same hardware, locations as Starlink PoP sites

Data Services over SpaceX Network



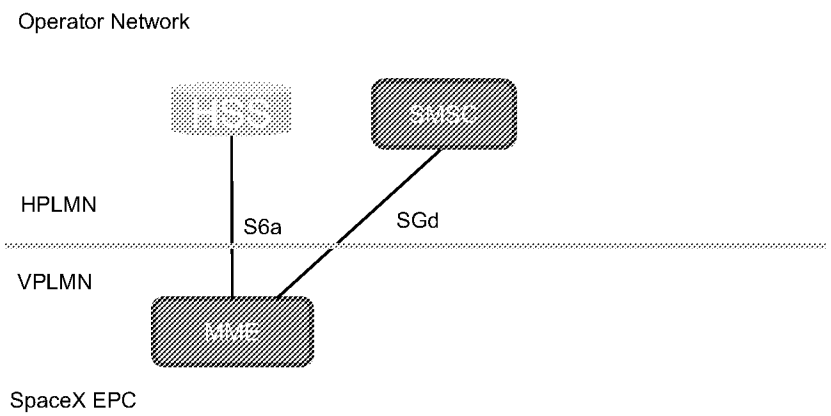
- SpaceX :
  - Use local breakout for default bearer, internet APN
  - IP address assigned from SpaceX AS domain
  - No handovers to/from terrestrial network

VoLTE Services over SpaceX Network



- SpaceX :
  - SpaceX does not plan to build an IMS network currently
  - Connect to Operator IMS core to provide VoLTE capability – S8HR Roaming
  - Assumption: Different APN used for IMS services

Text Services over SpaceX Network



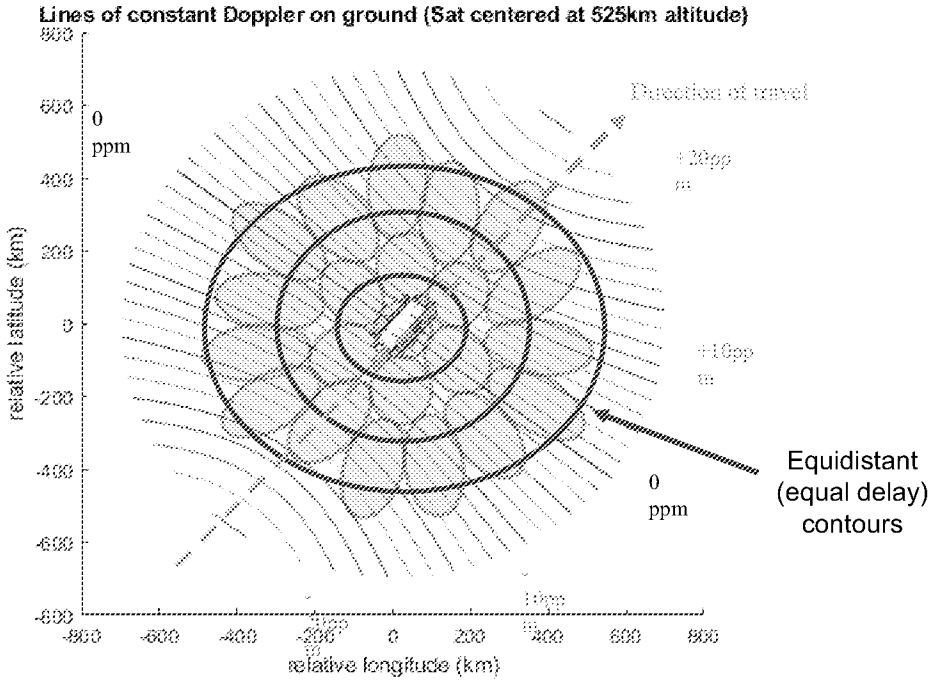
- SpaceX :
  - Connect to Operator SMSC over SGd to provide SMS/MMS Services

Core Network Interfaces and IP Inter-connect

- Connect to Operator core over standard interfaces
  - S6a between SpaceX MME and Operator HSS
  - S8 between SpaceX S-GW and Operator/HPLMN P-GW
- Security considerations
  - SpaceX does not plan to connect to operator network over a IPX network
  - Connectivity will be over public internet
  - Use IPSec tunnel for encrypting traffic to/from Operator Network

Partial Beam Geo Fencing

- PRACH Preamble timing offset and doppler estimate can be used to approximate user location within the beam
- Location within the beam at any time instance can be mapped to physical location on the ground
- Access barring (e.g. RRC Connection Reject) can be used based on configurable boundaries
- Resolution limited to estimation error for PRACH Preamble timing offset and doppler
- RRC Connection Reject includes waitTime (1-16 seconds)
- Some location ambiguity for nadir beam

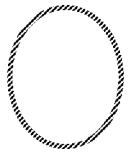


TAC Planning

Overview:
- Semi-static allocation of “virtual TAC” to ground cells
- SpaceX MME anchors virtual TAC from EPC point of view, maps virtual TAC to physical TAC for each beam
- Beam’s TAC may change over? [Ideally no]

Tracking Area Code (TAC) planning objectives:
- Semi-stationary UE never needs to do TAU
- Minimize number of sectors UE can traverse w/o TAU (paging overhead)
- Minimize rate of tracking area updates (connection overhead)
- Optimize virtual TAC shape and size to improve tradeoff
- NOTE: Max 16 TAC in tracking area list (TAL)

PLMN:
- Tracking area code should be unique within PLMN, so PLMN used must be for dedicated use in Direct-to-Cell system



Beam assigned physical TAC 22 with tracking area list (TIL) given by virtual TACs of green cells

