BIF™
BROADBAND INDIA FORUM
"Think Tank for Digital Transformation"

D2D: The Direct Line for Orbit to Device Integration

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DIRECT-TO-DEVICE SATELLITE CONNECTIVITY IS A SUPPLEMENTAL LAYER IN THE CONNECTIVITY ECOSYSTEM, EXTENDING REACH WHERE TERRESTRIAL COVERAGE IS UNAVAILABLE, INTERRUPTED OR DIFFICULT TO SUSTAIN.

ITS EARLY COMMERCIAL VALUE WILL EMERGE FROM CONSUMER AND ENTERPRISE/IOT APPLICATIONS-FROM EMERGENCY MESSAGING AND BASIC DATA SERVICES TO LOW-RATE IOT, ASSET TRACKING AND MONITORING-WITH SERVICE MODELS SHAPED BY DEVICE, SPECTRUM, NETWORK ARCHITECTURE AND APPLICATION.

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EXECUTIVE SUMMARY

Mobile connectivity now supports public safety, economic activity and daily life at a scale that was difficult to envisage a generation ago. Its reach is nevertheless still shaped by terrain, population density, network economics and the resilience of terrestrial infrastructure. Service can remain limited in remote communities, along transport corridors, at sea and in areas affected by disasters. D2D has moved from technical demonstration to early commercial use as a response to these gaps, although indoor use, obstructed environments, heavy foliage, dense urban areas and continuous broadband coverage remain challenging [35].

D2D is not a single service or architecture. The term covers satellite emergency features on selected smartphones, operator-led texting, direct-to-cell trials, satellite-to-IoT services and standards-based non-terrestrial networks [5], [35]. These implementations share a satellite link, but they differ in the devices they support, the spectrum they use, the services they can sustain and the commercial and authorisation arrangements through which they reach users. This report examines those differences across market need, standards, network architecture, spectrum, regulation, commercial models and the longer-term path toward greater satellite-terrestrial integration.

Satellite-to-IoT is a distinct D2D service category with requirements that differ materially from direct-to-smartphone services. IoT devices typically use small, intermittent payloads, constrained power budgets and long operating lives, and many applications can tolerate delay. These characteristics make MSS-based NTN, including NB-IoT NTN in non-IMT MSS spectrum, relevant to remote infrastructure, logistics, agriculture, maritime assets and other low-rate monitoring applications [23].

The global coverage picture explains why D2D has attracted attention even as mobile networks continue to expand. In 2024, 96 percent of the world's population had access to at least 3G. However, 4G coverage reached 99 percent of urban populations and 82 percent of rural populations. Only 30 percent of rural residents in low-income countries had 4G coverage, illustrating how national coverage averages can mask material rural gaps [41]. India's communications and digital landscape brings this broader pattern into sharper focus: a mobile market of exceptional and unprecedented scale continues to coexist with rural, transport-corridor and disaster-resilience gaps [80], [73].

CONNECTIVITY AND RESILIENCE CONTEXT (INDIA)

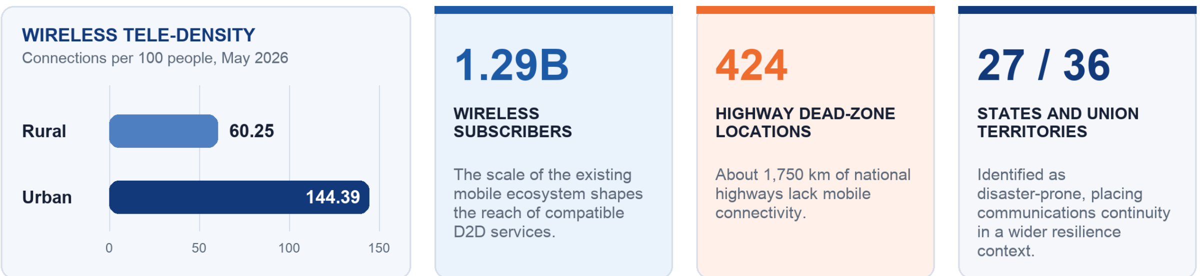

Exhibit ES.1: India's large mobile base coexists with rural, transport-corridor and disaster-exposure gaps

THE MARKET IS DEVELOPING IN STAGES

D2D propositions occupy different points on the maturity curve. Services that use small payloads and tolerate delay can already support emergency communications, basic messaging, location sharing, public warning, selected applications and low-rate IoT telemetry [9]. More continuous services place greater demands on satellite capacity, coverage continuity, device performance, network integration and national authorisation. The service ladder below distinguishes between capabilities that are available now, those that are beginning to scale and those that remain conditional or longer term.

CURRENT COMMERCIAL VALUE IS CONCENTRATED IN LOWER-BANDWIDTH SERVICES

The first commercial offers are concentrated where the public or operational value of a connection can be high even when data volumes and bandwidth requirements are low. Emergency SOS and distress messaging can preserve a communications channel when no terrestrial signal is available [14]. Basic text, public warning and location sharing can extend continuity for travellers, remote communities and disaster response. Low-rate IoT can support asset tracking, utilities, logistics and environmental monitoring in areas where continuous terrestrial coverage is difficult to justify.

D2D COMMERCIAL LANDSCAPE

1 | PUBLIC VALUE FIRST

READY NOW

- Emergency SOS and distress text
- Public warning and disaster fallback
- Basic messaging and location sharing
- Low-rate IoT telemetry

→

2 | ASSURANCE

SCALING NEXT

- Rural and corridor messaging
- Logistics, utilities and asset monitoring
- Selected apps and episodic data
- MNO-integrated plan features

→

3 | MORE DEMANDING

CONDITIONAL

- Dependable voice
- Richer app access and low-rate data
- More continuous mobility and handover
- Broader ordinary-phone compatibility

→

4 | NOT YET UNIVERSAL

ROADMAP

- Broadband-like service: not viable at meaningful area scale
- Indoor and obstructed use: remains challenging
- Seamless satellite-terrestrial roaming
- Deep 6G-era integration

Exhibit ES.2: Service maturing in stages; each step demands more capacity and regulatory alignment

The progression from messaging to dependable voice and richer data is not simply a change in product packaging. It requires a substantial increase in link reliability, available capacity, mobility management and interoperability across devices and networks. The more consequential limitation is area capacity. A satellite beam must share finite spectrum and payload power across a large footprint and many users. An acceptable data rate for one connection does not imply meaningful capacity across the covered area; aggregate capacity per square kilometre remains far below that of terrestrial mobile networks [21]. Current D2D is therefore principally relevant to deep-rural, rural and other low-density areas, and to temporary outage or emergency conditions. It is not a practical capacity solution for towns, dense urban areas or other high-demand locations.

READINESS DEPENDS ON THE COMPLETE DELIVERY CHAIN

3GPP has progressively defined NTN capabilities, but the successive releases should not be read as having resolved the principal deployment issues. Release 17 established an initial NTN baseline; Release 18 refined technical mechanisms relevant to deployment; and Release 19 continues standardisation toward 5G-Advanced [1], [4]. These releases specify capabilities and procedures, but they do not establish universal device support, interoperability or commercial readiness. The implementation ecosystem remains incomplete and uneven. Commercial service requires the standards baseline to be implemented consistently across modems and radio components, firmware, operating systems, applications, SIM entitlement, carrier integration, satellite and network capacity, testing, certification and national service authorisation. Because these elements are not yet aligned across devices and markets, D2D readiness remains limited to particular services, handsets, operators and jurisdictions.

Network architecture establishes a further set of practical limits. Ordinary smartphones have small antennas, limited transmit power and finite battery capacity. Their performance also changes with sky visibility, buildings, vegetation and device orientation. Low Earth orbit systems add moving satellites and beams, Doppler shift, timing variation, gateway dependencies and handover between coverage areas [16], [21]. For current mass-market D2D smartphone services, outdoor, open-sky operation remains the only consistently credible setting. Indoor use, dense urban or otherwise obstructed environments, and operation under heavy foliage remain challenging under current implementations because the handset-to-satellite path is easily blocked and service reliability varies significantly with sky visibility. Continuous

DIFFERENT SPECTRUM PATHWAYS AND CONTEXTS

Pathway	Design	Value	Rollout
D2D-MSS	Uses mobile-satellite spectrum; strongest fit for SOS, messaging and low-rate IoT.	Compatible device bands, certification, available MSS capacity and ecosystem maturity.	Often begins within existing satellite-licensing frameworks, with device, service and national authorisation conditions.
D2D-IMT	Uses terrestrial IMT spectrum from space; potential standard-phone compatibility is conditional on access to relevant terrestrial rights throughout every illuminated service area.	May reduce handset changes, but can constrain future terrestrial use of the same frequencies and creates co-channel, adjacent-band, licence-boundary and protection risks.	Requires rights-holder consent, band alignment and strict coexistence controls. In India, differing operator holdings across 22 LSAs could require extensive multi-operator coordination, frequency rearrangement or harmonisation, potentially making nationwide implementation impracticable.

Exhibit ES.3: Different design and regulatory approaches; local markets and regulatory designs define rollout terms

broadband coverage through ordinary smartphones is therefore not a current D2D capability. IoT modules however can be designed around different traffic, power and latency profiles, giving them a distinct technical and commercial pathway to integrate D2D.

TWO SPECTRUM PATHWAYS CREATE DIFFERENT REGULATORY CONTEXTS

Spectrum arrangements shape which devices can connect, how interference is managed and which authorisations apply. The report distinguishes between D2D using mobile-satellite service spectrum and D2D using terrestrial mobile spectrum from space. Both pathways can support direct connectivity, but they begin from different regulatory foundations and present different implementation constraints.The choice of pathway does not produce a uniform international model. Technical standardisation and spectrum regulation are separate tracks: 3GPP releases define network and device capabilities, but they do not allocate spectrum or create operating rights. WRC-27 Agenda Item 1.13 studies possible MSS spectrum allocations for direct connectivity between space stations and IMT user equipment [40], [44]. Any outcome would still require national implementation through licensing, coexistence, incumbent-protection, device-approval and service-authorisation rules. National approaches can therefore differ even as common technical standards advance.

WRC-27 will clarify possible international spectrum allocations and the coexistence and incumbent-protection conditions relevant to widespread deployment [44], [47]. In parallel, trials and nationally authorised early services can generate useful and practical evidence on network integration, device performance and coordination [65], [66]. Several jurisdictions have already moved from testing toward early rollout under national frameworks [48], [55], [57], [68]. This experience supports near-term learning, while WRC-27 outcomes remain critical for international harmonisation, incumbent protection and safe scaling [44], [47].

A SIMILAR EARLY SERVICE PATTERN IS EMERGING

Jurisdictions are following different regulatory routes. North America and the United Kingdom have adopted explicit or semi-explicit supplemental-coverage arrangements. Australia and New Zealand rely more heavily on flexible, market-led partnerships operating within existing frameworks, while Japan and CEPT/EU are pursuing structured technical evaluations of specific frequency bands and staged deployment pathways [18], [55]. These approaches differ in their legal maturity, technical scope and treatment of service providers.

In India, TRAI's 2026 consultation on satellite communication networks (SCNs) addresses authorisation conditions, partner eligibility, feeder- and user-link spectrum assignment, the timing of D2D-IMT services in relation to WRC-27, and the respective roles of network providers and entities authorised to serve end users, including under the GMPCS framework [69]. The consultation period has closed, but the resulting policy and regulatory framework remains under consideration. India therefore has a defined policy-development process, while D2D-specific operating conditions—

GLOBAL COMPARISON: DIFFERENT ROUTES, SIMILAR EARLY SERVICE PATTERN

Market	Regulatory Approach	Market Position
North America + UK	Explicit/Semi-explicit supplemental coverage frameworks	Starlink partnerships with T-Mobile, Rogers and O2 support live messaging and selected apps
Australia + New Zealand	Rely more heavily on flexible existing spectrum rights	Telstra/Starlink and One NZ/Starlink offer texting or data add-ons with plan and device limits
Japan + CEPT/EU	More technical and band specific	KDDI/Starlink and Orange Skylo illustrate messaging, resilience and phased deployment
India	GMPCS provides an MSS starting point; TRAI's 2026 SCN consultation covers authorisation scope, partner eligibility, feeder- and user-link spectrum, D2D timing and inter-provider arrangements.	D2D-specific spectrum and service question under examination
Common Market Pattern	**Across markets, live ordinary-phone offers are messaging first and closely integrated with plans and devices.**	

Exhibit ES.4: Global Comparison: Regulatory routes and market expression vary; Live service ceiling remains narrow

including spectrum selection, licensing terms and pricing—remain to be settled.Commercialisation is being organised through partnerships.

Consumer services are increasingly finding their way to market through partnerships between mobile and satellite operators [36]. Mobile operators manage customer identity, billing, service entitlement, support and emergency access; in D2D-IMT models, they also control or coordinate access to the relevant terrestrial IMT spectrum rights. Enterprise IoT follows a different model, with value linked more directly to operational continuity, asset visibility and remote-monitoring economics, and many deployments use non-IMT spectrum bands.

THE LONGER-TERM OUTLOOK IS ONE OF GRADUAL CONVERGENCE

Satellite messaging, emergency functions and enterprise IoT are advancing as technology, coverage and platforms mature. Deeper satellite-terrestrial integration is contemplated in the 6G roadmap and may be enabled by software-defined networks, edge computing and more advanced network management [8], [45]. At the same time, terrestrial-like broadband from ordinary phones, seamless global roaming and a single spectrum model remain challenging because they depend on devices, satellite capacity, spectrum rules, infrastructure, commercial agreements between mobile and satellite operators, and national service-authorisation rules.

Read Next	
Chapters 1-2	The terminology, implementation families, connectivity gaps and use cases that define the market.
Chapters 3-4	The standards roadmap, implementation ecosystem, network architecture and present service ceiling.
Chapters 5-6	Spectrum pathways, authorisation models, coexistence risks, deployment models and partnership structures.
Chapter 7	Post-2031 scenarios and the standards, spectrum, device, infrastructure, market and policy gates behind them.

1. INTRODUCTION

AT A GLANCE

1 HIGHLIGHT 1

Direct-to-device satellite connectivity has moved from concept to commercial experimentation.

The shift is visible across standards activity, smartphone-based satellite features, mobile-network-operator partnerships, ongoing consultations, the emergence of early national regulatory frameworks and deployment of pilot/commercial services.

2 HIGHLIGHT 2

The terminology is not interchangeable.

NTN is a broad standards category; D2D is used in this report as a satellite direct-to-device service umbrella; direct-to-cell is a narrower subset focused on cellular handsets or SIM-enabled devices; and satellite-to-smartphone and satellite-to-IoT describe distinct device and use-case categories.

3 HIGHLIGHT 3

D2D is complementary to terrestrial networks, not a replacement.

Its near-term value is strongest as a resilience layer for emergencies, disasters and no-coverage situations, while selected regular-service use cases are emerging in messaging, IoT, mobility, rural connectivity and limited broadband-oriented applications.

4 HIGHLIGHT 4

The implementation landscape is mixed.

Standards-based 3GPP NTN, OEM-led proprietary satellite features and operator-specific direct-to-cell models using terrestrial mobile (IMT) spectrum coexist, and they differ materially in spectrum model, device requirements, interoperability and service scope.

1.1 BACKGROUND AND CONTEXT

Direct-to-device satellite connectivity has become a live policy, standards and commercial agenda. The field is no longer defined by a single technology model or a single service proposition. It now includes emergency messaging on selected smartphones, satellite-enabled text and app services through mobile operators, direct-to-cell partnerships using terrestrial mobile (IMT) spectrum, standards-based non-terrestrial network development, and satellite-to-IoT propositions for enterprise and remote operations [35].

This report uses Direct-to-Device Satellite Connectivity (D2D) as the umbrella framing for satellite systems that connect directly to ordinary user devices, including smartphones, SIM-enabled devices and IoT modules. The framing is deliberately narrower than the full 3GPP concept of non-terrestrial networks (NTN), which includes satellite and other airborne platforms such as HAPS, but broader than direct-to-cell or direct-to-cellular (D2C) connectivity, which is focused primarily on cellular handsets or SIM/eSIM-enabled devices and typically their integration with mobile-network-operators [5].

The context matters because market language is moving faster than shared definitions. The same phrase can refer to an emergency feature on a specific smartphone, a 3GPP NTN-capable chipset, a satellite-to-IoT narrowband service, or an MNO-satellite partnership designed to extend mobile coverage outside terrestrial network reach [5]. These are related developments, but they are not equivalent systems.

D2D should be understood as a supplementary connectivity layer. It can improve resilience where terrestrial infrastructure is unavailable, damaged, congested or uneconomic to extend. It can also support selected everyday use cases where low-volume, intermittent or delay-tolerant connectivity creates value [35].

The policy, regulatory and stakeholder relevance of D2D is broad. Policymakers and regulators need clear distinctions for authorisation, spectrum sharing, emergency obligations and competition assessment. MNOs and satellite operators need to stitch together partnership models, service tiers and rollout economics. These could be either institution driven or be led by market forces. OEMs and chipset vendors need clarity on device eligibility, NTN readiness and interoperability. Infrastructure stakeholders need to understand where gateways, cores, billing, identity, roaming and control functions sit in different architectures [35].

1.2 WHY D2D HAS MOVED FROM CONCEPT TO COMMERCIAL EXPERIMENTATION

D2D has moved from concept to commercial experimentation because several enabling conditions have converged at the same time. The shift is not attributable to a single breakthrough. It reflects progress across the lowering of launch costs, satellite miniaturisation, improved payload capability and power efficiency standards, device integration, mobile-operator partnerships, regulatory authorisation and demand for resilient fallbacks [9].

The near-term commercial pattern is messaging-first. Current consumer propositions are concentrated on emergency communications, text, location-sharing and selected apps, while broader voice and data capabilities are still developing and depend on architecture, spectrum, constellation scale, device support and regulatory approval. The first commercially viable and available service layer for D2D is one where traffic volumes are lower, user value is high and the performance requirement is narrower than terrestrial broadband [9].

D2D is best described as serving both a resilience capability and an emerging supplementary connectivity layer. The resilience case is already visible in emergency messaging, disaster response and no-coverage situations. The regular-service case is more selective and should be evaluated use case by use case, especially for messaging, IoT, mobility, rural connectivity and broadband-oriented applications [9].

1.3 DEFINING DIRECT-TO-DEVICE, DIRECT-TO-CELL AND NTN CONNECTIVITY

NTN is a standards-oriented term. In 3GPP usage, non-terrestrial networks include networks or network segments using satellites or airborne platforms, including high-altitude platforms and uncrewed aircraft systems [5]. NTN is therefore broader than satellite-only connectivity and broader than D2D.

D2D, as used in this report, means satellite connectivity delivered directly to a smartphone or other user device without an intermediate user-owned satellite terminal. This is the current satellite-market usage. The report uses D2D to mean direct-to-device satellite connectivity, not the older 3GPP ProSe or sidelink meaning of device-to-device communication between nearby terrestrial user equipment [5].

Direct-to-cell, also referred to in some sources as direct-to-cellular, D2C, direct-to-mobile or direct-to-phone is a subset of D2D. It refers to satellite connectivity aimed at standard cellular handsets or SIM-enabled devices, typically integrated with mobile-network-operator spectrum, identity, service logic and customer relationships. Direct-to-cell is therefore narrower than D2D, because D2D can also include satellite-to-IoT modules and other device categories. The term D2C is observed routinely in frameworks/literature by governments, industry and academia as a practical market and regulatory shorthand for the handset-focused subset of satellite direct-to-device connectivity [5].

SAT-TO-SMARTPHONE AND SAT-TO-IOT CONNECTIVITY

Satellite-to-smartphone — HUMAN EXPERIENCE

SUCCESS TEST	A person can discover, activate and complete a useful connection.
TRAFFIC PROFILE	SOS, location sharing, text, selected apps; voice and richer data remain emerging.
DEVICE REALITY	Low-gain internal antenna, about 0.2 W transmit power and a clear view of sky.
COMMERCIAL PROOF	Apple/Globalstar, T-Satellite, O2/Starlink, Verizon/Skylo and other live offers.
POLICY FOCUS	Emergency claims, device eligibility, consumer disclosure, spectrum and service continuity.

Satellite-to-IoT — APPLICATION OUTCOME

SUCCESS TEST	A device reports the required data with acceptable delay, power use and reliability.
TRAFFIC PROFILE	Telemetry, tracking, metering, agriculture, logistics and remote monitoring.
DEVICE REALITY	Purpose-built modules can tolerate delay, low duty cycles and store-and-forward operation.
COMMERCIAL PROOF	NB-IoT NTN ecosystems involving Sateliot, Skylo, MediaTek and enterprise partners.
POLICY FOCUS	Module certification, roaming, spectrum, power management and cross-border fleet operation.

Exhibit 1.1: Satellite-to-smartphone and satellite-to-IoT connectivity: Distinct user expectations, use cases, policy focus and performance expectations.

Supplemental Coverage from Space is a specific U.S. regulatory construct, not a global synonym for D2D or NTN. The FCC's SCS framework enables arrangements between terrestrial licensees and satellite operators to serve terrestrial subscribers through satellite connectivity [28]. It is highly relevant to D2D policy, but it should not be used as a universal label for all direct-to-device satellite systems.

1.4 DISTINGUISHING SATELLITE-TO-SMARTPHONE AND SATELLITE-TO-IOT CONNECTIVITY

Satellite-to-smartphone and satellite-to-IoT connectivity should be treated as related but distinct categories. They share the broader D2D ambition of connecting ordinary devices directly to satellites, but they differ in traffic profile, user expectation, device constraints, service design and commercial logic [1].

Satellite-to-smartphone services are judged by human user experience. Users expect simple activation, clear availability, predictable message completion, acceptable battery impact and integration with familiar mobile applications. Current consumer services reflect those constraints. Apple's satellite-based service features features focus on emergency services, roadside assistance, messages and location-sharing on supported iPhones [11]. T-Satellite supports texting, location-sharing, selected apps, WhatsApp voice chat and text-to-911 on compatible devices [68]. O2 Satellite has been positioned around messaging, location-sharing and supported apps rather than normal voice calls.

Satellite-to-IoT services are evaluated differently. IoT use cases often involve telemetry, asset tracking, sensor reporting, agriculture, logistics, utilities, environmental monitoring or remote industrial operations. These applications can be lower throughput, more intermittent and more delay-tolerant than consumer smartphone services. 3GPP Release 17 recognised this distinction by including both NR over NTN and IoT over NTN, including NB-IoT and eMTC-oriented approaches for massive IoT use cases [2], [23].

The distinction affects policy and market assessment. A satellite-to-smartphone service may raise questions about emergency calling, consumer protection, handset certification, roaming, public warning, accessibility and user transparency. A satellite-to-IoT service may raise different questions about module cost, battery life, spectrum efficiency, cross-border device operation, enterprise service-level agreements and integration with industrial platforms [1].

The distinction also affects performance expectations. Smartphone users may interpret D2D through the lens of mobile broadband, even where the actual service is messaging-first or app-limited. IoT users may value reach, power efficiency, low device cost and periodic message delivery more than latency or throughput. This is why the report treats satellite-to-smartphone and satellite-to-IoT as separate analytical tracks rather than combining them into a single demand category [1].

1.5 OFF-THE-SHELF DEVICE FOCUS

This report focuses on D2D services that work with standard off-the-shelf devices. The focus is deliberate. D2D becomes strategically important when connectivity can be delivered to the devices that users, enterprises and public agencies already own or can procure through mainstream channels. That distinguishes D2D from traditional satellite-phone services, external satellite communicators and specialist terminals [21].

However, "off-the-shelf" must be used carefully. It should not be interpreted as meaning that every existing handset or device will work with every D2D service. Apple's satellite features are limited to supported iPhone models and supported geographies [11]. T-Satellite identifies compatibility conditions for supported smartphones [68]. Other direct-to-cell models depend on mobile-operator relationships, device eligibility, radio support, SIM status, certification and national regulatory and service authorisation.

The most precise definition is therefore: a standard off-the-shelf D2D device is a commercially available handset, module or connected device that can use satellite connectivity without a dedicated satellite handset, external satellite accessory or user-deployed terminal, subject to service-specific compatibility conditions [21].

The off-the-shelf focus has three implications [21].

First, it makes D2D relevant to mass-market adoption. A satellite feature embedded in a smartphone can be available at the moment of emergency, even where a user did not plan to carry specialist equipment. This is the core public-value logic behind emergency SOS-type services and supplemental coverage frameworks [21].

Second, it changes the commercial model. Services tied to existing smartphones can be distributed through MNO subscriptions, OEM software experiences, device bundles, enterprise connectivity contracts or public-safety procurement channels. This increases the importance of partnerships among MNOs, satellite operators, OEMs, chipset vendors and infrastructure providers [21].

Third, it raises the standard for transparency. Consumers and institutions need to know whether "works with ordinary phones" means all phones, recent phones, selected chipsets, selected operating systems, selected SIM profiles, selected geographies, or selected applications. The phrase is commercially powerful, but analytically incomplete unless the compatibility boundary is disclosed [21].

1.6 STANDARDIZED VERSUS PROPRIETARY IMPLEMENTATIONS

The D2D market should not be described as a simple binary between standardised and proprietary systems. A more accurate framing identifies at least three implementation families: standards-based 3GPP NTN, OEM-led proprietary satellite features, and operator-specific direct-to-cell models using terrestrial mobile (IMT) spectrum [5].

Standards-based 3GPP NTN is the most formalised technical path. Release 17 introduced NR over NTN and IoT over NTN, creating a common standards basis for satellite connectivity in the cellular ecosystem [1], [23]. This path supports long-term interoperability and chipset alignment, but commercial availability depends on NTN-capable devices, network support, spectrum arrangements and ecosystem maturity.

OEM-led proprietary satellite features are typically controlled through a specific device family, software experience and contracted satellite network. Apple's Emergency SOS via satellite is the leading example [14], [11]. This model can create a tightly integrated consumer experience and a well-bounded emergency use case, but it is less portable across OEMs and less comparable across markets.

Operator-specific direct-to-cell models using terrestrial mobile spectrum seek to extend mobile coverage through MNO-satellite partnerships. T-Mobile and SpaceX, AT&T and AST SpaceMobile, and Vodafone and AST SpaceMobile illustrate this model [68], [15]. It can leverage the existing mobile ecosystem, customer relationships and installed smartphone base, but it also raises complex questions about national authorisation, interference protection, cross-border coordination and coexistence with terrestrial networks.

"Standardised versus proprietary" is not a clean dividing line. Some services use elements of the terrestrial cellular ecosystem without relying fully on 3GPP NTN-capable handsets. Some proprietary services use standard consumer smartphones but a closed service layer. Some satellite-to-IoT services are more directly aligned with 3GPP NTN specifications than current smartphone-oriented direct-to-cell services [5].

D2D IMPLEMENTATION MODELS

	Standards-based 3GPP NTN COMMON TECHNICAL ROADMAP	OEM-led satellite features CONTROLLED USER EXPERIENCE	Operator-led direct-to-cell MOBILE COVERAGE EXTENSION
CORE LOGIC	NR-NTN and IoT-NTN built into the cellular standards roadmap.	A device maker controls hardware eligibility, software flow and satellite partner.	An MNO and satellite operator extend the terrestrial mobile service layer.
DEVICES	NTN-capable phones, IoT modules, wearables and other certified devices.	Supported models within a specific OEM portfolio.	Ordinary or recent handsets, subject to carrier and device compatibility.
SPECTRUM	Satellite/NTN bands and standards-based satellite operation.	The OEM partner's satellite network and spectrum arrangements.	Terrestrial mobile bands used from space under national authority.
SERVICE FIT	Low-rate IoT, messaging and selected handheld use cases.	Emergency SOS, assistance, messaging and location sharing.	Text, location, selected apps; broader voice/data is roadmap-dependent.
STRENGTH	Interoperability potential and chipset ecosystem alignment.	Fast consumer integration and a clearly bounded safety proposition.	Existing subscriptions, SIM identity, billing and customer relationships.
CONSTRAINT	Device support and commercial scale are still developing.	Limited portability across OEMs, devices and markets.	Hard coexistence, licensing, cross-border and capacity questions.
EXAMPLES / EXAMPLE / EXAMPLES	Release 17 NTN, Sateliot, Skylo and MediaTek ecosystem work.	Apple satellite features using Globalstar.	T-Mobile/SpaceX, AT&T/AST and Vodafone/AST.

Exhibit 1.2: Standards-based 3GPP NTN, OEM-led proprietary satellite features and operator-specific direct-to-cell using terrestrial mobile spectrum.

1.7 WRC-27 AGENDA ITEM 1.13 AND THE SPECTRUM PATHWAY FOR D2D

WRC-27 Agenda Item 1.13 is a key global spectrum issue for D2D [40], [44]. It concerns studies on possible new mobile-satellite service allocations that could support direct connectivity between space stations and IMT user equipment, with the objective of complementing terrestrial mobile coverage.

This matters because D2D cuts across satellite and terrestrial mobile frameworks. MSS-based D2D fits more naturally within existing satellite regulation, while novel mobile-band or IMT-linked D2D technologies raise more complex questions around interference, licensing, coexistence and cross-border coordination [40].

While WRC-27 studies continue, D2D deployment will be shaped by country-specific permissions, trials, licence variations and coexistence conditions. These national pathways can generate practical evidence and support early service. WRC-27 outcomes at the same time, will remain important to harmonisation, incumbent protection and the wider scaling of D2D-IMT [40], [44], [47].

1.8 GSO-BASED D2D EXISTS, BUT NGSO DRIVES THE SCALE NARRATIVE

D2D should not be read as an exclusively NGSO or LEO category. GSO/GEO-based D2D services and trials already exist, especially where the service requirement is narrow: voice, SMS, SOS, location sharing and low-rate IoT over MSS spectrum. Huawei's Tiantong satellite communications feature, for example, supports voice calls and SMS on compatible phones in open, no-coverage areas [76]. Viasat and Skylo have also described a Release 17-based D2D network using Viasat's geostationary L-band satellite constellation and licensed spectrum [77].

There is also growing GSO evidence in standards-based D2D trials and near-commercial deployments. Deutsche Telekom and Google reported successful peer-to-peer SMS over a GEO satellite to a Google Pixel 9, using Skylo's satellite service [78]. Space42 and Skylo have announced standards-based D2D connectivity through the geostationary Thuraya-4 satellite, including direct-to-device voice capability [79].

GSO-based D2D is technically and commercially relevant, particularly for MSS-based low-rate services. However, it also defines the boundary of current GSO use. Most mass-market D2D scale ambitions are centred on NGSO, especially LEO, because lower altitude improves latency and link-budget conditions, while larger constellations and moving beams can support greater spatial reuse, mobility and capacity growth. The report therefore treats GSO-based D2D as an important existing pathway, but gives greater analytical focus to NGSO-based D2D where the market ambition moves from SOS and messaging toward wider ordinary-phone coverage, voice, selected apps and broadband-oriented services [21].

For satellite-to-IoT, orbit selection is application- and service-dependent rather than being determined by the direct-to-smartphone model. GSO/GEO and LEO systems can support different MSS-based IoT requirements depending on coverage, terminal power, latency tolerance, continuity, capacity and economics [21].

D2D satellite connectivity is no longer a speculative concept, but it is also not a single market, technology or regulatory category. It is a family of emerging connectivity models that connect satellites directly to smartphones, cellular devices, IoT modules and other off-the-shelf devices under different technical and commercial arrangements [21].

D2D is a complementary layer in the broader connectivity stack. Its strongest near-term role is resilience: emergency communication, disaster response, not-spot coverage, outage backup and public-safety support. Its emerging regular-service role is more selective: messaging, location-sharing, selected applications, IoT telemetry, mobility services, rural and remote coverage, and broadband-oriented connectivity where the economics or geography of terrestrial networks are challenging [21].

2. MARKET NEED AND USE-CASES

AT A GLANCE

1 HIGHLIGHT 1

The clearest near-term D2D market need is supplemental continuity and coverage.

D2D is best framed as satellite-delivered fallback coverage for ordinary handsets and NTN-capable IoT devices when terrestrial networks are absent, weak, intermittent or disrupted. 3GPP Release 17 introduced the first mainstream 5G and IoT NTN building blocks, while Release 18 continued NTN and IoT enhancements.

2 HIGHLIGHT 2

Coverage gaps remain concentrated in the hardest geographies.

In 2024, 96% of the world population was covered by at least 3G, leaving the final 4% concentrated in the most difficult terrestrial business cases; Africa still had a 14% population-level mobile-broadband coverage gap, and only 30% of rural inhabitants in low-income countries had 4G coverage.

3 HIGHLIGHT 3

Weak coverage and outage risk are as important as absolute no-coverage.

OECD data show urban mobile speeds were 37.2% higher than rural speeds on average at end-2024.

4 HIGHLIGHT 4

Emergency messaging is the strongest public-interest use case today.

Existing commercial services are heavily text-first: Apple supports Emergency SOS via satellite, T-Mobile foregrounds satellite text-to-911, and Verizon supports satellite SOS and messaging on selected devices.

5 HIGHLIGHT 5

Regular-service D2D is emerging.

Low-rate messaging, alarms, IoT monitoring, logistics assurance and corridor safety are plausible near-term use cases; voice, broadband replacement and continuous rich-data service are emerging but remain roadmap-dependent.

2.1 NEED FOR D2D CONNECTIVITY

D2D connectivity should be understood as a supplemental coverage layer. Its strongest current role is to preserve basic communication when terrestrial mobile networks are unavailable, unreliable or disrupted. It is not a general substitute for terrestrial mobile broadband. That distinction is important because the most evidenced market needs are low-rate and resilience-oriented: SOS messaging, public warning, disaster fallback, basic off-grid text, asset location, low-power telemetry and selected infrastructure alarms [34].

The need for D2D has four components [34].

- There are still true no-coverage areas, especially in rural, remote, maritime, border and sparsely populated territories.
- There are thin-coverage areas, where coverage exists but is weak, single-operator, low-capacity or unreliable.
- There is a network resilience problem, where disasters, fibre cuts, power failures and misconfigurations can create temporary no-coverage even in well-served markets.
- There are episodic connectivity needs, where users or devices require only occasional messages, alerts or telemetry rather than continuous broadband.

2.2 NO-COVERAGE AREAS

No-coverage areas are the most intuitive D2D market need, but they are now highly concentrated rather than uniformly distributed. ITU reports that 96% of the global population was covered by at least 3G in 2024, meaning the residual 4% is disproportionately located in remote, rural, island, mountainous and economically difficult geographies. These areas are precisely where terrestrial rollout faces the weakest economics because population density is low, backhaul is costly and tower power or maintenance can be difficult [41].

The rural deficit is much sharper than the global average suggests. In 2024, global 4G coverage reached 99% of urban populations but only 82% of rural populations, while rural 5G access was 29% compared with 67% in urban areas. In low-income countries, only 30% of rural inhabitants had 4G coverage. Areas with no mobile broadband at all ranged from 2% of the rural population in Europe to 25% in Africa, with rural small-island developing states facing a 39% rural mobile-broadband coverage gap [41].

D2D's value in no-coverage areas is therefore selective but high. It is most compelling where the required service is narrow: distress messaging, basic text, location sharing, sensor telemetry or low-rate asset status. It is less compelling as a universal broadband strategy, because the same geographies that are expensive for terrestrial networks also impose capacity, power and device constraints on satellite-to-handset service [41].

2.3 THIN-COVERAGE AND WEAK-SIGNAL AREAS

Thin coverage is different from no coverage. A user may technically be within a mobile coverage footprint but still experience weak signal, low speeds, single-operator dependence, patchy indoor/outdoor availability or failure during congestion. This matters because many D2D use cases are triggered by the practical loss of service, not only by formal absence from a coverage map [53].

OECD evidence shows persistent urban-rural quality gaps even in advanced economies [53]. At end-2024, average mobile download speeds were 74.5 Mbps in cities and 54.3 Mbps in rural areas, a 37.2% urban advantage. Average 5G download speeds also differed materially, at 222.6 Mbps in cities versus 173.5 Mbps in rural regions. In 19 OECD countries, urban mobile speeds were at least 40% higher than rural speeds.

The UK illustrates the difference between headline coverage and resilient coverage. Ofcom reported 95% UK landmass 4G coverage from at least one MNO, but individual MNO geographic coverage was only 88–89% [54]. UK operator 5G landmass coverage was materially lower, ranging from 15% to 42% depending on operator and confidence level. For D2D, this creates a market need not just for remote wilderness coverage, but for an assurance layer where the user's own operator has no usable signal.

India reflects the same pattern of high aggregate network reach with hard residual gaps in remote and rural geographies. As of May 2026, India had 1.29 billion wireless subscribers, but rural wireless tele-density was still 60.25% compared with 144.39% in urban areas, indicating that access and usage remain materially weaker outside urban markets [80].

2.4 NETWORK RESILIENCE AS A CORE MARKET NEED

Network resilience is a core D2D market need because terrestrial outages can create temporary no-coverage almost anywhere. Disasters, power failures, backhaul cuts and operational failures can all disrupt mobile and fixed networks. The value of D2D is not that it replaces terrestrial networks, but that it can preserve minimum viable communication during the outage window [72].

Recent U.S. outage data make the resilience case concrete. During Hurricane Helene, FCC reporting showed that 48.7% of cell sites in affected North Carolina counties were out of service on 1 October 2024 [24]. During Hurricane Milton, 12.3% of cell sites in affected Florida areas were out of service on 10 October 2024, and 1,273,354 cable and wireline subscribers were out of service [25]. These are the conditions in which even low-bit-rate satellite messaging can have high public value.

Large outages are not limited to natural disasters. The FCC's public report on the 22 February 2024 AT&T outage found that the incident affected more than 125 million registered devices, blocked more than 92 million voice calls and prevented more than 25,000 calls to PSAPs/911 call centres [26]. That event shows that backup connectivity has relevance even in markets with extensive terrestrial coverage.

India provides a strong resilience case because disaster exposure and telecom-continuity requirements are both explicit. NDMA records that 27 of India's 36 States and Union Territories are disaster-prone, with 58.6% of the landmass exposed to moderate-to-very-high earthquake intensity, 12% exposed to flood and river erosion, 5,700 km of coastline prone to cyclones and tsunamis, and 5,161 urban local bodies prone to urban flooding [73]. In 2025, Jammu & Kashmir cloudbursts and landslides caused fibre damage and BTS outages across multiple districts; Uttarakhand cloudbursts required BTS/small-cell deployment and emergency fibre replacement; Punjab floods affected BTSs in water-logged pockets; and Cyclone Montha required ICR, Cell Broadcast testing, Cells-on-Wheels and mobile BTS pre-positioning, with the few outages mainly linked to power availability. DoT's 2025 resilience measures also include national-level control centres, and a pan-India broadcast system integrated with all major TSPs and 95% network readiness [74]. D2D is therefore relevant in India not as a replacement for disaster-hardened terrestrial networks, but as a minimum viable communications layer when towers, power, fibre, roaming arrangements or terrestrial alerting channels are impaired at the same time.

The resilience need also extends to infrastructure sectors. The World Bank's 2024 practitioner guide on resilient telecommunications infrastructure stresses that resilience requires multiple routes, service-continuity planning and risk-based identification of critical failure points [72]. NERC's 2025 reliability priorities report states that bulk power system operations increasingly depend on telecommunications for real-time monitoring, remote control, emergency response and restoration [52]. D2D can therefore serve both citizens and infrastructure operators when terrestrial reach is unavailable or degraded.

2.5 EMERGENCY MESSAGING AS THE PRIMARY PUBLIC-INTEREST USE CASE

Emergency messaging is the clearest near-term public-interest use case for D2D. It aligns with current technical capability, public policy priorities and observed commercial deployments. The required payload is small, the value of delivery is high and the user need is acute. A distress message with location can be useful even where voice, video and broadband are unavailable [14].

The market has already validated this use case. Apple's Emergency SOS via satellite enables supported iPhone users to text emergency services when off-grid. T-Mobile's satellite service foregrounds text-to-911, while Verizon supports satellite SOS and satellite messaging on selected devices [68], [71]. These services are intentionally text-first, reflecting the near-term D2D technical envelope.

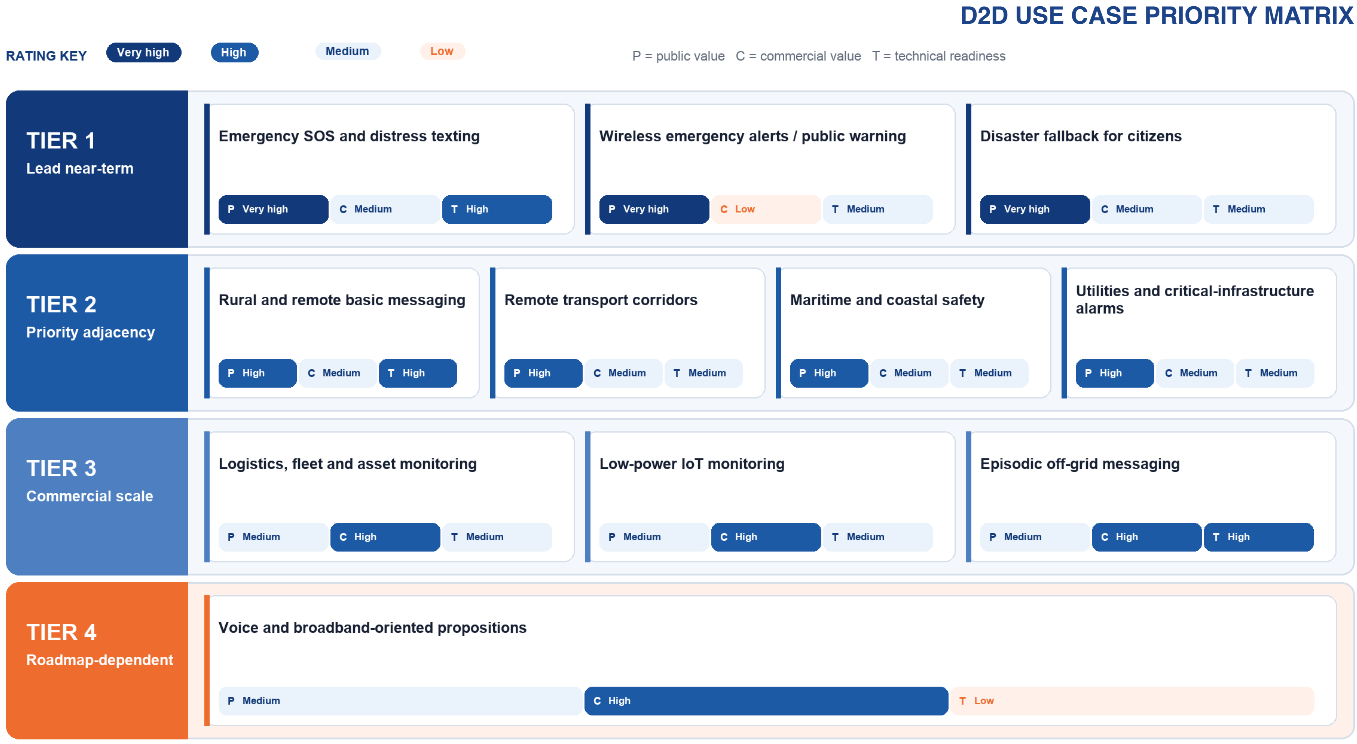

Exhibit 2.2: Near term value is strongest where payloads are small, reachibility is desirable and technical failure carries high costs

Emergency warning is the related one-to-many use case. T-Mobile demonstrated a satellite-based Wireless Emergency Alert and positioned it as a way to reach more than 500,000 square miles unreachable by earth-based towers [67]. ITU's work on satellite-supported warning systems similarly frames satellite as a complement to terrestrial warning infrastructure, while emphasizing that public-warning channels should not be repurposed for commercial messaging.

2.6 DISASTER RESPONSE, PUBLIC SAFETY AND CRITICAL INFRASTRUCTURE RESILIENCE

Disaster response, public safety and critical infrastructure resilience form a connected D2D use case because the underlying need is the same: preserving minimum viable communication when terrestrial networks are absent, damaged, congested or without power. In these situations, the problem is not only that some users are outside the coverage footprint; it is that the footprint itself may temporarily fail. D2D can provide a fallback layer while towers, fibre, power and backhaul are restored [24].

The near-term role is basic but valuable: SOS, short text, location sharing, alert receipt, low-rate telemetry and limited coordination. FCC data from Hurricane Helene and Hurricane Milton show that severe cell-site and wireline outages can occur during major disasters [24], [25]. The AT&T outage also shows that non-disaster network failures can prevent emergency calls at scale [26]. These examples support D2D as a resilience layer, not only as a rural or remote coverage product.

For public safety, the most mature near-term use case is citizen-facing rather than responder-grade. D2D can support citizen SOS, alert delivery, location sharing, responder situational awareness through low-rate data and backup continuity for selected field functions. It is less mature for mission-critical responder communications, where voice, priority broadband, group communications, high availability and QoS control require more capacity and deeper integration than today's mass-market text-first D2D services generally provide [24].

The same logic applies to utilities and critical infrastructure. Power, water, transport, pipeline, reservoir, environmental monitoring and other infrastructure assets often sit in remote or disruption-prone locations. NERC states that bulk power system operations increasingly rely on telecommunications for real-time monitoring, remote control, emergency response and restoration [52]. The World Bank also emphasizes that telecommunications resilience requires multiple routes, continuity planning and identification of critical failure points [72]. These findings support D2D as part of a layered resilience architecture.

2.7 RURAL AND REMOTE COMMUNITIES

Rural and remote communities remain a structural D2D market because terrestrial coverage gaps are persistent and economically difficult. ITU data show that rural 4G and 5G coverage lag urban coverage materially, and low-income rural areas face the deepest deficit. GSMA reported in 2025 that 2.9 billion people remained unconnected to mobile internet and that remaining barriers are concentrated in rural, poor and sparsely populated areas [34]. GSMA Intelligence, March 2026 says that in India, 47% are yet to be connected [75].

For rural communities, D2D's near-term fit is not full broadband replacement. The better fit is basic reachability: emergency text, off-grid messaging, location sharing, low-rate public-service connectivity and selected IoT applications for agriculture, water, energy or environmental monitoring. D2D can reduce the consequences of being beyond tower range, but it does not eliminate the need for terrestrial rural broadband investment [58].

2.8 REMOTE TRANSPORT CORRIDORS, LOGISTICS AND ASSET MONITORING

Remote transport corridors, logistics and asset monitoring create a distinct D2D use case because users and assets are mobile, incidents can be time-sensitive, and coverage gaps may be long but intermittent. Drivers, passengers, freight operators, road agencies and logistics platforms need the ability to report crashes, breakdowns, hazards, flooding, fires, stranded vehicles, route exceptions, security events and asset status. In many of these scenarios, a short text or low-rate data message with location can be operationally valuable [59].

The evidence is strongest where corridor dead zones have been mapped. India's National Highways Authority identified 424 highway locations covering about 1,750 km with no mobile connectivity [59]. That statistic shows that corridor connectivity is not only a consumer convenience issue; it is a road-safety, incident-response and logistics-continuity problem.

The strongest fit is periodic, low-rate communication: SOS alerts, breakdown messaging, location pings, condition monitoring, route exceptions, arrival/departure status, security events and asset recovery. Trucks, containers, rail assets, construction equipment, agricultural machinery and high-value cargo do not remain inside one operator's reliable footprint. For these users, D2D can function as a network-assurance layer that preserves minimum connectivity when terrestrial networks are unavailable [59].

Commercially, this use case is more mature than consumer broadband from space but less public-interest-critical than emergency messaging. Verizon has described Skylo-powered satellite IoT connectivity as a way to provide network assurance where terrestrial connectivity is challenged, with orchestration spanning up to 200 territories [70]. This points to an enterprise model in which D2D complements terrestrial IoT rather than replacing it.

2.9 MARITIME AND COASTAL CONNECTIVITY

Maritime and coastal connectivity is a high-value but evidence-constrained D2D segment. The core problem is that terrestrial cellular coverage over water is uncertain, variable and poorly mapped. Users may assume a smartphone will work near shore, but reliable offshore connectivity depends on distance, antenna orientation, weather, network design and maritime safety systems [61].

The plausible D2D role is coastal safety, distress text, near-shore backup messaging and alerting. It should not be positioned as a replacement for maritime radio, GMDSS or dedicated satellite maritime systems. For mass-market smartphones, the offshore proposition remains partial and dependent on service footprint, device support, sky view and regulatory authorization [61].

2.10 LOW-POWER IOT AND EPISODIC CONNECTIVITY NEEDS

Low-power IoT and episodic connectivity are strong near-term fits for D2D because both involve intermittent, low-rate communication rather than continuous broadband. Many sensors, users and assets do not need always-on connectivity. They need basic reachability when terrestrial coverage is absent, weak or temporarily unavailable [23].

Low-power IoT is one of the clearest technical fits for early D2D and NTN. Environmental monitors, water-level sensors, weather stations, agricultural devices, utility meters, oil and gas assets and pipelines, mining and industrial sites, offshore assets, disaster sensors and remote infrastructure alarms often transmit small payloads infrequently and require long battery life more than high throughput. These use cases complement the critical-infrastructure, logistics and asset-monitoring applications described in Sections 2.6 and 2.8. D2D can extend reach without requiring dense terrestrial infrastructure [23].

3GPP Release 18 includes IoT NTN enhancements, supporting the direction of travel toward standardized low-rate satellite connectivity for devices [3]. The service profile is narrow but useful: small data packets, scheduled reporting, event-triggered alarms, store-and-forward behaviour and tolerance for intermittent satellite visibility. This segment is technically plausible today for selected deployments, especially where devices are designed for NTN from the outset.

The same applies to episodic human and enterprise connectivity. Users may spend most of their time inside terrestrial coverage but occasionally travel through dead zones, work in remote field locations, hike, sail near shore, drive across isolated corridors or operate assets in sparsely covered terrain. These users do not necessarily need a dedicated satellite phone or continuous satellite service. They need basic reachability at the moment terrestrial service disappears [23].

This usage pattern fits current D2D better than always-on broadband. Existing mass-market services are activated around off-grid conditions and are focused on messaging, SOS or limited text-based functions. Ofcom also frames early D2D as basic backup coverage, with possible evolution toward richer services over time [55].

The market need today is therefore supplemental continuity. Emergency messaging, public warning, disaster fallback, rural and corridor safety, maritime and coastal backup, low-rate IoT and episodic off-grid reachability are the strongest near-term use cases. Consumer convenience and broader commercial services are emerging, but they should be treated as a medium- to long-term evolution rather than the core near-term D2D proposition [23].

3. CURRENT STATUS OF SPECIFICATIONS AND STANDARDS

AT A GLANCE

1 HIGHLIGHT 1

D2D satellite connectivity has moved from concept to standards-backed implementation, but maturity is uneven.

3GPP Release 17 established the first substantive NTN baseline; Release 18 addressed deployment blockers; Release 19 is extending NTN toward 5G-Advanced capabilities.

2 HIGHLIGHT 2

Standards are most mature for small-payload, delay-tolerant services.

These include emergency messaging, SMS/basic messaging and IoT NTN.

3 HIGHLIGHT 3

The global standards track and the spectrum-allocation track are related but distinct.

3GPP defines NTN radio, system and service capabilities; WRC-27 Agenda Item 1.13 is studying possible MSS allocations and coexistence conditions for direct connectivity between space stations and IMT user equipment in parts of the 694/698 MHz to 2.7 GHz range.

4 HIGHLIGHT 4

"Off-the-shelf device" support is emerging, but it is not yet universal plug-and-play interoperability.

Current D2D implementations depend on modem capability, firmware, operating-system integration, default messaging apps, carrier enablement, satellite-network certification and national regulatory approval.

5 HIGHLIGHT 5

Proprietary and operator-specific models can move faster than standards-only models.

They do so at the cost of interoperability.

3.1 OVERVIEW OF NTN STANDARDIZATION

Non-terrestrial networks are now a formal part of the 3GPP mobile standards roadmap rather than an adjacent satellite-industry concept [5]. 3GPP Release 17 introduced the first substantive baseline for both NR NTN and IoT NTN, covering satellite access for handheld and fixed platforms, delay-tolerant IoT, service continuity between terrestrial and satellite access, mobility, and low-power massive IoT support [2].

For direct-to-device satellite connectivity, this matters because scale depends on standard mobile-device economics. A D2D service that uses standardized 3GPP pathways can draw on mainstream modem roadmaps, global certification processes, roaming constructs, operator core-network integration and regulator confidence that the system is not a closed, one-off satellite product. Standardization also reduces the risk that every handset, network operator and satellite operator must build a custom interface for each commercial partnership [5].

A standards-based NTN radio interface however does not yet create a fully interoperable commercial service. Current implementations still depend on certification overlays, operating-system support, device eligibility, application behavior, carrier enablement and regulatory authorization. Skylo, for example, describes its service as 3GPP Release 17 standards-based but also requires “Skylo Standards Plus” certification and additional satellite-specific regulatory and third-party testing [2], [64]. The practical result is a four-layer standards landscape:

Standards maturity should therefore be understood in plain terms: a mature standard is not merely a published specification. It is a specification that device makers can implement, operators can certify, regulators can assess, roaming partners can trust and users can experience consistently. On that test, D2D is mature for some narrowband and emergency use cases, developing for low-rate data and IoT roaming, and still early for native voice and broadband-oriented services [5].

The technical standards path for NTN IoT is distinct from the policy process concerning satellite access to terrestrial IMT spectrum. 3GPP NTN specifications provide a technical foundation for narrowband satellite IoT in appropriately allocated MSS spectrum, subject to device, capacity, certification and national authorisation requirements [5].

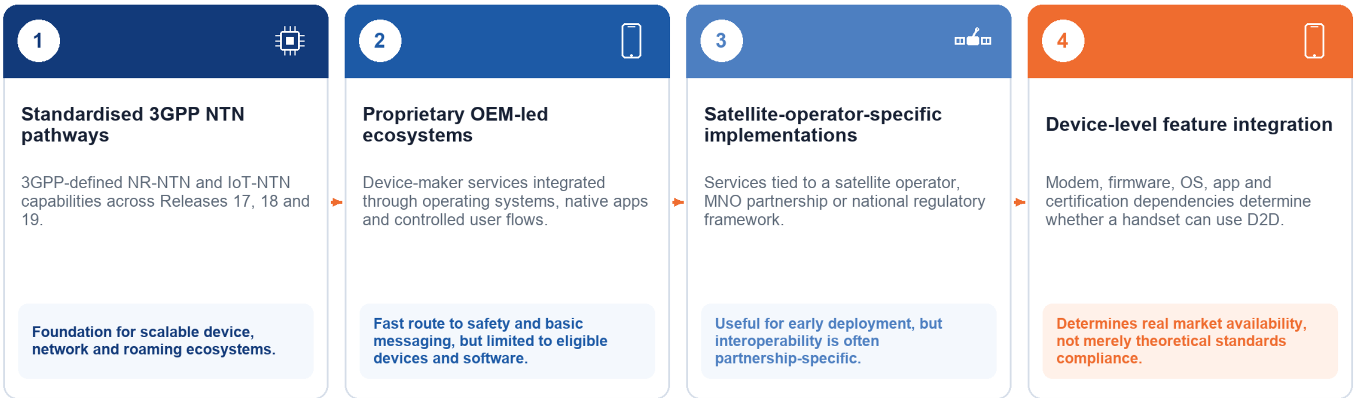

Exhibit 3.1: 3GPP NTN pathways, OEM ecosystems, satellite-operator-specific implementations and device-level feature integration.

3.2 RELEASE 17: NTN BASELINE

Release 17 is the point at which NTN became a concrete 3GPP capability set [2]. It introduced both NR NTN and IoT NTN baselines, including satellite access over NG-RAN, support for handheld and fixed platforms, delay-tolerant IoT, service continuity between terrestrial and satellite access, low-power MIoT, and NTN-aware timing and mobility.

For smartphones and handhelds, Release 17 established the foundational assumption that satellite access could be integrated into the 5G system architecture [2]. It also added FR1 NR NTN support for handheld and fixed platforms in n255/n256 with 5, 10, 15 and 20 MHz channel bandwidths.

For IoT, Release 17 is particularly important because it brought NB-IoT/eMTC NTN into the standards baseline [2]. This made delay-tolerant, low-power and low-rate satellite connectivity a formal 3GPP track rather than a proprietary satellite IoT architecture.

For messaging, Release 17 provides the underlying standards basis for low-data-rate and delay-tolerant services [2].

Release 17 also addressed the timing and mobility differences between terrestrial and satellite systems. NTN introduces long propagation delays, fast satellite movement, larger cell footprints and intermittent link conditions. Release 17 therefore added NTN-specific timing, NTN/TN mobility procedures, conditional handover triggers, multiple tracking-area-code handling, radio-link-failure and RRC re-establishment procedures, and service-continuity/QoS link-selection mechanisms between terrestrial and satellite access [2].

The practical interpretation is that Release 17 made D2D technically credible within the mobile ecosystem, but it did not by itself deliver universal smartphone satellite service. It is best understood as the baseline that enabled later deployment hardening in Release 18 and broader 5G-Advanced evolution in Release 19 [1], [4].

3.3 RELEASE 18: NTN AND IOT NTN ENHANCEMENTS

Release 18 moves NTN from baseline specification toward deployment practicality [3]. Its enhancements focus on the operational issues that arise when real user equipment interacts with sparse NGSO constellations, intermittent coverage and satellite-specific radio constraints.

A major Release 18 theme is discontinuous NGSO coverage. Sparse constellations can create periods when a UE is temporarily unreachable, followed by return-to-coverage events in which many devices may reconnect or receive stored data. Release 18 therefore addressed power saving, paging, stored mobile-terminated data, UE unreachability coordination and related procedures [3].

A second theme is smartphone uplink feasibility. D2D services must operate with small handset antennas, limited transmit power, body blockage and polarization loss. Release 18 explicitly targeted improved NR uplink coverage for commercial smartphones under assumptions that included low handset antenna gain and polarization loss [3].

A third theme is regulated-service location and continuity. Release 18 added network-verified UE location features relevant to emergency services, public warning and lawful-intercept contexts [3]. It also strengthened NTN-TN and NTN-NTN mobility and service continuity, including satellite switch and re-synchronization procedures.

Release 18 also expanded frequency and channel support, including band n254, 30 MHz support for n255/n256 and Ka-band work for wider NR NTN deployments [3]. These additions matter because D2D cannot scale solely through abstract architecture; it must map to realistic spectrum, channelization and device-radio constraints.

For IoT NTN, Release 18 did not create a wholly new IoT category [3]. Instead, it improved the practicality of IoT NTN by addressing discontinuous coverage, power-saving behaviour and follow-on performance requirements. This is especially relevant for sensors, trackers and devices that tolerate delay but need long battery life and predictable reconnection behaviour.

Release 18 is therefore the release most closely tied to near-term D2D deployment viability [3]. It addresses the practical blockers that determine whether a service can work on commercial smartphones and IoT modules: uplink coverage, reachability, location verification, power consumption, paging and handover.

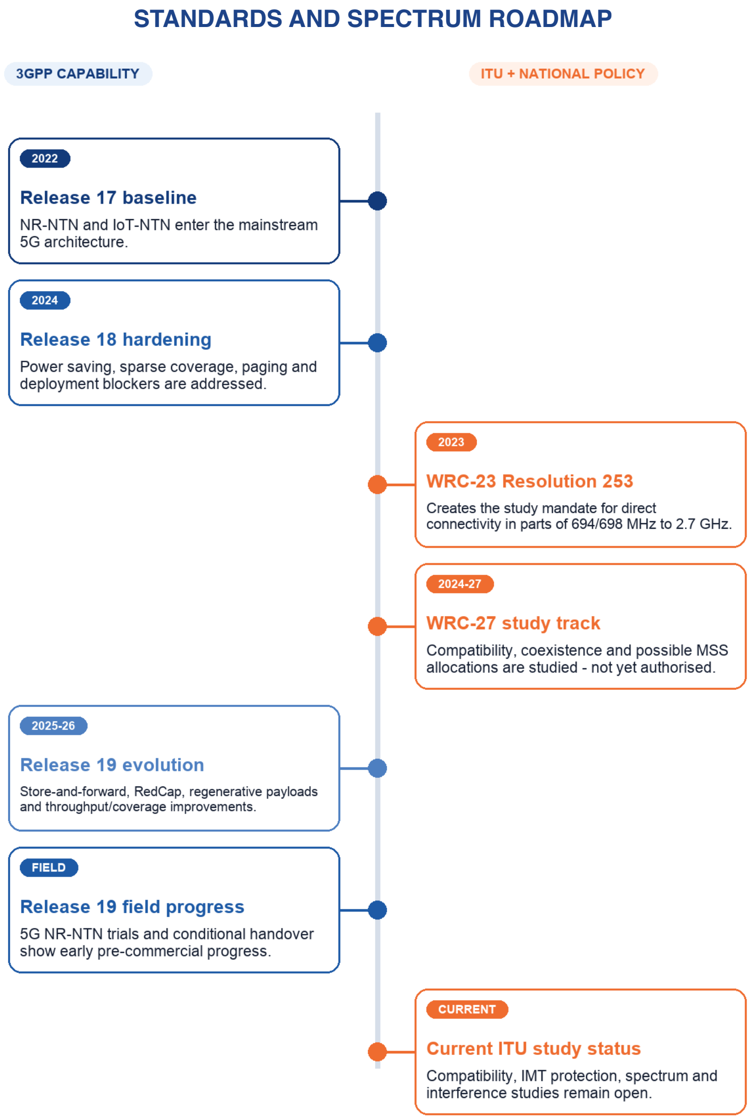

Exhibit 3.2: D2D standards and spectrum-policy roadmap
3GPP Release 17 to Release 19 and the WRC-27 study cycle.

3.5 RELEASE 19: 5G-ADVANCED NTN EVOLUTION

Release 19 is the second phase of 5G-Advanced and marks a shift from baseline NTN access toward more capable NTN system behavior. For NTN, Release 19 includes Phase-3 evolution covering regenerative payload support, store-and-forward operation, UE-satellite-UE communication, GNSS-independent operation, positioning enhancements, RedCap support and further NR NTN coverage and throughput enhancements [4].

The move toward regenerative payloads is significant because earlier NTN architectures often assume transparent satellite payloads, where the satellite largely relays radio signals to and from ground infrastructure. Regenerative payloads can process signals on the satellite, potentially improving flexibility, routing and resilience, although full operational implications depend on implementation and constellation design [4].

Store-and-forward is particularly important for D2D messaging and IoT. It allows a satellite to store information when immediate end-to-end connectivity is unavailable and forward it later when a link becomes available. This aligns naturally with sparse constellation coverage, delay-tolerant IoT and emergency/basic messaging use cases [4].

UE-satellite-UE communication is another important Release 19 direction. It implies scenarios where communication between user devices may be supported through satellite connectivity without requiring the same immediate terrestrial-network anchoring assumed in earlier service models. This has potential relevance for remote-area messaging, disaster response and resilient communications, but remains part of the evolving Release 19 standards path [4].

GNSS-independent operation addresses a key device-dependency issue. 3GPP's Release 19 overview states that GNSS-independent operation is being studied because Release 17 and Release 18 support GNSS-capable UEs, and Release 20 has already opened study work on GNSS-resilient NR-NTN operation [1], [4]. This shows that timing and positioning resilience remain unresolved standards issues rather than closed design points.

Release 19 also supports the broader device roadmap through RedCap support in NR NTN FR1, further downlink coverage and uplink throughput enhancements, and service-area signalling for broadcast [4]. These features matter because D2D will not be one service type: it will span IoT modules, wearables, mainstream smartphones, connected vehicles and potentially reduced-capability devices.

Industry progress indicates that Release 19 capabilities are already being trialed. MediaTek, ESA, Eutelsat, Airbus, Sharp, ITRI and Rohde & Schwarz announced a Release 19 5G-Advanced NR NTN connection over OneWeb LEO satellites using 50 MHz Ku-band and conditional handover [50]. This is an early proof point for broadband-oriented 5G-Advanced NTN, not evidence of universal commercial broadband D2D availability.

The Release 19 evidence base should be treated as less settled than Releases 17 and 18. 3GPP states that the formal Release 19 description document is published at the end of the release and that the work plan is the place to monitor growth before then [4]. Current Release 19 assessment therefore rests more on work items, stated evolution paths and trials than on a finalized end-of-release description.

3.6 WRC-27 AGENDA ITEM 1.13 AND MSS STUDY PATHWAYS

WRC-27 Agenda Item 1.13 is the main international spectrum-policy pathway relevant to D2D connectivity between satellites and IMT user equipment. It was established under Resolution 253 at WRC-23 and concerns possible MSS allocations for direct connectivity between space stations and IMT user equipment [40].

This agenda item is not a 3GPP work item. 3GPP defines technical standards for NTN access, system operation and service capabilities. WRC-27 Agenda Item 1.13 addresses whether, where and under what conditions the Radio Regulations should support MSS spectrum allocations for direct connectivity between satellites and IMT user equipment [40], [44].

The study range spans parts of the 694/698 MHz to 2.7 GHz range. The studies must examine spectrum requirements and technical, operational and regulatory conditions, while protecting incumbent and terrestrial mobile services [40].

The current ITU evidence shows that several technical and regulatory issues remain open [43], [44]. ITU-R working documents identify unresolved issues around beam definitions, beam-to-system structure, MIMO modelling, mitigation practicality, “remote area” definitions, overlapping beams and satellite antenna reference patterns.

A harmonised international framework would improve regulatory confidence and cross-border predictability. Existing MSS-based D2D may continue where established MSS allocations and applicable national authorisations provide a lawful basis. For D2D-IMT, WRC-27 is expected to clarify international allocation, coexistence and incumbent-protection conditions [40], [44]. In parallel, trials and nationally authorised early services can help generate evidence on network integration, device behaviour and coordination [65], [66].

WRC-27 will therefore influence the scale economics of D2D. Standards can define how devices and networks communicate, but spectrum allocation and coexistence rules determine where those communications can lawfully occur, how terrestrial networks are protected, and whether satellite D2D can evolve from domestic exceptions into a more globally repeatable service model [40].

3.7 STANDARDS IMPLICATIONS FOR OFF-THE-SHELF DEVICES

The phrase “off-the-shelf device” requires careful interpretation in D2D. The market is moving toward mainstream handset support, but current evidence does not support the conclusion that any ordinary handset can attach to any satellite network with terrestrial-like service parity [21].

The device ecosystem has made clear progress at the silicon level. MediaTek’s MT6825 is described as a Release 17 IoT-NTN solution for L/S-band messaging, tracking and emergency uses [81]. Qualcomm’s X80 adds integrated NB-NTN support [82]. Samsung’s Exynos 5410 advertises LTE DTC, NB-IoT NTN and NR-NTN on one modem.

Samsung’s Exynos 5410 also illustrates how service type maps to modem profile: LTE DTC is associated with voice calls, NB-IoT NTN with location sharing and simple text, and NR-NTN with higher-quality communication such as video calls [62]. This service mapping is a useful shorthand for the D2D maturity ladder: narrowband profiles support basic text and location most readily, while wider profiles are needed for richer media and broadband-like experiences.

However, modem support is only one part of off-the-shelf availability. Commercial service usually requires firmware integration, network certification, operator enablement, regulatory authorization and user-interface support. Skylo’s certification approach explicitly includes 3GPP NTN compliance, “Standards Plus,” satellite-specific regulatory requirements and third-party testing such as OTA, GCF/PTCRB and regulatory compliance [64].

This has three implications for scale. First, standardized NTN can reduce device fragmentation by allowing chipset vendors and OEMs to build to common capabilities. Second, certification and operator enablement remain gating layers even where the modem supports NTN. Third, device availability will likely develop by service tier: emergency messaging and basic SMS first, IoT and low-rate data next, and native voice or broadband later [21].

Standards also matter for roaming. A standardized NTN architecture gives operators a pathway to integrate satellite access into existing mobile-network relationships, charging models and service-continuity frameworks. Sateliot, for example, positions its LEO NB-IoT service as a 3GPP-standard, roaming-enabled IoT NTN model for telecom operators [63].

Regulators also benefit from standards maturity. A standards-based device and network ecosystem is easier to test, certify and assess for coexistence than a set of bespoke proprietary implementations. However, the current market still includes hybrid models where the radio/network layer may be standards-based while the commercial service layer, app layer or certification layer remains proprietary or operator-specific [21].

3.8 DEVICE COMPATIBILITY AND SOFTWARE DEPENDENCIES

D2D compatibility is a stack-level issue. A device may require a compatible modem, approved firmware, a supported operating-system version, a registered satellite service, an active SIM or carrier account, an enabled messaging client and line-of-sight operating conditions [10].

Apple’s satellite messaging model illustrates the OEM-led path. Apple supports satellite features on iPhone 14 or later, and Messages via satellite requires iOS 18 or later. iMessage over satellite requires iMessage to have been enabled before the device loses terrestrial coverage, while SMS over satellite depends on carrier support. Apple also states that photos, videos, audio messages, stickers and group messages are not supported in Messages via satellite [12].

Google’s Pixel Satellite SOS illustrates a software-gated emergency model. The feature is exposed through Pixel software and is available on Pixel 9-series devices except Pixel 9a [32]. Google notes that the feature requires software and API updates, registration on the satellite network and Google Messages as the default messaging app.

Verizon’s Android satellite service with Skylo illustrates a hybrid operator implementation. Verizon supports Satellite SOS and basic two-way text messaging on selected Samsung Galaxy and Pixel devices, but requires updated software, line of sight and Google Messages as the default app. Verizon states that MMS, RCS and attachments are not supported and that WEA/CMAS alerts are not supported on Skylo [71].

T-Mobile’s T-Satellite with Starlink illustrates an operator-specific direct-to-cell path. The service supports texting, location sharing, text-to-911, selected satellite-ready apps and app-based voice chat such as WhatsApp, but data is constrained and not equivalent to normal mobile broadband. T-Mobile also states that some apps may not function, gaps may occur and time-outs may occur [68].

Android’s application guidance shows that D2D is becoming an app-layer integration issue, not just a radio-interface issue. Android Developers treat constrained satellite networks as a separate application environment: apps do not use them by default, must opt in and may need message handling suited to bandwidth-constrained operation [10].

The implication is that device compatibility should not be framed as a binary question. A device can be NTN-capable at the modem level but unsupported at the service level. It can be supported for emergency messaging but not for rich messaging. It can support an OEM’s satellite service but not a mobile operator’s satellite partner. It can support basic SMS but not RCS, MMS, voice or broadband data [10].

3.9 MOBILITY, TIMING AND SERVICE CONTINUITY

Mobility, timing and continuity are among the most difficult D2D standards topics because satellite access is not simply a terrestrial cell tower placed in the sky. Satellites move relative to users, propagation delay is longer, coverage can be discontinuous and cell footprints can be much larger than terrestrial mobile cells [16].

For users, the practical effect is that D2D service continuity remains service-specific. Basic messaging can tolerate delay, retries and intermittent coverage. Voice and broadband are much less tolerant of link interruption, latency variability and handover failure. This explains why emergency/basic messaging and IoT are more mature than native voice and broadband-oriented services [16].

3.10 APPLICATION SUPPORT ACROSS STANDARDS RELEASES

Application support across standards releases follows the same maturity pattern as the underlying radio and system capabilities. The strongest near-term application fit is for small payloads that tolerate delay and limited bandwidth. Emergency text, SMS/basic messaging, location sharing, tracking and low-rate IoT align well with Release 17 and Release 18 capabilities [1], [3].

Release 17 supports delay-tolerant IoT, generic internet/streaming service requirements and service continuity concepts, but it should not be read as providing terrestrial-like application parity for mass-market smartphones [2].

Release 18 improves application feasibility by addressing sparse NGSO coverage, power saving, wake-up, paging and stored-data delivery [3]. It also initiated application-layer study work for intermittent IoT connectivity, caching and mission-critical use.

Release 19 extends application possibilities through store-and-forward, UE-satellite-UE communication, RedCap support, throughput and coverage enhancements, and broader application-layer support [4]. These features can support richer messaging, resilient IoT and selected low-rate applications more effectively than earlier releases.

Current commercial services confirm that app support is constrained. Apple's Messages via satellite does not support photos, videos, audio messages, stickers or group messages. Verizon's Skylo-based Android implementation does not support MMS, RCS or attachments [12], [71]. Android's constrained-satellite-network guidance requires applications to opt in rather than assuming satellite data is equivalent to terrestrial mobile data.

The main implication is that standards support for applications is not just a question of throughput. It also depends on latency tolerance, session persistence, handover behavior, app-level retry logic, messaging-client support and user-interface design [3].

3.11 STANDARDIZED IMPLEMENTATIONS

Standardized D2D implementations use 3GPP NTN pathways as the central technical basis [5]. The strongest evidence today is in NB-NTN, IoT NTN, standards-based satellite messaging and early NR NTN trials. Skylo is a leading example of a standards-based commercial NTN implementation with additional network-specific certification [64].

Sateliot represents a standardized IoT NTN path [63]. It positions itself as a LEO operator offering global NB-IoT connectivity with 3GPP standards and 5G NTN roaming for telecom operators.

The MediaTek and OneWeb Release 19 trial represents a standards-based pre-commercial NR NTN proof point [50]. The announced trial used Release 19 NR NTN configurations with 50 MHz Ku-band and conditional handover over OneWeb LEO satellites [4]. This demonstrates progress toward broadband-oriented 5G-Advanced NTN, but it remains a trial rather than evidence of widespread commercial handset broadband availability.

Standardized implementations matter because they create repeatability. A 3GPP-based model gives chipset vendors, device OEMs, satellite operators, mobile network operators and regulators a shared technical foundation. That foundation is essential for device availability, roaming, interoperability, testability and multi-vendor procurement [5].

However, the current standardized path is not purely plug-and-play. Even where 3GPP NTN is the basis, commercial service may require certification overlays, satellite-specific testing, approved devices and operator integration [5]. Skylo's "Standards Plus" model illustrates that the commercial interoperability layer may remain curated even when the radio and network approach is standards-based [64].

3.12 PROPRIETARY IMPLEMENTATIONS

Proprietary and operator-specific implementations have moved faster than standards-only deployment in several consumer-facing D2D categories. They are especially important in emergency messaging, satellite SOS and early text services. Their advantage is control: OEMs and operators can control the device list, operating-system integration, user interface, service workflow, satellite partner and regulatory launch market [35].

The trade-off is interoperability. A proprietary service may work well for an eligible device in an approved country with a supported software version and carrier configuration, but it may not support open roaming, third-party messaging clients, uniform emergency workflows or multi-satellite interoperability [35].

The market is not choosing between "standardized" and "proprietary" in a simple way. Many services are hybrid. They

IMPLEMENTATION ECOSYSTEM

	Standards-based ecosystem	OEM-controlled service	Operator-specific / hybrid
REPRESENTATIVE EXAMPLES	Skylo Sateliot MediaTek Qualcomm / operator integrations	Apple + Globalstar Selected Android satellite features Device-bundled safety services	Verizon + Skylo T-Mobile + Starlink AT&T / Vodafone + AST SpaceMobile Lynk + MNO partners
WHAT IT OPTIMISES	Common technical roadmap, stronger chipset alignment and IoT fit.	A tightly designed user journey for SOS, assistance, messaging and location sharing.	Uses MNO spectrum, identity, billing and customer relationships to extend coverage.
WHAT POLICYMAKERS SHOULD WATCH	Still needs certification, device support, operator integration and national approval.	Eligibility and interoperability remain bounded by device family, software and market.	Carries the highest coexistence, licensing, cross-border and capacity burden.

Exhibit 3.3: Examples of standardized, OEM-led and operator-specific/hybrid D2D implementations and their commercial dependencies.

may use standards-based radio or network elements, but still rely on proprietary UX flows, curated certification, specific default apps, satellite-operator rules or domestic regulatory frameworks [35].

For the near term, proprietary and operator-specific models are likely to remain important because they can launch quickly, manage user expectations and constrain technical complexity. For the medium term, standardized 3GPP NTN pathways are more important for roaming, multi-vendor device availability, regulatory confidence and global scale [5].

D2D standards are now credible but not complete. Release 17 and Release 18 provide a usable baseline for narrowband, messaging and IoT-oriented services. Release 19 points toward richer 5G-Advanced NTN capabilities, but the most demanding use cases (native voice, broadband, seamless mobility and global multi-network interoperability) remain active technical and standards questions [1], [4].

4. TECHNICAL ARCHITECTURE AND SERVICE CAPABILITY

AT A GLANCE

1 HIGHLIGHT 1

Off-the-shelf smartphones are the hardest D2D endpoint.

They have low-gain antennas, constrained transmit power, limited battery headroom, and no mechanically steered satellite antenna. The satellite, beamforming system, waveform, scheduling and user workflow therefore have to compensate for a weak handheld uplink and variable sky visibility.

2 HIGHLIGHT 2

LEO reduces delay compared with higher-orbit systems but does not make the radio problem terrestrial-like.

At 600 km and 1,200 km LEO reference altitudes, 3GPP identifies long slant ranges, non-terrestrial round-trip delays, significant Doppler and moving-beam effects that directly affect timing advance, random access, handover and session continuity.

3 HIGHLIGHT 3

Capability varies sharply by service type.

Emergency messaging and basic SMS are commercially demonstrated; IoT is technically well aligned with narrowband NTN; voice and low-rate data are technically demonstrated but less mature at scale; broadband-oriented direct-to-smartphone services remain the most roadmap-dependent proposition.

4 HIGHLIGHT 4

Spectrum choice is architecture choice.

MSS-based D2D can simplify coexistence but requires compatible devices and ecosystems. IMT band D2D improves the standard-phone proposition but introduces harder interference, licensing, coordination and capacity questions.

4.1 D2D WITHIN THE WIDER NTN ARCHITECTURE

Direct-to-device satellite connectivity sits within the wider non-terrestrial network architecture rather than outside it. In the 3GPP NTN model, the user equipment communicates with a satellite over the service link, while the satellite communicates with a gateway or ground network over the feeder link [5]. The satellite payload may be transparent, meaning that the satellite largely relays radio signals between the user link and ground infrastructure, or regenerative, meaning that some access-network functions are performed onboard the satellite. 3GPP Release 17 established the initial handheld and IoT NTN baseline, while later work has addressed more complex features such as regenerative payloads, store-and-forward operation and UE-satellite-UE enhancements [2].

Several technical families now sit under the broad D2D label:

“D2D” is not one architecture – but a group of architectures with different spectrum dependencies, device assumptions, link budgets, latency profiles and service ceilings [5].

4.2 LEO ARCHITECTURES AND CONSTELLATION DESIGN

Most current D2D propositions are centred on LEO because shorter orbital distances improve latency and path loss relative to higher-orbit systems. However, LEO does not remove the fundamental non-terrestrial constraints. 3GPP reference scenarios for LEO service links below 6 GHz use 600 km and 1,200 km orbital examples, with a 10° minimum elevation angle - implying maximum sat-to-user slant range is about 1,932 km at 600 km and 3,131 km at 1,200 km [16].

Those distances are far beyond terrestrial cell ranges. The consequence is that D2D constellation design must solve not only coverage, but coverage probability, service availability, beam dwell time, gateway reachability, user link margin and capacity per beam. A single successful connection or demonstration call does not prove a sustainable service layer. The FCC’s 2026 SpaceX conditions point in this direction by requiring evidence on SINR (Signal-to-interference-to-noise) ratio, 5th-percentile uplink throughput, spectral efficiency, service availability and full link-budget assumptions for each supplemental coverage licence area [30]. Per-user throughput however does not capture the larger constraint. The critical limitation is area capacity: finite satellite spectrum, payload power and beam resources must be shared across a large footprint, so aggregate capacity per square kilometre remains extremely low relative to terrestrial cellular networks. This confines current D2D to low-density demand, principally deep-rural and rural coverage, emergency fallback and sparse IoT. Adding users in urban or other high-demand areas would exhaust beam capacity long before D2D could function as a substitute for terrestrial mobile broadband.

LEO constellation design also affects delay. In 3GPP's reference cases, propagation-only round-trip delay for transparent-payload LEO is about 25.77 ms at 600 km and 41.77 ms at 1,200 km [16]. For regenerative-payload LEO, the comparable values are about 12.89 ms and 20.89 ms. These are manageable for messaging and many data applications, but they are not equivalent to terrestrial mobile-network timing and they materially affect service design.

The constellation question is therefore not simply "how many satellites are in orbit". For D2D, the relevant design questions are whether beams are earth-fixed, quasi-earth-fixed or earth-moving; whether payloads are transparent or regenerative; whether satellites have enough aperture, power and receive sensitivity to compensate for weak handheld uplinks; whether the gateway and feeder-link architecture can support national service obligations; and whether there is enough beam capacity to move beyond emergency or low-rate service into voice, low-rate data or broadband-oriented propositions [16].

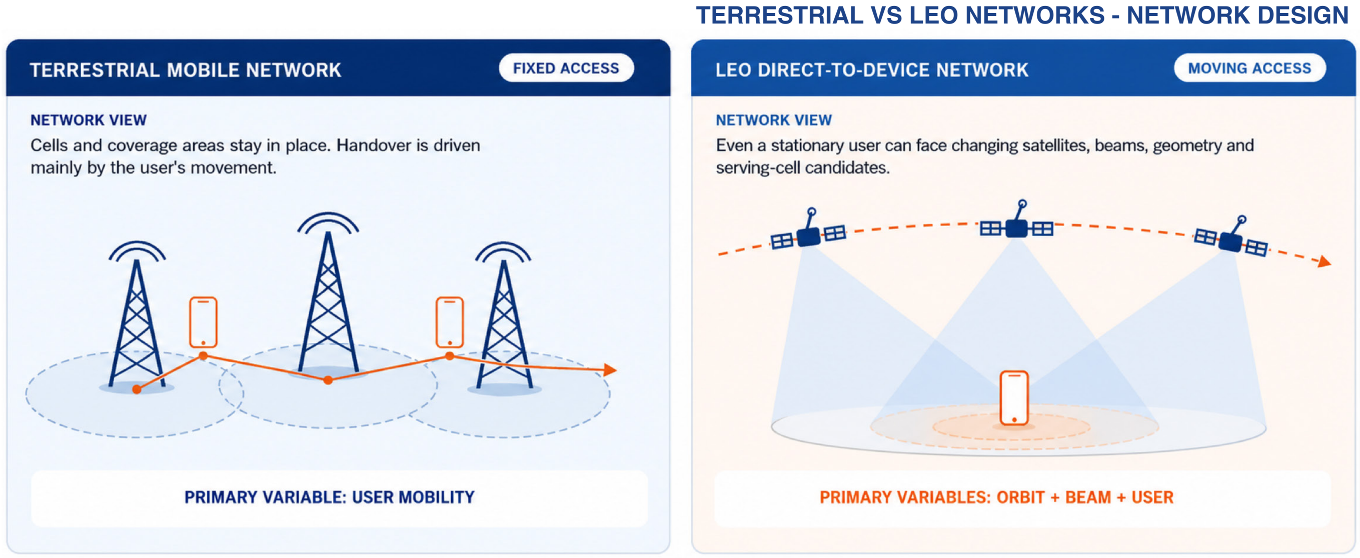

Exhibit 4.1: What moves - and what the network must manage
Terrestrial cells are fixed; in LEO D2D, the access layaer moves rapidly around the user

4.3 ORBIT, PAYLOAD AND BEAM DESIGN CHOICES

Payload design is one of the main architectural trade-offs in D2D. A transparent payload keeps more radio-access processing on the ground. This can reduce satellite complexity and allow ground-side upgrades, but the signal must traverse both the service link and feeder-link path before radio-access processing is completed. A regenerative payload moves more processing onboard the satellite. This can reduce delay and improve some aspects of routing and resilience, but it adds spacecraft complexity, power demand, thermal requirements and onboard processing constraints. 3GPP's own delay figures show the material difference between transparent and regenerative LEO cases [21].

Beam design is equally central. In terrestrial mobile networks, cell sites are fixed and user mobility is the main source of handover. In LEO D2D, the satellite itself is moving rapidly relative to the Earth, so a stationary user may still experience changing satellite geometry, changing beam conditions and changing serving-cell candidates. 3GPP recognises earth-fixed, quasi-earth-fixed and earth-moving beam models, with beam-to-cell mapping and satellite/gateway scheduling information used by network management and radio-access systems [21].

Large apertures and phased arrays are the principal way operators try to close the link to standard handhelds. SpaceX has stated that standard mobile phones have very low antenna gain and maximum transmit power around 0.2 W, and that its direct-to-cell satellites use custom silicon, sensitive receivers, high-power transmitters and 2.7 m × 2.3 m phased arrays [29]. AST SpaceMobile's broadband-oriented model similarly relies on very large phased arrays, many active cells per satellite and MNO spectrum partnerships, with stated ambitions for peak cell-level capacity in next-generation satellites [15].

Beam and payload design determine the service ceiling. A narrowband emergency-messaging service can operate

SMARTPHONE AND IOT D2D REQUIREMENTS

SMARTPHONE D2D	DESIGN DIMENSION	IOT D2D
SOS, location, text, selected apps; voice and richer data are emerging.	**Primary traffic**	Telemetry, tracking, metering, agriculture, logistics and remote monitoring.
Low beyond SOS and SMS; users expect responsive sessions.	**Latency tolerance**	Higher for delay-tolerant reporting and store-and-forward use cases.
Supported handsets, certified modems and compatible operating-system features.	**Device dependency**	Release 17-capable NB-IoT/eMTC modules or chipsets.
Low-gain internal antenna and about 0.2 W transmit power make the uplink hard.	**Radio + power**	Narrowband, low-duty-cycle operation reduces payload and power burden.
GNSS, ephemeris, timing logic and sometimes user guidance are needed.	**Positioning + timing**	May require NTN timing and position logic, but can operate more opportunistically.
An MNO-native experience is important for mass adoption.	**Network integration**	Single-SIM or roaming-style extension of IoT fleets is preferred.
Emergency SOS, basic messaging and selected operator-native SMS.	**Best current fit**	Remote sensing, asset tracking, agriculture, logistics and environmental monitoring.

Exhibit 4.2: The same satellite network must serve two very different endpoints, expectations and operating rhythms

with a much more forgiving technical envelope than a continuous voice service or broadband-oriented smartphone proposition. The more the service moves from SOS to SMS, voice, interactive data and broadband, the more it depends on aperture size, beamforming, payload sophistication, Doppler management, handover performance and usable spectrum bandwidth [21].

4.4 LINK BUDGET IMPLICATIONS FOR OFF-THE-SHELF DEVICES

Off-the-shelf smartphones are not satellite terminals. They are designed around terrestrial cellular assumptions: nearby base stations, internal antennas, constrained transmit power, limited thermal headroom, limited battery capacity and user behaviour that does not normally include pointing at the sky. 3GPP's reference UE assumptions include an omnidirectional antenna with 0 dBi gain and power class 3 transmit power up to 200 mW; SpaceX has separately described standard mobile phones as having very low antenna gain and maximum transmit power of 0.2 W [16].

This creates a structurally asymmetric link-budget problem. The smartphone cannot simply increase antenna gain, widen its aperture or transmit at satellite-terminal power levels. Instead, the satellite side must compensate through large receive apertures, sensitive receivers, high-gain beams, waveform design, lower-frequency spectrum, scheduling, repetition, coding, and user workflows that improve sky visibility [16].

The same constraint affects battery and user experience. Long acquisition attempts, GNSS positioning, ephemeris use, user-guided satellite pointing and retransmission under foliage or obstruction all consume time and device energy. Apple's user guidance shows the practical consequence: in ideal conditions, a satellite message may take around 30 seconds; under light or medium foliage, it may take more than a minute; under heavy foliage or other obstructions, connection may fail [13].

4.5 SMARTPHONE CONNECTIVITY REQUIREMENTS

Smartphone D2D requires the network to deliver a recognisable mobile-user experience through a device that was not originally designed as a high-gain satellite terminal. This creates requirements across RF design, modem support, positioning, user interface, core-network integration and service continuity [21].

For emergency and messaging services, the requirements are manageable because the payload size is small and the user can tolerate delay. Apple's satellite service requires supported iPhone models and a clear view of the sky and horizon; it also uses guided user interaction to help establish the link [11]. Skylo's smartphone model depends on certified device and modem support, including Snapdragon X80-based satellite messaging, location sharing and SOS [64].

D2D TECHNICAL REQUIREMENTS

TECHNICAL MODEL	SPECTRUM + NETWORK	DEVICE PROPOSITION	CURRENT SERVICE CEILING	EVIDENCE-BASED MATURITY
MSS-based safety overlay	Dedicated MSS spectrum; satellite-backed service logic.	Supported models only.	SOS, messaging, location sharing and assistance.	LIVE Commercial and proven for narrowband safety use.
Standards-based MSS D2D / D2H	3GPP cloud-native NTN with MSS-compatible spectrum.	Certified Android devices and compatible modems.	Emergency messaging, SMS and selected low-rate apps.	SCALING Live messaging; strategically scalable with broader certification.
Terrestrial-band text-first direct-to-cell	MNO terrestrial spectrum reused from space.	Ordinary phones can be the core proposition.	Messaging is strongest; voice/data remain selective.	DEMONSTRATED Commercially demonstrated, but coexistence and service continuity are hard.
Large-aperture broadband D2D	Existing cellular bands through very large phased arrays.	Everyday smartphones with no special hardware ambition.	Voice, video and 5G call demonstrations; not broad retail broadband.	ROADMAP High potential, but dependent on constellation scale, capacity and approval.
NB-IoT NTN	NTN-specific or standardised NB-IoT/eMTC arrangements.	Release 17-capable modules and chipsets.	Tracking, metering, agriculture, logistics and remote monitoring.	SCALING Technically well aligned and commercially relevant for low-rate IoT.

Exhibit 4.3: Architecture, spectrum dependency, device proposition, current service ceiling and evidence-based maturity.

For terrestrial-band direct-to-cell models, the strongest proposition is that ordinary or unmodified phones can connect without special satellite hardware. That is strategically attractive because it reduces device-friction and can use existing mobile subscriptions. It is also technically demanding because the satellite must close a link to a low-power, low-gain handset while managing interference into terrestrial mobile systems [21].

As smartphone D2D moves from SOS and SMS toward voice, low-rate data and broadband-oriented propositions, the requirements rise sharply. Voice requires lower and more stable latency, more reliable uplink continuity, stronger session control and integration with voice service architecture. Broadband-oriented services require still more capacity, larger apertures, more aggressive beamforming, tighter spectrum coordination and enough satellite density to provide continuity rather than isolated availability. AST SpaceMobile’s trial evidence demonstrates voice, video and 5G call milestones, but its broader broadband proposition remains tied to large-aperture, multi-beam satellite deployment and MNO partnerships [15].

4.6 IOT CONNECTIVITY REQUIREMENTS

IoT D2D has a different requirement profile. Many IoT use cases involve small payloads, low duty cycles, delay tolerance and intermittent reporting. This makes IoT better aligned with narrowband NTN than smartphone broadband. 3GPP Release 17 supports NB-IoT and eMTC NTN for massive IoT use cases, while MediaTek distinguishes IoT-NTN as a low-data-rate, non-real-time mode from NR-NTN, which is intended for higher-rate services such as voice, video calls and short media [2], [51].

Sateliot’s NB-IoT NTN positioning illustrates the IoT profile: existing SIM concepts, Rel-17-capable NB-IoT devices, delay-tolerant applications and store-and-forward style operation for agriculture, smart metering, logistics and remote sensing [63]. MediaTek’s MT6825 chipset is also positioned as a commercial 5G IoT-NTN chipset, reinforcing that IoT D2D is moving through a module and chipset ecosystem rather than only through smartphone operating-system integration [81].

4.7 MOBILITY MANAGEMENT AND HANDOVER

Mobility management is more complex in D2D than in terrestrial mobile networks because both the user and the access layer may be moving. Even a stationary user may need serving-satellite or serving-beam changes as a LEO satellite passes overhead. 3GPP NTN architecture therefore includes beam-to-cell mapping and distinguishes earth-fixed, quasi-earth-fixed and earth-moving beams [5].

Handover is also constrained by satellite ephemeris and gateway scheduling. TS 38.300 describes separate handling of serving and neighbouring satellite ephemeris and notes that NTN-terrestrial mobility does not require simultaneous connection to both terrestrial and satellite layers. It also states that DAPS handover is not supported in the relevant release. This indicates that satellite-terrestrial continuity is supported architecturally but should not yet be assumed to behave like mature terrestrial dual-connectivity or make-before-break mobility [16].

3GPP's reference scenarios do not assume that users are always stationary [16]. They consider UE motion of 500 km/h for trains and potentially 1,200 km/h for aircraft. However, the public commercial evidence base remains strongest for stationary or low-mobility messaging, emergency use and controlled demonstrations. Sustained in-motion handheld voice or data at mass-market scale remains less evidenced than SOS and SMS.

For strategy purposes, handover should therefore be treated as a capability differentiator. Operators that can manage moving beams, predictable satellite passes, gateway switching, device-state transitions and terrestrial fallback will be better placed to move from emergency messaging into voice and interactive data [16].

4.8 SERVICE CONTINUITY ACROSS TERRESTRIAL AND SATELLITE LAYERS

D2D's strategic value is strongest when it extends the terrestrial network rather than competes with it. The user experience should ideally shift from terrestrial mobile coverage to satellite fallback when terrestrial coverage is absent, then return to terrestrial coverage when available. This is the basis for operator-native D2D models, including SMS-over-satellite integration into MNO infrastructure and roaming-like direct-to-cell propositions [22].

However, service continuity should be described carefully. 3GPP supports NTN integration into the 5G system, but Release 17-era NTN mobility does not make satellite-terrestrial continuity identical to terrestrial mobility [2]. NTN-terrestrial mobility does not require simultaneous connection to both layers, and DAPS handover is not supported in the relevant release. This matters because seamless continuity for voice or interactive data is harder than completing a short message during a satellite availability window.

D2D can improve resilience, emergency reachability and geographic coverage, but it should not be represented as eliminating the need for terrestrial investment, indoor coverage solutions, backhaul expansion or rural network planning [22].

4.9 SPECTRUM-BAND DEPENDENCIES

Spectrum selection determines what kind of D2D architecture is feasible. 3GPP's handheld NTN reference work focuses on FR1 and service links below 6 GHz, reflecting the need for frequencies that can support handheld link budgets over long satellite paths [33].

The main policy distinction is between MSS-based D2D and IMT/mobile-band D2D. ACMA distinguishes MSS direct-to-mobile, which requires handset support for MSS bands, from IMT direct-to-mobile, which can work with standard phones but is harder from a spectrum and coexistence perspective [17]. Ofcom's framework for D2D in mobile spectrum bands requires licence variation, technical conditions and coexistence controls [55].

MSS-based approaches have the advantage of operating in spectrum already allocated for satellite use. This simplifyies coexistence with terrestrial mobile networks, but requires compatible device hardware, modem support, service certification and satellite-specific ecosystem integration. Apple/Globalstar and Skylo-style models illustrate this path [11], [64].

For low-power, low-data-rate and delay-tolerant IoT, established MSS/non-IMT spectrum is an independent service pathway rather than only a transition toward satellite use of terrestrial IMT bands. Its practical scope continues to depend on compatible devices, available MSS capacity, certification and applicable national authorisation [33].

Terrestrial-band D2D has the opposite trade-off. It promises better compatibility with standard phones and MNO spectrum assets, but raises harder interference, border coordination, terrestrial-network protection and licensing issues [33].

Spectrum also affects capacity. Narrowband MSS or NB-IoT NTN can support SOS, SMS and telemetry with relatively modest payloads [23]. Broadband-oriented direct-to-smartphone propositions require much more spectrum efficiency, more aggressive beam reuse, larger satellite apertures and higher-capacity payloads.

D2D is technically real and commercially meaningful today for outdoor emergency messaging, basic messaging and selected IoT services. Voice and low-rate data are technically plausible and partly demonstrated. Broadband-oriented direct-to-smartphone services are credible but remain the most dependent on constellation scale, beam capacity, spectrum access, device support and real-world performance validation [33].

5. SPECTRUM, AUTHORISATION AND REGULATORY PATHWAYS

AT A GLANCE

1 HIGHLIGHT 1

Spectrum and regulation are inseparable for D2D.

Direct-to-device satellite connectivity cannot scale unless regulators define the usable bands, the rights holder, the authorisation route, the protection status of satellite operations, and the coexistence obligations that apply domestically, at borders and between satellite systems.

2 HIGHLIGHT 2

There are two principal spectrum pathways.

The first is D2D-MSS, using spectrum allocated to the mobile-satellite service. This is the lower-friction regulatory path. The second is D2D-IMT, using terrestrial mobile spectrum from space. This has stronger ordinary-handset potential but creates harder coexistence, licensing and cross-border questions.

3 HIGHLIGHT 3

Regulators are treating D2D as supplemental coverage, not terrestrial replacement.

Across leading jurisdictions, D2D is being framed as a coverage-extension and resilience layer for areas without terrestrial service, weak coverage areas and outage conditions.

4 HIGHLIGHT 4

The most mature frameworks are hybrid satellite-terrestrial models.

The United States, Canada and the United Kingdom have moved furthest toward explicit frameworks for mobile-band D2D or supplemental mobile coverage, while Australia and New Zealand rely more heavily on existing flexible spectrum rights. CEPT/EU and Japan are proceeding through technical and band-specific work, and India remains in a consultative phase for a broader SCN/D2D framework.

5 HIGHLIGHT 5

Coexistence is now an operational compliance problem.

The key risks are co-frequency sharing with terrestrial mobile networks, adjacent-channel and out-of-band emissions, cross-border interference, inter-constellation coordination, radio astronomy protection and national licensing asymmetry.

6 HIGHLIGHT 6

WRC-27 is a major inflection point, but not an operating right.

WRC-23 Resolution 253 created the WRC-27 Agenda Item 1.13 study track for possible MSS allocations supporting direct connectivity between MSS space stations and IMT user equipment in parts of the 694/698 MHz to 2.7 GHz range. It did not itself create a harmonised D2D band or authorise D2D-IMT operations.

D2D REGULATORY AUTHORIZATION

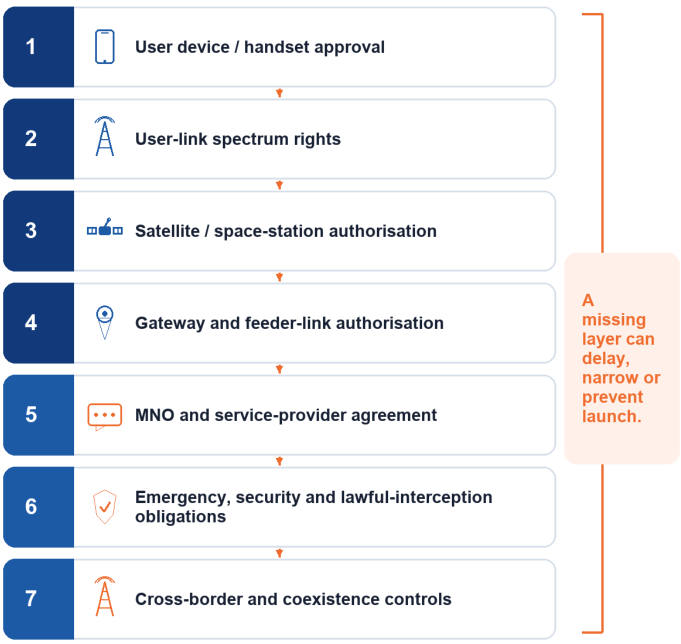

Exhibit 5.1: Required approvals from handset and user-link spectrum to emergency, security and cross-border controls.

5.1 WHY SPECTRUM AND AUTHORISATION MUST BE ASSESSED TOGETHER

D2D is not one regulatory category. It is a family of service models that use different spectrum bands, different device assumptions and different commercial structures. A satellite-led service using MSS spectrum raises different regulatory questions from an MNO-led service using terrestrial mobile spectrum. An emergency messaging service raises different obligations from a broadband-oriented direct-to-smartphone model. An IoT NTN service raises different certification, roaming and power-management issues from a consumer handset service [33].

These differences also affect regulatory treatment. Low-power, low-rate satellite IoT operating within established MSS allocations presents a different device, service and risk profile from terrestrial-band direct-to-smartphone voice or broadband, so the relevant obligations need to be assessed by capability and device class [33].

A D2D service may require some or all of the following:

satellite or space-station authorisation, user-link spectrum rights, feeder-link spectrum rights, earth-station or gateway approval, handset or terminal authorisation, MNO spectrum access, numbering and routing arrangements, lawful-interception capability, emergency access obligations and cross-border coordination [33].

5.2 THE TWO MAIN SPECTRUM PATHWAYS: D2D-MSS AND D2D-IMT

D2D-MSS uses spectrum already allocated to the mobile-satellite service, typically in L-band, S-band or other MSS-compatible bands. This model fits more naturally within existing satellite regulation because the user link is already grounded in a satellite service allocation. It is therefore the lower-friction regulatory pathway [33].

Its strengths are legal clarity, better fit with satellite authorisation frameworks and lower risk of direct conflict with terrestrial mobile assignments. Its constraints are narrower spectrum availability, device-band support, ecosystem maturity and capacity. MSS-based D2D is particularly well suited to emergency messaging, location sharing, low-rate messaging and selected satellite-to-IoT services [33].

Where satellite-to-IoT operates within existing MSS allocations and applicable national authorisations, its regulatory basis is not contingent on decisions about satellite access to terrestrial IMT spectrum [33].

D2D-IMT uses spectrum assigned for terrestrial IMT from a satellite platform. Potential compatibility with ordinary smartphones is its principal attraction, because devices already support mainstream mobile bands and MNOs hold the associated customer, SIM/eSIM, billing and core-network relationships. This advantage is conditional rather than automatic: satellite operation requires lawful access to the relevant terrestrial frequencies throughout the illuminated area and compatible network, device and service configurations [33].

The constraints are substantial. Terrestrial IMT bands were planned for ground-based networks, and using them from space can create co-channel and adjacent-band interference, cross-licence-area and cross-border spillover, and uncertainty over protection status and interference accountability. It may also restrict or complicate future terrestrial IMT use of the same frequencies [33]. In India, the relevant IMT channel may be held by different access providers in different licensed service areas. A nationwide arrangement could therefore require multi-operator consent across all 22 LSAs, extensive frequency alignment or rearrangement, and common technical conditions. Unless that alignment can be achieved without weakening terrestrial rights or capacity, national-scale D2D-IMT may be operationally impracticable [69].

5.3 FDD AND TDD CREATE DIFFERENT COEXISTENCE CONDITIONS

Within D2D-IMT, the method used to separate incoming and outgoing communications affects technical feasibility. Frequency-division duplexing, or FDD, places these transmissions in separate frequency blocks. A satellite can therefore follow the same transmission directions as a terrestrial mobile network. This does not remove interference or licensing concerns, but it reduces the risk of a satellite downlink affecting frequencies on which terrestrial base stations are receiving handset signals [42], [46].

Time-division duplexing, or TDD, uses the same frequency block for uplink and downlink at different times. Terrestrial TDD networks avoid interference by synchronising their frames—the repeating schedules that determine when networks transmit and receive—and by inserting short guard periods between transmission directions. Satellite signals have longer propagation delays, meaning they take more time to reach the ground. An NGSO satellite's delay also changes as it moves. A satellite downlink could therefore arrive while a terrestrial base station is scheduled to receive an uplink, causing cross-link interference. Additional guard time, coordinated schedules and beam controls can reduce this risk, but may also reduce usable capacity [39], [42].

India's 22 licensed service areas add another layer of complexity. Mobile spectrum is assigned separately in each area, so the same frequency block may be held by different operators in different parts of the country. Because a satellite beam can cover several licensed areas simultaneously, D2D-IMT may require spectrum rights and technical conditions to align across multiple operators. In a TDD band, frequency alignment alone would not be sufficient. The participating networks may also need compatible clocks and uplink-downlink schedules so that a satellite transmission coordinated with one area does not interfere with terrestrial reception in another [46], [69].

WRC-27 Agenda Item 1.13 preparatory studies recognise differing FDD and TDD arrangements as part of the coexistence question [42]. TRAI's 2026 SCN consultation similarly asks whether D2D-IMT should be considered only in FDD-based bands or whether TDD bands should also be included [69].

FDD bands are often viewed as a practical starting point for D2D-IMT because uplink and downlink use separate frequency blocks, reducing cross-link interference and simplifying coexistence measures such as power limits and guard bands. Early device, network and partnership activity has also centred largely on established FDD-aligned mobile bands since it provides a more mature ecosystem for initial deployment.

Current regulatory practice also suggests that FDD bands may provide a more practical initial pathway for D2D-IMT, while TDD arrangements require further study because of timing-synchronisation and coexistence risks [55], [69]. Existing frameworks include both sub-GHz and mid-band FDD bands, and suitability remains specific to each band and jurisdiction [17], [55]. TDD bands could be reconsidered as coordination techniques, coexistence evidence and international regulatory arrangements develop through the WRC-27 process [42], [44].

5.4 AUTHORISATION MODELS NOW EMERGING

The global regulatory landscape is not converging on one model. It is converging on a common set of design questions: who may provide the service, which spectrum rights are required, how terrestrial and satellite authorisations interact, how handsets are approved, how emergency access is handled, and how security and lawful-interception obligations apply [18].

MSS-based satellite-to-IoT may follow a distinct authorisation route within established MSS allocations. In assessing that route, the authorised entities, device classes, service capabilities and operating conditions can differ materially from those of direct-to-smartphone services using terrestrial mobile bands [18].

EMERGING D2D AUTHORIZATION MODELS

	1 MSS / GMPCS model	2 Hybrid satellite-terrestrial	3 Flexible existing rights	4 Band-specific technical studies
CORE LOGIC	Satellite operator uses MSS or mobile-satellite authorisation; separate user spectrum may be required.	Satellite authority is combined with MNO terrestrial spectrum rights and a formal partnership.	Existing spectrum licences or management rights are used with coordination guidance.	The regulator proceeds band by band after coexistence and protection studies.
JURISDICTIONS / EXAMPLES	India GMPCS; MSS-band D2D in New Zealand; EU 2 GHz MSS work.	United States SCS; Canada SMCS; United Kingdom licence variations.	Australia and New Zealand.	Japan 700 MHz work; CEPT D2D-IMT studies.
POLICY SIGNIFICANCE	Best fit for satellite-led or proprietary models.	Most mature model for mobile-band D2D.	Fast and pragmatic, but depends on rights-holder coordination.	Useful where service rules must follow technical protection conditions.

Exhibit 5.2: MSS/GMPCS, hybrid satellite-terrestrial, flexible-rights and band-specific approaches.

5.5 INDIA: TRAI'S SCN AUTHORISATION AND SPECTRUM ASSIGNMENT CONSULTATION

TRAI released Consultation Paper No. 06/2026, Consultation Paper on the Framework for Satellite Communication Network Authorisation, and Assignment of Spectrum to Satellite Communication Network Providers, on 8 April 2026 [69]. The formal comment window has closed. The resulting recommendations and policy framework remain under consideration. The paper examines the proposed SCN authorisation under Section 3(1)(b) of the Telecommunications Act, 2023 and the related assignment or use of spectrum by SCN providers.

The consultation covers the eligibility, scope, area of operation, terms and conditions and validity period of the authorisation; the tenure, terms and charging of any associated spectrum assignment; whether network service operators, other service-authorised entities and VNOs may obtain Satellite Communication Network as a Service (SCNaaS); whether the SCN provider should remain a network-level B2B provider with end-user or B2C services supplied by separately authorised service entities; and whether a mandated reference agreement, including any RIO-type obligation, should govern relationships between SCN providers and partners [69]. It also asks whether SCNs should support FSS, MSS and D2D using MSS or IMT spectrum, and whether D2D using IMT spectrum should be permitted now or examined after WRC-27.

Spectrum treatment is a central part of the paper [69]. TRAI asks whether feeder-link, user-link or both sets of rights should be held by the SCN provider or the partnering entity, and how FSS/MSS spectrum should be administratively

RISK SCALE: High | Med-high | Medium

COEXISTENCE AND INTERFERENCE MANAGEMENT

RISK AREA	LIKELIHOOD / IMPACT	MAIN CONCERN	PRIMARY MITIGATIONS
Co-frequency sharing with terrestrial mobile networks	LIKELIHOOD: High IMPACT: High	Satellite reuse of MNO bands may not follow terrestrial licence boundaries.	Secondary status; all-licensee-area conditions; MNO agreements; beam control; PFD limits; exclusion zones.
Adjacent-channel and out-of-band emissions	LIKELIHOOD: Medium IMPACT: High	Emissions may affect neighbouring mobile blocks, public safety or sensitive services.	OOBE masks; aggregate PFD limits; payload filtering; guard-band analysis; enforcement.
Cross-border interference	LIKELIHOOD: High IMPACT: High	Satellite footprints and sidelobes cross national borders.	Border PFD limits; geofencing; beam scheduling; bilateral coordination; stop-transmit obligations.
Inter-constellation coordination	LIKELIHOOD: Medium IMPACT: High	Multiple NGSO systems may operate in the same or adjacent bands.	ITU filings; EPFD/PFD-type limits; good-faith coordination; escalation mechanisms.
Radio astronomy and sensitive scientific services	LIKELIHOOD: Medium IMPACT: Medium-High	Sensitive sites require stricter protection.	Site-specific coordination; radio-quiet-zone controls; monitoring.
National licensing asymmetry	LIKELIHOOD: High IMPACT: Medium-High	A service may be legal in one country, secondary in another and unauthorised in a third.	Harmonised templates; WRC outcomes; mutual recognition where feasible.
Market-access foreclosure	LIKELIHOOD: Medium IMPACT: Medium-High	D2D-IMT may depend on incumbent MNO spectrum holdings.	Non-exclusive agreements; transparent access rules; competition review.

Exhibit 5.3: Coexistence and interference-management risk matrix for D2D-IMT deployment

assigned and charged. For D2D-IMT, the consultation specifically tests whether one access provider must hold the same relevant channel across all 22 LSAs or whether several providers may collectively cover them. This exposes a significant practical constraint in India: differing circle-level holdings could require extensive multi-operator coordination, harmonisation or frequency rearrangement before nationwide operation is feasible.

5.6 COEXISTENCE AND INTERFERENCE MANAGEMENT

Coexistence is the central operational challenge for D2D-IMT because it reuses terrestrial mobile frequencies from a satellite platform. These bands were planned for ground-based base stations, limited cell footprints and national licence areas, whereas satellite beams can cover large areas, cross borders and illuminate spectrum assigned to multiple operators or adjacent-band users. Interference can occur in both directions: satellite transmissions may affect terrestrial or adjacent-band services, while handset transmissions to satellites may raise the noise floor at terrestrial base stations. Terrestrial-band D2D therefore cannot be treated simply as another tower in the sky [44].

Small-scale trials may not reproduce aggregate beam loading, user density, repeated satellite passes, multi-operator conditions or cross-border and adjacent-band effects. They therefore cannot, by themselves, demonstrate that terrestrial networks, RAS, MSS and other incumbent services would remain protected at commercial scale. Within those limits, tightly controlled trials can provide evidence on network integration, device performance, monitoring and coordination. Trial evidence and WRC-27 outcomes serve different purposes: trials inform implementation, while international studies address broader allocation, sharing and incumbent-protection conditions. Both would feed into subsequent national authorisation and operational safeguards [44].

The regulatory question is whether interference can be predicted, limited, monitored and rapidly mitigated. Relevant safeguards include secondary status, no-interference/no-protection obligations, power limits, emission masks, geographic restrictions, border coordination, radio astronomy protections and stop-transmit requirements. Operators will also require capabilities such as beam scheduling, geofencing, exclusion zones, real-time monitoring and rapid shutdown. Without effective controls, using terrestrial mobile spectrum from space remains both the strongest ordinary-phone D2D proposition and the most difficult model to scale safely [44].

5.7 SPECTRUM RIGHTS, EXCLUSIVITY AND MARKET STRUCTURE

Spectrum rights determine whether D2D is protected, secondary, shared, exclusive, geographically limited or dependent on another licensee's consent. This has direct commercial implications [37].

In MSS-based models, exclusivity may sit with the satellite spectrum holder. In terrestrial-band D2D, exclusivity may sit with the MNO spectrum holder. In hybrid models, exclusivity may arise through the commercial partnership itself. This creates a competition issue: if satellite access to ordinary handsets depends on incumbent MNO spectrum, unaffiliated satellite operators may face market-entry barriers [37].

Non-exclusivity rules, access transparency and interference accountability are therefore central to D2D policy. Canada's non-exclusive SMCS agreement model is an important reference point because it directly addresses the risk of foreclosure in MNO-satellite partnership models [37].

5.8 EMERGENCY ACCESS, PUBLIC SAFETY AND CONSUMER DISCLOSURE

Emergency access is one of the least settled areas of D2D regulation. The policy challenge is that consumers may assume satellite connectivity behaves like terrestrial mobile service, especially for emergency calling. Current evidence does not support that assumption across all services [27].

The United States has adopted interim SCS 911 call and text routing, annual reporting and consumer-disclosure requirements [28]. Canada has recognised the public-safety value of SMCS but has left full 9-1-1 and public alerting obligations for further development [37]. New Zealand's live consumer-facing material discloses that emergency voice calling is not available over satellite where traditional cellular coverage is absent. EU rules provide a broader 112 and caller-location baseline rather than a D2D-specific emergency regime.

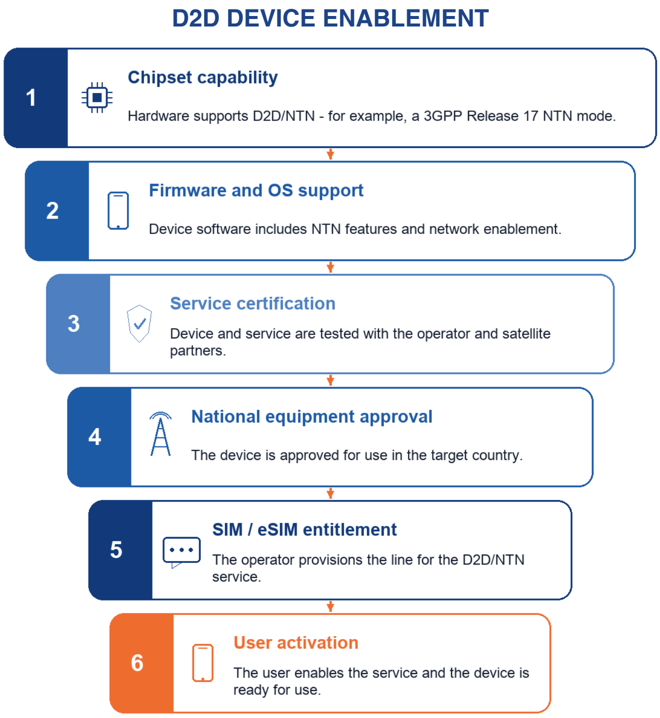

Exhibit 5.4: NTN-capable hardware still requires software support, service certification, national approval, SIM entitlement and user activation.

5.9 DEVICE APPROVAL AND TERMINAL TREATMENT

D2D changes the regulatory character of an ordinary smartphone. A handset that usually operates as terrestrial user equipment may become an earth station or earth-station-like terminal when communicating with a satellite [38].

Different jurisdictions solve this differently. The United States uses licence-by-rule treatment for SCS earth stations and requires equipment authorisation to reflect SCS capability [28]. Canada applies existing user-equipment requirements within its SMCS framework [37]. Australia relies on compliance with existing spectrum-licence conditions. New Zealand requires equipment to meet supplier and radio-standard requirements. The EU uses the Radio Equipment Directive framework. India applies MTCTE to notified telecom equipment.

For India, the open implementation issue is how satellite-capable smartphones, software activation, eSIM/SIM provisioning, NTN modes and imported devices should be treated under MTCTE and telecom security requirements.

The approval question also extends to NTN-capable IoT modules, sensors, trackers and embedded devices. Their conformity and authorisation profile may differ by transmit power, operating spectrum, service capability and installation type; handset-specific requirements may therefore be technically inapplicable to some device classes [38].

5.10 SECURITY, ROUTING, LAWFUL INTERCEPTION AND DOMESTIC GATEWAYS

Security treatment is less harmonised globally than spectrum treatment. India is the clearest example of a security-led posture. The GMPCS framework requires privacy, lawful interception, Indian gateways and routing of Indian traffic through gateways established in India [19]. TRAI's 2026 SCN consultation also examines domestic operating and control requirements, gateway arrangements, user-terminal registration, equipment identity and real-time traffic monitoring [69]. These security questions sit alongside the broader authorisation, partner-eligibility, interconnection and spectrum-assignment issues summarised in Section 5.4.

This will affect architecture. A satellite constellation may be global, but India-facing D2D service may still need domestic gateways, domestic control interfaces, lawful-interception integration and real-time monitoring before commercial authorisation [19].

The implications of these requirements vary by service category and architecture. Low-rate IoT telemetry differs from consumer voice, broadband and emergency calling in traffic patterns, terminal behaviour and service functions, creating a distinct set of routing, monitoring, gateway and lawful-interception considerations [19].

5.11 CROSS-BORDER SERVICE CONTINUITY

D2D beams do not naturally stop at borders. This creates a mismatch between global satellite coverage and national telecom law. A service may be technically available but not legally authorised in a neighbouring jurisdiction. Cross-border issues include interference, roaming, emergency routing, lawful interception, foreign devices, maritime use and service continuity near borders [33].

D2D-MSS can rely more readily on established satellite coordination mechanisms where filings and allocations are in place. D2D-IMT has less mature cross-border treatment because one country's authorisation of satellite use in a terrestrial mobile band does not create matching rights in another country [33].

Cross-border coordination should therefore be treated as a precondition for commercial scale, not a post-launch compliance detail. Regulators need common assumptions on PFD levels, measurement locations, service areas, emergency exceptions, complaint handling and stop-transmit obligations. Operators need geofencing, beam scheduling, border exclusion capabilities and operational coordination contacts [33].

5.12 WRC-27 AND THE INTERNATIONAL SETTLEMENT

WRC-27 Agenda Item 1.13 is the main multilateral pathway for D2D between MSS space stations and IMT user equipment [40], [44]. The study range covers parts of the 694/698 MHz to 2.7 GHz range and requires studies of spectrum requirements, technical conditions, operational rules, regulatory treatment and incumbent protection. Its significance is high, but it should not be overstated. Resolution 253 does not create an immediate operating right; it creates a study mandate and a possible route to future regulatory action.

Until WRC-27 is settled, some countries are using national tools such as secondary MSS overlays, licence variations, management-right licensing, handset exemptions and Article 4.4-based approaches [18], [55]. These arrangements are not equivalent across the two spectrum pathways. MSS-based D2D may continue where it operates within existing MSS allocations and applicable national authorisations. D2D-IMT raises a different question because it would use terrestrial mobile spectrum from space while the international allocation, sharing and protection framework remains under study.

This sequencing applies to D2D-IMT in the candidate bands under WRC-27 Agenda Item 1.13; it does not make WRC-27 a prerequisite for satellite-to-IoT operating within existing MSS allocations and applicable national authorisations [33], [44].

WRC-27 will clarify the international treatment of D2D-IMT spectrum and the conditions for protecting terrestrial networks, radio astronomy and adjacent-band mobile-satellite services [40], [44]. In parallel, trials and authorised early services can generate evidence on network integration, device performance, monitoring and coordination. Experience in several markets shows that testing, limited authorisation and early rollout can proceed while international studies continue [48], [55], [57], [65], [66], [68]. Such activity does not establish future spectrum rights or demonstrate commercial-scale coexistence. WRC-27 outcomes and subsequent national implementation will remain important to harmonisation, incumbent protection and widespread scaling and deplyment of D2D services [44], [47].

The global regulatory pattern is clear: D2D is being enabled as supplemental coverage and resilience, not as a substitute for terrestrial mobile networks [18], [55]. The most mature models combine satellite authority with MNO spectrum rights through leases, licence variations, generic earth-station licences, management rights or formal partnership agreements. However, national approaches remain fragmented.

6. COMMERCIAL DEPLOYMENT AND PARTNERSHIP MODELS

AT A GLANCE

1 HIGHLIGHT 1

D2D has commercialised first as resilience, emergency, messaging and IoT connectivity, not as mass-market broadband.

Live services are strongest in SOS, basic messaging, selected apps and enterprise IoT.

2 HIGHLIGHT 2

Commercial deployment is splitting into two spectrum-led models.

These are MSS-based D2D, such as Apple/Globalstar and Verizon/Skylo-style services, and terrestrial mobile-band D2D, such as Starlink-MNO partnerships and AST SpaceMobile's MNO-partnered model.

3 HIGHLIGHT 3

MNO-led partnerships are the dominant consumer route to scale.

In most live deployments, the mobile operator owns the retail proposition, pricing, customer care and plan integration, while the satellite operator provides the coverage-extension layer.

4 HIGHLIGHT 4

The service ladder is consistent across markets.

SOS comes first, followed by SMS/basic messaging, selected apps and IoT, and then richer voice/data where constellation capacity, spectrum, devices and regulation permit.

5 HIGHLIGHT 5

Commercial launch should not be confused with trials or regulatory approval.

A service should be treated as commercially live only where customers can access it through a plan, add-on, device feature or enterprise contract.

6.1 COMMERCIAL DEPLOYMENT IS REAL, BUT STILL NARROW

D2D is no longer only a trial-stage technology. Several commercial services are already live across consumer smartphones, operator partnerships and enterprise IoT. However, the service profile remains narrow. Most live offerings focus on emergency messaging, text, location sharing, selected low-bandwidth apps or remote IoT connectivity [36].

Apple/Globalstar demonstrates the OEM-led safety model. T-Mobile/Starlink, One NZ/Starlink, Rogers/Starlink, KDDI/Starlink and O2/Starlink demonstrate the MNO-led coverage-extension model. Verizon/Skylo shows a standards-based MSS-oriented model using selected Android devices. Lynk demonstrates SMS-first D2D using ordinary phones in smaller and geographically challenging markets. Deutsche Telekom's multi-orbit IoT service shows that enterprise NB-IoT NTN is already commercially relevant [36].

AST SpaceMobile is strategically important because it targets broadband-oriented connectivity to standard smartphones [15]. However, its current classification should remain regulatory-authorised / advanced pre-commercial, not generally available retail broadband.

6.2 MAIN COMMERCIAL MODELS

D2D commercialisation is occurring through four main models [36].

1. OEM-LED PROPRIETARY MODEL

In the OEM-led model, the device maker controls the user experience, device eligibility, software workflow and customer proposition. Apple/Globalstar is the clearest example [11], [31]. The model is strong for emergency SOS, off-grid messaging, location sharing and roadside assistance because the service is embedded directly into the handset experience.

The limitation is ecosystem scope. The service works only on supported devices, operating-system versions and approved geographies. It is therefore commercially mature as a safety and messaging feature, but not as an open, interoperable D2D broadband model [36].

2. MNO-LED WHOLESALE PARTNERSHIP MODEL

This is the most important consumer-scale model. The MNO controls plans, pricing, billing, customer care, emergency messaging and retail packaging. The satellite operator supplies the space-based coverage-extension layer [36].

T-Mobile/Starlink, One NZ/Starlink, Rogers/Starlink, KDDI/Starlink and O2/Starlink all follow this broad structure [36].

The model is attractive because it uses existing mobile subscriptions, MNO brands, SIM/eSIM relationships and compatible smartphones. It also lets D2D appear to users as an extension of their mobile plan rather than as a separate satellite service.

The limitation is regulatory complexity. These models often depend on terrestrial mobile spectrum, national authorisation, emergency-routing rules, device eligibility and coexistence obligations [36].

3. SMS-FIRST MNO-INTEGRATED MODEL

Lynk's model shows that D2D can reach market through a narrowband, SMS-first approach using ordinary mobile phones [49]. This is particularly relevant for island states, remote regions and markets where basic resilience is more urgent than broadband capability.

The strength of this model is early practicality. The limitation is service ceiling: SMS-first D2D is commercially useful but should not be treated as evidence that broadband D2D is already mature [36].

4. ENTERPRISE AND IOT NTN MODEL

Enterprise and IoT models are among the strongest near-term commercial use cases because they require lower data rates and have clearer operational value. Deutsche Telekom's multi-orbit IoT model, using terrestrial and satellite NB-IoT connectivity, illustrates how D2D/NTN can support asset tracking, logistics, utilities, agriculture, maritime operations and remote monitoring [20].

Unlike consumer smartphone D2D, satellite-to-IoT need not be brought to market primarily through an MNO-led model. Commercial structures may involve direct or indirect relationships among satellite operators, MSS service providers, IoT platform providers, system integrators and enterprise customers, depending on the architecture and application [36].

This model is less dependent on mass-market smartphone behaviour and more dependent on certified modules, SIM provisioning, roaming, enterprise platforms and usage-based pricing. It is likely to scale to meaningful levels earlier than mass-market broadband D2D [36].

COMMERCIAL D2D DEPLOYMENT MODELS

Model	REPRESENTATIVE EXAMPLES	CURRENT SERVICE PROFILE
OEM-led safety and messaging	Apple + Globalstar	Emergency SOS, messaging, location sharing and assistance.
MNO-led direct-to-cell	T-Mobile, One NZ, Rogers, KDDI, O2 + Starlink	Texting, location, selected apps and limited data features.
MSS / standards-based messaging	Verizon + Skylo and related ecosystems	Emergency messaging, location sharing and native SMS on selected devices.
SMS-first D2D	Lynk + MNO partners	Periodic SMS, two-way SMS and alerts in selected markets.
Broadband-oriented D2D	AST SpaceMobile + MNO partners	Voice, video and data ambition; trials and approvals rather than broad retail.
Enterprise IoT NTN	Deutsche Telekom, Skylo, Sateliot and partners	NB-IoT, asset tracking, remote sensors and operational monitoring.

Exhibit 6.1: OEM-led, MNO-led, MSS-based, SMS-first, broadband-oriented and enterprise IoT models.

6.4 D2D PLANS/ADD-ONS

D2D plans are now commercially visible across several markets, but they should not be read as a single global product category. The current market splits into three distinct plan types: carrier-integrated ordinary-phone D2D, OEM-managed satellite features, and dedicated or paired-device satellite communicators. The attached plan research reaches the same conclusion: live ordinary-phone offers are still mostly messaging-first, with selected app connectivity and limited practical voice support rather than open mobile broadband [36].

The central pattern is clear: D2D is being sold first as coverage assurance, not as mobile broadband. The most common pricing models are premium-plan inclusion, low-cost monthly add-ons, device-bundled free periods and narrow SMS/SOS features. The richest live ordinary-phone offers are adding satellite-ready apps, but even these remain constrained by device eligibility, sky visibility, national authorisation, app whitelists and emergency-service limitations. The commercial test for the next phase is whether operators can move from SMS and selected apps to dependable voice and broader data without overstating coverage, capacity or emergency reliability [36].

GLOBAL D2D PLAN LANDSCAPE

MARKET / PROVIDER	STATUS	CURRENT CUSTOMER PROPOSITION	COMMERCIAL READING
United States - T-Mobile / Starlink	LIVE RETAIL	Texting, satellite-ready apps, location sharing and text-to-911; plan inclusion or add-on.	Clear MNO integration; resilience and selected apps first.
United States - Verizon / Skylo	LIVE - SELECTED DEVICES	Satellite SOS and basic messaging via Skylo on selected Android devices.	MSS/standards route; narrower than Starlink app offers.
Canada - Rogers / Starlink	LIVE RETAIL	Texting, text-to-911, alerts and apps; plan inclusion and paid access.	Broad retail availability with device and coverage limits.
New Zealand - One NZ / Starlink	LIVE RETAIL	Satellite text and data add-ons; selected apps; no satellite emergency calling.	Beyond SMS with an app catalogue, but emergency limits remain.
Japan - KDDI / Starlink	LIVE RETAIL	Messaging, alerts, J-Alert and selected text services; large subscriber reach.	Mature resilience focus and messaging-led scale.
Australia - Telstra / Starlink	LIVE RETAIL	Text messaging included on selected plans; not for 000/112 emergency calls.	A deliberately narrow proposition with clear disclosure.
Chile - Entel / Starlink	LIVE RETAIL	SMS and selected apps, including some maritime availability.	Important Latin American example with local rules and devices.
United Kingdom - O2 / Starlink	LIVE RETAIL	Texting, location sharing and selected apps; add-on or plan inclusion.	Major market milestone, but app-limited and not for emergency calls.
France / selected countries - Orange / Skylo	LIVE / PHASED	SMS and geolocation in France and multiple countries; paid after introductory period.	MSS-style service; narrower but standards-aligned.
Apple / Globalstar	DEVICE-BUNDLED	Messages via satellite, Emergency SOS, roadside assistance and Find My on supported devices.	OEM safety and messaging feature, not an open telecom subscription.
Lynk + selected MNOs	LIMITED / EXPANDING	SMS-first service in smaller markets; no voice or broadband.	Shows reach beyond major markets, with a deliberately low service ceiling.
AST SpaceMobile + MNO partners	BETA / PRE-RETAIL	Broadband ambition on ordinary phones; voice, video and data trials.	Highest upside and highest execution dependence.
Amazon Leo / Globalstar	PLANNED	Future advanced voice, data and messaging support; linked to broader device ecosystems.	Strategically important, but not a current retail plan.

Exhibit 6.2: Ordinary phone offers are mostly messaging-first and highly market specific

6.5 WHY MNO PARTNERSHIPS DOMINATE CONSUMER D2D

MNO partnerships dominate consumer D2D because most smartphone-oriented services need more than satellites. They need spectrum access, subscriber identity, billing, customer support, emergency routing, device eligibility, roaming logic and regulatory compliance. MNOs already control many of these layers [36].

For satellite operators, partnering with MNOs reduces go-to-market friction and provides access to existing customers. For MNOs, D2D offers a way to improve geographic coverage, strengthen premium plans, reduce dead-zone anxiety and improve resilience during outages. For users, the service is easier to understand when it appears inside an existing mobile plan [36].

The commercial trade-off is value sharing. The satellite operator supplies the differentiated coverage layer, but the MNO usually controls the customer relationship and retail economics. This makes wholesale pricing, revenue share, exclusivity and plan positioning central to the business model [36].

Current pricing suggests that consumer D2D is being monetised as a bundle enhancer rather than as a high-ARPU standalone subscription [36]. Apple embeds satellite features into the device proposition. T-Mobile and O2 use low-cost add-ons and premium-plan inclusion. One NZ uses separate satellite text and data add-ons. Rogers moved from beta toward plan inclusion and paid access. KDDI initially launched free for au users.

This pricing pattern reflects the current service envelope. Users may value D2D highly in emergencies, but everyday usage is expected to be occasional. For that reason, the economics are more likely to come from premium-plan differentiation, churn reduction, brand value, public-safety positioning and enterprise contracts than from heavy consumer data usage in the near term [36].

Enterprise and IoT pricing is different. It can be usage-based, device-based or contract-based, and buyers can justify the cost through asset visibility, avoided field visits, downtime reduction and operational assurance [36].

WHY MNO PARTNERSHIPS DOMINATE

FUNCTION	USUALLY OWNED BY MNO	USUALLY OWNED BY SATELLITE OPERATOR
1. Customer relationship	✓	
2. Billing and plan design	✓	
3. SIM / eSIM entitlement	✓	
4. Emergency-routing interface	✓	SHARED
5. Satellite coverage layer		✓
6. Space infrastructure		✓
7. Beam and satellite network operations		✓
8. Regulatory coordination	SHARED	SHARED

Exhibit 6.3: Wholesale pricing, revenue share, exclusivity and plan positioning central to model dominance

Commercial D2D is becoming real, but its maturity is uneven. The strongest live market is resilience-oriented connectivity: emergency SOS, basic text, location sharing, selected apps and low-rate IoT. The most scalable consumer route is MNO-led partnership, where satellite service is packaged as mobile coverage extension. The most mature commercial revenue case may emerge first in enterprise and IoT, where low-rate connectivity has measurable operational value [36].

Broadband-oriented direct-to-smartphone D2D are an emerging strategic priority, but yet to be proven as a mass-market retail product. For consumer direct-to-smartphone services, the evidence supports a staged commercial path from SOS and messaging toward selected applications and richer data as capacity, spectrum, devices, gateways and regulation align. Enterprise and satellite IoT follow a distinct commercial pathway and can scale independently based on device availability, MSS spectrum, network capability, interoperability and enterprise demand. [36].

7. FUTURE OUTLOOK BEYOND 2031 AND 6G

AT A GLANCE

1 HIGHLIGHT 1

D2D's post-2031 future is likely to be staged convergence, not a sudden 6G leap.

The most defensible outlook is gradual integration of satellite and terrestrial mobile networks, starting with emergency messaging, then SMS/location/IoT, then selected voice and data, and later deeper 6G-era convergence.

2 HIGHLIGHT 2

D2D aligns with IMT-2030 and 6G goals.

Ubiquitous connectivity, resilience, sustainability and connecting the unconnected are natural fits for satellite-enabled coverage extension.

3 HIGHLIGHT 3

6G-native D2D is still standards-dependent.

3GPP Release 20 and Release 21 will determine whether NTN becomes embedded into future mobile architecture or remains a specialised overlay.

4 HIGHLIGHT 4

Spectrum remains the main policy gate.

WRC-27 Agenda Item 1.13 is the key multilateral pathway for possible MSS allocations supporting direct connectivity between satellites and IMT user equipment below 2.7 GHz.

5 HIGHLIGHT 5

Device readiness is improving but remains selective.

Apple, Android, Qualcomm, MediaTek, Samsung and wearable platforms show momentum toward OS- and modem-level satellite support, but compatibility remains limited by device model, chipset, software, carrier support and national approval.

6 HIGHLIGHT 6

The most plausible post-2031 outcome is a normalised resilience and coverage layer.

Broader voice, data and 6G integration are possible, but only where standards, spectrum, satellite capacity, device support, economics and regulation align.

7.1 D2D IN THE IMT-2030 AND 6G CONTEXT

D2D fits naturally within the wider 6G ambition of ubiquitous, resilient and inclusive connectivity. Its relevance is strongest where terrestrial networks cannot provide consistent reach: remote areas, disaster zones, transport corridors, maritime/coastal environments, sparse rural territories and critical infrastructure sites [45].

However, D2D should not be treated as the defining feature of 6G. The better framing is that 6G may provide a more mature architecture into which satellite access can be integrated. Terrestrial mobile networks will continue to carry most traffic. D2D's role is likely to be coverage extension, resilience and service continuity, not wholesale substitution [45].

The 6G timeline also matters. Release 20 and Release 21 are expected to shape how NTN is handled in future mobile architecture, including radio design, mobility, policy control, charging, emergency treatment, application support and operations [6], [7]. This means meaningful 6G-era D2D outcomes will depend on late-2020s standardisation being converted into real devices, deployable networks and national authorisations.

D2D 6G INTEGRATION STACK

1. Radio and waveform
2. Mobility and handover
3. Authentication and identity
4. Policy, charging and billing
5. Emergency routing and lawful intercept
6. Application behaviour and user experience
7. Regulatory authorisation and spectrum rights

Figure 7.1: Every layer must mature for deeper TN/NTN convergence

7.2 STANDARDS AND SPECTRUM DEPENDENCIES

The post-2031 outlook depends on two linked but separate tracks: standards and spectrum [8], [44].

The standards track is led by 3GPP. Release 17 and Release 18 created and hardened the NTN baseline, while Release 19 moves toward 5G-Advanced NTN capabilities such as regenerative payloads, store-and-forward, RedCap, UE-satellite-UE communication and improved coverage/throughput [1], [4]. Release 20 and Release 21 will determine how far NTN becomes part of 6G architecture rather than a bolt-on feature.

The spectrum track is led by ITU and national regulators. WRC-27 Agenda Item 1.13 is especially important because it studies possible MSS allocations for direct connectivity between space stations and IMT user equipment in parts of the 694/698 MHz to 2.7 GHz range [40], [44]. This range matters because ordinary handheld devices have tight antenna, power and link-budget constraints.

Even a positive WRC-27 outcome would not automatically create global commercial D2D. Countries would still need domestic implementation, licensing rules, coexistence limits, emergency obligations, gateway requirements, lawful-interception treatment and device approval processes [44].

7.3 DEVICE AND PLATFORM OUTLOOK

Device readiness is one of the strongest positive signals for the post-2031 outlook. Satellite support is moving from specialist terminals toward mainstream platforms. Apple has embedded satellite features into selected iPhones. Android has added satellite-connectivity platform support. Qualcomm, MediaTek and Samsung are integrating NTN capabilities into modem roadmaps [81], [82]. Wearable platforms are also beginning to support narrowband NTN.

This does not yet mean universal compatibility. A device may support satellite capability at the modem level but still require operating-system support, carrier entitlement, approved firmware, certified apps, compatible spectrum bands, a supported messaging client and national authorisation [8].

The likely device adoption path is tiered. Premium devices will support more satellite functions first, followed by upper-mid-tier devices where modem costs fall and operator demand grows. Low-cost mass-market support will depend on whether satellite features become standard enough to justify inclusion across broader chipsets and device portfolios [8].

7.4 COMMERCIAL ROADMAP BEYOND 2031

Commercial development is likely to remain sequenced. Messaging and emergency services are already the strongest live categories. Operator-led texting and selected app access are expanding. Enterprise and IoT services are likely to scale where low-rate connectivity creates measurable operational value. Broadband-oriented direct-to-smartphone services have the largest upside but remain most dependent on constellation scale, spectrum rights, satellite capacity, gateways and cost per usable bit [56].

WHAT IS PLAUSIBLE AND WHAT REMAINS SPECULATIVE

PLAUSIBLE BEYOND 2031	STILL SPECULATIVE
Satellite messaging becomes a normal mobile-plan feature.	Terrestrial-like broadband from ordinary phones almost everywhere.
Emergency satellite capability becomes common in premium devices.	Full global D2D spectrum harmonisation by the early 2030s.
Enterprise and IoT NTN scale in remote sectors.	One universal D2D model across all regions.
MNO-led satellite coverage extension expands.	Seamless 6G satellite roaming without national friction.
TN/NTN integration becomes a serious 6G architecture theme.	D2D replacing terrestrial rural-broadband investment.

Exhibit 7.2: Plausible versus speculative D2D outcomes beyond 2031.

Satellite-to-IoT in established MSS/non-IMT spectrum follows a distinct pathway from direct-to-smartphone D2D and from the parallel evolution of rules for satellite access to terrestrial IMT spectrum, as discussed in Chapters 4-6 [23].

The market is unlikely to become globally uniform [18], [55]. Different regions may adopt different models: U.S.-style supplemental coverage, European secure-connectivity and MSS pathways, Asia-Pacific satellite-terrestrial industrial strategies, and country-specific security and gateway-localisation requirements.

THREE POST-2031 SCENARIOS

1 Conservative evolution	2 Accelerated adoption	3 Integrated satellite-terrestrial convergence
MOST LIKELY BASELINE	POSSIBLE, DEPENDENCY-HEAVY	STRATEGICALLY PLAUSIBLE
WHAT THIS LOOKS LIKE	**WHAT THIS LOOKS LIKE**	**WHAT THIS LOOKS LIKE**
D2D remains primarily a resilience and coverage-extension layer. Emergency messaging, SMS, location sharing and selected IoT become common; voice and data remain selective and regionally fragmented.	D2D becomes a broader operator-managed satellite extension of mobile service. Premium and upper-mid-tier devices expand, MNOs bundle satellite text, voice and selected data, and post-WRC spectrum frameworks become clearer.	D2D becomes part of a wider 6G-era TN/NTN service fabric. Networks select terrestrial or satellite access according to coverage, priority, subscription, location and regulatory permission.
EVIDENCE READING	**EVIDENCE READING**	**EVIDENCE READING**
Extends the current evidence base with lower execution risk.	**Requires better capacity, wider device support and stronger commercial integration.**	**Requires alignment across standards, spectrum, devices, MNO cores, emergency routing and national rules.**

Exhibit 7.3: Staged convergence I Messaging and IoT lead I Device support and regulation determine how far the market climbs

D2D's post-2031 role is likely to remain complementary to terrestrial networks rather than substitutive [45]. It may become a more integrated resilience and coverage layer within mobile networks, while broader 6G-era integration will depend on standards, spectrum, devices, satellite capacity, economics and regulation.

8. CONCLUSION

Direct-to-device satellite connectivity is entering the communications landscape as a practical but bounded capability, currently characterised primarily by emergency messaging, low data rates and a clear line-of-sight requirement [9], [35]. The evidence reviewed in this report points to a consistent conclusion: D2D is a supplementary safety net, not a substitute for terrestrial mobile networks, fibre networks or universal broadband investment. Its strategic value lies in extending minimum viable connectivity when terrestrial networks are unavailable, weak, disrupted or uneconomic to build. D2D matters not because it can replicate terrestrial broadband, but because it can provide basic connectivity where its absence carries high social, operational or safety costs.

The global pattern is therefore one of staged adoption [9], [21]. Emergency SOS, distress messaging, basic text, location sharing, public warning, disaster fallback and low-rate IoT form the strongest near-term service layer. These uses align with the current technical envelope of outdoor, open-sky, low-data-rate connectivity and with the public-interest case for resilient fallback connectivity. Voice, selected applications and richer data services are emerging, but remain dependent on satellite capacity, link budgets, spectrum rights, supported devices, constellation density, gateways, service continuity and national service-authorisation frameworks. Broadband-oriented direct-to-smartphone services remain roadmap-dependent and are constrained by per-user link performance and very low aggregate area capacity in the near term. Accordingly, their near-term role is likely to remain focused on deep-rural, rural and other low-density settings rather than serving as a capacity substitute for dense terrestrial networks in towns, cities and other high-demand environments.

D2D can only scale where spectrum rights, satellite authorisation, device approval, emergency obligations, lawful-interception arrangements, gateway treatment, consumer disclosure and coexistence controls are aligned. MSS-based D2D offers a lower-friction route because it fits more naturally within existing satellite-service frameworks, but it depends on compatible devices, satellite-band support and available MSS capacity. Terrestrial mobile-band D2D may reduce handset compatibility barriers, but this must be weighed against possible constraints on future terrestrial IMT use, interference and protection obligations, and the need for aligned spectrum rights across each illuminated service area. In India, fragmented holdings across LSAs make nationwide D2D-IMT coordination particularly difficult and potentially impracticable. WRC-27 Agenda Item 1.13 is therefore an important international inflection point, but it should not be mistaken for an immediate operating right or a complete framework [40], [44]. In parallel with the WRC process, trials and authorised early services can generate evidence on network integration, device performance and coordination [65], [66]. Experience across multiple jurisdictions shows that practical learning and early rollout can proceed while international studies continue [48], [55], [57], [68]. WRC-27 outcomes will remain ccritical for international harmonisation, incumbent protection and scaling beyond nationally bounded arrangements, with national implementation still required [44], [47].

Commercially, the market is becoming partnership-led [9], [36]. The most scalable consumer model is likely to be MNO-led coverage extension, where the mobile operator controls the customer relationship, billing, SIM or eSIM entitlement, support and plan packaging, while the satellite operator supplies the space-based coverage layer, with the partnership defining how supporting network resources and infrastructure are shared. OEM-led services will remain important where a tightly integrated device experience can deliver safety, messaging and location features. Enterprise and IoT models may scale faster than consumer broadband because low-rate connectivity can be monetised directly through asset visibility, avoided field visits, outage prevention, logistics assurance and remote monitoring. This reinforces a central economic point: the strongest near-term business case is not “satellite broadband for every phone,” but resilience, reassurance and operational assurance.

For policymakers, the practical implication is to regulate D2D by capability, not by marketing label [33], [69]. Emergency-only messaging, two-way SMS, public warning, IoT telemetry, voice-capable service and broadband-oriented service should not carry identical obligations or consumer expectations. A credible framework should define the service category, spectrum basis, protection status, eligible operators, device conformity requirements, emergency routing obligations, disclosure rules, domestic gateway or security requirements, and mechanisms for cross-border coordination. It should also ensure that claims about ordinary-phone compatibility, coverage, indoor performance, supported applications and emergency availability are accurate and auditable.

Satellite-to-IoT in established MSS/non-IMT spectrum is distinct from direct-to-smartphone D2D [1], [23], with its low-power, low-rate and delay-tolerant profile creating different authorisation, device-approval, security and interference considerations. Approaches in Canada, the United Kingdom and New Zealand are broadly neutral as to technology, orbit and architecture while remaining spectrum-specific. Obligations follow service capability, spectrum rights, interference risk, device characteristics and incumbent protection [37], [55], [60]. MSS-based services can therefore be assessed independently of evolving rules for satellite access to terrestrial IMT spectrum.

D2D is likely to become a more integrated but complementary part of mobile resilience and coverage strategy, and 6G-era satellite-terrestrial integration may deepen that role [45]. However, convergence will be gradual. Its success will depend on disciplined spectrum policy, credible standards implementation, scalable device support, viable commercial models, sufficient satellite capacity and clear national rules. D2D’s highest near-term value will come from a managed resilience, safety and coverage-extension role while technology, standards and regulation continue to evolve.

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GLOSSARY

Term	Definition
3GPP	3rd Generation Partnership Project; the global body that develops cellular standards including 5G, NR and NTN specifications.
3GPP NTN	The set of 3GPP standards that adapt cellular systems for satellite and other non-terrestrial access.
Agenda Item 1.13	The WRC-27 agenda item studying possible MSS allocations for direct connectivity between satellites and IMT user equipment.
Capacity	The amount of traffic a network, satellite, beam or link can support within a given time.
Cell Broadcast	A public-warning method that sends alerts from mobile networks to devices in a defined area.
Coexistence	The ability of different networks or radio services to operate in nearby or shared frequencies without harmful interference.
Constellation	A group of satellites working together to provide coverage or capacity.
Core network	The central part of a telecom network that handles routing, identity, billing, mobility, policy and service control.
Cross-border coordination	Coordination between countries or operators to manage satellite coverage, interference and authorisation near borders.
D2D	Direct-to-device satellite connectivity; satellite connectivity delivered directly to ordinary user devices such as smartphones, SIM-enabled devices or IoT modules.
D2D-IMT	A D2D pathway using terrestrial mobile or IMT spectrum from satellites, usually through mobile-operator partnerships.
D2D-MSS	A D2D pathway using mobile-satellite service spectrum rather than ordinary terrestrial mobile spectrum.
Delay-tolerant	Able to function even when messages or data arrive later rather than instantly.
Direct-to-cell	A subset of D2D focused on connecting satellites directly to cellular handsets or SIM-enabled devices, usually through mobile-operator integration.
Direct-to-device satellite connectivity	The report's umbrella term for satellite systems that connect directly to ordinary user devices.
Emergency SOS	A satellite-enabled emergency messaging function used when normal terrestrial coverage is unavailable.
FCC	Federal Communications Commission; the U.S. communications regulator.
Feeder link	The satellite link between the satellite and a gateway or ground network.
Gateway	A ground station or network point that connects a satellite system to terrestrial telecom networks or the internet.
GEO	Geostationary Earth Orbit; an orbit where a satellite appears fixed over one point on Earth.
Geofencing	Using geographic controls to enable, disable or limit service in specific areas or jurisdictions.
GMPCS	Global Mobile Personal Communication by Satellite; an Indian licensing framework relevant to satellite communication services.
Handover	The transfer of a user connection from one cell, beam, satellite or network layer to another.
IMT	International Mobile Telecommunications; the ITU framework for mobile technologies such as 3G, 4G, 5G and future 6G.
IMT spectrum	Spectrum identified or used for terrestrial mobile networks.
IoT	Internet of Things; connected sensors, trackers, meters, machines or devices that exchange data over networks.
IoT NTN	3GPP non-terrestrial network support for IoT services, including NB-IoT and eMTC over satellite.
IoT telemetry	Small data readings or status updates sent by sensors, machines or remote assets.
ITU	International Telecommunication Union; the UN specialised agency for telecommunications and radio spectrum coordination.
Latency	The time delay between sending and receiving data over a network.
Lawful interception	Legally authorised access to communications by security or law-enforcement authorities under applicable law.
LEO	Low Earth Orbit; a satellite orbit closer to Earth than MEO or GEO, often used for lower-latency D2D systems.
Line of sight	A relatively unobstructed path between a device and the satellite; important for satellite connectivity.
Link budget	The engineering calculation of gains and losses that determines whether a radio link can work reliably.

Term	Definition
Low-rate service	A service designed for small amounts of data, such as text, alerts, location or sensor updates.
Messaging-first	A service strategy where initial commercial D2D services focus on SOS, SMS and basic messaging before richer data services.
Minimum viable connectivity	The basic connectivity needed for essential use cases such as SOS, text, alerts, location or telemetry.
MNO	Mobile Network Operator; a telecom operator that provides mobile services to customers.
MSS	Mobile-Satellite Service; satellite service supporting communication with mobile terminals.
MSS allocation	A spectrum allocation that permits mobile-satellite service operations in a defined band.
MTCTE	Mandatory Testing and Certification of Telecom Equipment; India's framework for telecom equipment testing and certification.
Narrowband	A communication mode using relatively small bandwidth, suited to text, alerts and low-rate IoT.
NB-IoT	Narrowband Internet of Things; a low-power cellular IoT technology suited to small data packets.
NGSO	Non-geostationary satellite orbit; orbits where satellites move relative to the Earth, including LEO.
NR	New Radio; the 5G radio interface defined by 3GPP.
NR-NTN	A hyphenated form of NR NTN; 5G New Radio over non-terrestrial networks.
NTN	Non-terrestrial network; a 3GPP category covering networks using satellites or airborne platforms.
OEM	Original Equipment Manufacturer; a device maker such as a smartphone manufacturer.
Ofcom	The UK communications regulator.
Off-the-shelf device	A commercially available device that can use satellite connectivity without a dedicated satellite handset, external accessory or user-deployed terminal.
Payload	The satellite equipment that performs communication functions, such as relaying or processing signals.
RedCap	Reduced Capability; a 5G device category for lower-complexity devices between high-end smartphones and narrowband IoT devices.
Regenerative payload	A satellite payload that processes signals onboard rather than only relaying them to the ground.
Release 17	The 3GPP release that introduced the first substantive NTN baseline for NR NTN and IoT NTN.
Release 18	The 3GPP release that hardened NTN for practical deployment issues such as discontinuous coverage, paging, power saving and mobility.
Release 19	The 3GPP 5G-Advanced release extending NTN toward regenerative payloads, store-and-forward, RedCap and other advanced capabilities.
Satellite-to-IoT	Satellite connectivity directly to IoT modules or connected devices for telemetry, tracking and monitoring.
Satellite-to-smartphone	Satellite connectivity directly to smartphones, usually for SOS, messaging, location sharing or selected apps.
SCS	Supplemental Coverage from Space; the U.S. FCC framework for satellite coverage supplementing terrestrial mobile networks.
Secondary status	A regulatory operating status where a service must not cause harmful interference to primary services and may need to accept interference.
Service authorisation	Permission to offer a defined communication service within a jurisdiction.
Service continuity	The ability to maintain or resume service as a user moves between terrestrial and satellite layers, beams or satellites.
Service link	The satellite link between the user device and the satellite.
SMCS	Supplemental Mobile Coverage by Satellite; Canada's framework for mobile-satellite supplemental coverage agreements.
Spectrum	Radio frequencies used for wireless communication.
Store-and-forward	A satellite capability where data is stored temporarily and forwarded when the next link becomes available.
Telemetry	Automated measurement data sent from remote sensors, devices or systems.
Transparent payload	A satellite payload that mainly relays signals between user links and gateways without substantial onboard processing.
UE	User Equipment; the 3GPP term for a user device such as a phone, module or connected device.
Uplink	The radio path from the user device toward the satellite or network.
WRC-27	The 2027 World Radiocommunication Conference, important for future D2D spectrum decisions.

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