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This is our fourth update in as many years. In our last update, we noted that 3GPP was placing hooks in the standards for cellular mobile networks to integrate with non-terrestrial networks (NTN). The past year has seen advances in this direction as satellite direct to mobile user device initiatives have gathered momentum. In the press, this capability is often abbreviated as D2D. Let's review developments.

Apple is live with their one-way location messaging and "Emergency SOS" service that can be two-way depending on the public safety answering point capabilities. The satellite service only works on Apple iPhone 14 devices (so far) and requires the iPhone have a SIM card installed and be out of cellular and Wi-Fi range. The handset must have a clear view of the sky and to be pointed at the satellite to ensure the text transfer. The cost for the first two years of the service is currently included in the purchase price of any iPhone 14 handset. The satellite service uses **Globalstar**'s narrowband low earth orbit (LEO) constellation. Globalstar announced last year (2022) that they are acquiring 17 new satellites to replenish and extend the life of their existing 48 satellite constellation. The new satellites are under construction now for launch in 2025. Although the iPhone must be pointed toward a satellite, one of the co-authors has used the location messaging feature from the dash board of a vehicle moving at high speed.

What about service to unmodified mobile cellular mobile devices? Two companies, AST Space Mobile and Lynk Global, have prototype satellites in orbit and are conducting tests to unmodified mobile devices.

AST Space Mobile achieved the first voice call between two standard unmodified cell phones in May 2023 over their prototype BlueWalker-3 satellite which has a large 64 square meter antenna. Unmodified also means use of standard cellular mobile frequencies. AST has an agreement with AT&T to use their spectrum in the 700 MHz and 850 MHz bands. Note that use of spectrum that is allocated for terrestrial mobile needs regulatory approval. In the US, the FCC is considering rules using the term Supplementary Coverage from Space (SCS). AST plans a LEO constellation of 168 large antenna satellites – each a cellular base station tower in the sky.

Lynk Global is the first company with a D2D license from the FCC for commercial operations using frequencies in the band from 617 MHz to 960 MHz. The license covers 10 satellites. Currently 3 satellites (60 kg each) are in orbit with more launches later this year and early 2024. Depending on funding, up to 1,000 are planned for 2025, with up to 5,000 satellites being required for optimal global coverage. Each satellite beam is designed to provide 10 to 15 Mbps capacity. Lynk recently announced an agreement with Rogers Communications with the expectation that text only service will be available in Canada in 2024 when 12 satellites should be in orbit. Continuous coverage across Canada will not be available until more satellites are in orbit (maybe 2025). Rogers conducted tests over the prototype satellites in British Columbia and expects to start tests in Atlantic Canada. A similar demonstration was performed recently in New Zealand.

Starlink is among the D2D "announcements only" crowd. Starlink and T-Mobile announced plans in August 2022 to use 1.9 GHz spectrum for D2D service. In April 2023, Starlink announced an agreement with One New Zealand for D2D text message service by late 2024, with voice and internet to follow later. With the advantage of having the lowest cost per kg to LEO orbit provided by the SpaceX Falcon9 platform, Starlink is a serious contender and current satellite market leader. Starlink has over 4,000 satellites launched (May 2023) and over a million broadband internet customers in service. This is four years after starting to launch satellites (in 2019) and just two years after starting commercial service (in February 2021) when they had 1,000 satellites in orbit. Starlink provides internet globally, currently in 54 countries. Starlink has started launching "minV2" satellites that have a four-fold increase in throughput compared to the V1.5 satellites presently in service. Ookla reported that median downlink speed tests for Starlink service in 1st Quarter 2023 for various countries ranged from 46 Mbps to 110 Mbps. In addition to the usual use-cases, the Ukraine defense against Russia's invasion in 2022 is illustrating the value of ubiquitous, high data-rate and resilient communications via large constellation LEO satellites for war fighting.

In January 2023, **Qualcomm**, a leading manufacturer of mobile chipsets, announced an agreement with **Iridium**. Qualcomm is developing a Snapdragon Satellite chip with the capability of connecting mobile devices to the Iridium narrowband LEO satellite constellation, enabling D2D emergency text messaging. Subsequently in March 2023, six mobile handset makers stated they would develop products incorporating the Snapdragon Satellite chip, including **Motorola** and **Xiaomi**. Iridium is a competitor of Globalstar for voice and narrowband data LEO service. The Qualcomm and Iridium initiative should be a market level set for the Android ecosystem against Apple's Emergency SOS service. Of course, the chip's use is not limited to mobile phones – think laptops, vehicles, etc.

Inmarsat and **MediaTek** are working toward a satellite D2D play. The intent is to provide D2D text messaging following 3GPP Release 17 standards that define low bit rate connections between



satellites and user devices. Inmarsat is already a player in the mobile satellite service market. Although their satellites occupy geostationary earth orbits, resulting in longer propagation delay than LEO orbit satellites, this is not an issue for low bit rate messaging. MediaTek, a Taiwan based chip manufacturer, provides the chip for the "Motorola Defy Satellite Link" service that connects any mobile device to **Bullit's** proprietary satellite network. The MediaTek 6825 chip may be integrated into any mobile device and enable connectivity to a satellite network, adding only about \$10 to the cost. This Inmarsat - MediaTek initiative is noteworthy because: (i) it is standards based D2D; (ii) the MediaTek 6825 is proven silicon; (iii) it does not rely on launching new satellites (Inmarsat has satellites in orbit and access to spectrum); and (iv) although a clear view of the sky is necessary to work, the user device does not have to be pointed at the sky to work.

Stepping back from a focus on D2D, **what other satellite initiatives are on the horizon?** Here is a snapshot of some of the activity, some of which points to a growing realization of the strategic value of large constellation satellite infrastructure.

Announcements for **Amazon's project Kuiper** included a launch schedule and range of customer terminals. The first two prototype satellites were scheduled to launch in May 2023. However, there were problems, and the launch has been delayed, perhaps until the summer. Assuming all goes to plan, production satellites will start launching in 2024, after which beta service may be available for select customers. Customer terminals will be available for three market segments: (i) a roof mounted 30 cm square antenna weighing 2 kg for \$400 with 400 Mbps throughput; (ii) a smaller portable model supporting 100 Mbps; and (iii) a larger model supporting 1 Gbps.

Rivada Space Networks signed a \$2.4 billion contract with Terran Orbital to build 300 satellites (288 plus 12 spares) for launches beginning in 2025 and service beginning in 2026. Another 300 satellites may be added by 2028, bringing the constellation to 600 total satellites (500 kg each) and arranged in 24 LEO orbital planes. The company reportedly has access to an ITU spectrum filing in the Ka band from Trion Space.

The **O3b** mid-earth orbit (MEO) satellite constellation that is operated by **SES** is being upgraded with 11 next generation satellites. When the upgrade is complete and operational later this year, 2.5 Gbps beams will be available. The O3b inclined orbit provides coverage between 50° North and 50° South latitude. Existing customers include, for example, mobile network operators, cruise ships and Microsoft cloud services.

In March, the **European Union** approved an all-European initiative to reduce reliance on foreign satellite networks. The Infrastructure for Resilience, Interconnectivity and Security by Satellite constellation, or **IRIS²**, targets satellite launches starting in 2025 and service starting in 2027 over Europe and Africa. The purpose is to ensure resilient connectivity for security operations and to connect critical infrastructures, manage crises and to support border and maritime surveillance. The plan envisions an integrated multi-orbit constellation of geostationary, MEO and some 170 LEO satellites. Potential contractors are forming consortia to bid for the €6 billion program implementation.

China allowed private investment in the space sector starting in 2014. Although some two dozen startups announced satellite constellation related projects, not a lot actually got off the ground. However, in 2020 China filed with the ITU for spectrum allocations for two broadband satellite LEO constellations, referred to as GW-A59 and GW-2. In 2021, China formed a new state enterprise, China Satellite Network Group or simply **China SatNet**, to operate the two constellations as a single network with up to 12,992 satellites.

Conclusion: Satellite technology for consumer applications has entered a renaissance phase, and nations are recognizing satellite constellations as strategic infrastructure. Progress is impressive with new capabilities being announced, and demonstrated, at what seems to be an accelerating rate. Where are we headed? To a future where everyone everywhere with a cellular mobile device will be connected to everyone and everything else all the time. And that's a good thing, right? OK, maybe consider that a work in progress. The authors are confident that the technology and sector are safe bets; however, availability of capital and spectrum, and market size at achievable price points, likely mean a few more bankruptcies and some more consolidation.

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