Results from Rapid Testing of Space-based Mobile Network Technology

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ABSTRACT

Lynk (formerly UbiquitiLink) is building a network of small satellites to provide affordable cellular coverage to unmodified cellular devices, enabling messaging, data, IoT, and emergency communications everywhere on the planet. This paper will discuss the details of the approach for Lynk's technology development program to-date. Since December 2018, test spacecraft Lynk 01, Lynk 02, Lynk 03, and Lynk 04 have all been launched to orbit and tested.

Lynk flies new space hardware every ~6 months to incrementally space qualify our LEO-to-phone space technologies. Each 6-month cycle includes the design, fabrication, assembly, and test of a new spacecraft iteration before handover for launch. During initial technology development, Lynk has leveraged the ISS and NASA's cargo resupply (CRS) missions; these missions offer frequent and affordable access to orbit in support of Lynk's rapid prototyping and agile development timelines.

These spacecraft have enabled Lynk to conduct the world's first orbiting cell tower demonstrations for a space-based cellular network. In a very short period, the test program has already successfully demonstrated critical functionalities needed for satellite-to-phone messaging initially using GSM technology; LTE is next. Tests have demonstrated connectivity from a satellite to unmodified cellular devices using frequencies already in use by common cellular phones. The discussion of technical achievements will include: link budget verification and payload validation; software development to project and coordinate test site overpasses; transmission from satellite over specific test sites; and demonstration of a "cellular network in a box" creating a private network cell within a beam focused on the Earth. A review of the challenges experienced, the implications for the testing program, and the solutions implemented will be included.

INTRODUCTION

Lynk's innovative approach to technology development has enabled an agile and rapid advance toward demonstrating the core technologies needed to deploy a space-based cellular network *which is backward compatible for the cell phone in everyone's pocket around the planet.*

The company's core technology is a software modification to a typical telecom software stack for LTE, GSM, and/or other 3GPP technologies. The initial step in the Lynk technology development roadmap was to develop, test, and demonstrate the ability of our proprietary telecom stack modifications to handle the Doppler shift and the propagation delay experienced between a standard cell phone and an orbiting satellite. Without these changes the phone would not work with a spaceborne "tower". Our objective was to prove that we could move telecommunications traffic between a base station (or cell tower) in orbit and an unmodified standard cell phone on the ground. To achieve this goal, two critical objectives must be met: 1) write the software that can complete the connection, and 2) design and develop a spacecraft system that can fly it in orbit to conduct a successful field demonstration.

The technical and programmatic approach is to push the limits on space mission timelines and development cycles – squeezing design, build, test, flight iterations into time periods shorter than 6 months. To accommodate this schedule, the team made use of existing platforms and technologies as best it could to bootstrap the Lynk technology development roadmap. To that end, the first several missions have leveraged both commercial off-the-shelf components, some open source software, and hosted payload platforms. To-date, Lynk has now launched 4 different payload and spacecraft design iterations in just under 15 months.

Access to orbit is abundant via cargo resupply (CRS) missions to the ISS. As such, the initial Lynk technology demonstration missions were flown to the ISS on these launches. Our six-month design, build, test cycle was synchronized to match the six-month CRS launch cadence.

To-date Lynk has launched all space hardware on Space-X cargo resupply missions, and each unit has been installed at station onto the SEOPS Slingshot deployment system on the docked nose of the Cygnus cargo resupply spacecraft .

TECHNOLOGY DEVELOPMENT

In April 2018, Lynk began work on the first space mission design iteration, to be handed over in October for launch in December of the same year. To go from nothing to a fully functioning spacecraft payload in this timeline with a new team was aggressive, and making the first iteration was the hardest. To support the initial development cycles, a simpler, hosted payload architecture was selected. This choice allowed the focus of technical energy to be spent on the payload knowing that the team could utilize reliable and well-proven bus functionalities for T&C, power, attitude control, etc.

Lynk flew it's first three missions as hosted payload missions on the Cygnus spacecraft. Figure 1 describes the mission CONOP for the first three hosted payload missions

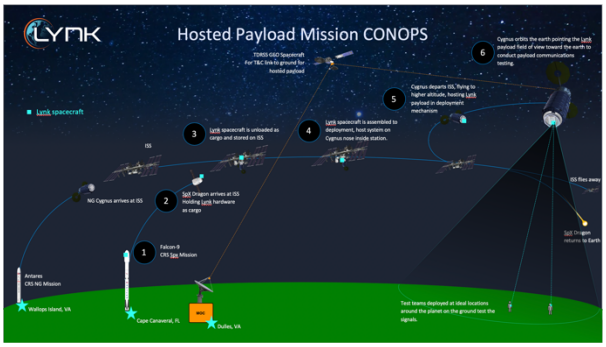

Figure 1 - Lynk hosted payload mission CONOPS

After the initial three hosted payload missions, Lynk began developing the systems required to upgrade the payload into a free flying spacecraft itself – adding critical bus functionalities such as attitude control, T&C, and power systems to support the payload.

The following sections outline the specific Lynk technology missions flown to date.

LYNK TECHNOLOGY MISSIONS

The Lynk technology missions have been conducted on rapid timelines. The following discusses the technology development schedule, mission operations, and results.

Lynk 01

The Lynk 01 Mission was flown to the International Space Station (ISS) on the CRS-18 SpaceX mission on December 3, 2019. The design phase for the hardware began in April 2018. At that time, Lynk only had single board computers and software defined radios under test with the payload software. No flight hardware had been designed or developed.

The hardware for the first hosted payload was rapidly designed, prototyped, integrated, tested, licensed, and put through the ISS Safety Review process in approximately 6 months.

Lynk handed over the Lynk 01 payload on October 10, 2018 – 2 months prior to launch - at the Johnson Space Center in Houston, TX.

Approximately 2 months after launch to the International Space Station, the Lynk 01 payload was attached, along with the SEOPS Slingshot system, to the exterior of the nose of the Cygnus Spacecraft. Shortly after assembly, in February 2019, the Cygnus spacecraft departed ISS to complete a 2-week hosted payload mission with the Lynk 01 payload. Testing began on February 8 and ended on February 25, 2019.

Figure 2 shows some of the Lynk technical team at hardware handover for the Lynk 01 mission.

Figure 3 shows some images of Lynk 01 taken from orbit as well as images of test sites in New Zealand and Falkland Islands.

Figure 2 - Lynk team at hardware handover of Lynk 01 payload.

Figure 3 - Images from Lynk 01 testing and operations

For this mission, RF spectrum usage licenses were acquired across 9 countries and 40 unique test sites. Site surveys confirmed the suitability of the selected site locations, and several sites became repeat destinations for subsequent missions.

The Lynk 01 mission operations were focused mostly on demonstrating our ability to appropriately command the payload to turn on at the right time, frequency, and power for each test session. Ground teams were focused on validating payload RF front end performance with signal measurements on the ground.

The expectations for the first mission results were low, yet the payload performed quite well. The RF front end performance and system link budgets were verified. Peak signals during each overpass were within 1 dB of what Lynk predicted based on in-house link budget models. During these tests, cellular devices were recorded being able to receive and camp on downlink control channels. This is the first step in the call flow process for sending telecommunications traffic between mobile devices and the network.

These field tests proved key functionalities of the payload as well as the company's ability to conduct tests around the globe even with a small team. Despite the short mission duration and short time between missions, these tests also guided design changes in the subsequent Lynk 02 spacecraft which was under development during the Lynk 01 flight.

Figure 4 is an image taken of a spectrum analyzer in the field during Lynk 01 testing.

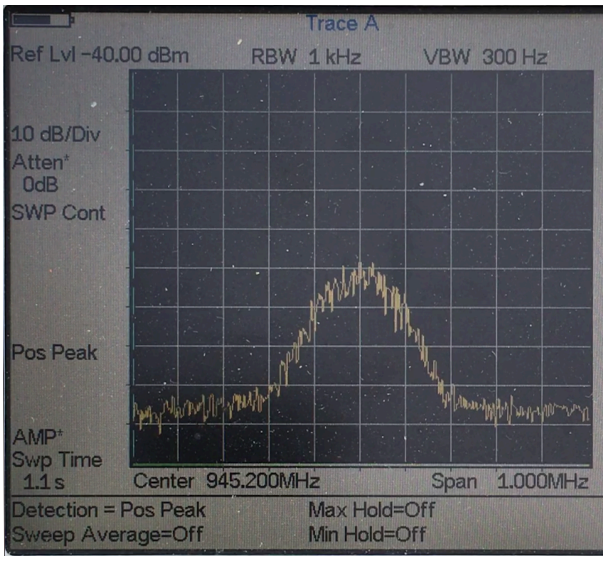

Figure 4: Spectrum analyzer capture of GSM transmission from Lynk 01 testing in New Zealand

Lynk 02

The Lynk 02 payload was an iteration based on the lessons learned from the development of the Lynk 01 payload. The design of the Lynk 02 payload began in December 2018, shortly after the Lynk 01 payload was launched to the ISS. After the completion of the Lynk 01 mission in February 2019, there remained approximately three months until the Lynk 02 hardware handover date. This time allowed for some lessons learned from mission operations to be easily adapted into the Lynk 02 design.

After an initial development cycle of the payload, the team iterated on the design and implemented several upgrades. Some upgrades included, an improved RF front end with better performance (which can also accommodate nearly all GSM and LTE bands below 1 GHz). In addition to front end improvements, an additional flight computer and software-defined radio option were selected to be tested. The flight software architecture was improved to be more robust and allow the payload to be fully reprogrammed and reconfigured while on orbit. The payload mechanical layout was also redesigned to accommodate a smaller form factor.

The Lynk 02 payload was designed, prototyped, assembled, tested, licensed, and put through the NASA safety review process in less than 5 months. The hardware was turned over to Johnson Space Center in Houston, TX on May 10, 2019.

Figure 5 shows some of the Lynk technical team at hardware handover of the Lynk 02 payload.

Figure 5 - Image of Lynk team at Lynk 02 handover.

As with the previous mission, the Lynk 02 payload was affixed to the nose of the Cygnus Spacecraft two months after the payload's launch to the ISS. In August 2019, the Cygnus spacecraft departed ISS to complete a six-month hosted payload mission with the Lynk 02 payload and other hosted payloads. This was a good opportunity to determine how the payload performed during longer-term testing. The mission began on August 3, 2019 and ended on December 5, 2019.

Figure 6 shows an image of Lynk 03 on orbit assembled to the nose of the Cygnus spacecraft.

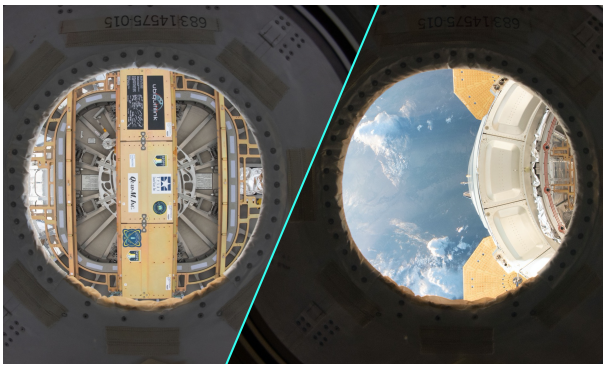

Figure 6 - Images of Lynk 03 assembled to nose of Cygnus spacecraft and leaving station

Field testing of the Lynk 02 spacecraft was conducted by teams in many countries. Data collected on the ground provided valuable information about the performance of the updated RF payload in the LEO environment, much of which informed the design of the Lynk 03 payload which was under development concurrently with the Lynk 02 mission.

Additionally, the Lynk 02 mission demonstrated our ability to handle commanding, collect telemetry, and reprogram flight and payload computer software through and inter-satellite link between the payload and a commercial communications constellation. This capability is a critical part of our technology roadmap and plays a large role in later designs.

Lynk 03

The Lynk 03 payload was a very similar payload to Lynk 02. The payload design process began in June 2019, with handover planned for November 2019. Since the design, development, and testing phase of the Lynk 03 mission overlapped with Lynk 02 mission operations, allocating technical resources was a challenge, but one that offered the opportunity to focus on payload improvements most associated with improving mission operations, and command, telemetry, and data handling.

Lynk 03 was originally intended to be a free-flying satellite, but as development progressed on this new design, it became clear more time would be needed to complete a flight-worthy free-flying spacecraft. Fortunately, the build process Lynk established in its first and second missions permitted flexible allocation of addition time to free-flier development while still leaving time to deliver flight hardware for the planned Lynk 03 launch date. Since the Lynk 02 flight unit had been built alongside an identical flight spare and a flatsat, we were able to deliver the Lynk 02 flight spare (with relatively minor modifications and improvements) on time for the Lynk 03 mission launch.

Lynk 03 was turned over on October 22, 2019 in Houston, TX.

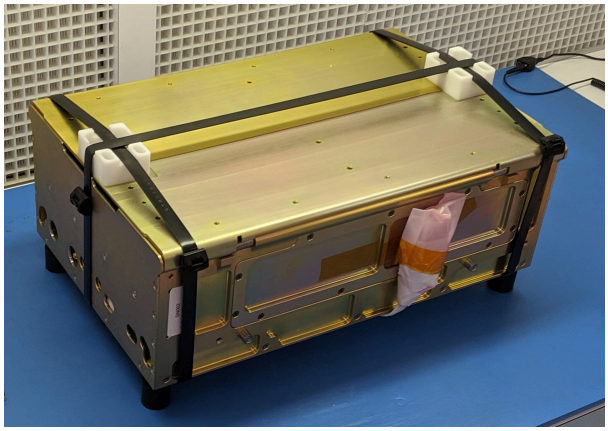

Figure 7: Lynk 03 awaiting vibration testing

The Lynk 03 payload launched to the ISS on December 4, 2019 on the CRS-20 SpX mission. The Lynk 03 hosted payload was assembled to the nose of the Cygnus spacecraft two months later in February 2020, which

then departed the ISS for a three-week mission hosting the Lynk 03 payload.

Figure 8 shows an image taken of the Lynk 03 payload on orbit assembled to the nose of the Cygnus spacecraft.

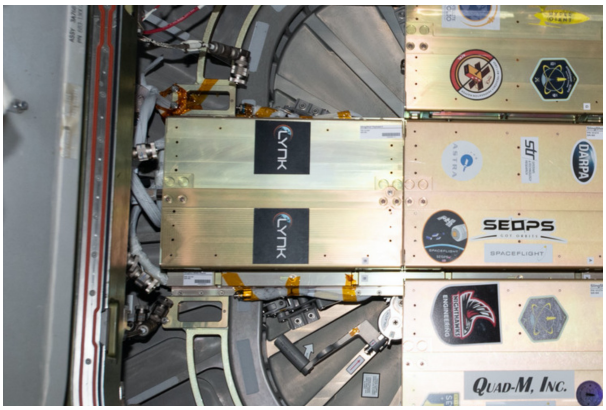

Figure 8 - Lynk 03 payload assembled to nose of Cygnus inside ISS.

The Lynk 03 mission was planned to only last three weeks but was extended by another month, allowing extensive additional ground testing at sites around the world.[1] Due to the unexpected mission extension, the Cygnus spacecraft was limited to TDRSS-only communications for the latter portion of the mission, but the operators and the Lynk team were able to accommodate a large number of tests in a variety of payload configurations nonetheless. During this extended mission, Lynk teams successfully demonstrated the first space-to-ground cellular broadcast, proving a key functionality and product demonstration on the company's technology roadmap. It was also an opportunity to demonstrate this achievement to independent third parties who were on hand to witness this test.

Figure 9 shows a screenshot image of a successful SMS message delivered to a standard smartphone from the Lynk 03 hosted payload. The medium for message delivery was the SMS cellular broadcast channel. Lynk released a recording of the world's first text message sent from a satellite in orbit to a standard ordinary phone in March 2020[2].

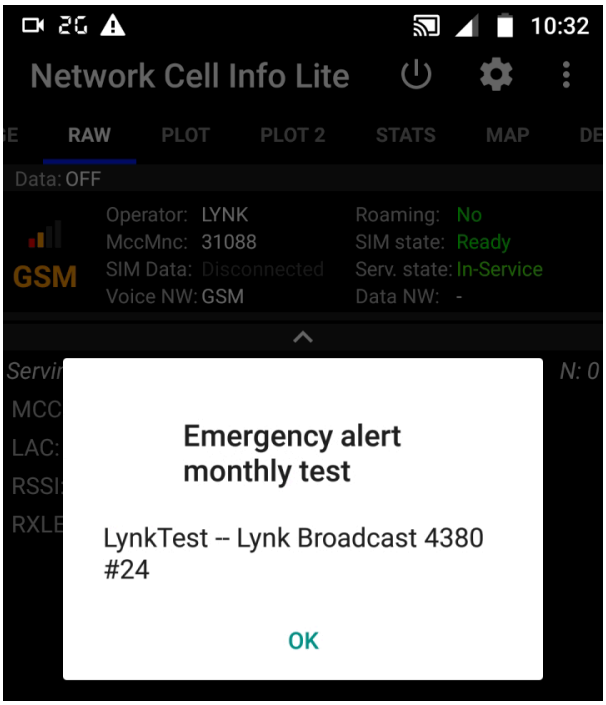

Figure 9: Screenshot from a consumer cell phone receiving data from the Lynk 03 orbiting cell tower

Lynk 04

The Lynk 04 mission is the company's first small satellite free flier. The free flier design drew heavily on the prior hosted payload design implemented in Lynk 03. The additional systems to provide TT&C, attitude control, and power generation and storage, were the focus of the design and development phase for this mission. The payload stayed largely unchanged, except for minor modifications.

Lynk 04 was turned over on January 30, 2020 in Cape Canaveral, FL.

Figure 10 shows a picture of some of the Lynk team with the Lynk 04 spacecraft at Lynk facilities in Falls Church, VA.

1 https://spacenews.com/cygnus-mission-extended-for-tests-of-communications-payload/

2 https://www.theverge.com/2020/3/18/21184126/lynk-mega-constellation-text-message-android-smartphone-cell-towers-space

Figure 10 - Lynk team prior to Lynk 04 ship to handover in Florida

The Lynk 04 spacecraft launched to the ISS on March 4, 2019 on the CRS-21 SpX mission. In May 2020, the Lynk 04 spacecraft deployer was mounted to the interior nose of the Cygnus spacecraft and released after Cygnus left station.

Lynk 04 is currently under early operations and test at the time of this writing.

Public Benefits

A major benefit of the Lynk network is that it will provide an automatic, instantaneous backup communications layer everywhere on Earth. We have seen cellular systems go down around the world due to hurricanes, wildfires, earthquakes, and terrorism. Lynk allows people to call/text 911 for help, allows emergency responders to coordinate their efforts, and allows people to let family and friends know their status – all with the phone in their pocket

Lynk has already demonstrated one-to-many message communications from a satellite in orbit to an unmodified mobile phone on the ground. This technology enables cellular broadcast messages, the same as used for tornado warnings, hurricane updates, and Presidential alerts. By incorporating the Lynk system, warnings can reach everyone, no matter how close they are to the city or a well-travelled roadway. Lynk has already proven the technology required to save lives by sending alerts, and messages, to anyone that is located anywhere around the globe.

Conclusion

Since February 2019, Lynk has conducted four orbital missions to test its cellular network technology in space. Three early hosted-payload missions that flew aboard ISS resupply vehicles enabled a fast and flexible design process, which led to a free-flying satellite in the Lynk 04 mission. In each mission, the flight unit has been exercised on orbit and the cellular network functionality tested by field teams on the ground, all with the goal of validating prototype spacecraft hardware and software subsystems. With four successful launches behind us, the Lynk team is turning its focus toward Lynk 04 testing, and the Lynk 05 mission currently under development. Future flights are planned to complete the path down the company's roadmap toward building out a global constellation of small satellites enabling accessible communication everywhere on Earth. And with a terminal that customers already own!

Lynk would like to recognize the help provided by the Northrop Grumman ISS resupply team, SEOPS, and NASA.