5G Backhaul Integration of LEO JoeySat Satellite

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CONTEXT

This work was carried out as part of the SUNRISE partnership project between European Space Agency, Eutelsat OneWeb, and ourselves at the University of Surrey

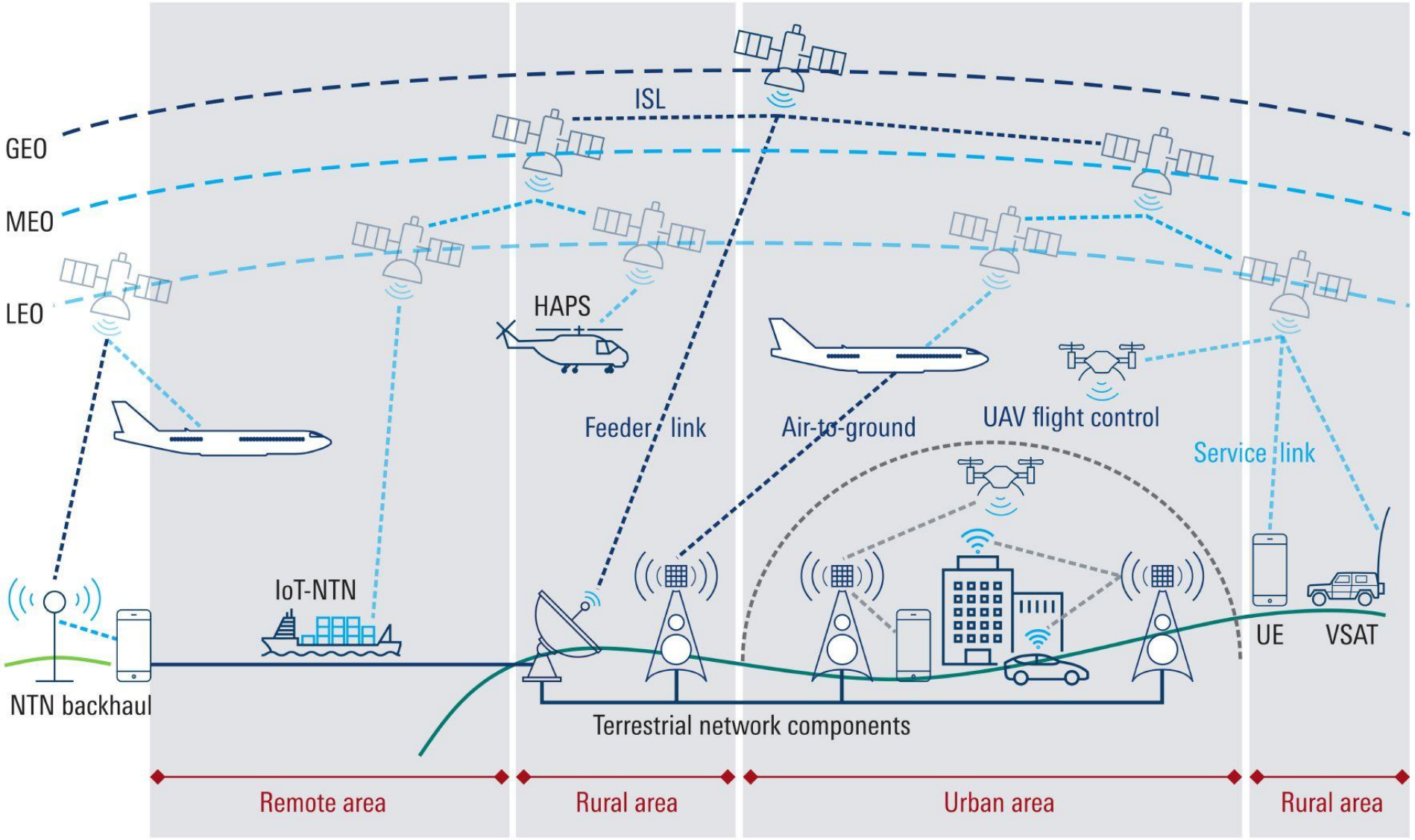
We have already integrated the OneWeb Gen 1 LEO constellation into a 5G cellular network
[Fitch M, Evans B, Allen B, Girault N.'Integrating a 5G network with a LEO satellite constellation-Sunrise5G Pilot tests' ICSSC/Ka band satellite conference, Bradford UK, October 2023]

Here we describe the next stage in the project:
Integration of a single LEO in-orbit demonstrator representative of a regenerative multi-beam satellite. The satellite is nick-named JoeySat.

The satellite link goes in the 'backhaul' between the CN and the RAN base-stations (gNBs).

Direct to UE (Uu) over satellite is not in the scope of this project.

NON-TERRESTRIAL NETWORK (NTN) GENERAL DIAGRAM



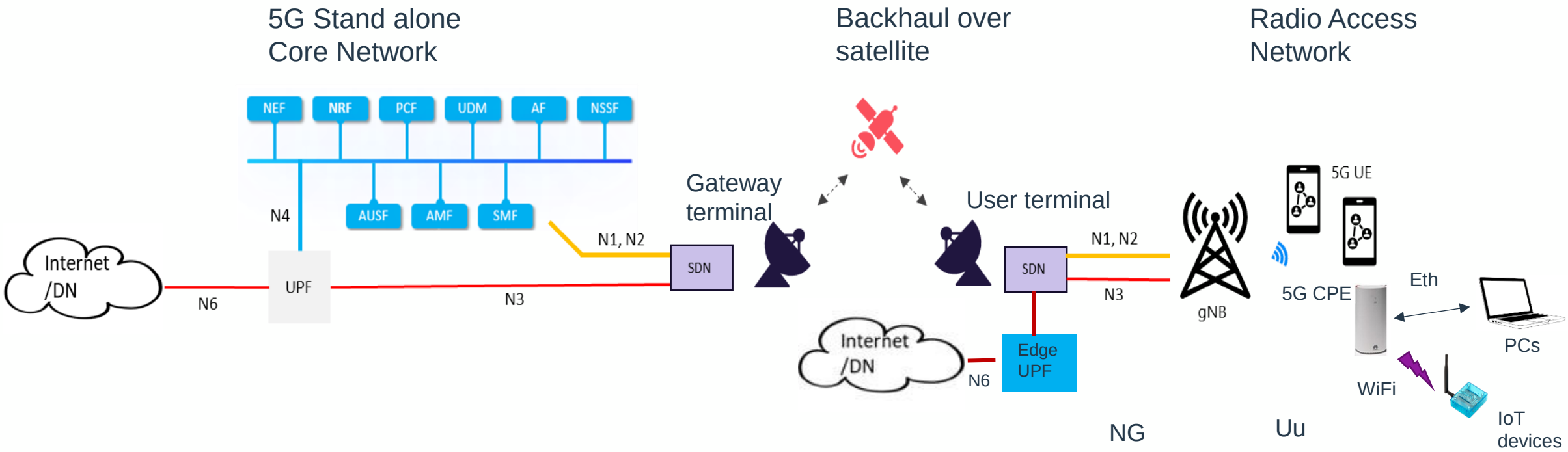
35800km

2000km – 20,000km

< 2000km

Stolen from Rhode and Schwarz website

5G STAND ALONE NETWORK WITH SATELLITE IN BACKHAUL (GENERIC DIAGRAM)



N1 and N2 towards AMF, plus N4 N9 if multiple UPFs (control plane)

Radio bearers

N3 PDU session(s), GTP-U tunnel(s) towards UPF

Edge UPF

CN UPF

End to end slice, UE to UPF (allocation of resources)

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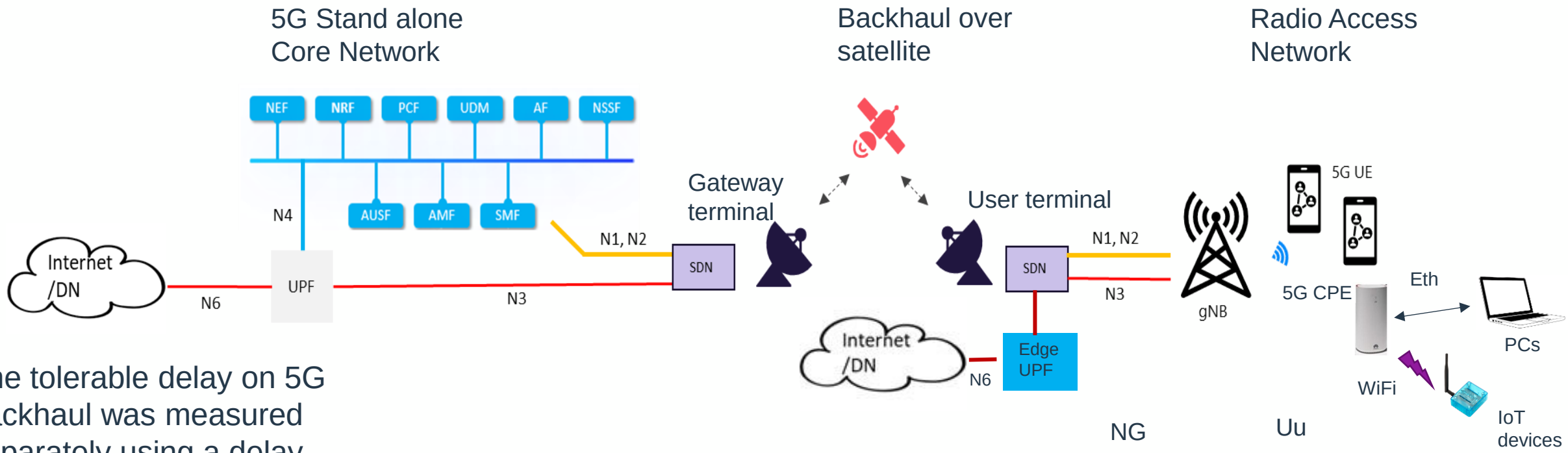

The tolerable delay on 5G backhaul was measured separately using a delay emulator, and is of the order of 2 seconds RTT before the gNBs and UEs won't connect.

N1 and N2 towards AMF, plus N4 N9 if multiple UPFs (control plane)

Radio bearers

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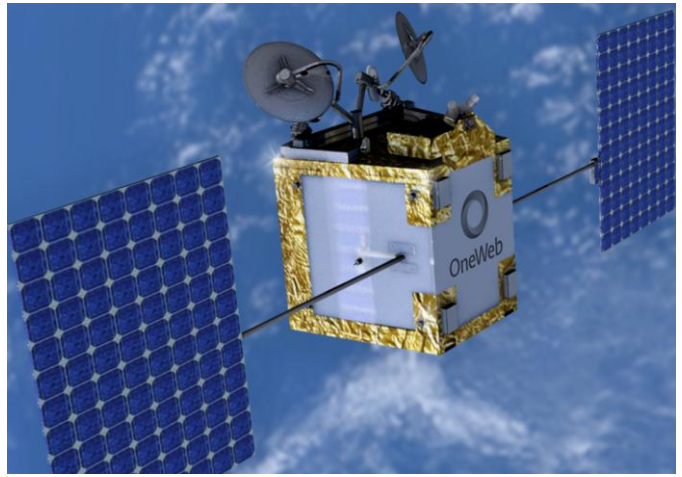
JOEYSAT



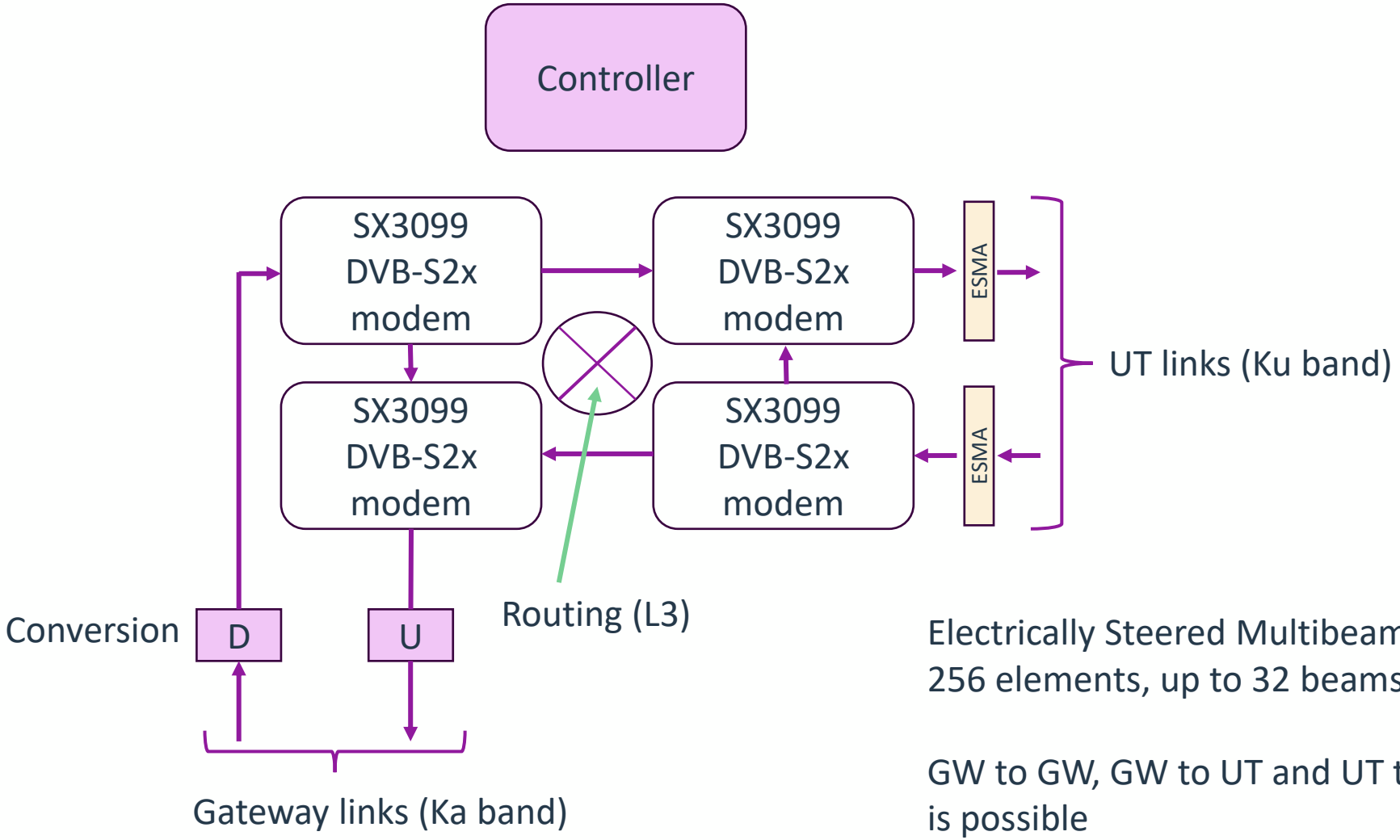
Launched May 2023:

- Single satellite operated by Eutelsat OneWeb,
- Same satellite platform as OW Gen 1 constellation,
- Mass 150kg, about the size of a domestic fridge,
- Payload power 100W,
- Feeder links Ka band,
- User links Ku band,
- Near polar orbit at 625km altitude (right now being raised to 1200km)

JoeySat representative of next generation systems:

- Regenerative payload (demodulation / modulation and on-board routing), whereas OW Gen 1 satellites are analogue transparent,
- Uses DVB-S2x waveform on all links, OW Gen 1 uses SC-FDMA derivative,
- Has electronic multi-beam steering antennas on user links dynamically pointing to four user sites, current system has fixed beams,
- Has beam hopping capability, two pairs of user beams can hop up to 1000 times per second (but we did not use BH in the tests),

JOEYSAT PAYLOAD

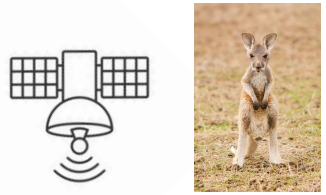


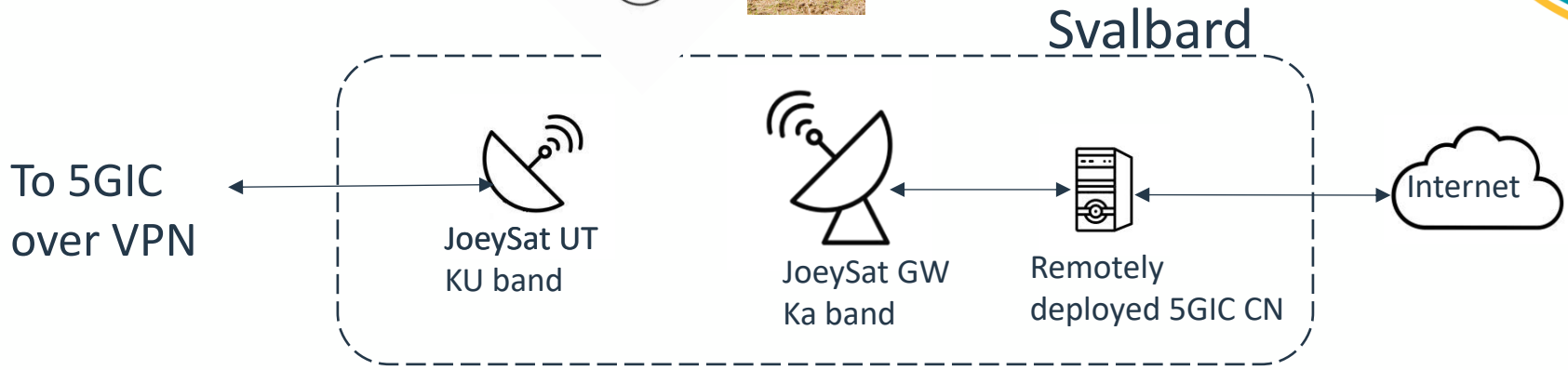
Electrically Steered Multibeam Arrays
256 elements, up to 32 beams [UT links]

GW to GW, GW to UT and UT to UT routing is possible

Payload built by Satixfy (MDA Space)

JOEYSAT GATEWAY AND UT ARE BOTH AT SVALBARD



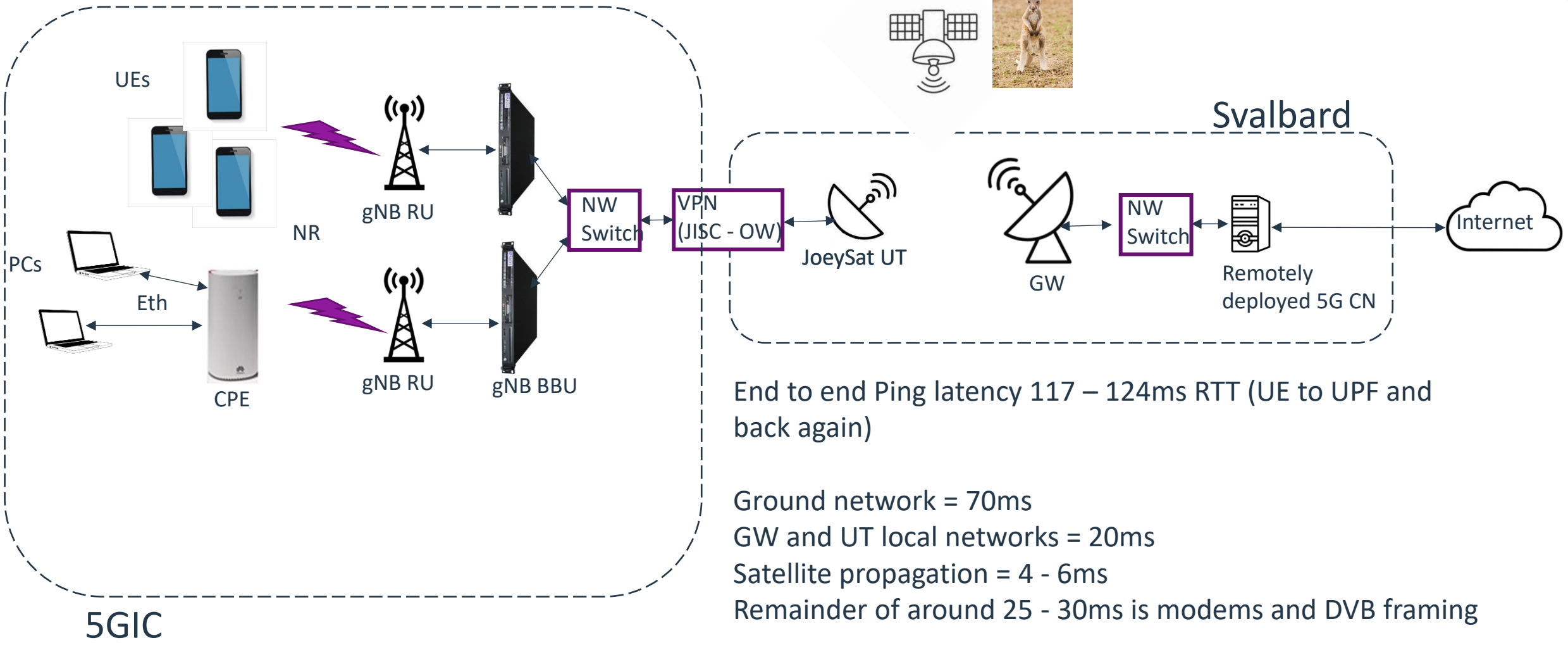


Both gateway and UT are at Svalbard Norway, co-located to maximise pass times,
JoeySat passes are around 3 – 4 minutes, 4 – 5 times a day,

Modulation rate was 5Mbaud, and we used mostly QPSK with 2/3 coding, resulting in a maximum bit-rate of approx. 6.5Mbit/s on both forward and return links. This very low capacity will be scaled up in future generations,

At the end of the test campaign we tried higher mod / cod, that was 16APSK with 4/5 coding where the expected user link bit-rate was 16Mbit/s.

JOEYSAT INTEGRATED IN BACKHAUL



End to end Ping latency 117 – 124ms RTT (UE to UPF and back again)

Ground network = 70ms
GW and UT local networks = 20ms
Satellite propagation = 4 - 6ms
Remainder of around 25 - 30ms is modems and DVB framing

IPERF Results for Forward Link, UPF to UE

iPerf Server (iperf3 -s)

Server listening on 5201

```
-----------------------------------------------------------
Accepted connection from 10.45.0.3, port 42098
[  5] local 10.5.0.80 port 5201 connected to 10.45.0.3 port 42104
[ ID] Interval           Transfer     Bitrate       Retr  Cwnd
[  5]   0.00-1.00   sec   393 KBytes   3.22 Mbits/sec    0   60.1 KBytes
[  5]   1.00-2.00   sec   314 KBytes   2.57 Mbits/sec    0   69.6 KBytes
[  5]   2.00-3.00   sec   188 KBytes   1.54 Mbits/sec    0   79.2 KBytes
[  5]   3.00-4.00   sec   188 KBytes   1.54 Mbits/sec    0   90.1 KBytes
[  5]   4.00-5.00   sec   502 KBytes   4.12 Mbits/sec    0    104 KBytes
[  5]   5.00-6.00   sec   251 KBytes   2.06 Mbits/sec    0    139 KBytes
[  5]   6.00-7.00   sec   691 KBytes   5.66 Mbits/sec    0    194 KBytes
[  5]   7.00-8.00   sec  1005 KBytes   8.24 Mbits/sec    0    270 KBytes
[  5]   8.00-9.00   sec  1.35 MBytes   11.3 Mbits/sec    0    365 KBytes
[  5]   9.00-10.00  sec   942 KBytes   7.72 Mbits/sec    0    479 KBytes
[  5]  10.00-10.28  sec  0.00 Bytes    0.00 bits/sec     0    51  5 KBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate       Retr    ------
[  5]   0.00-10.28  sec  5.72 MBytes  4.67 Mbits/sec    0     sender
-----------------------------------------------------------    ------
```

Raw iPerf results

Average = 4.67Mbit/s

IPERF Results for Return Link, UE to UPF

iPerf Server (iperf3 -s)

```
 Server listening on 5201
-----------------------------------------------------------
Accepted connection from 10.45.0.3, port 43268
[  5] local 10.5.0.80 port 5201 connected to 10.45.0.3 port 42200
[ ID] Interval           Transfer     Bitrate
[  5]   0.00-1.00   sec  77.8 KBytes   637 Kbits/sec
[  5]   1.00-2.00   sec   235 KBytes   1.92 Mbits/sec
[  5]   2.00-3.00   sec   158 KBytes   1.30 Mbits/sec
[  5]   3.00-4.00   sec  76.5 KBytes   626 Kbits/sec
[  5]   4.00-5.00   sec  69.6 KBytes   570 Kbits/sec
[  5]   5.00-6.00   sec  56.0 KBytes   459 Kbits/sec
[  5]   6.00-7.00   sec  56.0 KBytes   458 Kbits/sec
[  5]   7.00-8.00   sec  57.3 KBytes   470 Kbits/sec
[  5]   8.00-9.00   sec  42.3 KBytes   347 Kbits/sec
[  5]   9.00-10.00  sec  51.9 KBytes   425 Kbits/sec
[  5]  10.00-10.14  sec  8.19 KBytes   487 Kbits/sec
- - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bitrate         --------
[  5]   0.00-10.14  sec   889 KBytes   718 Kbits/sec       receiver
-----------------------------------------------------------  --------
```

Raw iPerf results

Average = 718kbit/s

Uplink from UT is less reliable that downlink resulting in packet losses, adaptive mod-cod (AMC) was not used.

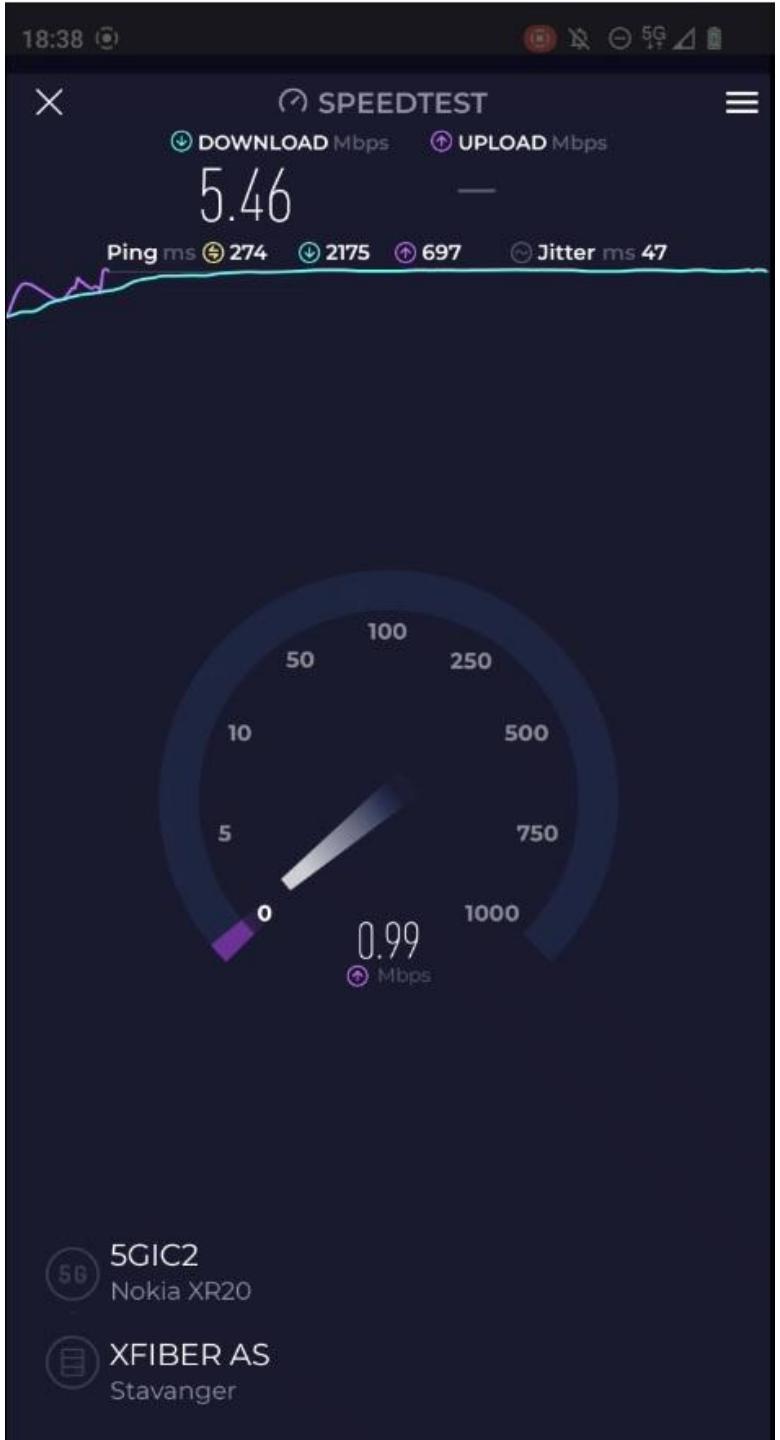
Two example speed tests from connected UE

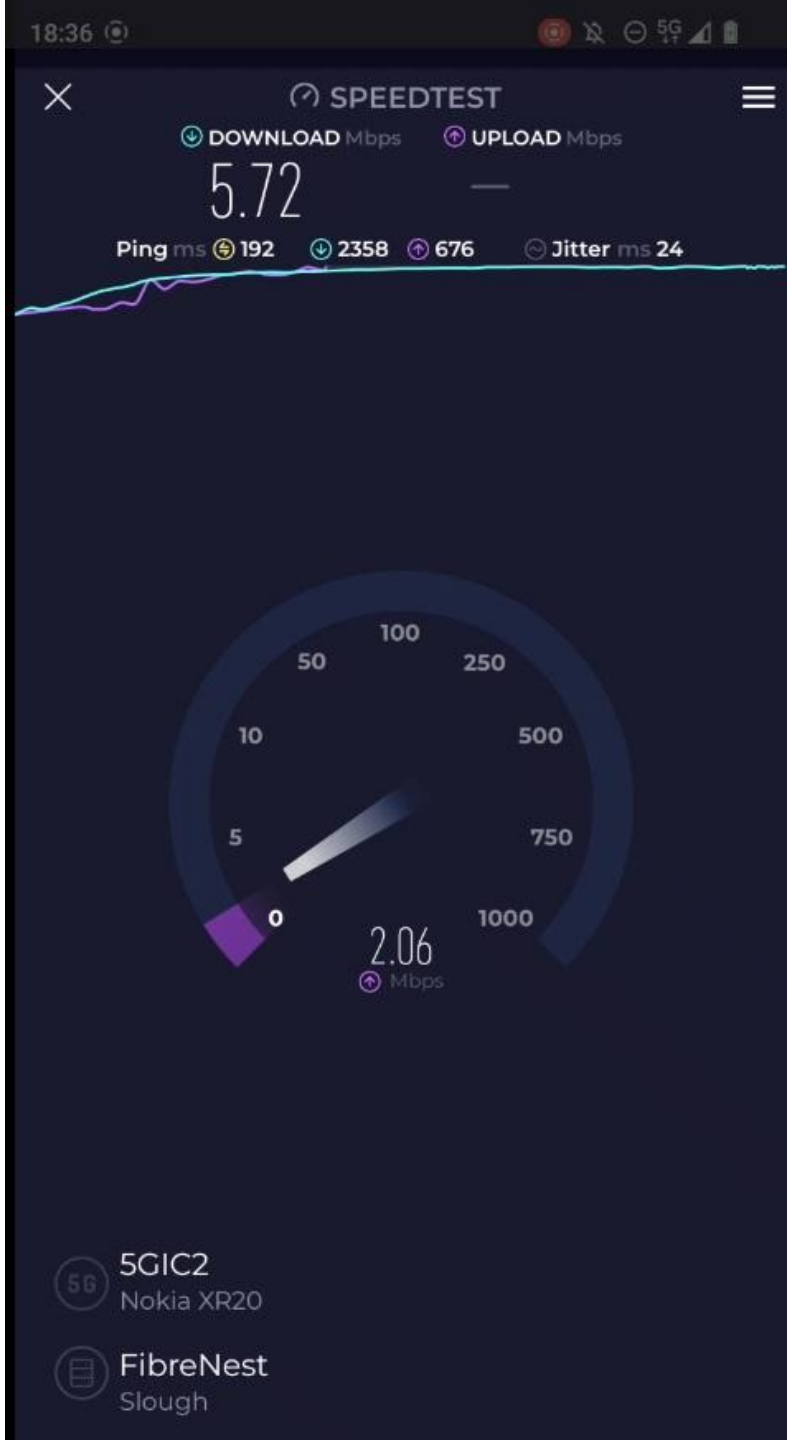
Left:

DL 5.46 Mbit/s
UL 0.99 Mbit/s

Right:

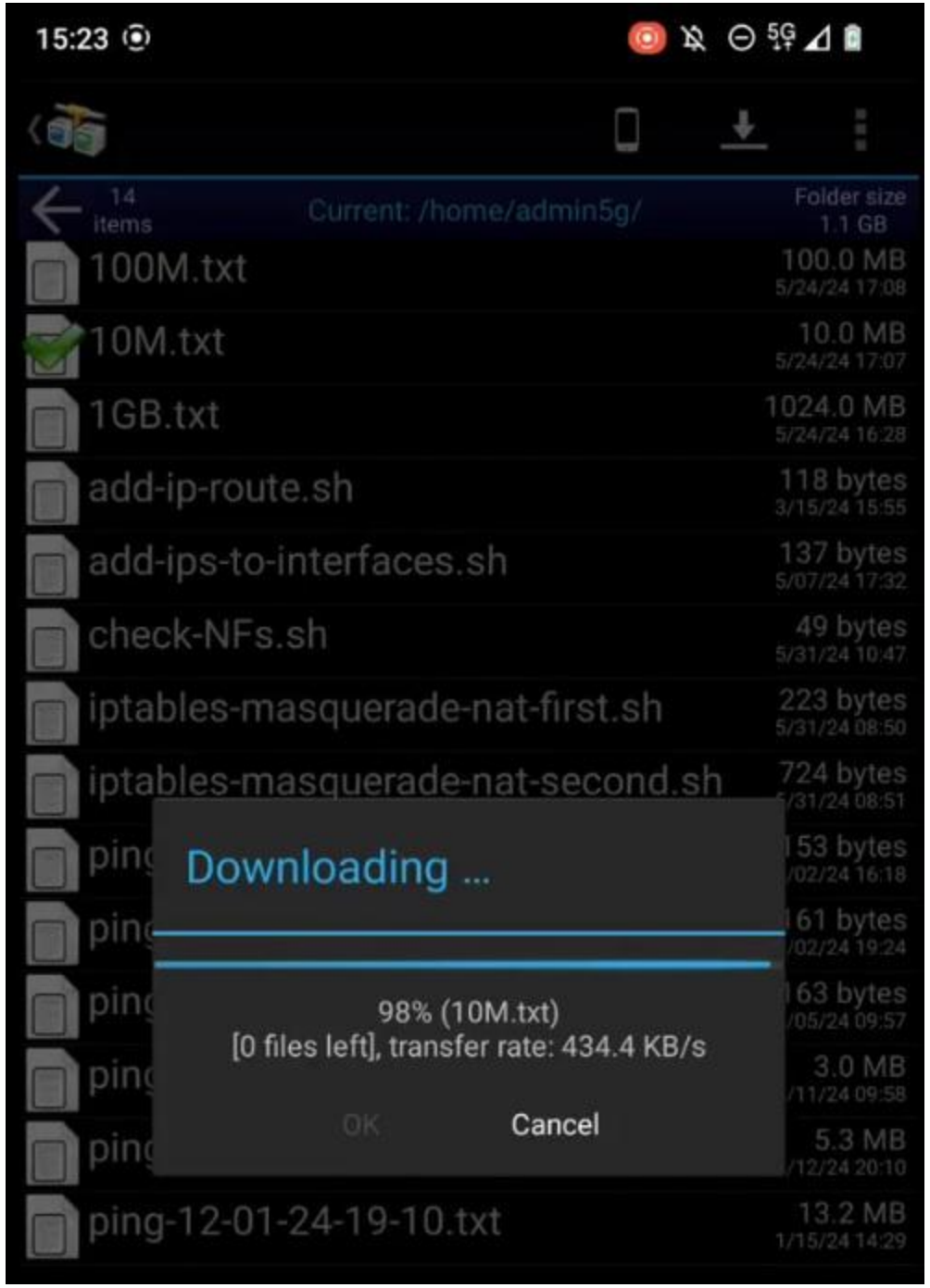
DL 5.72Mbit/s
UL 2.06Mbit/s



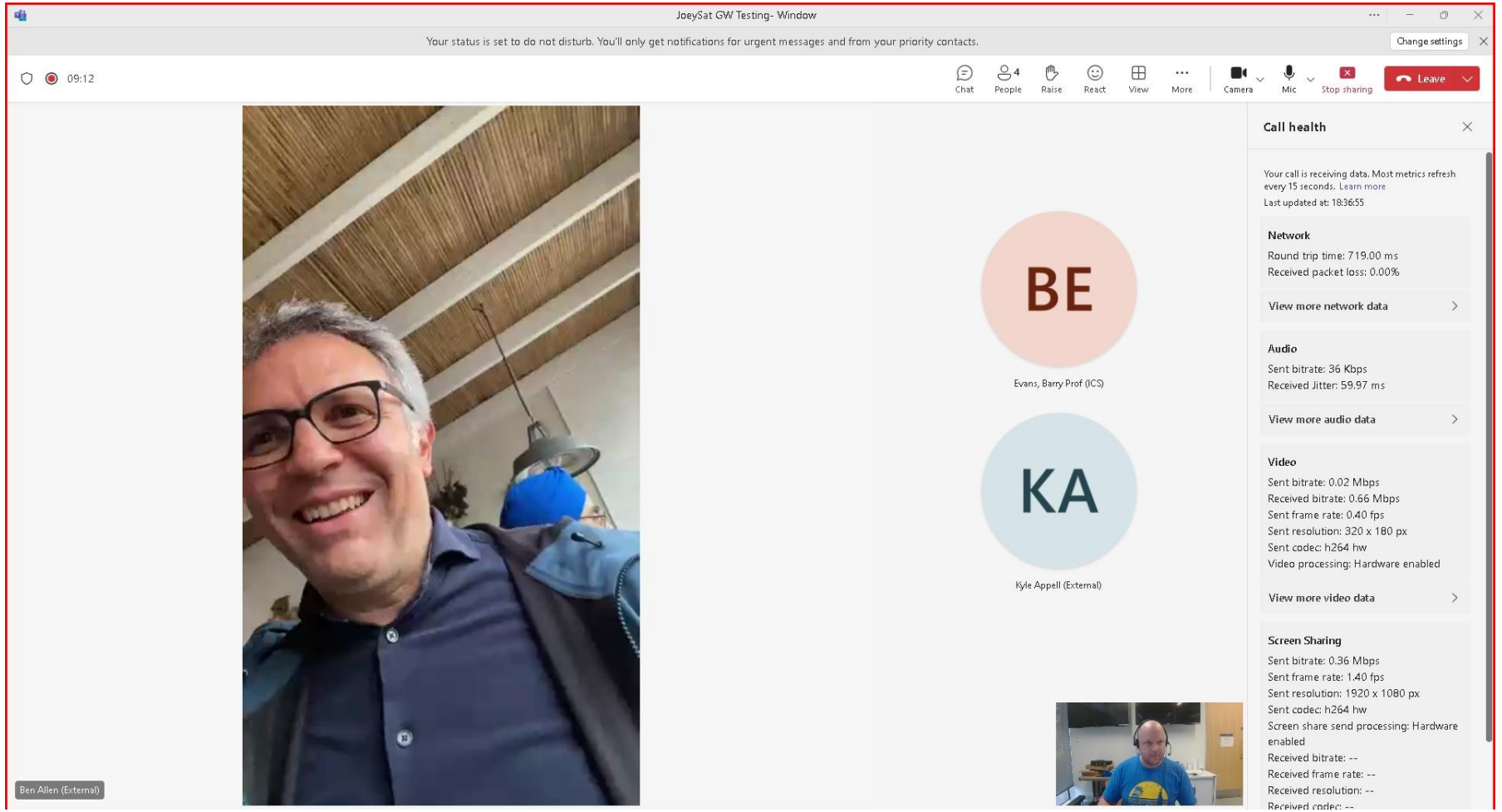


File Download
Rate = 434.4KB/s

(3.5Mbit/s)



TEAMS VIDEO CONFERENCE



Video conferencing (TEAMS) Between UE at 5GIC and UE in London

Call health log: Audio 36kbit/s, Video 700kbit/s

HIGHER MOD-COD

At the end of the test campaign, we managed one speed test at higher mod / cod, that was 16APSK with 4/5 coding where the expected user link bit-rate is 16Mbit/s

We achieved 10.33Mbit/s on the forward link, less than expected because of packet losses on a marginal link quality

We did not succeed with a return link measurement because the satellite link was not sufficiently stable.

Learnings from JoeySat to future LEO systems

- Regenerative LEO satellites can be used successfully in the backhaul of 5G networks, and AMC is needed to preserve link stability on forward and return links,

- In the case of JoeySat, the end to end latency was around 125ms (round trip) made up of 30ms in the DVB-S2x modems, but this may be reduced with a higher symbol rate that would be used in future commercial systems,

- The ground network latency was around 90ms, but this would typically be less if the gateway and user terminals are closer to the 5G network (CN, RAN).

- The end to end latency of a LEO system should support applications that require latencies of a few 10s of ms. Applications that require very low latency require edge UPF, since the satellite ground network latency is a significant proportion of the total. Applications that are tolerant to high latencies of say 600ms RTT can be carried over GEO satellite if this option is available in 3D- NTN.

NEXT STEPS

- JoeySat has just arrived at its higher altitude of 1200km. We will be repeating the end to end and use-case tests over the next month, and write up,

- SUNRISE phase 3 has kicked off where 3D NTN in backhaul is evaluated, and GEO and LEO satellite links are available including JoeySat. Neutral Hosting, 5G Slicing, Orchestration and Interference Mitigation are the four main topics of SUNRISE 3. Watch out for updates over the next year.

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