Test Resource Management Center (TRMC)

National Spectrum Consortium (NSC) / Spectrum Access R&D Program

FRN Project Summary and Next Steps

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Flightline Radio Network

Goals

- **High Throughputs**: With the rapid increase in the amount of telemetry data being collected on test aircraft and with the spectrum crunch faced by test ranges, the demands of real time data streaming are taxing the capabilities of existing systems.
- **Free-up SST Resources**: Currently, SST resources are used to stream telemetry data when the test aircraft is on the ground. Use of SST resources while an aircraft is on the flightline prevents the use for aeronautical mobile telemetry. Using separate radio resources for flightline and aerial use will improve the efficiency and capacity of the test range network.
- **Flightline/Hangar Coverage**: In addition to the capacity issues noted above, existing SST ground stations do not have line of sight RF coverage over the entire flightline area and when aircrafts are in hangars, which limits the areas on the flightline where real time telemetry streaming can be done.

Approach

- Use commercial 4G LTE-A cellular technologies in non-congested C-Band spectrum. High spectral efficiency of LTE can offer high throughputs for streaming telemetry data.
- Develop a FRN network coverage plan to provide 4G LTE-A service in the Flightline, Runways and Hangar areas.
- Develop autonomous and manual methods to handover telemetry streaming to an SST radio link when the aircraft transitions to an airborne test segment and use the FRN network when the aircraft is on the ground.

Key Technology Challenges

- C-Band coverage for the target areas of the flightline
- TMoIP over LTE network
- Handover from/to uni-directional SST radio links

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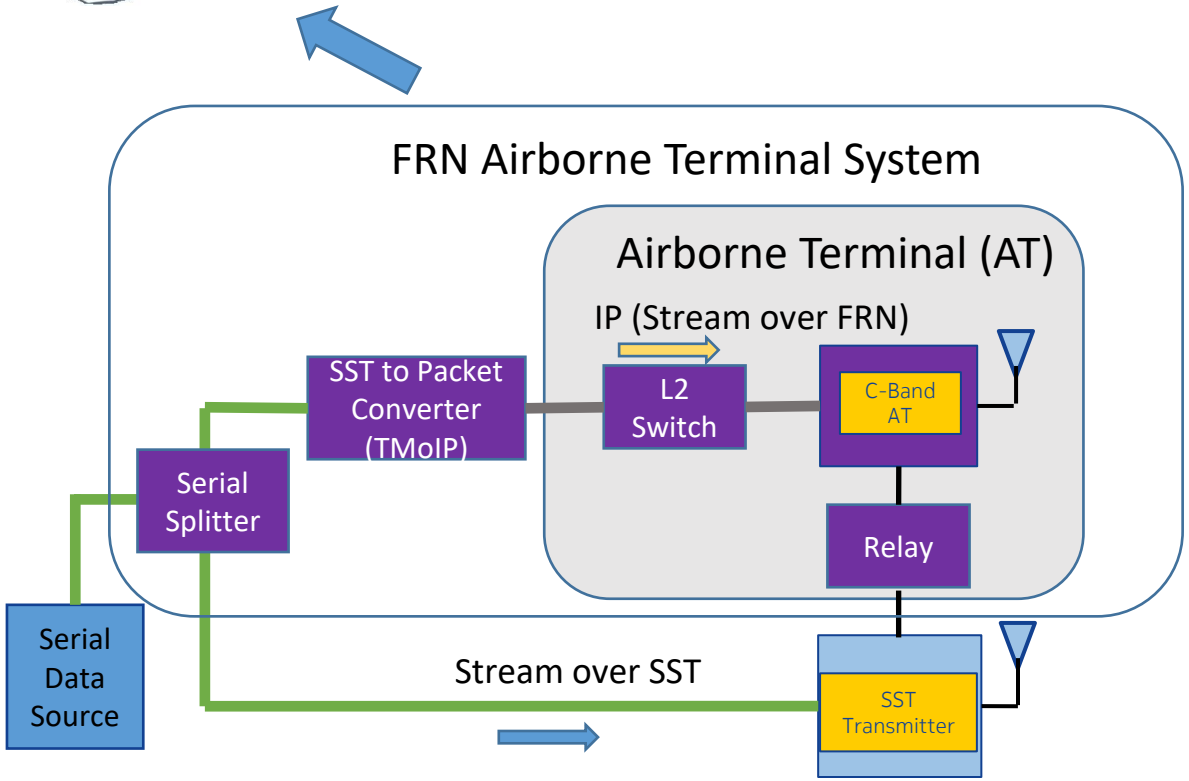
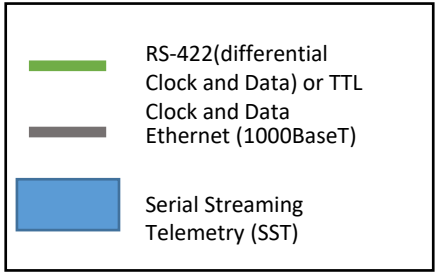
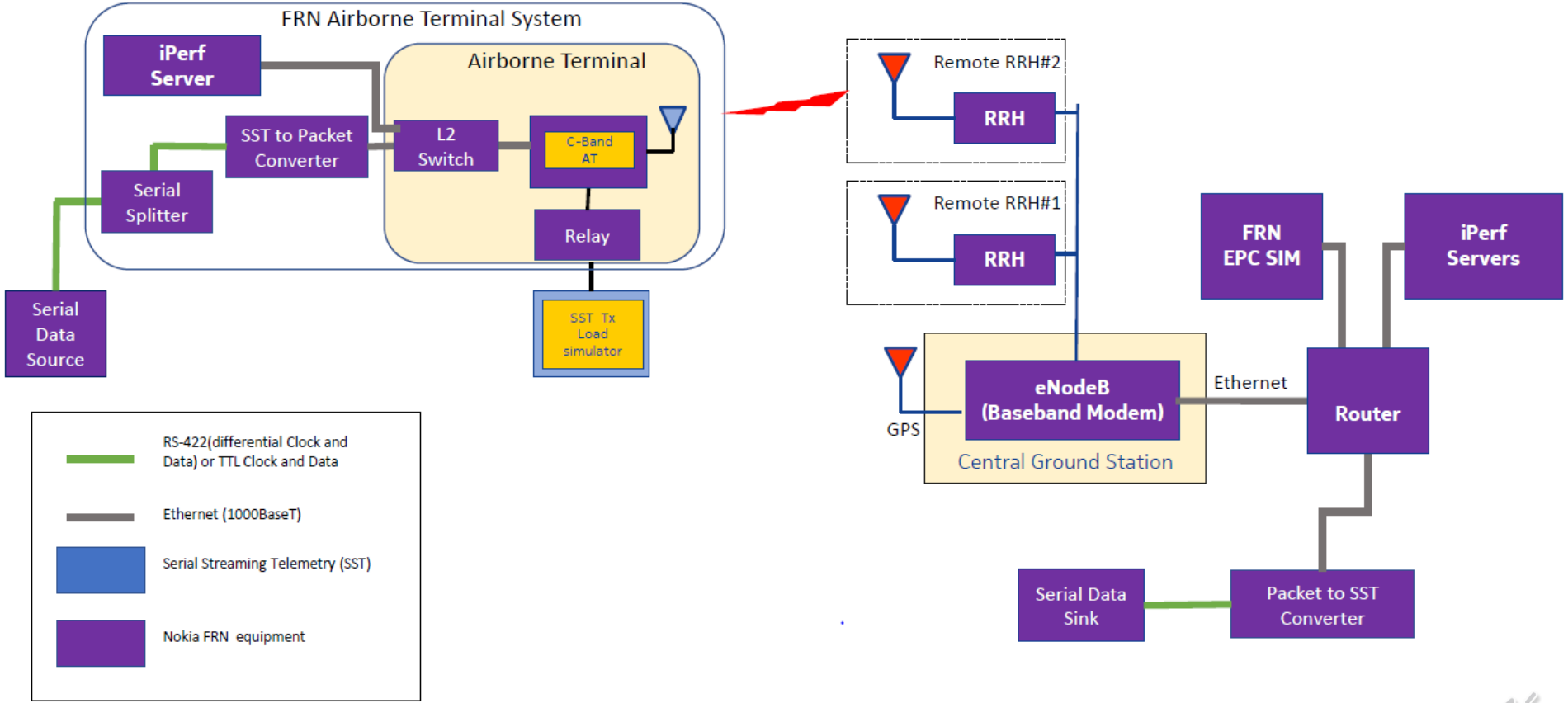
FRN Airborne Terminal





FRN Network Diagram for the Demo



SST – FRN Handover: Concept of Operation

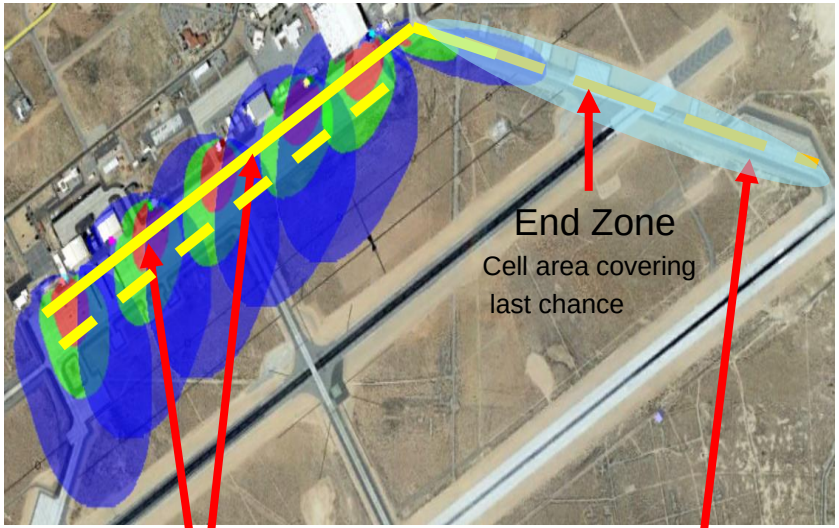
1. Test Aircraft in Hangar: Telemetry stream path is over FRN
   - FRN AT is connected to FRN network
   - SST transmit is OFF
2. Test Aircraft moving in FRN: Telemetry stream path is over FRN
   - SST transmit is OFF
   - LTE Handovers maintain connectivity. No change in data path
3. Test Aircraft at Last Chance: Telemetry stream path is over FRN and SST
   - SST is turned ON by FRN AT
   - MMCR verifies SST stream is OK and can initiate switch to stream over SST.
   - MMCR issues “OK to TakeOff” command
4. Test Aircraft takes off: Telemetry stream path is over SST
   - SST transmit is ON
   - FRN LTE connection remains ON. The LTE connection drops when the aircraft has gone out of coverage of FRN network
5. Test Aircraft ready to land: Telemetry stream path is over SST
   - SST transmit ON
   - FRN AT has no connection to FRN network
6. Test Aircraft lands and reaches last chance or in end zone: Telemetry stream path is over FRN and SST
   - FRN AT automatically establishes connection to FRN network
7. Test Aircraft completes FRN connection establishment: Telemetry stream path is over X.1
   - If FRN AT is configured for automatic handover, then SST transmit is turned OFF, else can be instructed by MMCR to switch over to FRN by issuing “Ok to Land” command.
   - MMCR monitors X.1
8. Test Aircraft moving in FRN: Telemetry stream path is over FRN
   - SST transmit OFF
   - LTE Handovers maintain connectivity as aircraft moves towards hangar

❑ Ok to take-off command can be remotely executed from ground control or from Pilot

FRN Over-the-Air Layout for the Demo

Planned FRN Coverage at EAFB

- "Last Chance": 1.7 to 2 Km
- Tarmac areas: 0.5Km



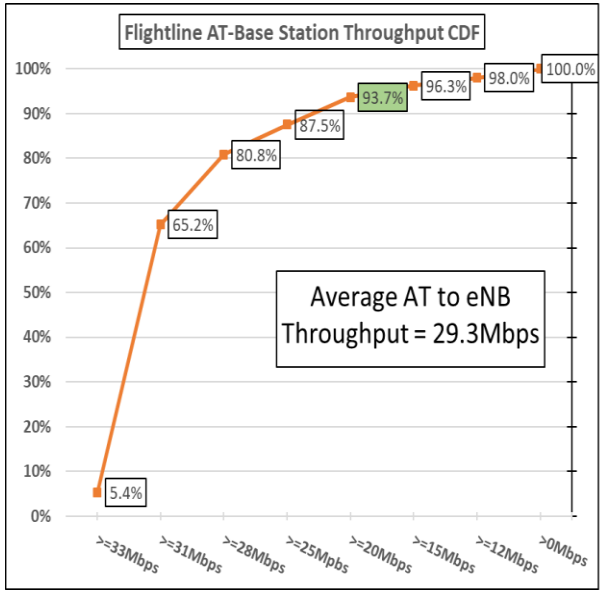
Drive testing in Naperville

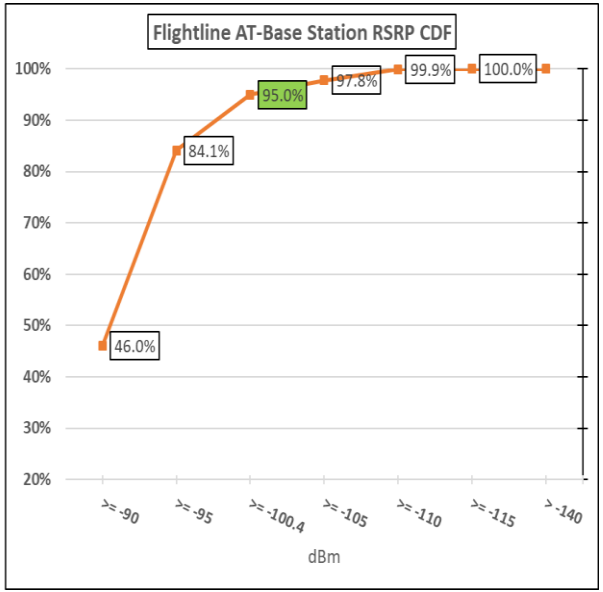
- ~0.5km range is similar to EAFB "Flightline" environment
- ~2.2km is similar compared to EAFB "Last Chance"

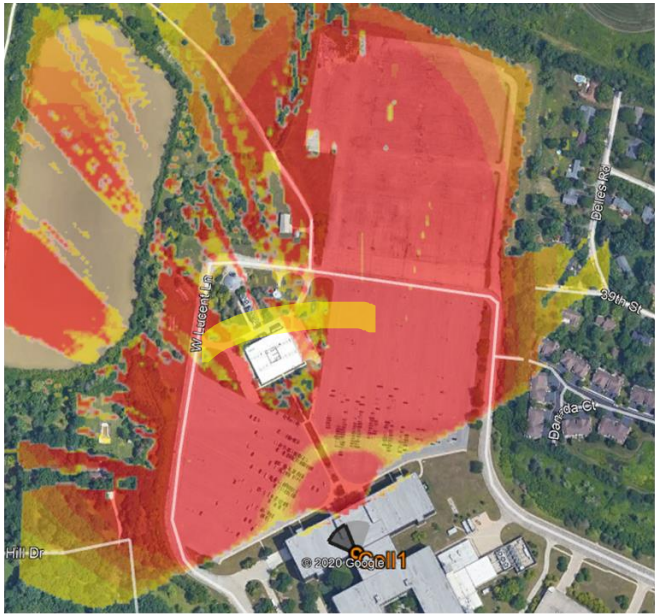
- Non end zone cell "Flightline"
- Nokia Office
- End zone cell "Flightline"
- Last Chance location

FRN Coverage Results

Drive Data Measured >20Mbps 93.7%
Target was 20Mbps



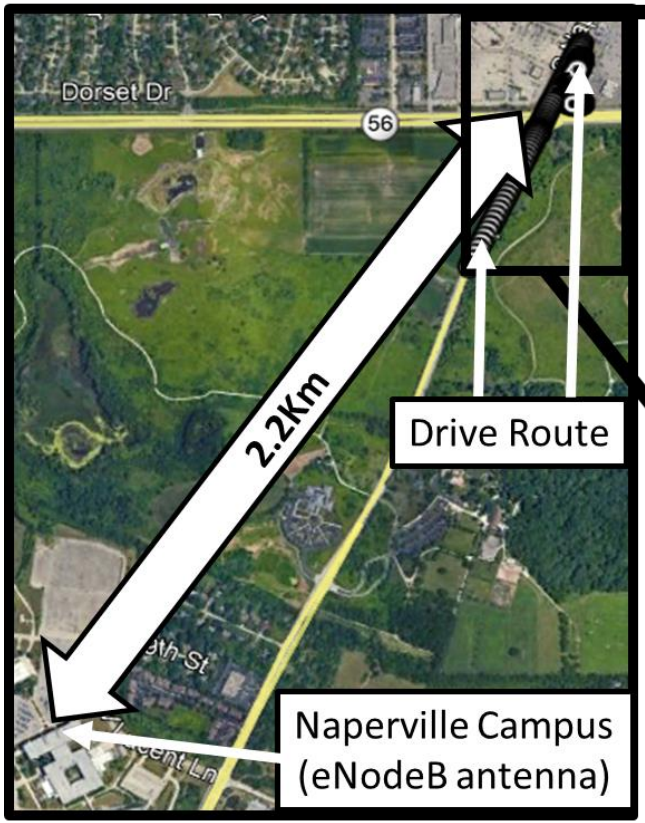


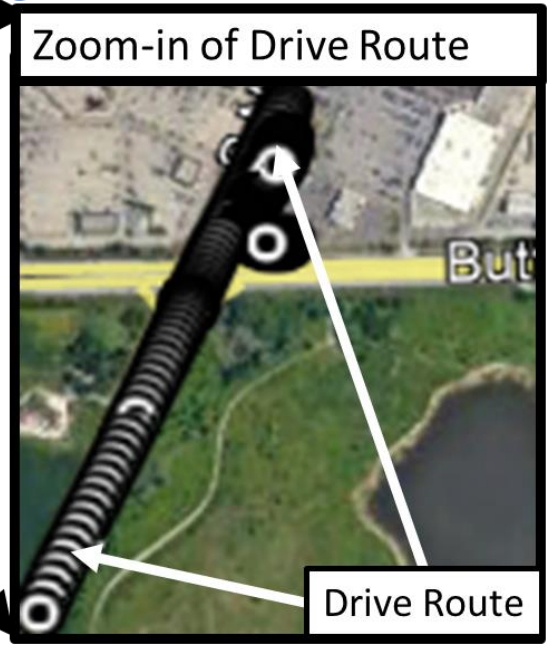


Copy of Naperville Crosswave Uplink User Throughput 20mb

- Effective RLC Throughput per User (UL) (kbps) >=33,000
- Effective RLC Throughput per User (UL) (kbps) >=30,000
- Effective RLC Throughput per User (UL) (kbps) >=27,000
- Effective RLC Throughput per User (UL) (kbps) >=24,000
- Effective RLC Throughput per User (UL) (kbps) >=20,000

FRN coverage at Last Chance



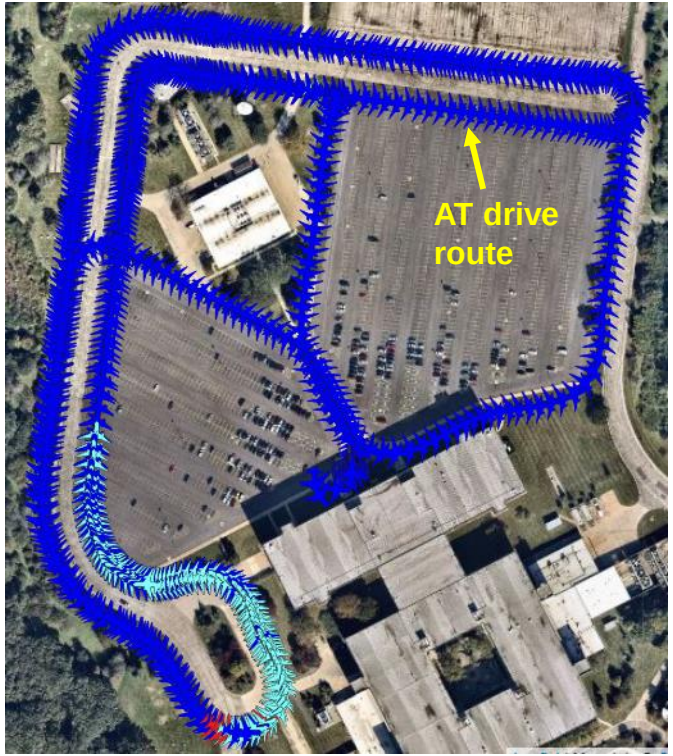


Drive Data Measured 1.75Mbps

RF design target was 500Kbps to 3Mbps
The variance is due to foliage in the drive route

- Proposed antenna-to-Last Chance distance at EAFB was 1.7-2Km.
- Area tested in Naperville is 1.7-2.2Km and includes some unavoidable foliage loss (results will be conservative relative to EAFB Last Chance).

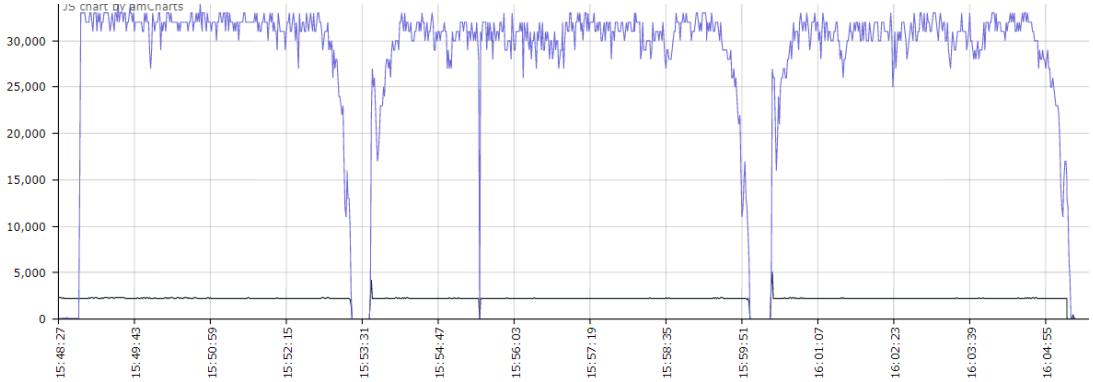
FRN AT to Network (Uplink) Throughput



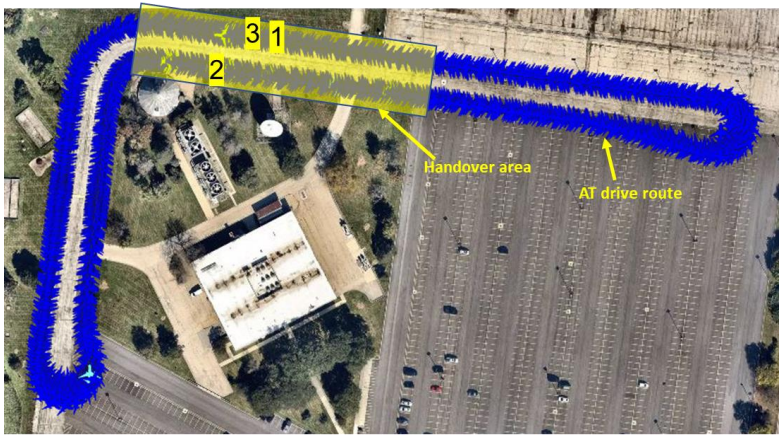
Objective: Demonstrate Single Cell throughput

Setup: Offer UL/DL rate of 35/2M from iPerf

Results: **Verified maximum expected throughput of 32Mbps**



FRN Handover and Latency performance



FRN_END_ZONE

Objective: Demonstrate Inter Cell Handovers

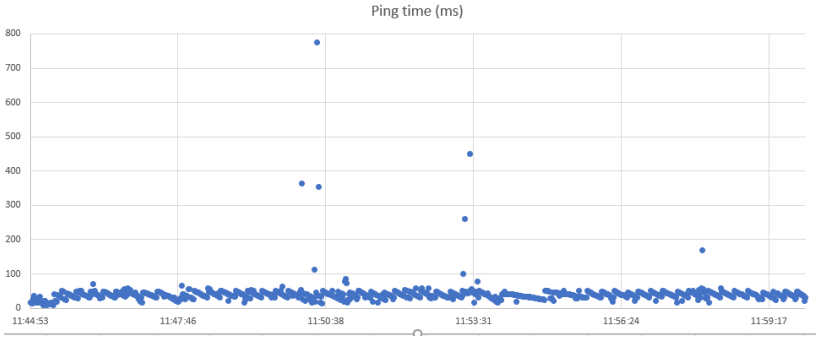
Setup: Offer UL/DL rate of 35/2M from iPerf

Results: **Handover success rates > 95%**

Objective: Demonstrate Packet Latency

Setup: Offer UL/DL rate of 35/2M from iPerf

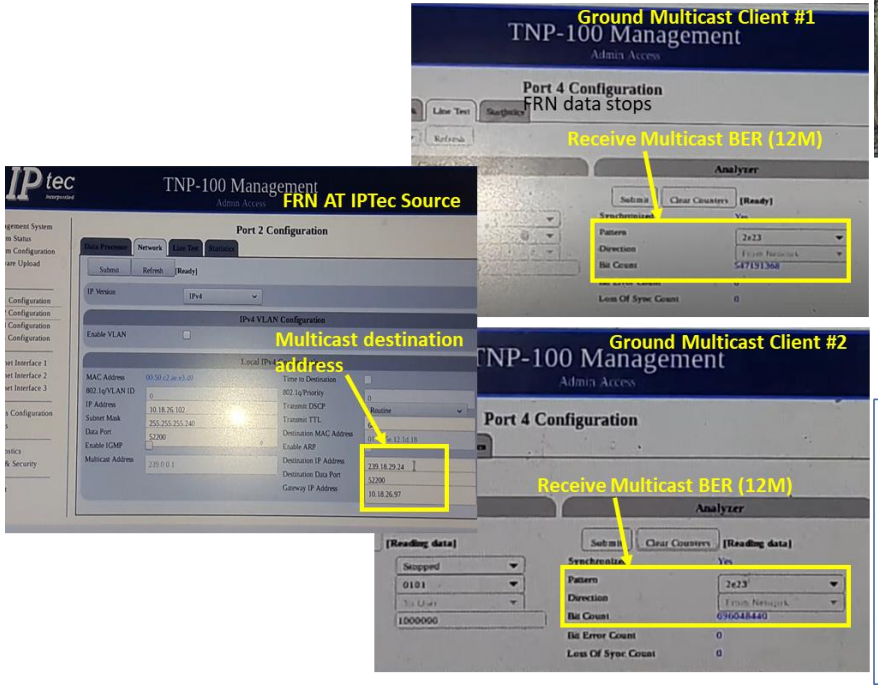
Results: **98% of time round trip latency(RTT) < 60 msec and 93% of time < 50msec**

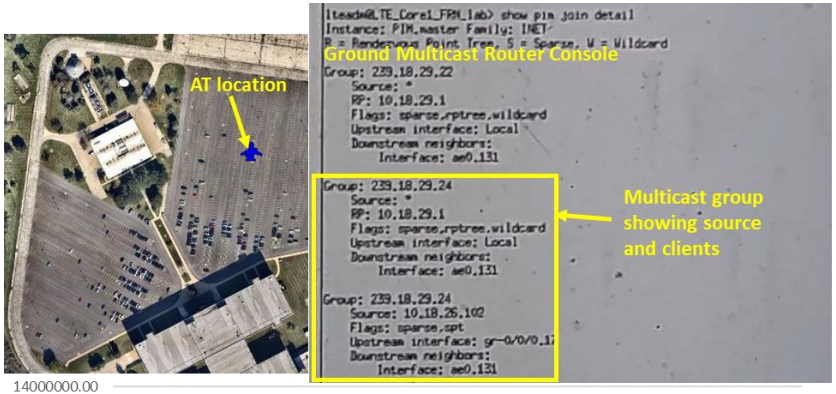


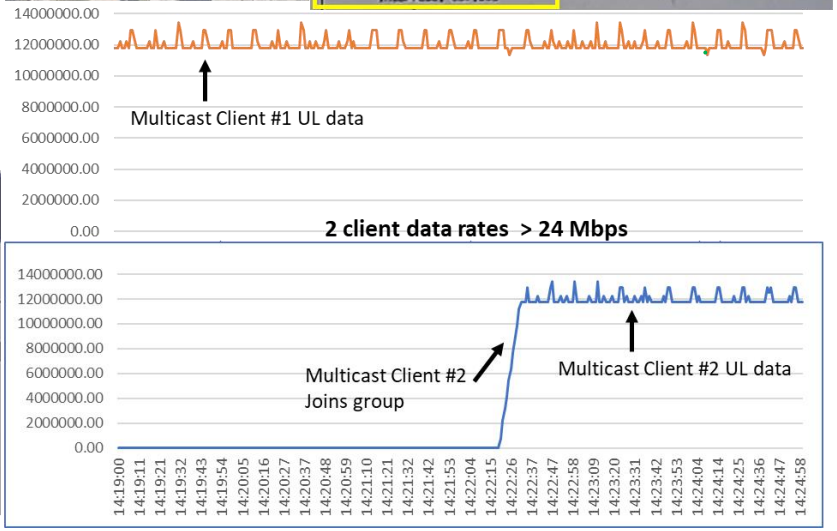
Multicast Streaming over FRN

Result:

- ✓ **Demonstrated single IPTec data stream from FRN-AT can be seen on 2 clients simultaneously**



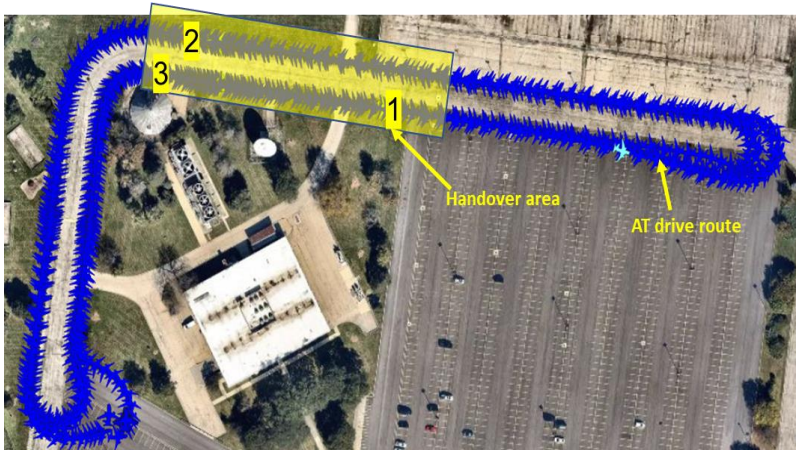




FRN –SST Handover Take-off and Landing CONOPS

Takeoff CONOP

- FRN/SST Auto handover
  - FRN AT FRN and SST modes set to auto.
  - FRN AT connected to non-End Zone cell
  - FRN AT enters End Zone cell, SST Tx automatically enabled
- FRN/SST ground control-based handover
  - Similar to above except SST Tx enabled by ground command regardless of FRN AT location
  - “Ok to Takeoff” issued similar to above
- Manual Override Switch
  - SST Tx enabled and FRN disabled regardless of AT location.



Landing CONOP

- FRN/SST Auto
  - FRN AT FRN and SST modes set to auto.
  - FRN AT enters End Zone cell, FRN data automatically enabled
  - FRN AT enters non-End Zone cell, SST Tx automatically disabled.
- FRN/SST ground control
  - Ground command “Ok to Land” command sent enabling FRN data source and disabling SST TX regardless of FRN AT location.

FRN Next Steps – Low SWaP

The FRN proof-of-concept demonstrated the capabilities of a commercial 4G LTE technology to meet the objectives of a C-Band Flightline network. The next logical step of maturation is to develop an Airborne Terminal that can be deployed in a fast mover. With the object to get to a low SWaP platform in C-Band, our recommendation for next steps are as follows:

- Move from LTE-A stack to 5G: As commercial technology is rapidly advancing towards 5G and the target C-Band of operation maps to a 3GPP band, it is strongly recommended to move towards a 5G waveform. This will benefit the AT design by leveraging commercial product ecosystem in a 3GPP supported C-Band (n79)
- Move from a generic CPU to an highly integrated MPSoC+FPGA platform for reducing the SWaP.
- Add support for 5G mmWave in addition to cmWave (C-Band) for higher bandwidth and MIMO/beamforming benefits. This would enable throughputs in Gbps.

FRN Next Steps: 5G Ready Flightline Telemetry Network

- Key Capabilities
  - Greatly increases spectrum capacity
  - Multiple users on one shared frequency
  - “Always On” therefore available “on demand”
- Technology Benefits
  - COTS 5G m-MIMO mmWave and cmWave radio and core network
  - 5G Standalone Core Architecture
  - Spectrum sharing and enhanced security using network slicing
  - Seamless handover between FRN and SST for immediate benefit real time streaming ground SST AMT
- Cost Advantage
  - Reduce development and sustainment costs by leveraging COTS equipment
  - Operational efficiency

FRN Next Steps – Best Source Selection

The proof-of-concept FRN network was designed to show use of FRN for flightline telemetry and handovers between FRN & SST networks. One of the artefacts of the handover was presence of two telemetry streams for the duration of handover. For ease of use, it would be desired to have a single stream visible at the control room for the complete duration of the telemetry data streaming. This requires the introduction of a best source selector component in the overall solution. The best source selector would take the streams from FRN and SST radio link and based on inputs & policy definitions pick the best stream to send to the control room. Nokia's opinion is that this component as an entity outside the FRN network, that co-ordinates the streams from SST and FRN.

Conclusion

- The FRN proof-of-concept technology demonstrated the capability of using cellular technology for telemetry real time data streaming and data offload in the Flightline, Runway and Hangars.
  - The solution can perform seamless handover to existing Serial Streaming network when the aircraft moves out of the FRN coverage area.
  - High throughputs (>20Mbps) can be achieved to stream telemetry data on the FRN network.
  - Using a C-Band FRN network frees up SST resources for other AMT purposes
- The proof-of-concept leveraged the C-Band AT developed for Cellular Range Telemetry and was thus in a SWaP that cannot be deployed on a fast mover. As the next step of maturation of this solution, our recommendations are:
  - Build a 5G Low SWaP C-Band AT, leveraging commercial technology in 3GPP standardized C-Band (n79)
  - Build out a 5G Flightline Radio Network at the test range
  - Build a best source selector that can provide the end-user a simplified view with a single stream of telemetry data.

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