LTE-Based Aeronautical Mobile Telemetry – Lab and Field Test Experiments

Eric Beck, Shobha Erramilli, Sarry Habiby, William Johnson, Achilles Kogiantis, Nan Maung, Kiran Rege, Zulfiquar Sayeed, Anthony Triolo and Jeffrey Young

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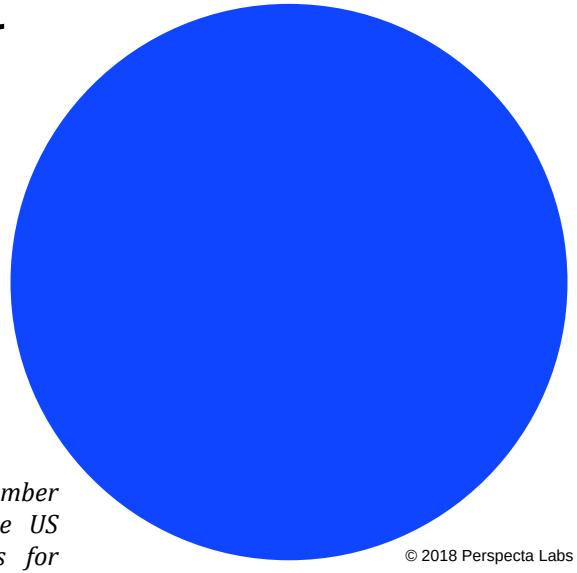

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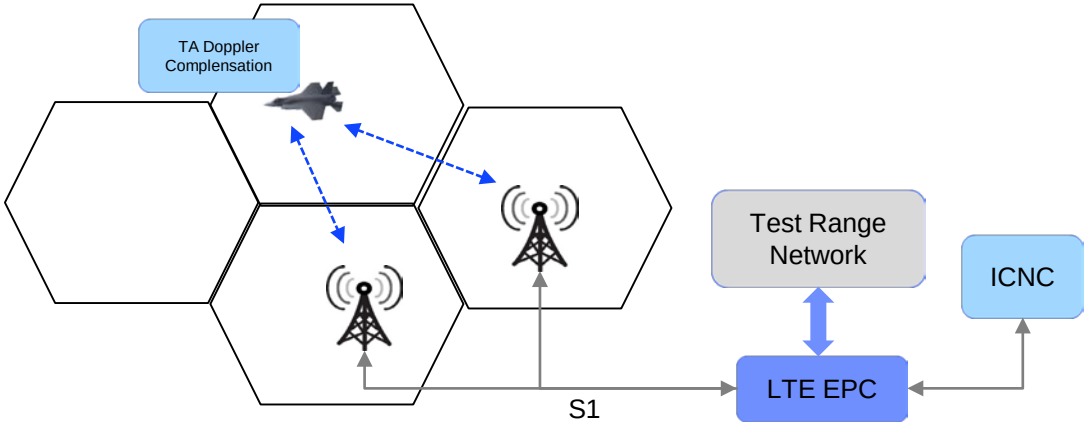
Problem Statement: LTE-based Aeronautical Mobile Telemetry



- Address the key challenges with:
  - Doppler Pre-Compensation at the Test Article
  - Supervise Mobility Management on the ground via directed handovers when necessary
- Solution is at the stage of field testing
  - Developed a laboratory setup for complete emulation of communications link in flight path

A Doppler compensation appliqué

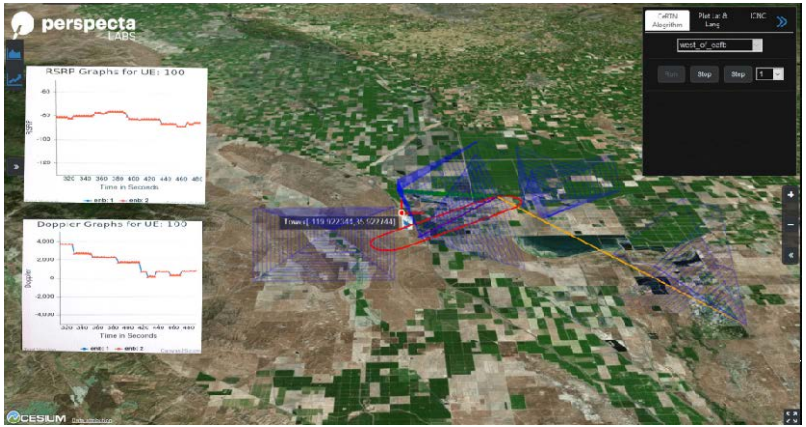
- Operates autonomously at the TA in a completely asynchronous manner
- Does not need indication of the desired base station
- Analyzes the structure of transmitted uplink signals to apply Doppler compensation
- Can be added to any standard LTE User Equipment (UE) device
- Implemented in FPGA for real-time operation
- Capable of rapid tracking of Doppler for high-speed operation
- In lab tests, showed residual error of at most a few hundred Hz, well within the capability of base station receivers.
- In field tests and flight emulation can track rapid Doppler rate of change

Testing Validation of Doppler Applique

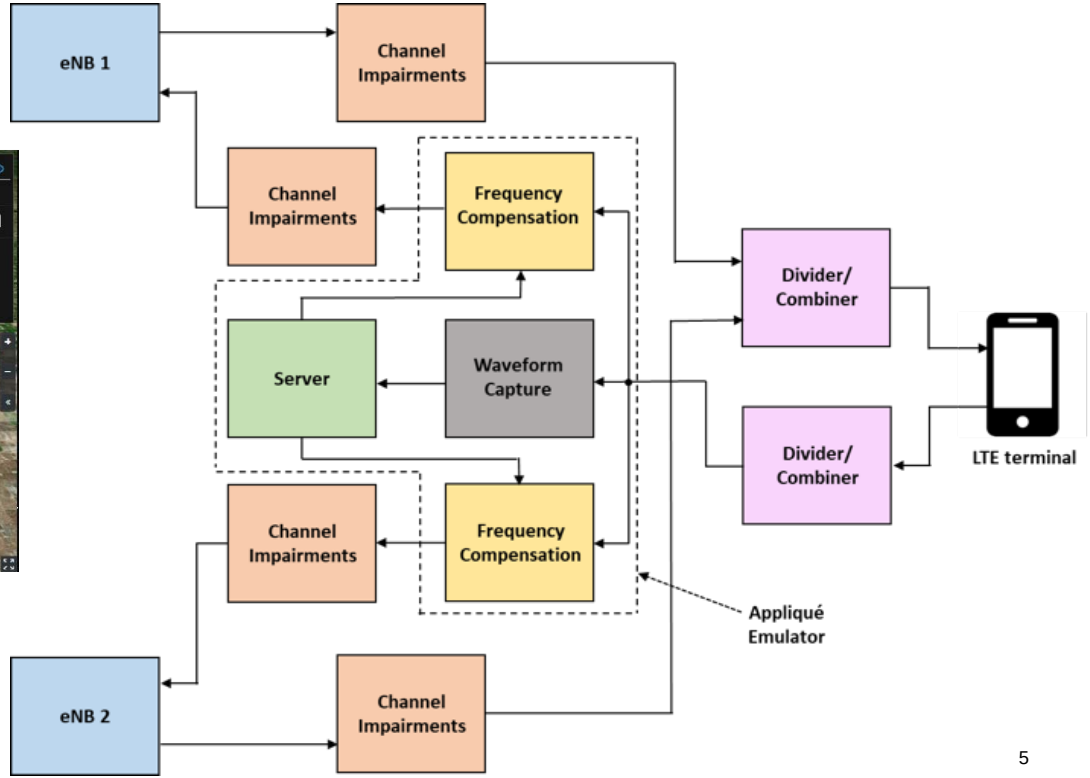
- Key Performance Metrics:
  - Ability to maintain link even at high and time-varying Doppler shifts
    - Maintaining connectivity in mobility
    - Delivering good user rates
    - Avoiding frequent radio link failures
- Not-interfering with native LTE signaling mechanisms
  - (e.g. handovers) when a neighbor cell becomes sufficiently stronger than the serving cell.
- The Appliqué-based AMT solution is being thoroughly tested to ensure that it performs as expected when deployed in the field.
  - Lab tests
  - Field tests.

Developed Laboratory multi-eNB flight path emulation Tool

- Reproduce an accurate emulation of an actual flight plan in the lab:
- Two eNBs, one TA: Doppler, Gain, and Distance from each eNB calculated from flight plan and played back in real time

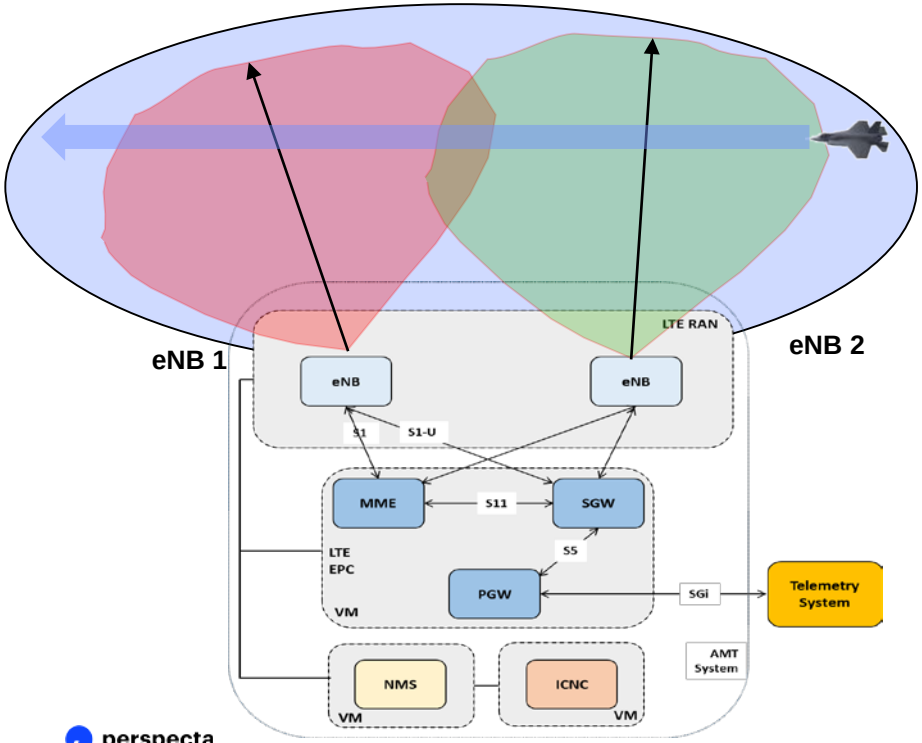


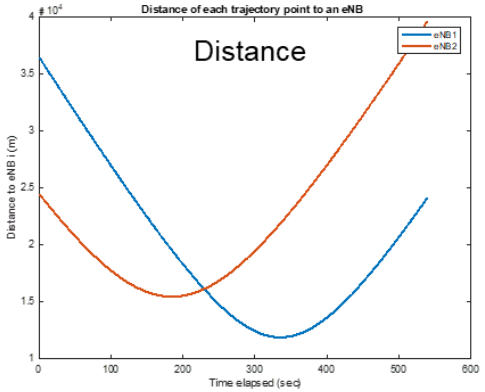
Flight Emulation → ICNC

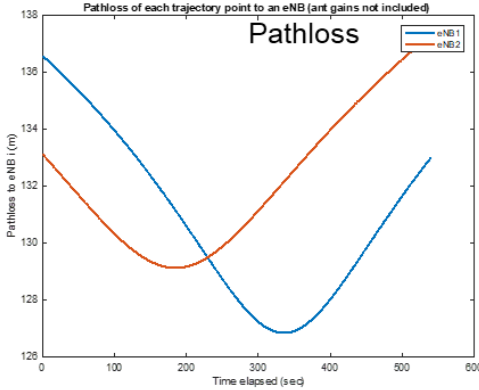


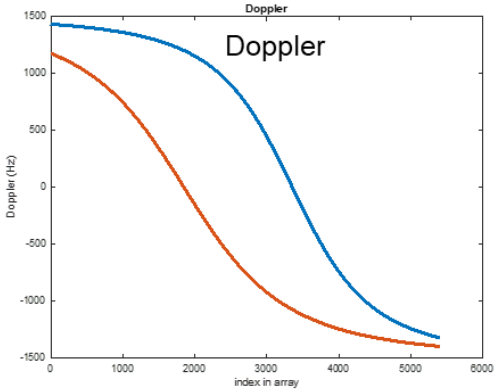
Flight Emulation in lab and correspondence with field tests

- The trajectory assumed in tthe flight path emulation runs from East to West









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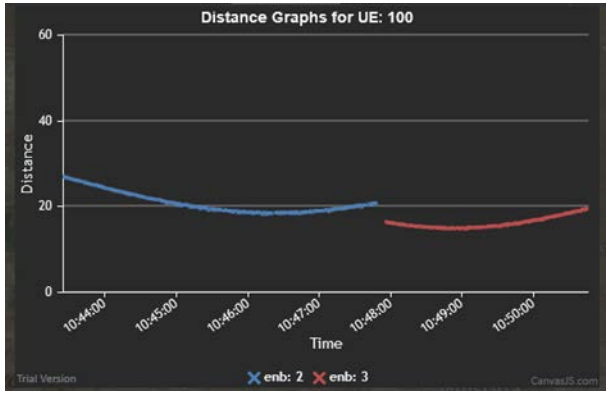
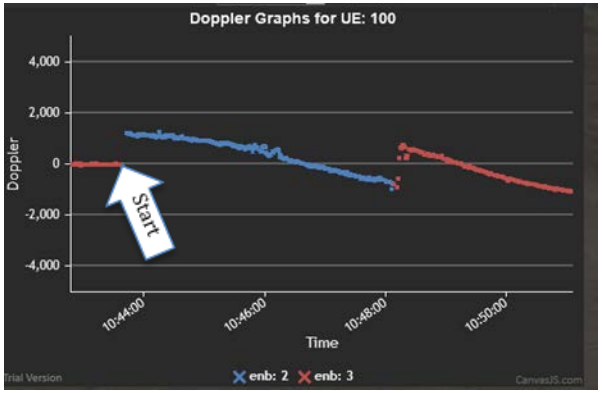
Doppler estimation by the appliqué in the lab test

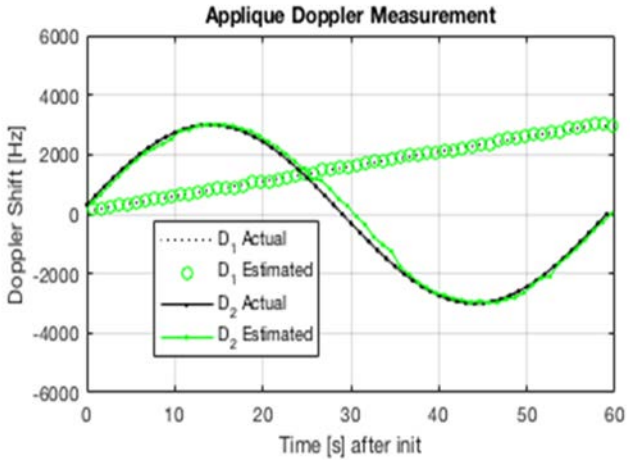
- Measurements reported by the eNBs to the ICNC every 1-2 sec:
  - Distance is reported for the connected TA to its serving eNB
  - Signal strength is reported by the TA to the serving eNB for connected and neighbor cells
- Doppler is reported by the TA (over the actual LTE link) via an over-the-top application we developed - so it is available in real-time at ICNC)
- Time series evolution matches those of predicted emulation patterns at previous cells

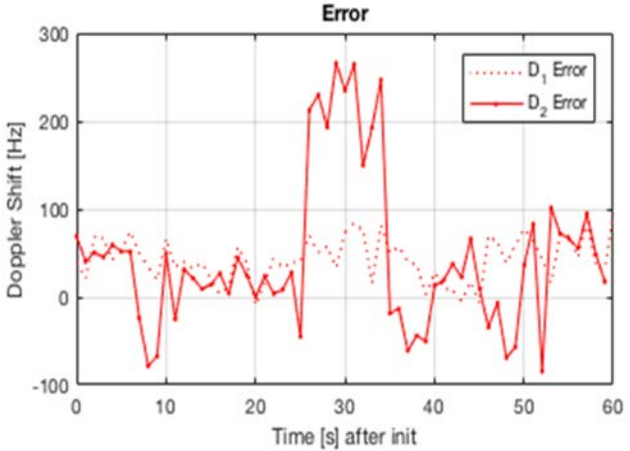




A test of the appliqué's ability to track more complex Doppler variations

- Tracking during varying rates of change of Doppler
- TA fly-over produces S-curve on Doppler
  - Highest rate of Doppler change at zero crossing
  - Error stays within receiver performance limits





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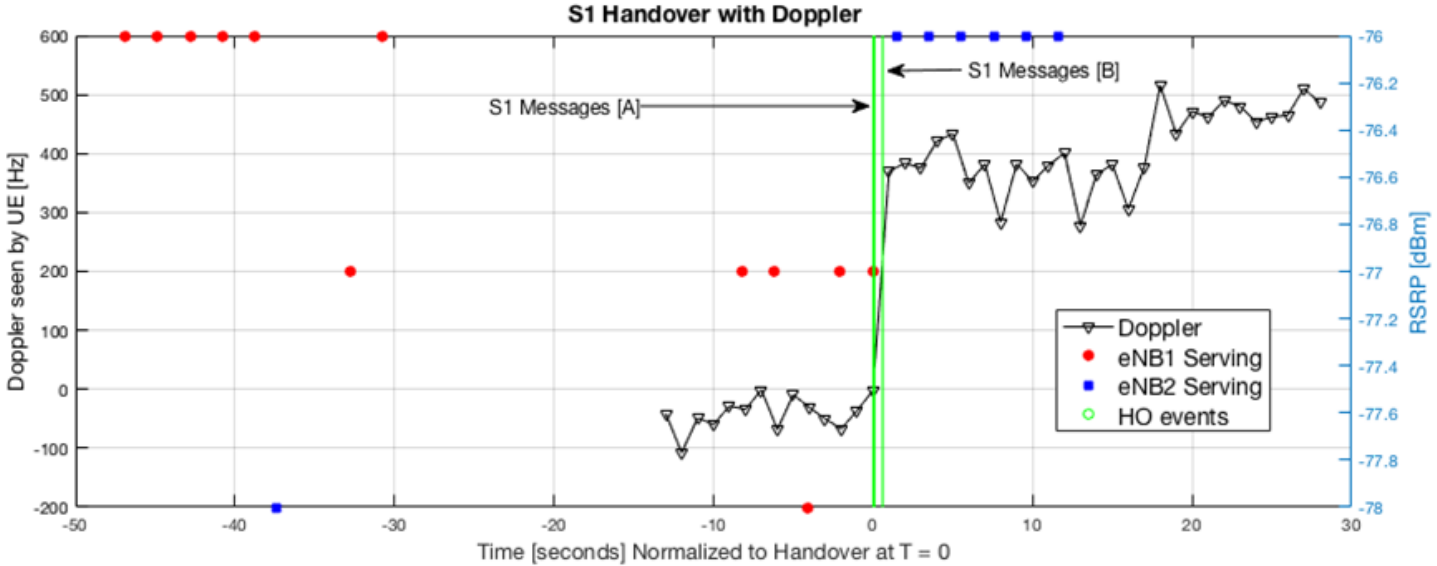
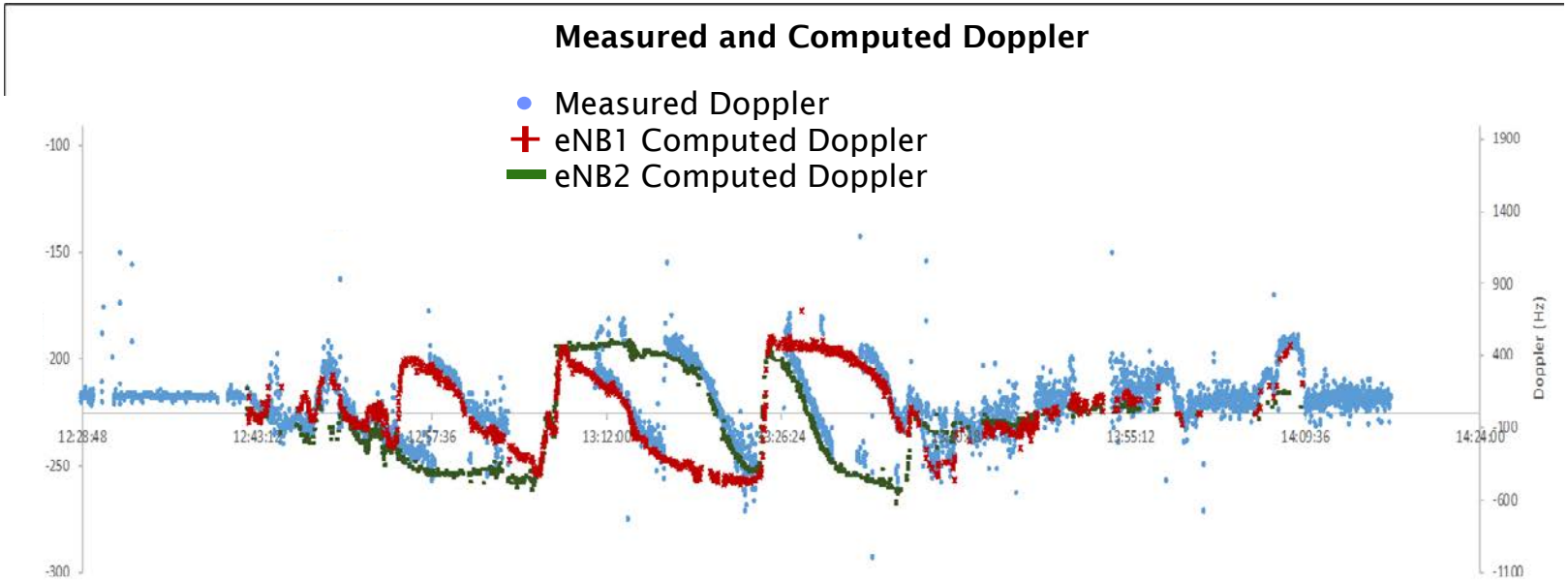
An illustration of a handover test in the lab

- Handover under controlled setup between eNBs with different Dopplers
- Tracking of LTE RRC messages show fast successful completion
  - 100-200 msec in radio link interruption
  - 1-2 sec for backhaul to complete all messaging between eNBs



Doppler shift tracking by the appliqué in a (ground) field test

- Tracking during Handover events
- Computed Doppler generated from GPS readings of the TA
- Measured Doppler estimated and applied at the applique



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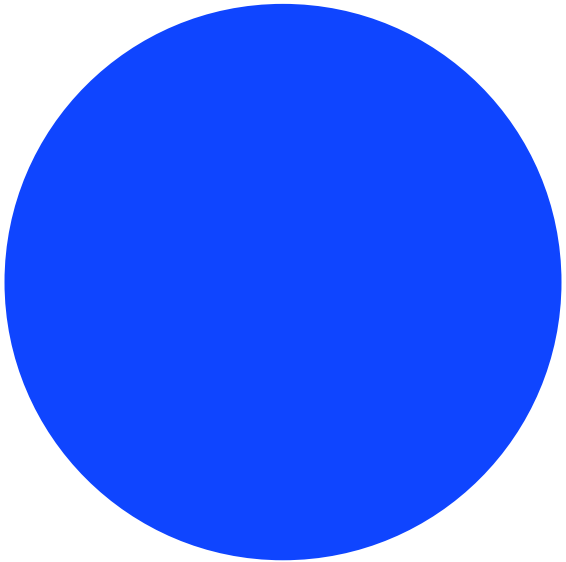
Conclusion

- The Doppler Compensation Applique augments the 3GPP LTE's standard operational envelope for Aeronautical Mobile Telemetry applications.
- Lab experiments demonstrated the ability of the Doppler estimator/compensator (i.e. the appliqué) to handle Doppler shifts that can easily reach several kHz for most RF bands of interest
- The residual frequency shift is well within the capability of the base station receiver.
- Throughout the ground-based field tests (as well as the lab tests), the appliqué was able to accurately estimate and compensate for the Doppler shift associated with the serving eNB and helped maintain the LTE link.
- Some conclusions from the ground-based field tests:
  - The path-loss exponent for air-borne tests is likely to be close to 2 (free-space propagation). Consequently, expected to achieve above 10Mbps user data rates at large distances (e.g. 40-50Km) with modest power amplification.
  - Link quality and Handover dynamics are likely to be smoother – no shadowing, no sudden changes in RSRP levels.
- Airborne fields tests are to be conducted this month

Thank you



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14. ABSTRACT

Aeronautical mobile telemetry (AMT) based on 3GPP's LTE standard is implemented in a proof-of-concept system. The solution tackles the very high Doppler shifts expected in flight tests with the use of an appliqué that can be inserted between the transmit/receive ports of the Test Article (TA) and the antennas. This appliqué estimates the Doppler shift and proactively compensates for it on the uplink signal being transmitted by the TA.

The overall system has been tested under different operational conditions in a laboratory setup as well as in the field. In the laboratory setup, the desired operating conditions are created with a set of Software-Defined-Radio-based channel emulators coupled with a computer to control their behavior. In order to carry out field tests, an operational LTE network has been created at the Edwards Air Force Base (EAFB) with two base stations, backhaul links, and a core network.

In this paper, we provide descriptions of both laboratory and field test setups as well as the results of several tests that have been carried out to date. The results of lab and field tests lend strong support to the viability of this AMT solution.

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Telemetry, spectrum, frequency, Long Term Evolution(LTE)

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