[DISTRIBUTION STATEMENT A. Approved for public release; Distribution is unlimited 412TW-PA-19306]

A Doppler Compensation Appliqué for LTE-Based Aeronautical Mobile Telemetry

William Johnson, Achilles Kogiantis, Kiran Rege

June 11, 2019

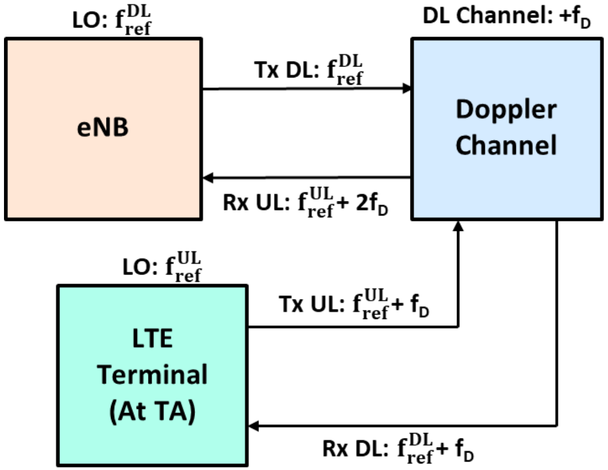
perspecta LABS

The Need for Doppler Estimation and Compensation

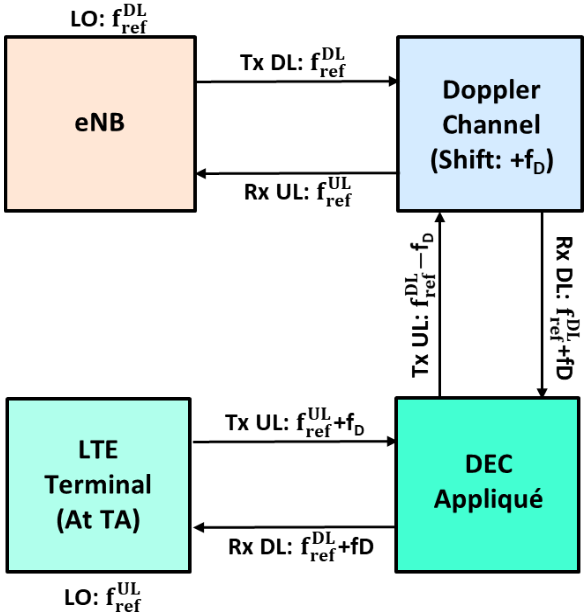
- One of the key performance-limiting factors in the implementation of LTE-based airborne telemetry systems is the high Doppler shift experienced by the TA† and base station transceivers.
  - Standard LTE systems are not designed for very high Doppler shifts. (They are designed to handle Doppler shifts for speeds up to 350 kmph.)
  - At high Doppler shifts, TAs cannot access base stations even at high SNRs.
- Our two-pronged approach to the Doppler Problem:
  - Proactively directed handovers to preferably connect to base stations that have low Doppler shifts as well as good SNR; and
  - Doppler estimation and compensation at the TA. (Needed because proactively directed handovers cannot completely overcome the Doppler problem.)
- Two possible implementations of Doppler Compensation:
  - **Downlink-based** – requires indication of desired signal
  - **Uplink-based** – does not require indication of desired signal; exploits the fact that the TA receiver derives its frequency reference from the DL signal.

† The term "Test Article" refers to the aircraft providing telemetry data. We also use it to refer it to the transceiver through which this data is transmitted.

Addressing high Doppler shifts in Aeronautical Mobile Telemetry (AMT) – the Appliqué solution



LTE Doppler Problem



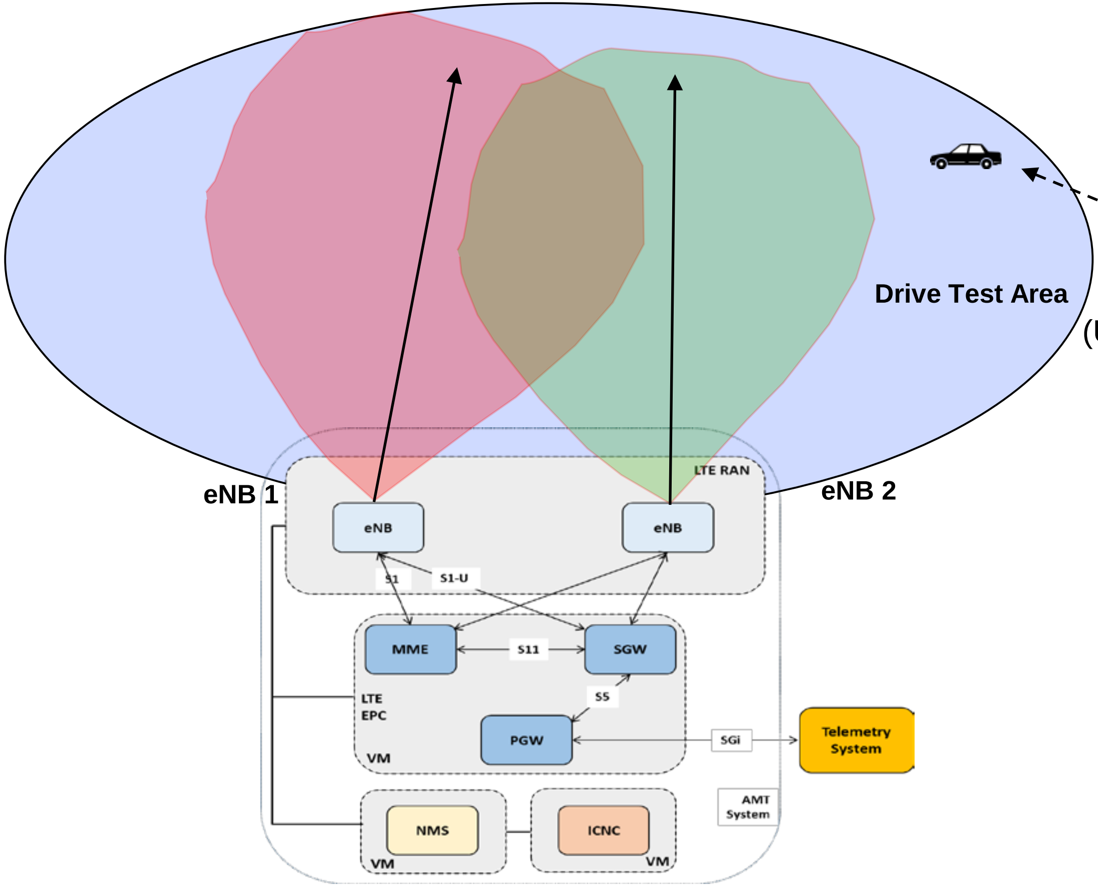
LTE UE Augmented with Appliqué

perspecta LABS

A Doppler Compensation Appliqué

- Uses the uplink signal transmitted by the TA to estimate the Doppler shift
- Does not need indication of the desired base station
- Operates in a completely asynchronous manner
- Can be added to any standard LTE User Equipment (UE) device
- Based on COTS Software Defined Radio (SDR) hardware
  - FPGA implementation 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.

The field test setup – ground test



Car with an appliqué-LTE terminal combination and a separate GPS device

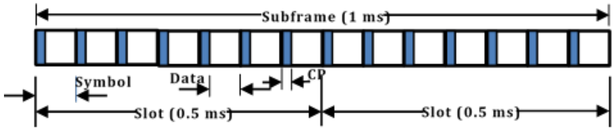
(UE Augmented with Appliqué)

perspecta LABS

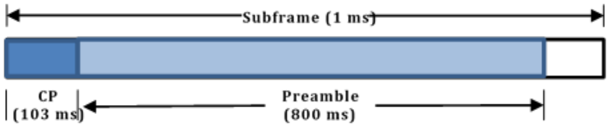
Appliqué Algorithmic Principles

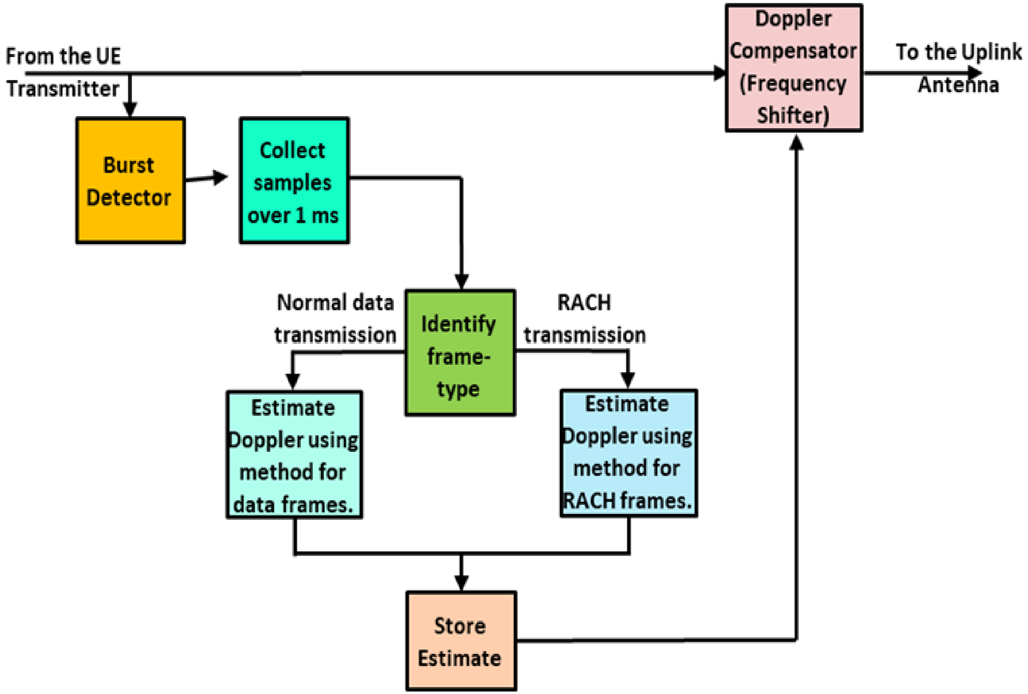
- Blind detection of data and RACH channels
- Doppler estimation and tracking from either path – automatic switch during handover

LTE Data Traffic (Uplink)



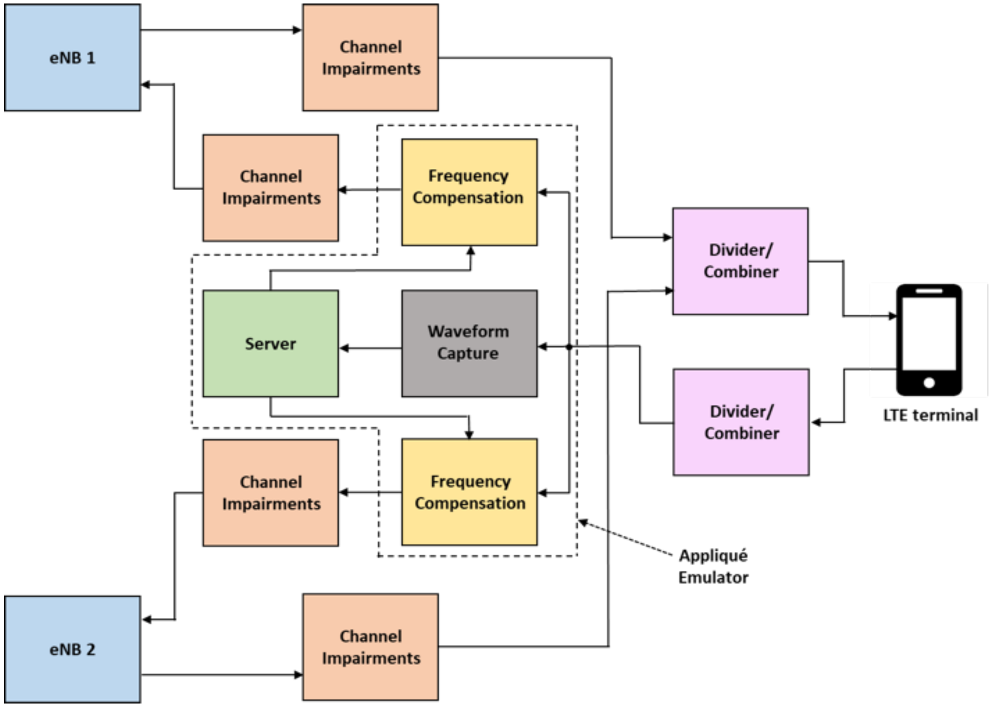
LTE Random Access Preamble (Uplink)





Laboratory flight path emulation

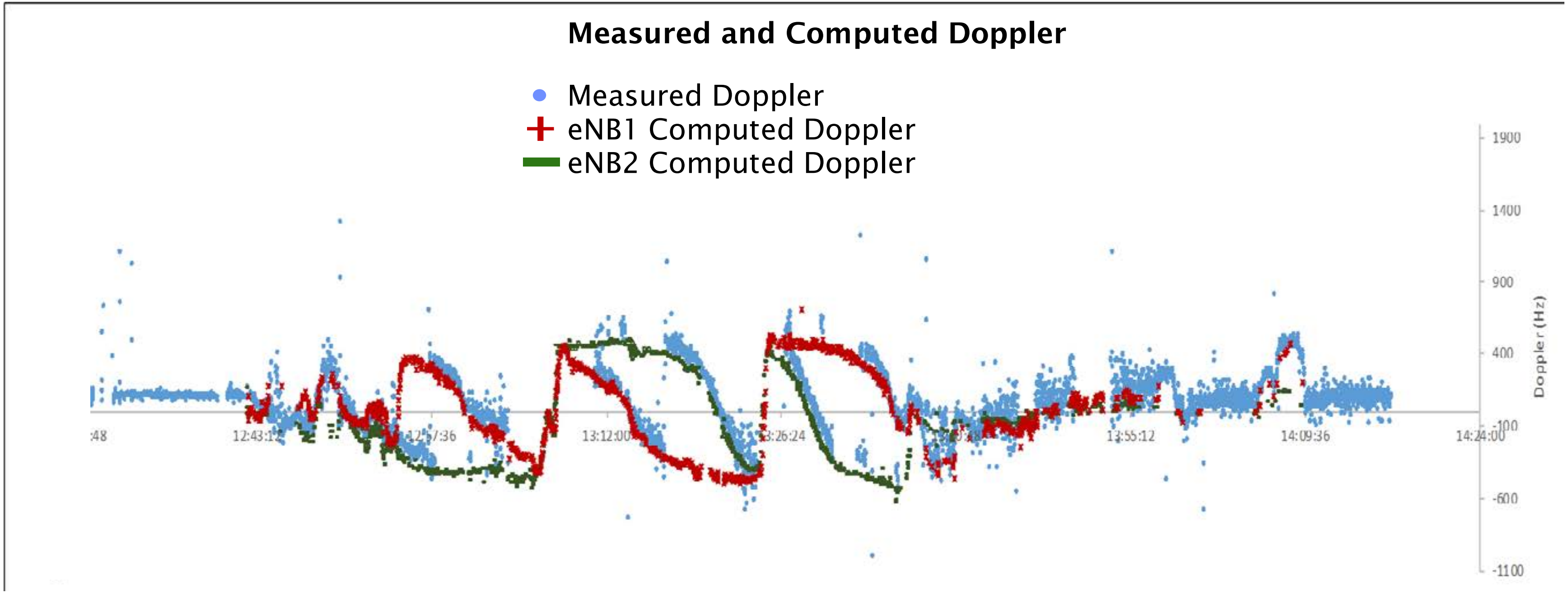
- Reproduce an accurate emulation of an actual flight plan in the lab:
- Two eNBs, one TA: Doppler, Gain, and Distance from eNB calculated from flight plan and played back in real time



perspecta LABS

Appliqué Doppler shift tracking

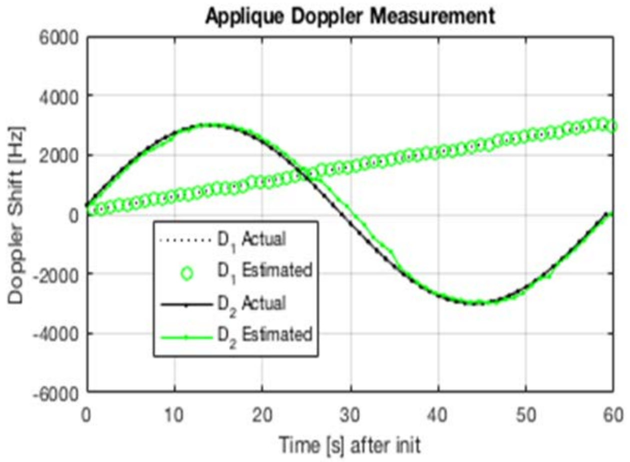
- Tracking during Handover events
- Computed Doppler generated from GPS readings of the TA
- Measured Doppler estimated and applied at the appliqué

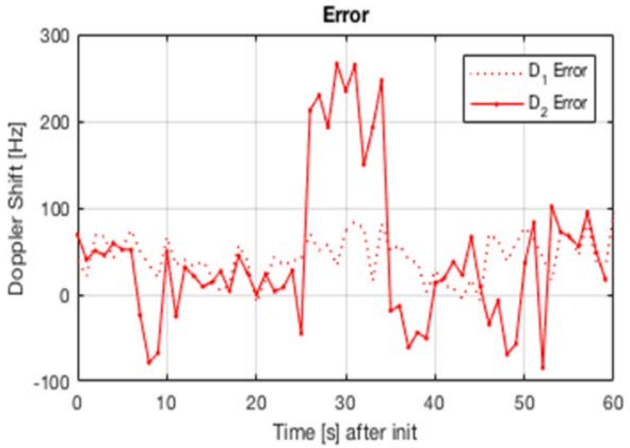


perspecta LABS

Appliqué Doppler Testing in the lab

- 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





perspecta LABS

Conclusion

- The viability of Airborne Mobile Telemetry based on 3GPP's LTE standard is severely limited by the very high Doppler shifts encountered at the base station receivers.
- Lab experiments demonstrated the ability of the Doppler estimator/compensator to handle Doppler shifts exceeding 4 kHz.
- The residual frequency shift is well within the capability of the base station receiver.
- Throughout the field test (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.
- Ground Field Test analysis complicated by several factors:
  - Presence of shadowing
  - lack of a large number of independent measurements.
- Some conclusions can still be drawn from the available data:
  - These measurements lead us to believe that for an airborne TA, the path-loss exponent is likely to be close to its free-space value of 2. (Higher received power levels at similar distances.)
  - Often, (per-UE) throughput levels of multiple Mbps were reached. It is reasonable to expect an airborne TA to attain good LTE throughputs at even significant Doppler shifts.

Thank you

perspecta LABS

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
03-06-2019	Briefing slides	June 11-13, 2019

4. TITLE AND SUBTITLE
A Doppler Compensation Appliqué for LTE-Based Aeronautical Mobile Telemetry

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
William H. Johnson, Achilles Kogiantis, Kiran M. Rege

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
Perspecta Labs
331 Newman Springs Road
Red Bank, New Jersey 07701

8. PERFORMING ORGANIZATION REPORT NUMBER
412TW-PA-19306

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
412th Test Wing
195 E Popson Ave
Edwards AFB CA 93524

10. SPONSOR/MONITOR'S ACRONYM(S)
N/A

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release A: distribution is unlimited.

13. SUPPLEMENTARY NOTES
European Test and Telemetry Conference, Toulouse, France

14. ABSTRACT
We have identified and resolved major challenges in implementing Aeronautical Mobile Telemetry (AMT) in a wireless LTE network. The key challenge involves addressing the high Doppler shifts that are likely to be present in typical AMT scenarios. Our proposed LTE-based AMT system includes a commercial off the shelf (COTS) LTE mobile terminal combined with a Doppler estimator/compensator appliqué. The appliqué estimates the Doppler shift using signals transmitted by the terminal, and proactively compensates for it in the uplink signals transmitted over the air interface. This paper presents a description of the appliqué. A prototype of this appliqué has undergone extensive testing in the laboratory and in outdoor over-the-air live links to assess its performance in the field. The paper also provides a representative sample of the test results.

15. SUBJECT TERMS
"Aeronautical Mobile Telemetry," Long-Term Evolution(LTE), Cellular, Doppler, Estimation

16. SECURITY CLASSIFICATION OF: Unclassified			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			412 TENG/EN (Tech Pubs)
Unclassified	Unclassified	Unclassified	None	12	19b. TELEPHONE NUMBER *(include area code)* 661-277-8615