Test Resource Management Center (TRMC)

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

LTE HANDOVER ENHANCEMENTS FOR HIGH SPEED CELLULAR RANGE TELEMETRY

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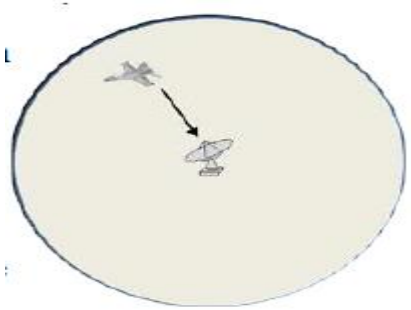
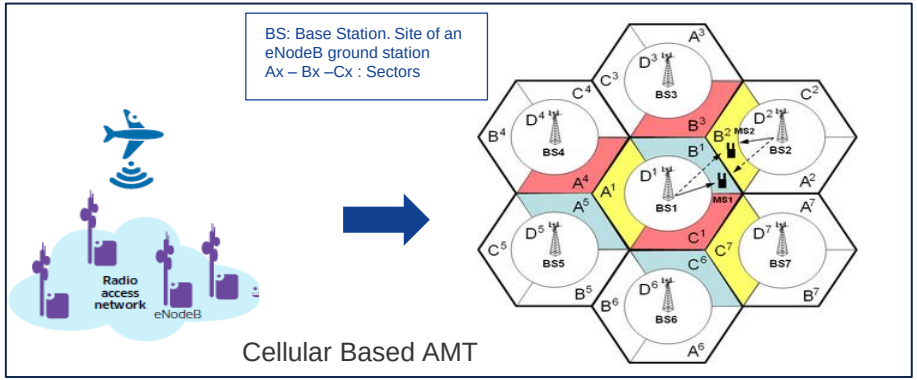
Cellular Range Telemetry



Traditional AMT



Cellular Based AMT

Technology focus

- Provide test range coverage using a “cellular” paradigm (frequency re-use with inter-cell handover)
- Use of lower C-Band spectrum which is less congested
- Use of LTE’s spectrally efficient OFDM waveform capable of providing high throughput
- Seamless handover as multiple test articles move across the cells covering the test range

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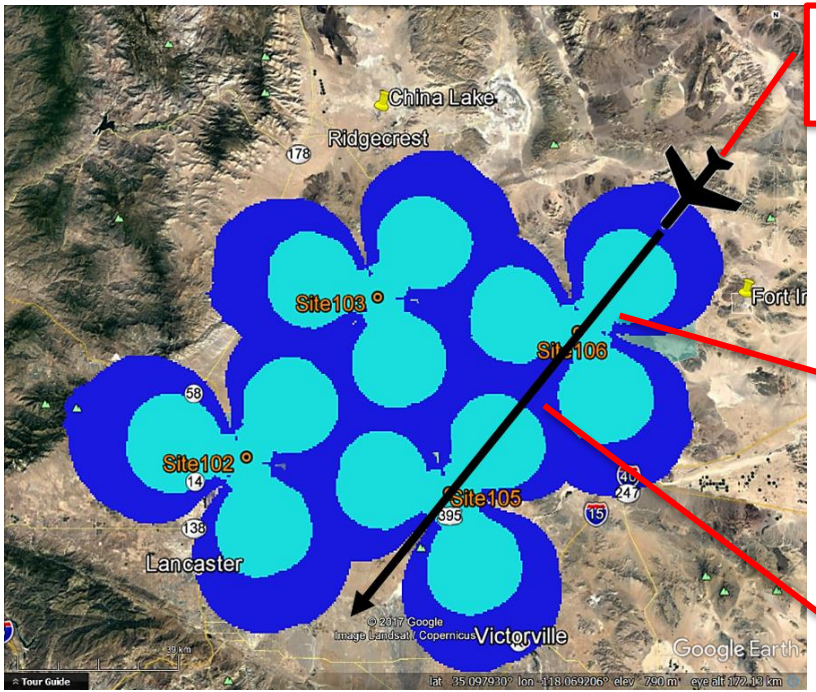
Why is Handover needed?

- Handover in LTE refers to the procedure used by the LTE network to provide continuous and seamless data service as the UE moves through the different cells of the network. As the UE moves from the coverage of one cell to another cell, the handover procedure is initiated to maintain seamless mobility. The basic objectives of handover procedures are to maintain the connectivity and the data service as the UE moves in the coverage area of the network.



Aircraft Flying at Mach 2.5

Intra-Site Handover

Inter-Site Handover

Notional Flight Path

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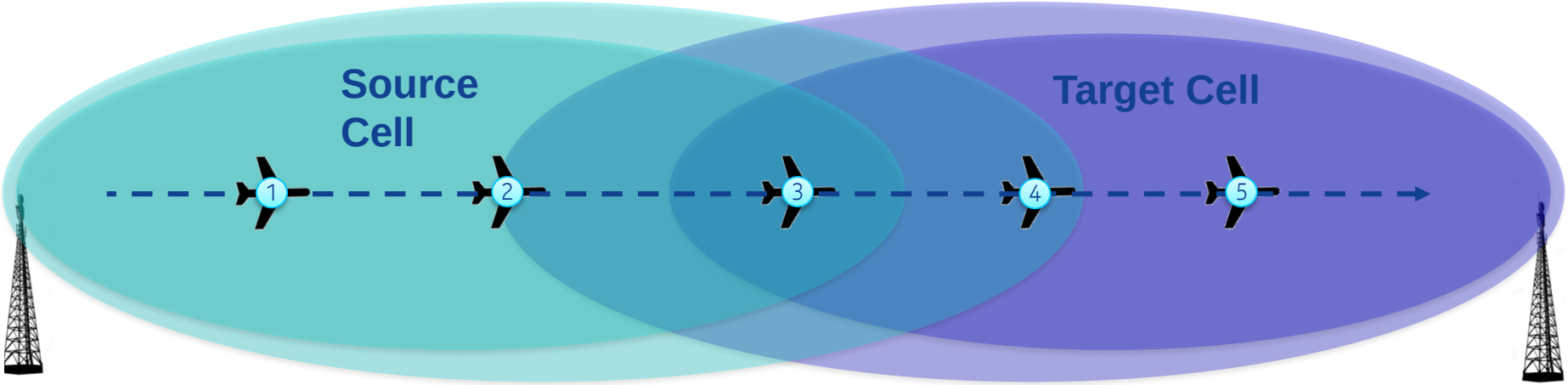
LTE Handover Procedure



1. UE connected to Source Cell
2. UE detects neighboring Target Cell, included in measurement report
3. Measurement report triggers handover initiation at Source Cell
4. Handover to Target Cell completes with RRC Connection Reconfiguration Complete message
5. UE connected to Target Cell

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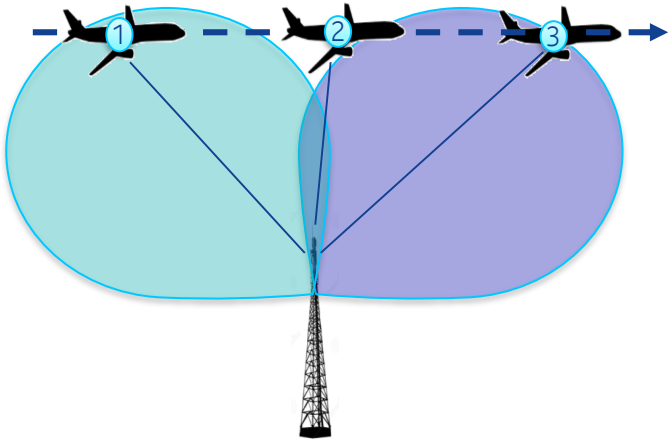
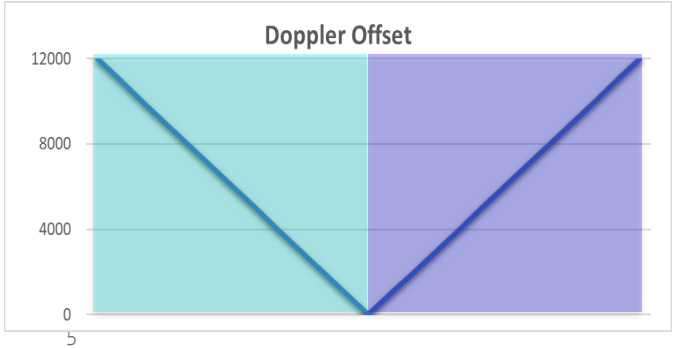
Intra Site Handover Analysis





Technical Challenge

Maximize handover success rates

- High Doppler impacts UE measurement capability & ability to connect target cell on handover.
- Handover execution time limit depends on the speed. Long time can result in failed handover

Analysis Results

Doppler impacts

- Doppler offset approaches zero at handover
  - Tangential or near-tangential flyby
  - Applies to over-flight, or fly-by

Handover execution timing

- Target cell measurements cannot start until Airborne terminal can "see" the target cell

Conclusions

- Doppler offset is of little to no concern for Intra Site handover.
- Time available for handover execution will impact Intra Site handover success rates.
- As part of RF planning need to design for maximum RF overlap between the sectors served by the same site.

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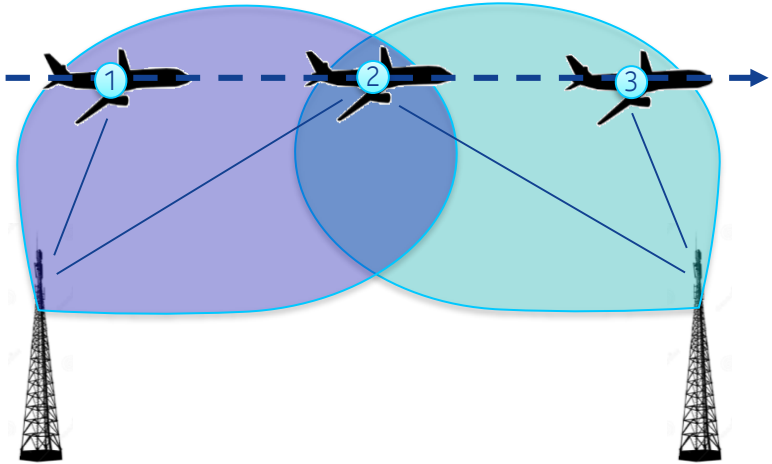
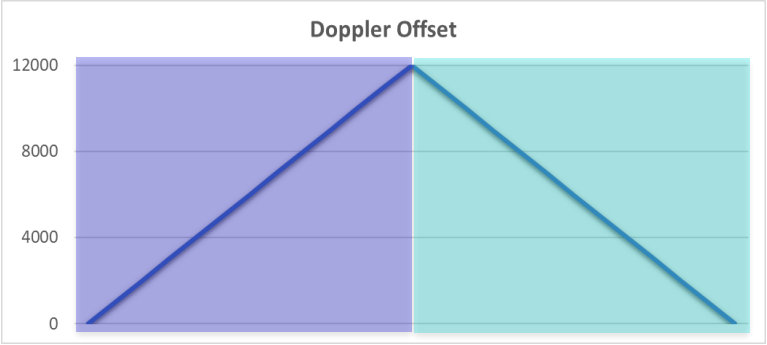
Inter Site Handover Analysis





Technical Challenge

Maximize handover success rates

- High Doppler impacts UE measurement capability & ability to connect target cell on handover.
- Handover execution time limit depends on the speed. Long time can result in failed handover

Analysis Results

Doppler impacts

- Maximized, due to extreme Doppler offset from each site.
- Transition from high negative Doppler to high positive offset during handover.

Handover execution timing

- Simpler timeline in this scenario due to significant Site-to-Site RF coverage overlap

Conclusions

- Doppler impact is the highest for Site-to-Site handover.
- For lower C-Band operation and speeds approaching MACH 2, the Doppler estimation component needs to handle Doppler offsets as high as 12KHz for the serving and neighbor cells.

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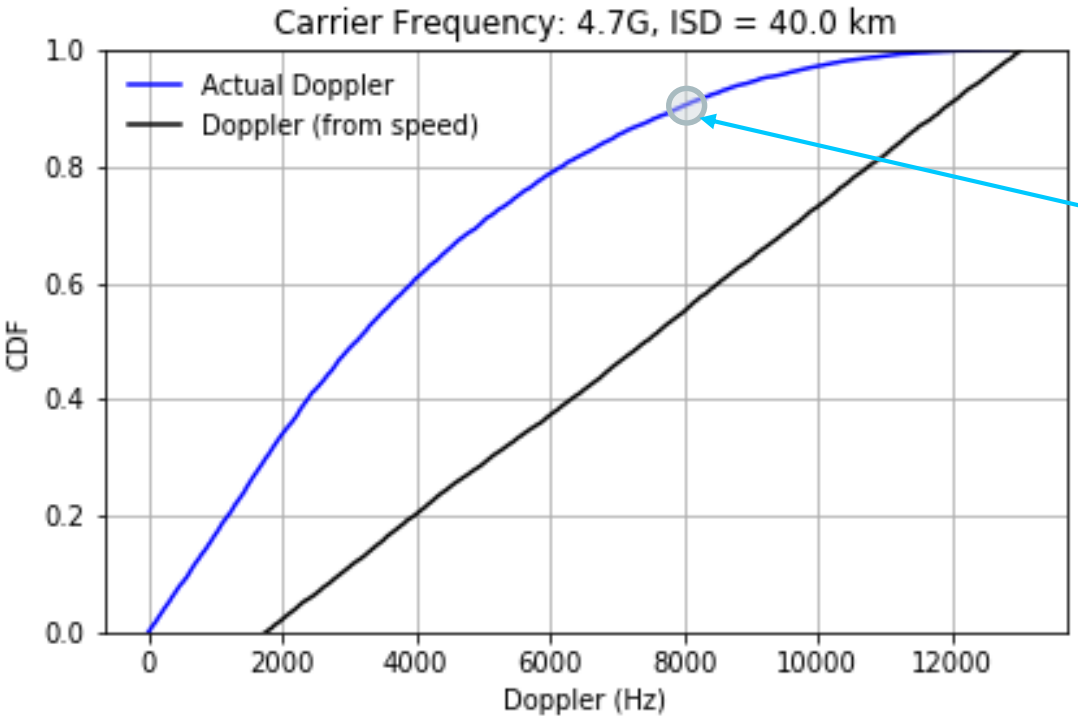
Analysis of Doppler Shift vs Speed in Lower C-Band

A Monte Carlo Characterization



$$f_d = \frac{\vec{v}.\vec{r}_{1,u} f_c}{c}$$ Doppler Equation

Analysis Results

Monte Carlo Doppler characterization with airborne test article having a velocity ceiling of MACH 2.5 and altitude between 150 m and 15 km

- 90%-ile Doppler shift is 8 kHz.

Conclusions

- 90%-ile Doppler shift is within the LTE subcarrier spacing of 15 kHz.
- The actual Doppler shifts at 4.7 GHz is less stringent than the calculated Doppler shift.

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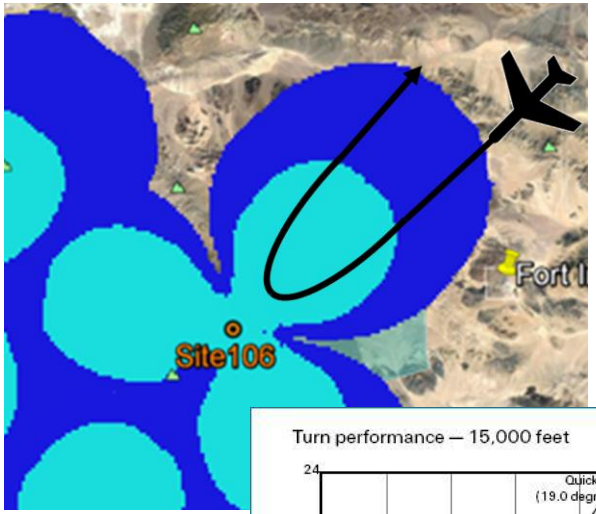
Maximum Doppler Rate of Change Analysis



Technical Challenge

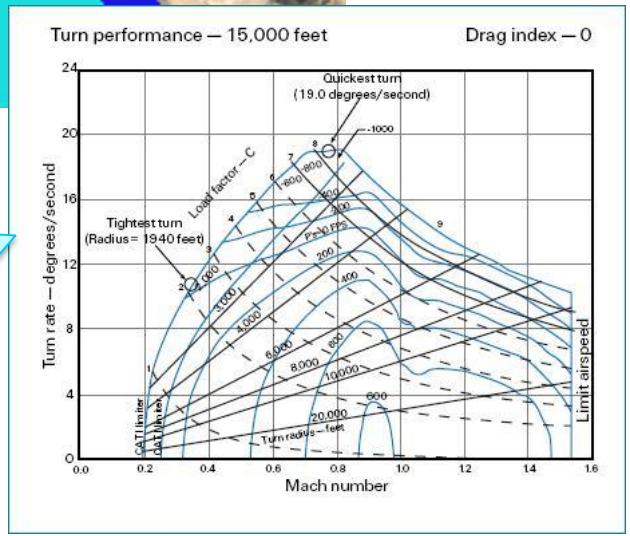
Maximize Cell Attach Success rates

- Limits on rate of change of Doppler influence the capability of the Airborne Terminal to attach to the network and maintain connection.

Analysis Results

- Maximum rate of change of Doppler happens when Aircraft executes a tight turn, heading directly toward site and reverses direction within the coverage of a sector
- Evaluated maximum Doppler rate of change at airspeed of highest turn rate
  - Mach 0.75, 19 degrees/sec = 803 Hz/s (F16)
  - Mach 0.75, 6 degrees/sec = 254 Hz/s (Cessna Citation)

e.g, F-16 Specific Energy Curves



Conclusions

- Rate of change of Doppler are in the limits that can be handled by the Airborne Terminal using sufficient doppler measurement updates.
- Need to design the Doppler estimation component with sufficient margins to handle such rate of changes of Doppler.

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Handover Time-Distance Analysis

Technical Challenge

- Maintaining data interruption times (i.e. Latency of LTE Handover) of the radio segment within commercial performance limits

Analysis Results

- Data interruption times i.e. handover latency, is dependent on the type of handover (intra-eNodeB or inter-eNodeB).
- Distance travelled by aircraft during the handover time is small enough that no significant changes to RF channel is expected. Implies UE measurement conditions prior to and post handover should not change much, thus avoiding false handovers.

Conclusions

- Using a neighbor cell measurement configuration optimized for CRTM, the LTE solution can maintain data interruption times in range of commercial performance limits.
- Phase 2 testing will validate data interruption times for high speeds and lower C-band operation.

Handover Type	Handover Delay (ms)	Distance Traveled (meters)	
		Mach 2	Mach 2.5
Intra-eNodeB	60	41	51
Inter-eNodeB	120	82	102

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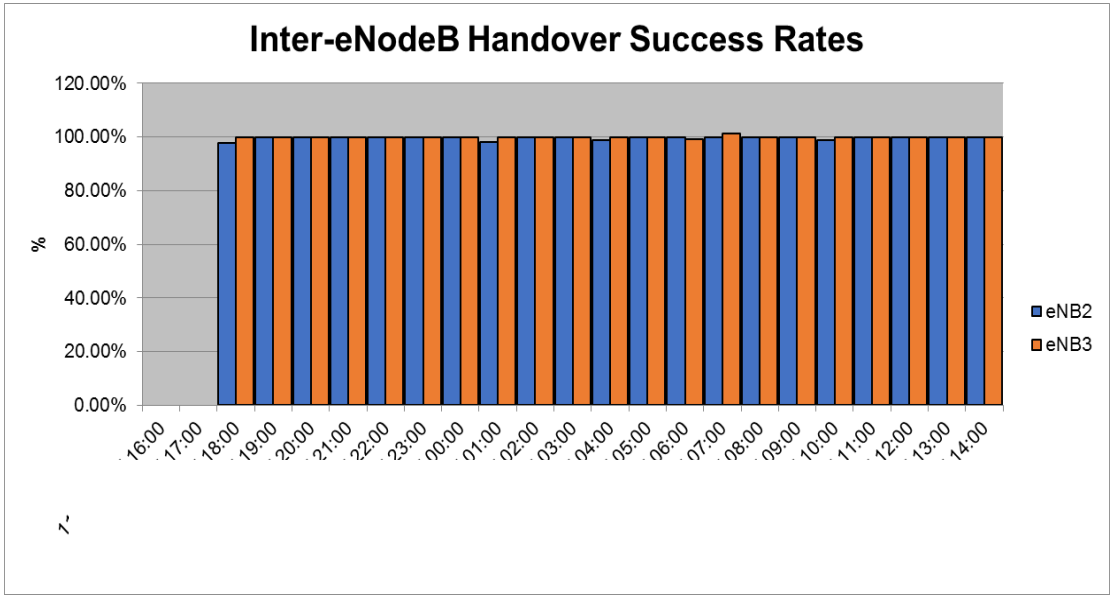
Handover Test Results – Handover Success Rates

Handover Test Setup

- UE operating in S-Band
- Doppler shifts under 2 KHz (i.e. up to MACH 1 speeds)



OBSERVATIONS

- Successfully able to extend 3GPP Doppler compensation limits and UE Measurement Capabilities with Air 2 Ground Doppler compensation design.
- Latest lab test results show the Airborne Transceiver's cell tracker successfully tracking and compensating for Doppler shifts up to 6.5KHz
- Gives confidence that the Doppler compensation approach can work for MACH2 speeds in lower C-Band.
- Testing for > MACH 1 speed and lower C-Band operation are in progress

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Handover Test Results – Handover Latency

Handover Test Setup

- UE operating in S-Band
- Static Channel
- Doppler shifts under 2 KHz (i.e. up to MACH 1 speeds)

OBSERVATIONS

- Data service interruption times within expected range (60ms)
- Our inference from testing is, for > MACH 1 speed and C-Band the impact to latency time should be marginal.
- Testing in next phase will validate > MACH 1 latency

Testcase Inra eNodeB Handover RSRP -115dBm

UDP Handover Cell0 -> Cell1		
No Backhaul Delay		
	Air to Ground Data Interruption Time ms	Ground to Air Data Interruption Time ms
Cell 0 to Cell 1 (1)	63	82
Cell 0 to Cell 1 (2)	62	86
Cell 0 to Cell 1 (3)	53	70
Average	59.33	79.33

UDP Handover Cell1 -> Cell0		
No Backhaul Delay		
	Air to Ground Data Interruption Time ms	Ground to Air Data Interruption Time ms
Cell 1 to Cell 0 (1)	52	69
Cell 1 to Cell 0 (2)	53	70
Cell 1 to Cell 0 (3)	56	60
Average	53.67	66.33

Testcase Inter eNodeB Handover RSRP -115dBm

UDP Handover eNodeB0 -> eNodeB1		
No Backhaul Delay		
	Air to Ground Data Interruption Time ms	Ground to Air Data Interruption Time ms
eNodeB 0 to eNodeB 1 (1)	49	60
eNodeB 0 to eNodeB 1 (2)	44	57
eNodeB 0 to eNodeB 1 (3)	46	63
Average	46.33	60

UDP Handover eNodeB1 -> eNodeB0		
No Backhaul Delay		
	Air to Ground Data Interruption Time ms	Ground to Air Data Interruption Time ms
eNodeB 1 to eNodeB 0 (1)	48	65
eNodeB 1 to eNodeB 0 (2)	50	70
eNodeB 1 to eNodeB 0 (3)	57	63
Average	51.67	66

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Conclusion

- This paper shows the challenges for extending 3GPP LTE seamless handover to work at the high speeds for Aeronautical Mobile telemetry.
- Nokia is building upon its commercial Air to Ground LTE solution to address these challenges for Cellular Range Telemetry.
- The studies and simulations performed by Nokia using its S-Band Air to Ground LTE equipment indicate that Doppler and handover timing constraints can be addressed with
    - modification to the Airborne Terminal's Doppler estimation and compensation algorithms
    - Optimization of the handover measurement configuration

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