SEAMLESS HANDOVER AT HIGH SPEEDS FOR CELLULAR RANGE TELEMETRY

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ABSTRACT

Cellular based Range Telemetry provides a lot of benefits over legacy Aeronautical Mobile Telemetry, such as:

- Higher capacity, allowing multiple test articles (i.e. telemetry radio links) which have active telemetry data measurements exchanged in near real time.
- Bi-directional radio links, that can allow new signaling with the avionics equipment on the test articles.
- Higher performance provided by spectrally efficient OFDMA waveform used in LTE and the dynamic link adaptation that is built into the LTE waveform.

With the CRTM cellular approach, the overall range coverage area is broken into multiple coverage areas, each served by a single cell. To maintain seamless service throughout the test flight, CRTM must support seamless mobility as the aircraft moves between the coverage areas of these cells. This is achieved using the connected mode handover procedures supported by LTE technology.
Traditional LTE networks rely on signal strength measurements made by the User Equipment (UE) to make handover decisions. The measurement system and handover procedures have been designed to support mobility at speeds under 500 km/hr. To support mobility at higher speeds, the following need to be taken into account:

- **LTE User Equipment (UE) RF Signal Measurements**: Accuracy of measurements depends on UE's capability to measure the signal strength of a neighbor cell while synchronized to its serving cell. The higher Doppler shifts expected in an AMT environment due to the higher test article speeds and the higher frequency of operation along with the difference in Doppler shifts between the serving cell and neighbor cells complicates cell measurements.

- **Handover Processing Time**: The serving eNodeB needs to process the measurements from the UE and initiate handover in a timely manner. Delays in handover processing can result in radio link failures. The higher speeds of test articles in the AMT environment reduces the time available to the eNodeB for handover processing.

This paper explains the handover procedure in 4G LTE, with the focus on:

- Measurement reports that support handover decisions

- Decisions impacting data service delays during handover

impacts to the handover processing when the UE (i.e. test article in CRTM) is moving at very high speed.

TERMINOLOGY

- AMT: Aeronautical Mobile Telemetry
- CRTM: Cellular Range Telemetry
- eNodeB: Ground Station of the LTE network
- EPC: Evolved Packet Core
- HSS: Home Subscriber Server
- LTE: Long Term Evolution
- MME: Mobility Management Entity
- PCRF: Policy and Control Function
- PGW: Packet Gateway
- RAN: Radio Access Network
- SGW: Serving Gateway
- UE: User Equipment (Airborne node in CRTM)
- VoLTE: Voice over LTE

INTRODUCTION

Legacy telemetry systems are facing technical headwinds in meeting demands for throughput, spectrum availability and test capability. To address these concerns, one of the proposed solutions is to migrate the existing radio communication system used at test ranges to a cellular approach, gaining the wireless communication technology advances available in commercial systems. The figure below shows the migration from a traditional AMT system to Cellular based AMT system.

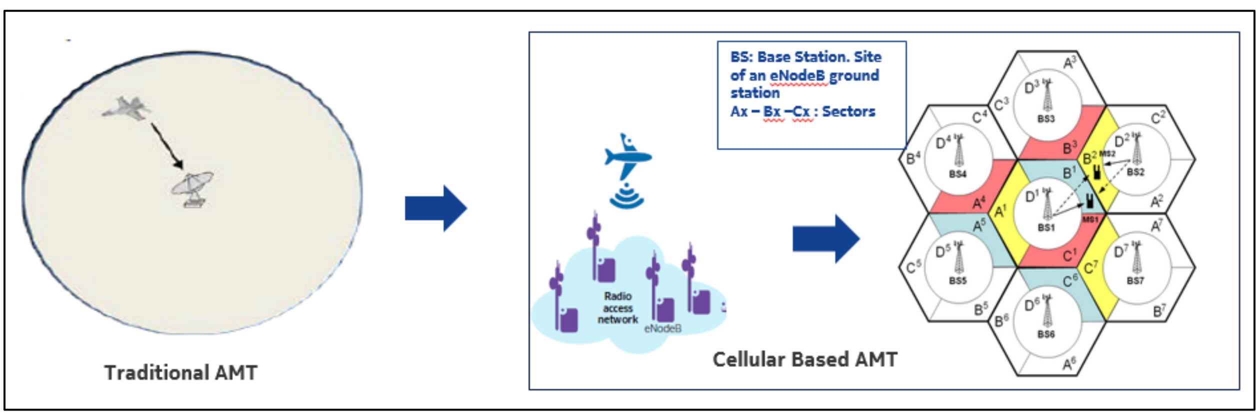

Figure 1: Migration to Cellular Range Telemetry

4G LTE Cellular technology provides a high capacity and high performance scalable architecture for the next generation telemetry systems. However, commercial LTE cellular technology has been designed for terrestrial application and needs enhancements to meet the goals of a telemetry application. The key technical challenge areas are:

- Doppler Shift due to high speeds

- Ground Station Antenna Patterns for vertical and horizontal coverage
- Air to Ground Throughput
- Seamless Handover at the high speeds

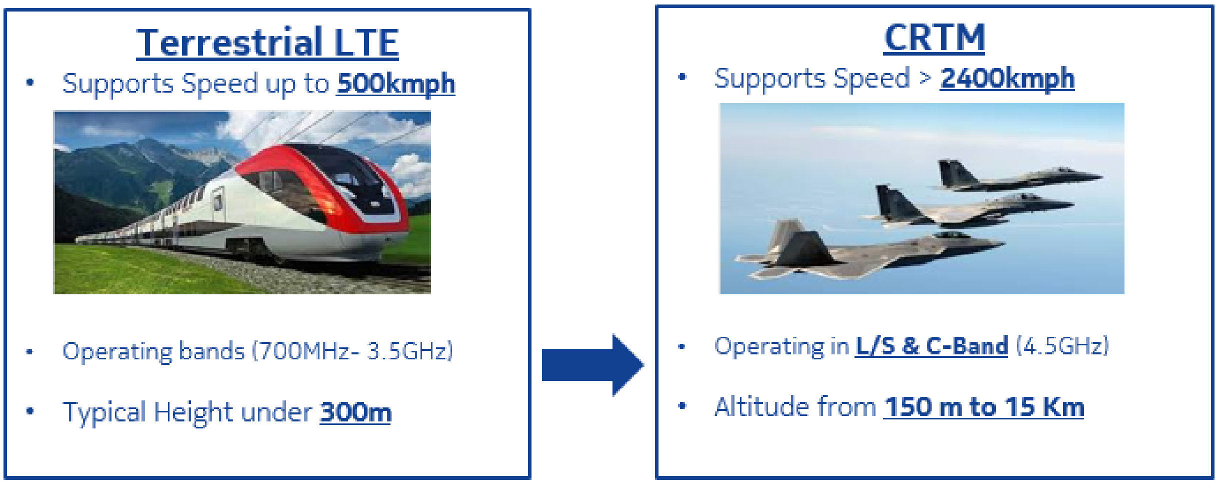

Figure 2: LTE Technology evolution to Cellular Range Telemetry

This paper explains the concepts of handover in an LTE network and covers the design challenges for performing a seamless handover at the extremely high aircraft speeds in a telemetry application. It is assumed that the reader has a basic understanding of the 3GPP LTE architecture and network elements.

3GPP LTE Handover Overview

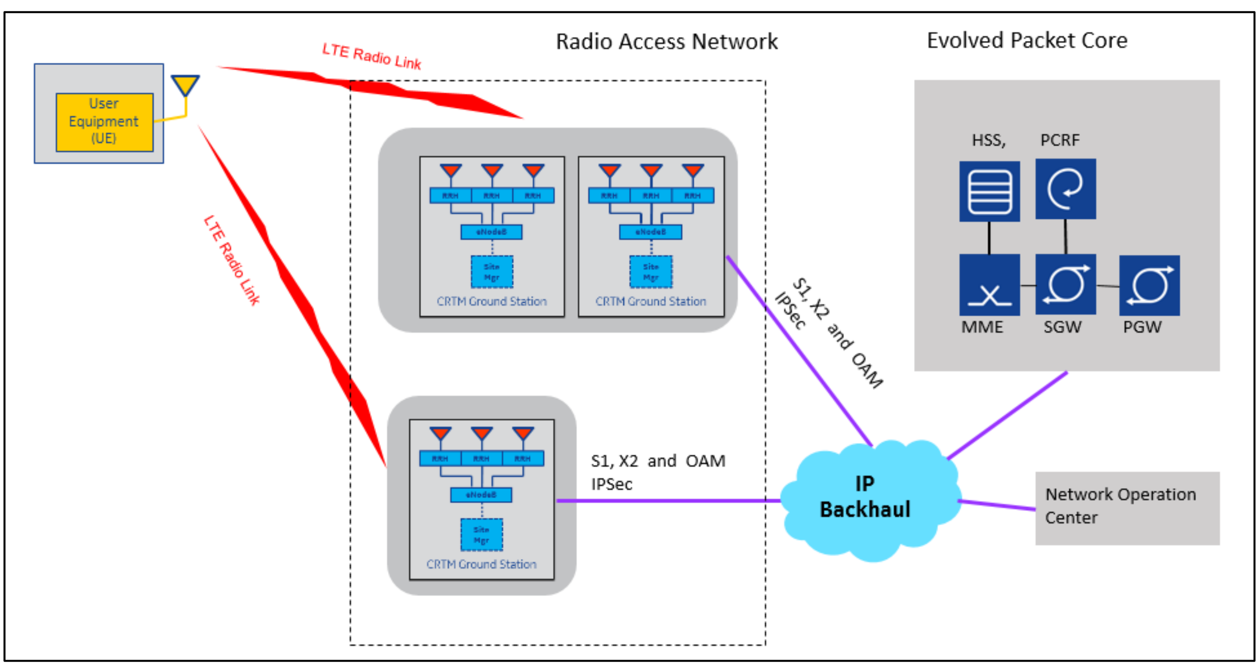

Figure 3: High Level LTE Network Architecture

Shown in figure above, a typical LTE network is comprised of:

- Radio Access Network (RAN): The RAN provides the radio link data and management functionality of the cellular network. It consists of Ground Stations, known as eNodeB in LTE terminology, that provide the RF coverage for a geographical area (Cell). The eNodeBs are connected to the LTE Evolved Packet Core Network (S1 & OAM interface) and to other eNodeBs in the RAN (X2 interface).
- Evolved Packet Core (EPC): The EPC provides the management and control of the radio link and the data path between the UE and the network operation center.
- User Equipment (UE): The UE is at the other end of the radio link in a cellular network. It provides the radio data link and IP network layer services to end user applications. For CRTM, the airborne modem in the test article represents the UE entity of a LTE network.

Handover is a term used in the 3GPP standards to define 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:

- Quality of Service (QoS) should be maintained all the time, both during and after handover.
- UE should able to continue its normal services before and after handover. For example, a voice call before handover should be maintained after handover as well.
- Data integrity should be maintained through handover.

In a LTE network, the handover decisions are made by the network (eNodeB) using measurement information provided UE. The UE receives a measurement configuration on establishing and radio connection with a cell (serving cell) and based on this configuration makes periodic measurement of the Received Signal Strength and/or Quality of the serving cell's and neighboring cell's radio signals. There are different types of measurement configurations that define the radio conditions that will trigger a measurement report from the UE. For e.g. the configuration could be set to report if:

- The serving cell's signal is lower than an operator configured threshold
- The serving cell's signal is lower than a threshold and a neighbor cell's signal is better than a threshold
- The neighbor cell's signal is better than the serving cell's signal by a configured threshold.

The eNodeB based on the measurement reports from the UE then makes handover decisions:

- whether to initiate a handover to a neighbor cell (target cell) and
- to which target cell should the handover be made if there are more than one good candidate target cells.

The selection of the measurement configuration type and thresholds are based on the radio network planning and desired performance of the operator. Poor selection of the measurement configuration can result in too early or too late handoffs. The end outcome would be dropped connections or longer delays in establishing service.

There are different types of mobility scenarios supported within a LTE network, mainly:

- Intra-eNodeB Handover
- Inter-eNodeB Handover

A) Intra-eNodeB Handover

When the UE moves between the coverage areas of two cells that are served by the same eNodeB, an intra-eNodeB handover is performed. For such handovers, there is little signaling between the eNodeB and the core network (MME, Serving Gateway and Packet Gateway). Shown below is the message sequence flow for a CRTM scenario where the test article (UE) moves across cells that are served by the same ground station. Refer to [1] & [2] for further procedure and message details.

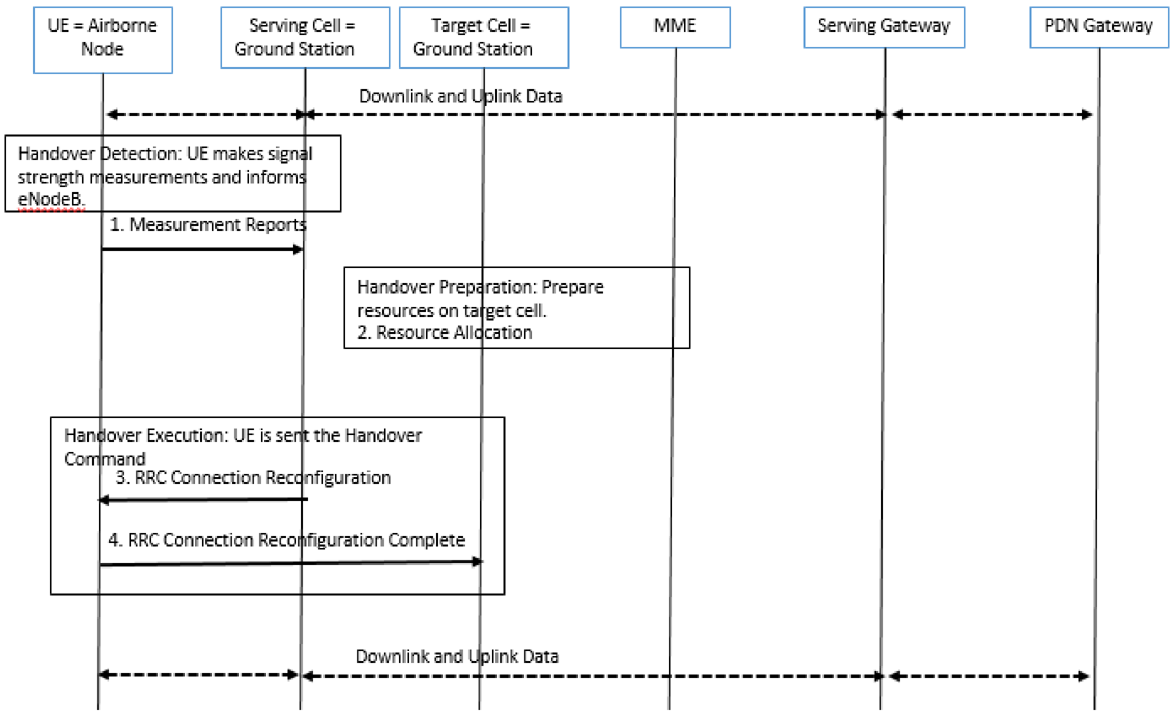

Figure 4: Intra eNodeB Handover Procedure

1) UE makes serving and target cells signal strength measurement and the measurement report is sent.
2) The serving cell eNodeB determines the best handover target cell and in this scenario, it is another cell served by the same eNodeB. It prepares the resources on the target cell.
3) The serving cell sends to the UE the handover command. The handover command points the UE to the target cell and the radio configuration it is assigned on the target. From this point the data exchange with UE is paused.
4) The UE connects to the target cell and acknowledges the handover.
5) Data exchange is resumed.

Data exchange between UE and eNodeB is paused between steps 3 & 4. Data gets buffered at the eNodeB and UE for this period and the transmission of the buffered and new data begins once the service is resumed at step 5. The data service interruption duration is around 30 to 50ms.

B) Inter-eNodeB Handover

When the UE moves between the coverage areas of two cells that are served by the different eNodeB, an inter-eNodeB handover is performed. The LTE core network needs to be involved for such handovers and there can be multiple variants depending on the Operator's core network deployment and which entities within the core network are involved. For CRTM, the LTE core network does not have a significant impact. Shown below is the message sequence flow for an inter-eNodeB handover scenario where the test article (UE) moves across cells that are served by the different ground stations with no need of switching data paths in Serving Gateways. Refer to [1], [2], [3] & [4] for further procedure and message details.

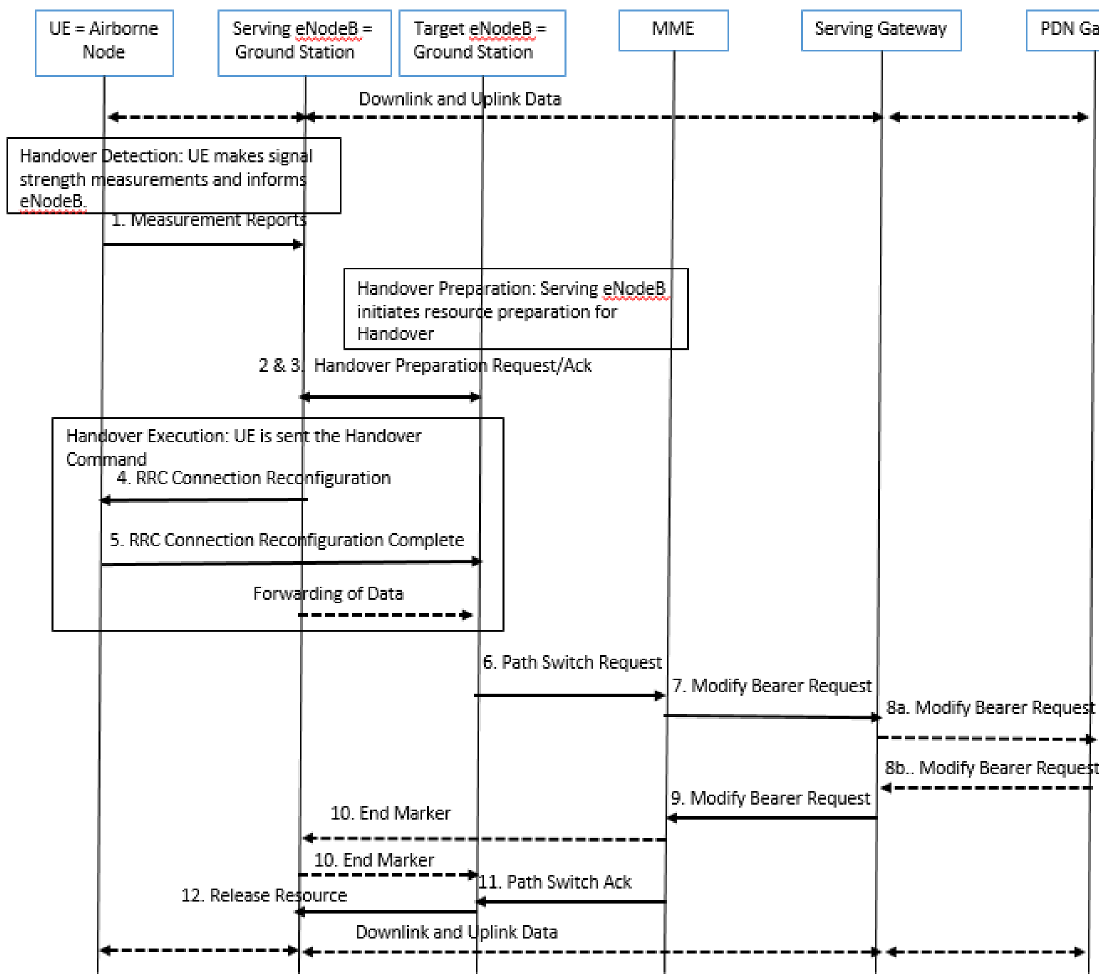

Figure 5: Inter eNodeB Handover Procedure

1) UE makes serving and target cells signal strength measurement and the measurement report is sent.
2) The serving cell eNodeB determines the best handover target cell and in this scenario, it is another cell on a neighbor eNodeB. The source eNodeB initiates a Handover Request.
3) The target eNodeB prepares the resources on the target cell and sends an acknowledge to the source eNodeB. The acknowledge message contains the handover command.

4) The serving cell sends to the UE the handover command. The handover command points the UE to the target cell and the radio configuration it is assigned on the target. From this point the data exchange with UE is paused. Any unsent data on the source cell and any data for the UE received from the serving gateway is forwarded to the target eNodeB.
5) The UE connects to the target cell and acknowledges the handover.
6) The target eNodeB informs the MME to switch the downlink Path from the serving eNodeB to the target.
7) The MME sends a Modify Bearer Request to the Serving Gateway the path modification information.
8) The steps a) & b) are conditional. It depends on whether the Serving Gateway has received the User Location Information IE and it needs to inform the PDN Gateway
9) The Serving Gateway starts sending downlink packets to the target eNodeB using the newly received path information. A Modify Bearer Response message is sent back to the MME.
10) In order to assist the reordering function in the target eNodeB, the Serving GW shall send one or more "end marker" packets on the old path immediately after switching the path.
11) The MME confirms the Path Switch Request message with the Path Switch Request Ack message. At this point the Handover is considered completed.
12) By sending Release Resource the target eNodeB informs success of the handover to source eNodeB and triggers the release of resources.

Data exchange between UE and eNodeB is paused between steps 4 & 11. Any received data by the source eNodeB is forwarded to the target eNodeB. Data gets buffered at the target eNodeB and UE for this period and the transmission of the buffered and new data begins once the service is resumed at step 11. The data service interruption duration is around 50 to 70 ms.

Challenges for Handover at High Speed

Commercial LTE is built around applications for terrestrial use, UEs move at speeds up to 500 km/hr. UEs typically have sufficient time and capability to perform handover measurements at these speeds and complete a handover. Also, commercial applications (VoLTE, FTP, Web browsing etc.) are more tolerant to brief interruptions in data connectivity. However, as the data is streaming from the test article continuously in a telemetry application and is sensitive to latency, longer pauses during handover or due to handover failures are of a bigger concern. The paragraphs below address the key challenges for performing successful handovers and minimizing the interruptions to data service.

A) UE Neighbor Cell Measurements

- Accuracy of neighbor cell measurements depends on the UE's capability to sync to candidate neighbor cells.
- In a conventional LTE system, a neighboring cell may be a few hundred Hz offset from the serving cell due to Doppler shift from UE motion. Since this is a small fraction of the 15 kHz sub-carrier spacing, the impact of this frequency misalignment on neighbor cell

measurement quality (accuracy) is generally acceptable and the same frequency correction used for the serving cell is general used for the neighbor cells.

- At very high speeds and at higher frequencies, the signals will experience a Doppler shift significantly higher than terrestrial LTE. For e.g. a typical Doppler shift would be +/- 250 Hz for a terrestrial UE, but for CRTM operating at C-Band frequencies and at speeds of up to 2400 km/hr the Doppler shift can be +/- 8 kHz. This means that the UE, which is tracking the Doppler shift relative to the serving cell, will see a significant Doppler shift on signals received from each neighbor cell. This shift can represent a significant fraction of the 15 kHz sub-carrier spacing. Unless independent Doppler correction is provided for each cell, the resulting inter-subcarrier interference degrades the cell measurement accuracy.

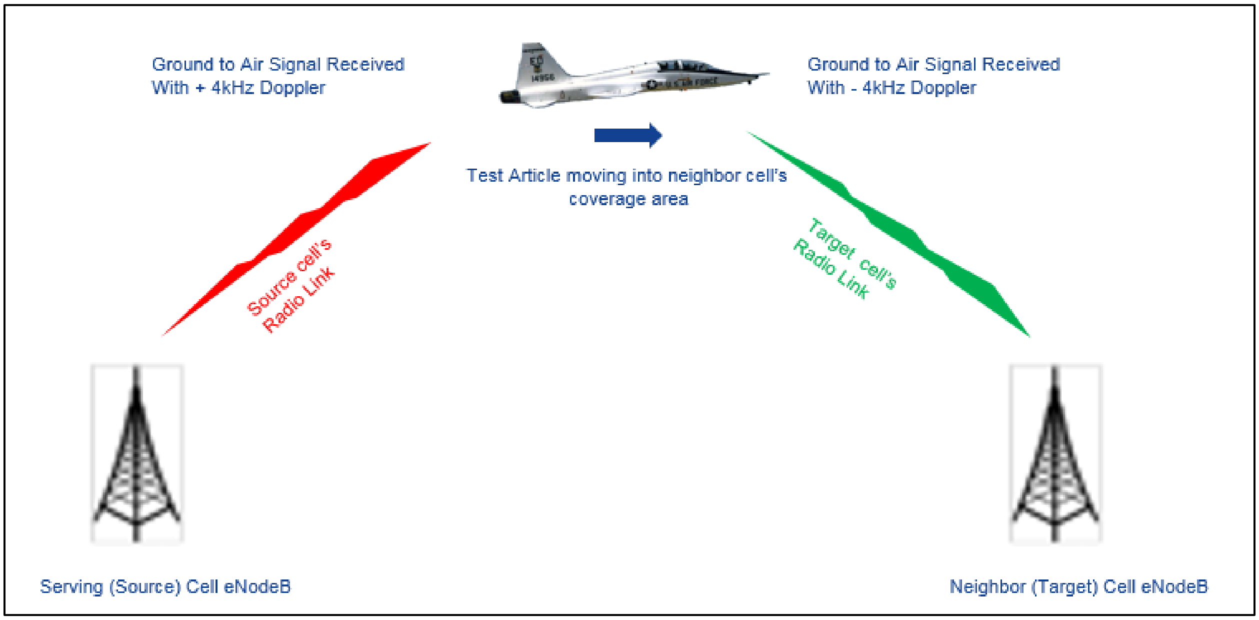

Figure 6: Doppler Shifts between Serving and Neighbor cell signals

- Inaccurate measurements can either delay the trigger for Handover or lead to selection of a wrong target cell for the handover. This will result in loss of connectivity and thus cause longer pauses in data exchange.
- In order to mitigate the high Doppler offset difference between the serving and measured neighbor cell, UE design changes are necessary for the neighbor cell measurements.

B) Timing Advance

- Once the UE is given the command to leave the serving cell and connect to the target cell (Step # 3 of Intra- and Step # 4 of Inter-eNodeB handover), the UE attempts to make a connection with the target cell. To do this, it selects an initial timing advance value when sending its first transmission (Random Access Connection Request). Due to high speeds and the possibility of having cells larger than 100 km in radius, the initial timing advance computation is a challenge in a CRTM deployment.
- Incorrect Timing Advance will result in the target eNodeB being unable to detect the Random Access Connection Request, which will eventually lead to a handover failure.
- Design changes will be needed at the UE to select an initial timing offset that it can use to adjust the timing of the Random Access Request transmission.

C) Handover Processing Time

- Handover processing for commercial LTE systems is designed for supporting speeds up to 500 km/hr. The time between the UE detecting that a measurement threshold has been met to the point where the serving cell informs the UE to connect to the specified target cell is typically in the order of 100-150ms.
- For CRTM, the test article is moving at very high speeds, and this limits the amount of time available for a system to do a handover. A very fast UE can move out of the coverage area of the serving cell and into the coverage area of the neighbor cell very quickly. Taking too long to initiate a handover can result in a handover failure. This in turn would result in call drops and a longer interruption in data service.

CONCLUSIONS

This paper shows the major challenges for extending 3GPP LTE seamless handover in terrestrial applications to the high speeds of a telemetry application. Enhancements are needed to the eNodeB and UE design to handle the doppler shifts caused by high speeds and higher operating frequencies and to the timing advance and handover processing algorithms on the eNodeB and UE.

Nokia is building upon its commercial Air to Ground LTE solution to address these challenges for Cellular Range Telemetry. ([5][6][7])

REFERENCES

[1] 3GPP TR 24.301: "Non-Access-Stratum (NAS) protocol for Evolved Packet System (EPS)".

[2] 3GPP TS 36.331: "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC) protocol specification".

[3] 3GPP TS 36.413: "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)".

[4] 3GPP TS 36.423: "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 Application Protocol (X2AP)".

[5] Apparatus, method and computer program for determining a frequency offset, Nokia Patent European Patent # EP2490389A1

[6] Access to a wireless communications network by a transceiver equipment adjusting the timing advance value used for sending a Random Access Channel preamble to a base station broadcasting cell radius information, Nokia European Patent #EP2427018A1

[7] Method for random access to a wireless or mobile communication network, and corresponding transceiver equipment, Nokia European Patent #EP2408353A1