High Speed LTE

Using Extended Doppler Support

SEQUANS COMMUNICATIONS

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1. Introduction

The 3GPP standards body in their LTE release specifications has set minimum requirements for the speed and performance of the LTE modem that establishes a baseline level of performance that must be met in order to be compliant with the standard. However, there are several applications that require a level of performance well above this baseline. Examples include air-to-ground communications for high-speed vehicles, or underground trains such as used in Elon Musk's Hyperloop program[1], or commercial and military airplanes, such as deployed in the European Aviation Network[2].

Sequans, a leader in LTE with 15 years of experience developing and refining 4G modem technologies, has successfully addressed several of these extraordinary scenarios by customizing and enhancing orthodox 3GPP LTE solutions that are already commercially deployed. This paper discusses the various aspects of meeting the challenges of developing LTE for high-speed applications.

To ensure a high-quality communication link in airplanes and other high-speed vehicles, the user equipment (UE) should be capable of not only managing synchronization when the link is established, but also maintaining the quality of the link during the entire time of communication, which becomes increasingly difficult as speed increases. Communication at high speed causes a shift of the received frequency offset, a phenomenon called the Doppler shift. Effects of the Doppler shift include drifting, which is caused by changes in the velocity and the position of the UE relative to the eNodeB. Moreover, the UE must be able to identify and measure signals coming in from other frequencies, intra or inter-cell. Depending on the initial position of the UE during the first cell acquisition, the UE might be moving away from the serving cell and moving towards a neighboring cell, thereby affecting signal measurements. Given that all operations use the same oscillator correction, this can result in doubling the effect of the Doppler shift between the serving and neighboring cells, causing it to fall outside the capture range of conventional receivers.

Sequans LTE solutions can be modified to support even ultra high speed (up to MACH 3) profiles.

The discussion that follows is based on the assumption that the issues to be addressed are mainly on the UE side while leaving the eNodeB and infrastructure operating as close as possible to the 3GPP LTE baseline standard. This approach was chosen after a thorough consideration of the various possibilities for improving the performance of the UE modem device and the Infrastructure equipment, and reaching the conclusion that a fully transparent solution for the infrastructure equipment is not only possible, but is most efficient.

2. Standard Requirements and Challenges

The 3GPP LTE requirements for high-speed applications are limited to the high-speed train (HST) application, which is described in Section B.3 of ETSI document, TS 36.101[3]. In this scenario, there is described a simple AWGN channel with maximum Doppler shift defined as +/- 750 Hz. The Doppler inversion occurs in this scenario very rapidly, resulting in a peak HST rate of Doppler change of 36.43 kHz/s with a minimum UE-to-eNodeB distance of two meters. This means that in the HST case the capture range of the algorithm needs to be twice the maximum Doppler shift.

Recently, there have been partial attempts to address the challenge of the high-speed profiles with LTE-R[4], which is defined for services such as real-time monitoring, train multimedia dispatching, and railway emergency communications, and is planned for deployment only in limited regions. LTE-R is not like conventional LTE, as it is not defined for broadband wireless access, which requires wider bandwidth. The maximum speed of LTE-R is defined as 500 km/h, which is a non-negligible increase with respect to standard 3GPP LTE HST requirements. In Sequans' products, the target speed for such non-standard communication is much higher.

In high-speed scenarios such as in airplanes or in even higher speed use cases, the duration of the Doppler inversion can be much longer than in lower speed use cases. Thus it can be deduced that even at the very high speed of an airplane, the longer duration of the Doppler inversion provides a relaxation of the maximum Doppler change rate. Table 1 shows a comparison between an HST channel and an example airplane channel. Apart from the relaxation of the maximum Doppler change rate, there are several additional challenges that come with maximum Doppler shift support, including the need of supporting a channel delay spread consisting of more than line-of-sight, handover, and cell range. These challenges require solutions more sophisticated than conventional 3GPP LTE solutions, which remain limited. Sequans met these challenges in technology it developed with Thales and Nokia for the on-board devices designed for the European Aviation Network.[5]

Table 1: Comparison of HST
And an example airplane channel characteristics.

Parameter	HST [8]	Airplane Channel
Cell Diameter	300 m	300 km
SAW Filter	2 m	3000 m
UE Velocity	360 km/h	1200 km/h
Maximum Doppler Shift	+/-750 Hz	+/-2500 Hz
Maximum Doppler Change Rate	+/-36.43 kHz/s	(e.g.) +/-300 Hz/s

At speeds on the order of 1200 km/h, which is much higher than the standard 3GPP LTE UE velocities, a UE can experience a maximum Doppler shift above +/- 2.2 kHz with typical S-band carrier frequencies (see example use case described in ETSI document referenced in footnote 3). This is an important value and presents an additional obstacle to maintaining a high quality communications link. The conventional methods used in LTE UEs, which satisfy the 3GPP LTE requirements, are not sufficient to capture the maximum Doppler shift for the high speed scenario and fails to demodulate any data. Several methods may be needed to compensate for the resulting Doppler shifts from physical layer algorithms to system level procedures. LTE solutions can be modified to support even ultra high-speed (up to MACH 3) profiles.

3. Sequans Brings New Solutions to Support High Speed Applications

High-speed applications have strict requirements for data rate, transmission delays, and decoding capabilities. Sequans' technology provides efficient connectivity of UEs by satisfying all these requirements even at very high-speed conditions.

Sequans' solutions cover physical layer procedures from UE power adjustment to the fine-tuning of frequency synchronization, including the system level aspects of the update of the baseband algorithms. The required customizations not only improve the low level estimation methods, but also improve the algorithms for LTE system measurements, and adapt to major 3GPP LTE procedures such as random access using physical random access channel (PRACH), to take care of the Doppler effect and the extended cell range, the cell reselection, the handover completion speed, and finally, the cell scanning itself.

One of the main acceptance criteria is to maintain throughput similar to what is mandated by 3GPP in various scenarios. As an example, at 900 Km/h, a device can sustain average throughput up to 90 Mbps downlink and 20 Mbps uplink.

Supporting high-speed profiles requires the support of cell sizes much larger than what is defined by 3GPP in the standard. Sequans' solutions can adapt to support cell sizes that are 50 percent larger, or up to 150 kilometers.

Going from a standard 3GPP LTE solution to an advanced solution supporting high-speed features from the physical layer to the application layer allows Sequans to serve a wide range of markets. Features can apply to commercial applications and also to mission critical military applications where providing a secure LTE link is of paramount importance.

Both Sequans' Cassiopeia and Monarch solutions are capable of supporting the demanding requirements of high-speed applications efficiently. Sequans products with advanced features are already implemented and deployed in both high-end and low-end devices (see additional references). These solutions are mature, proven in the marketplace, and deployed worldwide in the USA, Europe, and Asia.

4. Footnotes

- [1] SpacEx Hyperloop, http://www.spacex.com/hyperloop
- [2] European Aviation Network, www.EuropeanNetworkAviation.com
- [3] ETSI, "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception" (3GPP TS 36.101 version 14.3.0 Release 14) http://www.etsi.org/deliver/etsi_ts/136100_136199/136101/14.03.00_60/ts_136101v140300p.pdf, April 2017
- [4] He, Ruisi, et. al., "High Speed Railway Communications: From GSM-R to LTE-R," IEEE Explore Digital Library, https://ieeexplore.ieee.org/document/7553613/ Volume 11, Issue 3, Sept. 2016.
- [5] Sequans, "Sequans Teams with Thales and Nokia on First Successful Test Flight of the European Aviation Network," http://www.sequans.com/sequans-teams-with-thales-and-nokia-on-first-successful-test-flight-of-the-european-aviation-network/, January 2017

5. Additional References

- Sequans and Nokia Provide Technology for a World-First Trial of LTE on the Paris Metro, Sequans
- Engineers from Sequans and Nokia work on the world's first LTE network trial on a Paris metro train, (YouTube video), Systuff6HD
- The European Aviation Network, Inmarsat
- 4G LTE for airports and air-to-ground, Nokia
- First test flight within the European Aviation Network (YouTube video), Nokia

6. Abbreviations

- 3GPP: 3rd Generation Partnership Project
- AWGN: Additive White Gaussian Noise
- E-UTRA: Evolved Universal Terrestrial Radio Access
- GSM: Global System for Mobile Communications
- GSM-R: Global System for Mobile Communications - Railways
- HST: High Speed Train
- LTE: Long-Term Evolution
- LTE-R: 3GPP LTE version for Railways
- PRACH: Physical Random Access Channel
- UE: User Equipment