Technology Reports (Special Articles) 3GPP Release 16 LTE/NR HST

Special Articles on 3GPP Release 16 Standardization Activities

# Performance Enhancement Technologies in High-speed Moving Mobile Environments in LTE/NR Release 16

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Japan, China, and other countries are studying new train services traveling at speeds exceeding 300 km/h. To provide stable mobile communication services in such high-speed mobile environments, new LTE and NR specifications were studied for 3GPP Rel-16. This article describes technologies introduced in Rel-16 to realize stable communication quality in environments with anticipated speeds up to 500 km/h, and related discussion.

## 1. Introduction

Recently, in Japan, China, and other countries, progress is being made to introduce transportation facilities that achieve speeds higher than Shinkansen bullet trains. The 3rd Generation Partnership Project (3GPP) is holding discussions on preserving mobile communication quality in such high-speed mobile environments. 3GPP Release 14 (here in after referred to as "Rel-14") already gives specifications for implementing improvements to LTE communication quality in environments with speeds comparable to Shinkansen bullet trains [1]. With the new mobile communication system added in Rel-15, called New Radio (NR) [2], use of NR in high-speed mobile environments can be expected to increase. Generally, the effects of Doppler frequency shift*1 become strong with high frequencies and moving at high speeds. A reference signal is used to compensate for this Doppler frequency shift, but the signals used by NR are different than those used by LTE, so further study was required for NR.

With this background, the Rel-16 specifications were defined to preserve LTE and NR communication quality on the uplink and downlink at speeds of up to 500 km/h.



*1 Doppler frequency shift: Shift in carrier-wave frequency due to the Doppler Effect.

This article describes technologies introduced in the Rel-16 specifications for achieving stable communication quality in environments at speeds of up to 500 km/h, and related discussion.

## 2. Issues in High-speed Mobile Environments

### 2.1 Doppler Frequency Shift Compensation

In high-speed mobile environments, the amount of Doppler frequency shift increases with increases in both frequency and traveling speed, and the phase rotation*2 that this produces in the received signal can greatly affect communication quality. This effect would be large when traveling at speeds up to 500 km/h, and the main frequencies currently being used with NR, the 3.7 GHz band (n77*3, n78) and the 4.5 GHz band (n79), are even higher than those used by LTE, further increasing the effect. As such, the issue was discussed at 3GPP, including differences with LTE. Note that discussion of the 28 GHz, millimeter-wave band (n257) was not in the scope of high-speed wireless interface for Rel-16.

Generally, when there is Doppler frequency shift, it causes phase rotation in the time domain. Both the base station and the user equipment use a reference signal to measure and compensate for phase rotation due to Doppler frequency shift. As the time-domain interval between reference signals is decreased, more-rapid phase fluctuations can be tracked, and larger Doppler frequency shifts can be corrected. Note that the original phase can be recovered for phase rotations up to inversion (up to +/-180 deg.).

With LTE, Doppler frequency shift is estimated by user equipment using the Cell-specific Reference Signal (CRS)*4, which it receives from the base station with the downlink signal, and by base stations using the DeModulation Reference Signal (DM-RS)*5 [2], which the base station receives from the user equipment with the uplink signal.

On the other hand, with NR, base stations do not transmit the CRS, so user equipment estimates Doppler frequency shift using the Tracking Reference Signal (TRS)*6 [2], which is sent periodically by the base station. Similar to LTE, NR base stations estimate Doppler frequency shift using a DM-RS, which they receive with the uplink signal, but the DM-RS intervals, the symbols*7, and the number of Resource Elements (RE)*8, are different than with LTE, so the conditions for correcting for Doppler frequency shift are different.

NR has also defined new, wider subcarrier*9 spacings of 30 and 60 kHz, in addition to the subcarrier spacing of 15 kHz as in LTE, so it may be necessary to compensate for larger Doppler frequency shifts than with 15 kHz subcarriers. In particular, with a 15 kHz subcarrier spacing as shown in **Figure 1**, downlink NR communication has an interval of four symbols between TRS. This is wider than the three symbols with LTE CRS, so the range of Doppler frequency shift that can be corrected will be smaller.

On the other hand, with a 30 kHz subcarrier spacing, the interval between TRS is four symbols, which is equivalent to an interval of two symbols with a 15 kHz subcarrier spacing, so the range of Doppler frequency shift that can be corrected is larger than with LTE. Looking at the NR uplink, there is a wider range of choices for subcarrier spacing, and settings for the density and position of the Physical Uplink Shared CHannel (PUSCH)*10 DM-RS are more flexible [2], so by placing the DM-RS at

*2 Phase rotation: The change in phase that occurs in a signal passing through a radio channel.

*3 n77: A Time Division Duplex (TDD) frequency band defined NR (3,300 to 4,200 MHz).

*4 CRS: Reference signal for measuring cell quality, specific to each cell.

*5 DM-RS: A reference signal used for channel estimation, used for decoding data transmitted on the uplink and downlink.

*6 TRS: A reference signal used for tracking fluctuations in time and frequency on the downlink.

a smaller interval than is used for LTE, it is possible to compensate for larger Doppler frequency shifts.

## 2.2 Base Station Deployment Configurations

To maintain communication quality in high-speed mobile environments, special base station deployment scenarios suitable for high-speed mobile environments as well as normal environments were proposed and discussed for 3GPP Rel-14. Discussion of base station deployment configurations were also held for Rel-16, based on the earlier discussions and covering functions and characteristics of NR.

An overview of base station configurations discussed for Rel-16 is shown in **Figure 2**. The Single

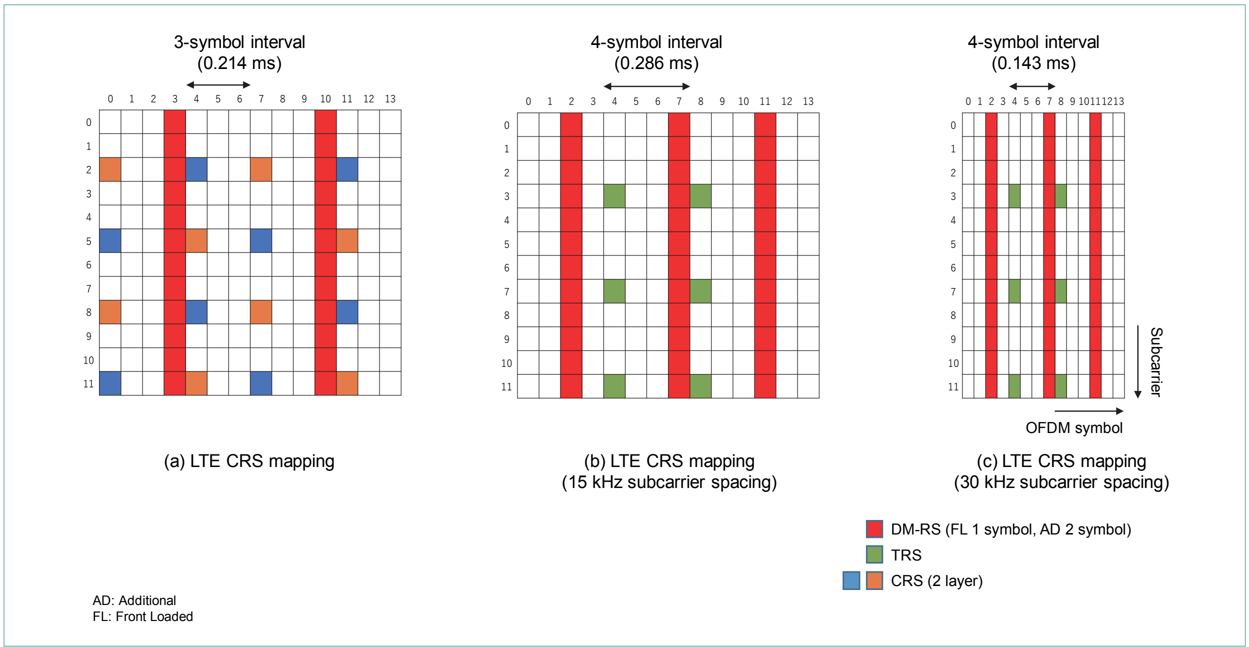


**Figure 1　Comparison of LTE and NR downlink reference signal intervals**

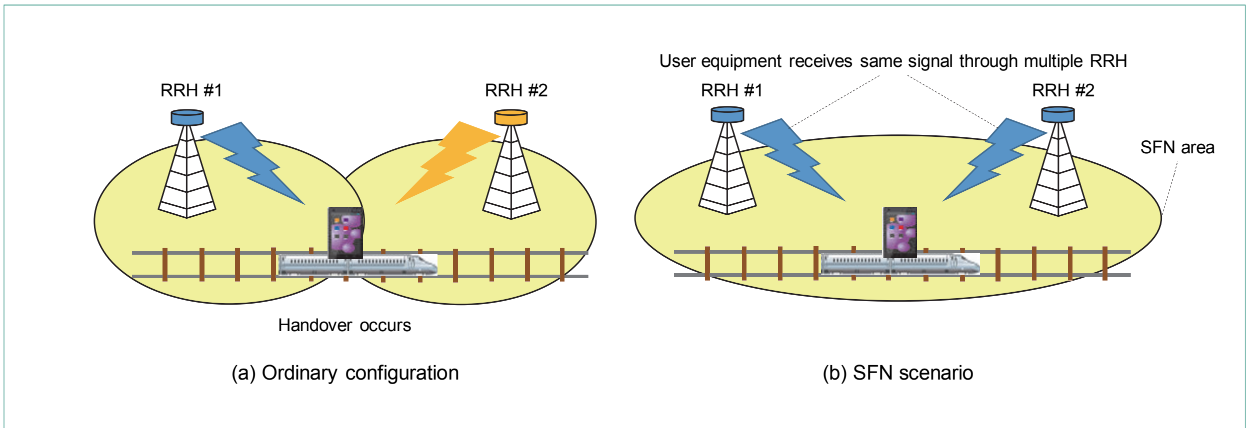


**Figure 2　Base station deployment for high-speed mobile environments**

*7 Symbol: A time unit of transmitted data, consisting of multiple subcarriers with Orthogonal Frequency Division Multiplexing (OFDM). Multiple bits (2 bits in the case of Quadrature Phase Shift Keying (QPSK).

*8 RE: A component of the downlink resource composed of one subcarrier and one OFDM symbol.

*9 Subcarrier: An individual carrier used for transmitting signals in a multi-carrier transmission scheme such as OFDM.

*10 PUSCH: Data transmitted on the uplink.

Frequency Network (SFN)[*11] scenario was also discussed for Rel-14 [1]. It deploys multiple Remote Radio Heads (RRH)[*12] in succession, each transmitting and receiving the same signal at the same frequency, so that the area covered by all of them can be considered a single cell. As such, switching from one RRH to the next does not require handover[*13], so this deployment scenario is excellent for high-speed mobile environments. On the other hand, this deployment scenario requires simultaneous tracking of received signals that have positive and negative Doppler frequency shifts.

## 3. Introduced Requirements and Their Effects

Reception performance requirements and test conditions for LTE and NR in Rel-16 and prior to Rel-16 are shown in **Table 1**. Considering the issues discussed above, Rel-16 NR defines test conditions assuming DM-RS with an arrangement of three symbols, so that channel estimation[*14] can be

Table 1　Reception requirement and test conditions introduced for high-speed trains

| Release | Communication direction | Base station deployment configuration | LTE | | | NR | | |
|---|---|---|---|---|---|---|---|---|
| | | | Traveling speed | Tolerable Doppler frequency shift | Frequency*1 | Traveling speed | Tolerable Doppler frequency shift | Frequency*1 |
| Rel-15 and earlier | Downlink (user equipment reception) | Ordinary configuration | 300 km/h | 750 Hz | 2.7 GHz | 300 km/h | 750 Hz (15 kHz subcarrier spacing) | 2.7 GHz |
| | | | | | | | 1,000 Hz (30 kHz subcarrier spacing) | 3.6 GHz |
| | | SFN scenario | 350 km/h | 875 Hz | 2.7 GHz | No requirement | | |
| | Uplink*2 (Base station reception) | Ordinary configuration SFN scenario | 350 km/h | 1,340 Hz | 2.06 GHz | No requirement | | |
| Rel-16 | Downlink (user equipment reception) | Ordinary configuration | 500 km/h | 972 Hz | 2.1 GHz | 500 km/h | 972 Hz (15 kHz subcarrier spacing) | 2.1 GHz |
| | | | | | | | 1,667 Hz (30 kHz subcarrier spacing) | 3.6 GHz |
| | | SFN scenario | 500 km/h | 972 Hz | 2.1 GHz | 500 km/h | 870 Hz (15 kHz subcarrier spacing) | 1.88 GHz |
| | | | | | | | 1,667 Hz (30 kHz subcarrier spacing) | 3.6 GHz |
| | Uplink*2 (Base station reception) | Ordinary configuration SFN scenario | 500 km/h | 1,944 Hz | 2.1 GHz | 500 km/h | 1,740 Hz (15 kHz subcarrier spacing) | 1.88 GHz |
| | | | | | | | 3,334 Hz (30 kHz subcarrier spacing) | 3.6 GHz |

*1　Value computed from the traveling speed and the tolerable Doppler frequency shift.
*2　For the uplink, to synchronize with the downlink signal with added Doppler frequency shift, a larger Doppler frequency shift must be considered.

*11　SFN: A network consisting of master and relay stations all using the same transmission frequency.

*12　RRH: One component of base station equipment installed at a distance from the Base Band Unit (BBU) using optical fiber or other means. It serves as radio equipment for transmitting/receiving radio signals.

*13　Handover: A technology for switching base stations without interrupting a call in progress when a terminal moves from the coverage area of one base station to another.

*14　Channel estimation: The process of estimating the amount of fluctuation in received attenuation and phase rotation in the received signal when a signal is transmitted over a radio channel.

done reliably at speeds of up to 500 km/h. The SFN scenario discussed above has also been defined, in addition to the ordinary deployment scenarios, and reception requirements have been introduced, accounting for the maximum Doppler frequency shift that can be corrected, for the TRS on the downlink and the DM-RS on the uplink. With the introduction of these stipulations, it will be possible to maintain communication quality at speeds up to 500 km/h, and we can expect LTE and NR areas to be created and quality improved within Shinkansen bullet trains and other high-speed trains.

## 4. Conclusion

This article has described new standard specifications in 3GPP Rel-16 for improving communication quality in high-speed mobile environments and their characteristics. This functionality will help maintain communication quality in high-speed mobile environments such as Shinkansen bullet trains. NTT DOCOMO will continue to promote the study of specifications that consider issues and demand in real environments.

### REFERENCES

[1] T. Takada et al.: "Performance Enhancement Technologies in High-speed Moving Mobile Environment in LTE-Advanced Release 14," NTT DOCOMO Technical Journal, Vol.19, No.3, pp.64–70, Jan. 2018.

[2] K. Takada et al.: "NR Physical Layer Specifications in 5G," NTT DOCOMO Technical Journal, Vol.20, No.3, pp.49–61, Jan. 2019.