Technology Reports 3GPP Release 14 High-speed Moving Mobile Environment SFN Scenario

Performance Enhancement Technologies in High-speed Moving Mobile Environment in LTE-Advanced Release 14

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As demands have grown for mobile communications quality improvements in high-speed moving environments such as high-speed rail, basic studies on performance enhancements in high-speed moving environments were discussed in 3GPP Release 13 and technical specifications for these performance enhancements have been specified in Release 14. This article describes the technologies newly specified in Release 14 for improving mobile communications quality in high-speed moving environments.

1. Introduction

In recent years, the demands for broadband mobile communications in high-speed moving environments such as high-speed rail have been increasing. In addition, high frequency bands can be used for mobile communications. In general, in high-speed moving mobile environments, the higher the frequency, the greater the Doppler frequency shift*1 effects, which results in major technical issues to ensure mobile communications quality. In addition, as deployment planning*2 on commercial networks becomes more diversified, technical issues with deployment planning in high-speed moving mobile environments have been emerging, which were not sufficiently considered in early 3GPP specifications.

Due to this situation, mobile communications quality improvements in high-speed moving mobile environments were discussed as a Study Item (SI)*3 in 3GPP Release 13. Based on the results of this SI, new specifications were defined in Release

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

*2 Deployment planning: The design of base station positioning and parameters to fulfill area and quality requirements.

*3 SI: Work to "consider achievability, and generally defined functions that should be specified."

14 to improve the communications quality of new deployment planning, and improved Random Access CHannel (RACH)*4 detection characteristics. This article describes these Release 14 specifications.

2. Issues in High-speed Moving Mobile Environments

2.1 Improving Communications Quality in High-speed Movement in SFN Scenarios

1) SFN Scenario Overview

An example of a Single Frequency Network (SFN)*5 scenario is shown in **Figure 1**. Essentially, SFN refers to a network on which the same radio frequency is used with master and relay stations. Here, the SFN scenario refers to a deployment planning in which same signals are sent and received with the same frequencies through multiple Remote Radio Heads (RRH)*6 installations covering the area. This scenario is suitable for high-speed moving mobile environments such as areas in high-speed rail tunnels because there is no interference from adjacent RRH signals, and hand over*7 does not occur when mobile terminals move from RRH1 area to RRH2 area because the cell does not change, as shown in Fig. 1.

2) The Doppler Frequency Shift Issue with High-speed Movement in SFN Scenarios

In the SFN scenario, the same signals are sent from each RRH. Signals arriving from the RRH in front of the mobile terminal and signals arriving from the RRH behind the mobile terminal are affected by positive Doppler frequency shift and negative Doppler frequency shift, respectively. An example of this phenomenon is shown in **Figure 2**. When the mobile terminal passes through RRH1 and RRH2, the signal arriving from RRH1 has a negative Doppler frequency shift effect, while the signal arriving from RRH2 has a positive Doppler frequency shift effect. Because the Doppler frequency shift with high-speed movement is significant, at the timing for switching the RRHs connected to the high-speed moving mobile terminal, i.e., in the halfway area between the two RRHs, signals affected by positive and negative Doppler frequency shift with significant absolute values arrive at the high-speed moving terminal with almost

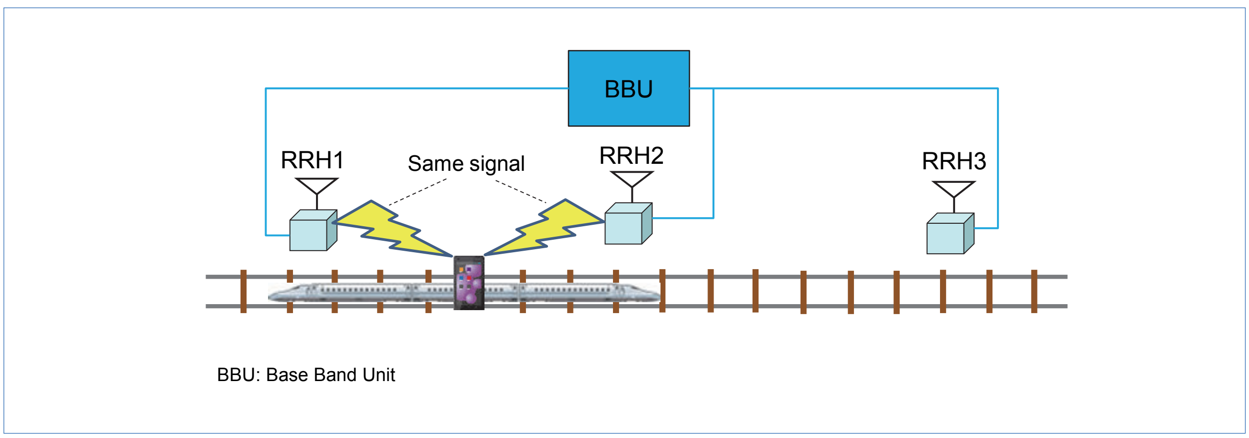

Figure 1 SFN scenario

*4 RACH: A common uplink channel that is used for transmitting control data and user data. It is shared by multiple users and is independently and randomly transmitted by users.

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

*6 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.

*7 Hand over: 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.

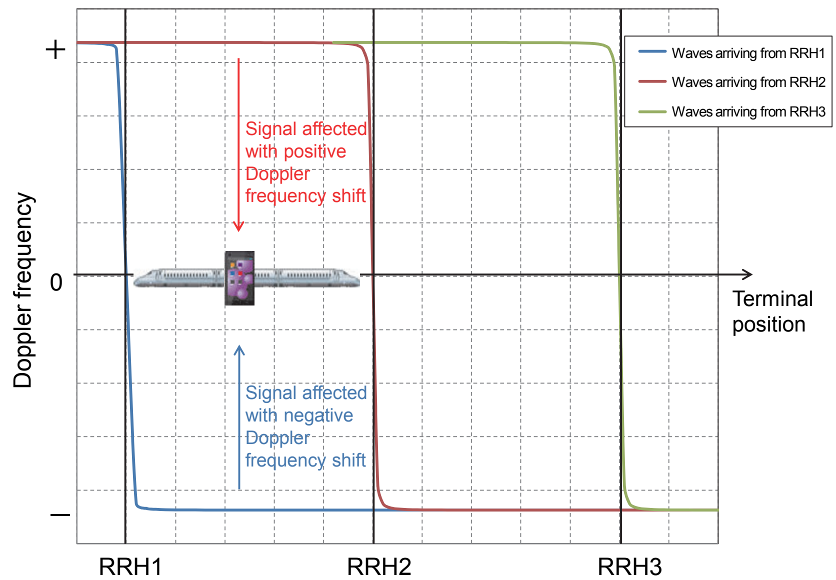

Figure 2 Doppler frequency effects

the same timing. Since the high-speed moving mobile terminal must switch RRHs while receiving these two signals simultaneously, it is difficult for the terminal to track the sudden Doppler frequency shift change from negative to positive, which results in degraded communications quality.

2.2 RACH Detection Performance Improvement in High-speed Moving Mobile Environments

1) Restricted Set of Cyclic Shifts in Release 8 LTE

When a base station receives an uplink signal from a high-speed moving mobile terminal, in addition to the Doppler frequency shift of the transmitted uplink signal, it's necessary to consider the larger Doppler frequency shift compared to that in case of a downlink signal reception at the mobile terminal, as transmitting mobile terminals synchronize with downlink signals that have been Doppler frequency shifted. This issue is not limited to SFN scenarios, but also occurs in general deployment scenarios. Considering the above, the Physical Random Access CHannel (PRACH)*8 in Release 8 LTE was designed so that base stations can detect PRACH with Doppler frequency shift up to +/– 1.25 kHz in high-speed moving mobile environments. This enables sufficient PRACH detection performance at 2 GHz up to 350 km/h.

(a) PRACH CS detection in normal scenario

The PRACH transmission sequence is generated by applying Cyclic Shift (CS)*9 to Zadoff-Chu (ZC) sequence*10. The CS value applied is selected by the mobile terminal from candidate values according to the base

*8 PRACH: Physical channel for transmitting the random access preamble.

*9 CS: Cyclic shift processing of the relationship between time indexes and elements for sequence etc.

*10 ZC sequence: A Constant Amplitude Zero Auto Correlation (CAZAC) sequence, in which the amplitude is kept constant for the time index, and is characterized by a delta function as the autocorrelation function.

station settings. In cells that don't assume high-speed moving mobile terminals, the integral multiple values of N_{CS}, which is the PRACH reception timing window length, are set as the CS candidate values (**Figure 3** (a)). At the base station, by detecting the CS value that generates a correlation*11 peak between the received PRACH sequence and the ZC sequence template, it's possible to recognize the transmission sequence selected by the mobile terminal and the timing error in the N_{CS} range.

(b) Restricted set of PRACH CS for high-speed movement scenarios

In high-speed movement scenarios, multiple correlation peaks between the received PRACH sequence and the ZC sequence template are observed at the base station due to Doppler frequency shift effects. To prevent degradation of PRACH detection performance due to the shift of the maximum correlation peak position, restricted set of PRACH CS was introduced in Release 8 LTE. By preparing three timing detection windows for a CS, $+d_u$ and $-d_u$ for the CS at the base station where d_u is the CS corresponding to the reciprocal of the PRACH preamble*12 sequence time length, correlation peaks observed at each detection window are used in combination so that the base station can recognize the PRACH transmission sequence selected by the mobile terminal and timing errors in the N_{CS} range even with certain level of Doppler frequency shift (Fig. 3 (b)). Hence, to prevent recognition errors in the PRACH transmission sequence, CSs that can

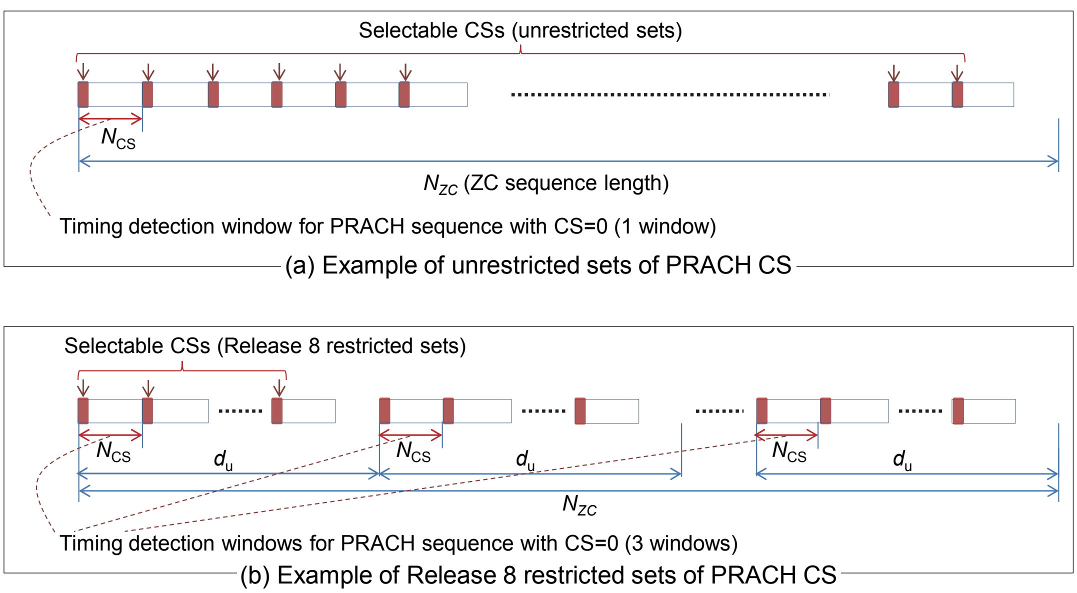

Figure 3 Conventional CS selection and detection methods for PRACH sequence

*11 Correlation: An index expressing similarity between different signals. Expressed as a complex number, its absolute value ranges from 0 to 1. Similarity is higher for a value closer to 1.

*12 Preamble: A signal with a fixed pattern positioned at the beginning of packets. Receivers use these to detect packets, control gain, and synchronize frames and frequencies etc. as preparation to receive the data portion.

be selected by the mobile terminal are restricted so that no candidate CS overlaps with other candidate CSs, $+d_u$, and $-d_u$ positions of other candidate CSs.

2) Issues of PRACH Detection in High-speed Moving Mobile Environments

As described above, PRACH in Release 8 LTE was designed to handle Doppler frequency shift in high-speed moving mobile environments with up to +/− 1.25 kHz. However, there is increasing necessity for advanced PRACH detection performance with higher frequencies or in environments such as SFN scenarios where Doppler frequency shift effects are emerging. Also, when the Doppler frequency shift is large, the maximum correlation peaks are observed at the $+2d_u$ and $-2d_u$ positions. In such cases, the restricted set in Release 8 has the issue of recognition errors in the PRACH transmission sequence.

3. New Requirements and Their Performance

3.1 New Requirements for Downlink Reception Performance with High-speed Movement in SFN Scenarios

To solve the issues described in Section 2.1, new high-speed moving mobile environment model simulating an SFN scenario similar to that in Fig. 1 was defined in Release 14, and throughput performance requirements for using this model were added. When these new throughput performance requirements were discussed, the following mobile terminal receiver functions were considered as standard studies.

- The terminal tracks all signals affected by positive and negative Doppler frequency shift with significant absolute values arriving at the high-speed moving terminal at the same time, estimates the Doppler frequency shift and modifies the center frequency shift.
- Advanced propagation path estimation to improve interpolation accuracy especially in the time domain*13.

An evaluation result example is shown in **Figure 4** [1]. The horizontal axis shows the Signal-to-Noise Ratio (SNR)*14 while the vertical axis shows the throughput. Comparing conventional receivers (red in Fig. 4) and receivers designed for the above standards (green in Fig. 4), it can be seen that the throughput is greatly improved when moving at 350 km/h.

However, as the behaviors of these receivers are specialized for SFN scenarios, operating these receivers in low-speed or high-speed moving environments outside SFN scenarios can lead to degraded performance and increased power consumption. For this reason, control signaling (network assisted signaling) was introduced to enable receiver functions to be switched ON/OFF. **Figure 5** describes an overview of these receiver functions including the ON/OFF function. This control signal is included in the System Information Block (SIB)*15 sent from the base stations in SFN scenarios, so that when a high-speed moving mobile terminal receives the signal, the defined receiver function starts.

3.2 PRACH Enhancement for High Doppler Frequency Shift Environments

To solve the issues described in Section 2.2, new restricted sets of PRACH CS that can handle

*13 **Time domain**: In signal analysis, this domain is used to show the temporal makeup of a signal's components. A time-domain signal can be converted to a frequency-domain signal by a Fourier transform.

*14 **SNR**: The ratio of the desired signal power to the noise power.

*15 **SIB**: Various types of information broadcast simultaneously to each cell, such as the location code required for judging whether location registration is needed for a mobile terminal, information on surrounding cells and radio wave quality required for services in those cells, and information for restricting and controlling outgoing calls.

up to +/− 2.5 kHz Doppler frequency shift in high-speed movement scenarios were introduced in Release 14. With the new restricted sets, selectable CSs at the mobile terminal are further restricted so that no candidate CS overlaps with other candidate CSs, $+d_u$, $-d_u$, $+2d_u$ and $-2d_u$ positions of other candidate CSs. Base stations are equipped with N_{CS} range timing detection windows at the above five positions used for detection by combining the correlation peaks observed in each detection window (**Figure 6**). This improves PRACH detection performance in high-speed moving mobile environments e.g., above 350 km/h at 2 GHz with up to +/− 2.5 kHz Doppler frequency shift.

4. Conclusion

This article has described characteristic functions

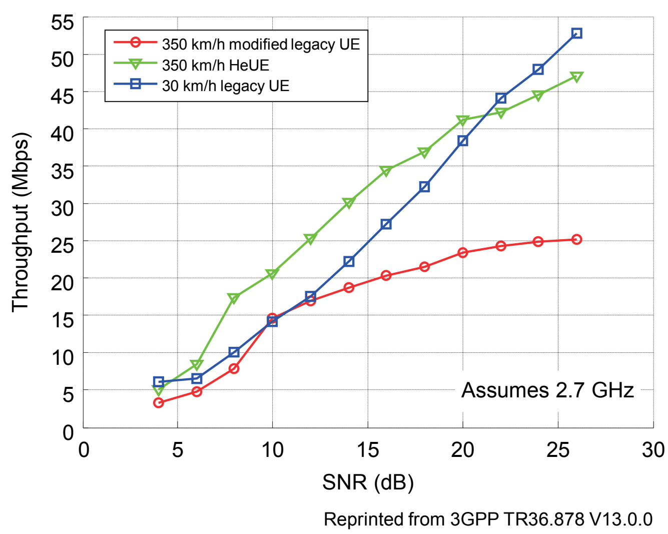

Figure 4 Example of SFN scenario evaluation results

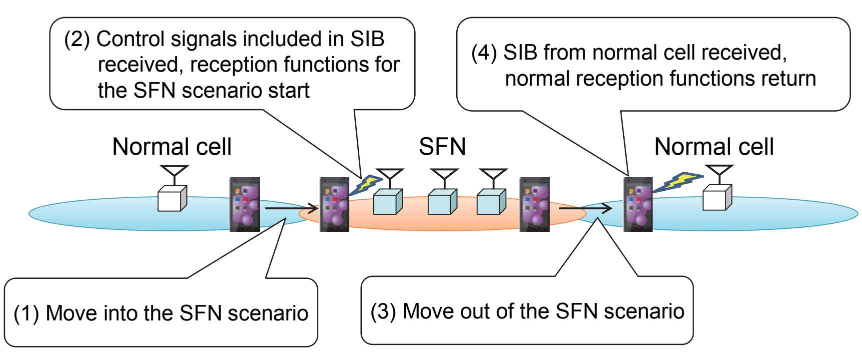

Figure 5 Overview of reception functions specialized for SFN scenarios

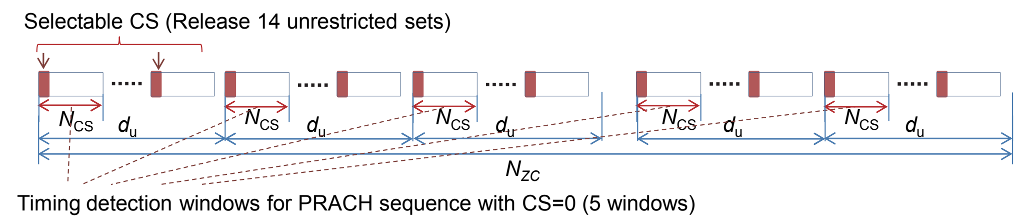

Figure 6　Example of Release 14 restricted sets of PRACH CS

and basic behaviors for performance enhancements in high-speed moving mobile environments in 3GPP Release 14, specifically reception requirements for new deployment planning, and the specifications to improve PRACH performance. These functions enable further improvements to communications quality in high-speed moving mobile environments such as high-speed rail.

REFERENCE

[1] 3GPP TR36.878 V13.0.0: "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on performance enhancements for high speed scenario in LTE," Feb. 2015.