

Mobile Device Field Tests with Excellent Reproducibility

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[Summary]

Ensuring the performance and functionality of mobile devices requires testing in actual on-site field environments as well as laboratory testing based on specific test cases. However, field test results may not necessarily be reproducible due to changes in base station operating conditions and radio propagation channels. This article proposes a Field Simulation Test (FST) solution to overcome these field-test problems. This solution tests devices in the laboratory based on radio propagation channels captured on-site supporting repeated laboratory tests under the same conditions as actual field conditions. Additionally, we introduce examples of how this solution is applied in on-site field tests.

1 Introduction

Following commercial rollout in 2020, the fifth-generation mobile communication system (5G) has spread rapidly and 5G subscriptions are predicted to account for half of all mobile subscriptions by 2028¹⁾. Moreover, commercial deployment of the sixth-generation mobile communication system (6G) is expected around 2030, and discussions have started on requirements, use cases, and fundamental technologies^{2), 3)}.

Before user equipment (UE), such as smartphones and tablets, reaches users, it must be verified and evaluated to ensure stable, high quality. For example, during R&D, various tests are conducted on radio frequencies (RF), protocols, data throughput, power consumption, etc., to evaluate device performance and functionality. Additionally, conformance tests^{4), 5)} and carrier acceptance tests (CAT)⁶⁾ are also conducted before deployment to verify interconnectivity between devices and mobile networks. Conformance tests evaluate whether a device complies with the technical standards specified by the Third Generation Partnership Project (3GPP). CAT verify whether the device has the unique functions defined by the carriers. Generally, these tests are conducted in laboratory environments based on test cases that assume specific conditions.

On the other hand, device testing is also conducted in actual on-site field environments to complement the test cases specified in laboratory testing⁴⁾ and to evaluate device quality as experienced by users⁷⁾. In the future, mobile communication services are expected to expand from best-effort type to quality-assured type to support demanding emerging applications¹²⁾, such as autonomous vehicles like

drones⁸⁾ and self-driving cars⁹⁾, industrial Internet of Things (IoT)¹⁰⁾, and telemedicine¹¹⁾. Therefore, the importance of device field testing is expected to continue increasing. However, in actual field environments, there are issues, such as the difficulty of repeatedly conducting device tests under identical conditions due to changes in the operational status of base transceiver stations (BTS) and radio propagation environments, meaning that test results may not always be reproducible^{13), 14)}. Consequently, device testing based on actual field environments but with controllable conditions is needed.

In these circumstances, this article proposes a Field Simulation Test (FST) solution to analyze BTS signals measured in actual field environments, model the radio propagation environment, and use that model to test devices in the laboratory. This solution can repeatedly test devices under identical conditions matching actual field environments. Additionally, we evaluate the model generation accuracy in known radio-propagation environments to demonstrate the effectiveness of this solution, and introduce an actual field application example.

2 Proposed Solution

2.1 Overview of Field Simulation Test (FST)

Figure 1 shows the concept of the FST solution. Although 3GPP specifies test cases including radio-propagation conditions for device testing, it is difficult to cover all environmental conditions. Therefore, device field tests aim to complement test cases⁴⁾. At conventional field tests, staff from device manufacturers travel to actual field environments to conduct tests using the device under test

(DUT). This requires enormous time and costs because field tests are repeated for each new device development as well as to verify improvements. Furthermore, field-test results may not necessarily be reproducible due to changes in BTS operational status and radio propagation environments. In response to these efficiency and reproducibility issues with device field tests, this FST solution test devices in a laboratory while simulating the radio propagation environment acquired in actual field environments, making it possible to repeatedly test devices under identical conditions in a laboratory based on actual field environments.

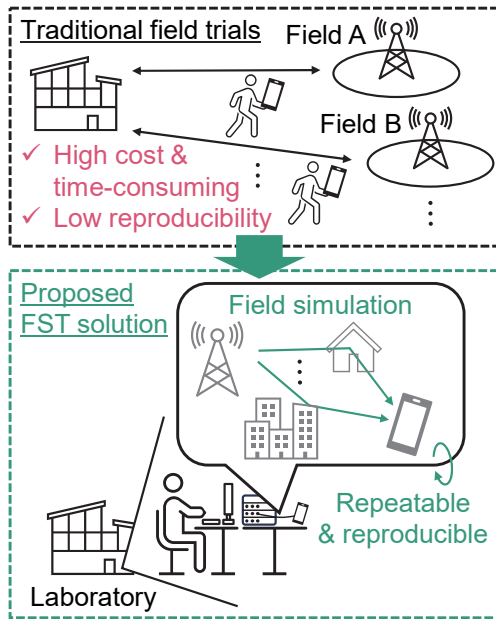


Figure 1 FST solution concept

Figure 2 shows the overall configuration of the FST solution, consisting of three steps: capturing, analysis and modeling, and testing. At the first capturing step, UE logs containing communication protocol sequence data are captured in the actual field environment, and downlink (DL) signals transmitted from BTS are captured as baseband in-phase and quadrature (IQ) data. The next analysis and modeling step generates fading models characterizing the radio propagation environment by analyzing the recorded IQ data while using the UE logs. The last testing step simulates the actual field environment using a BTS simulator and fading simulator based on the generated model to evaluate device connectivity.

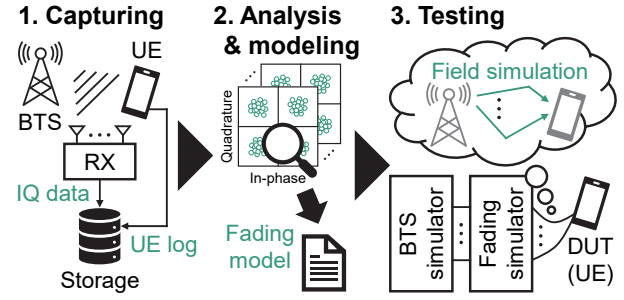


Figure 2 Overall configuration of FST solution

The following sections describe each of these three steps in detail.

2.2 Capturing

At the capturing step, DL signals transmitted from 5G New Radio (NR) or 4G Long Term Evolution (LTE) BTS are captured as baseband IQ data simultaneously with UE logs for any required time period. Figure 3 shows the configuration of the RF Air Monitor System for recording IQ data. As shown in this figure, this solution supports either a standard configuration for long-term multi-band recording, or a lite configuration that fits in a backpack, depending on requirements.

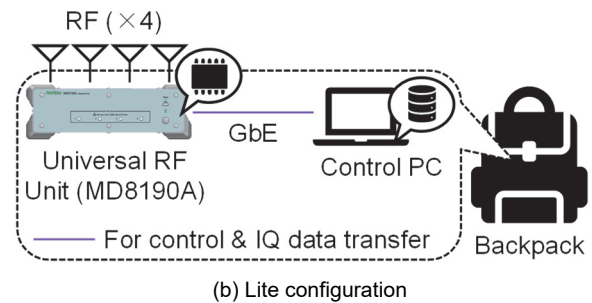
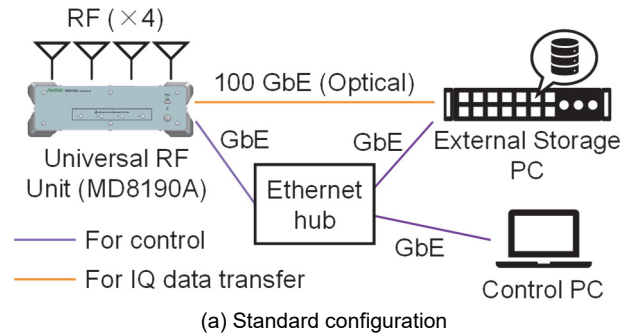


Figure 3 RF Air Monitor system configuration

The standard configuration in Figure 3(a) consists of a Universal RF Unit (MD8190A), PC for external storage, and control PC. The Universal RF Unit is a general-purpose RF interface device for converting analog RF signals to digital baseband IQ data. Using this solution, the Universal RF Unit with connected antennas receives RF signals transmitted from

BTS and converts them to IQ data. The external storage PC with large-capacity solid state drive (SSD) is connected to the Universal RF Unit via 100GbE optical fiber. IQ data converted by the Universal RF Unit are transferred in real-time to the external storage PC for storage on the SSD. The control PC is connected to both the Universal RF Unit and external storage PC via a GbE cable and controls both using the Log Capture Control Software (MX879000PC). Additionally, the RF Air Monitor System supports simultaneous capture using two Universal RF Units. This enables simultaneous recording of two NR standalone (SA) or LTE bands with carrier aggregation, as well as simultaneous recording of both NR and LTE NR non-standalone (NSA) bands. This configuration requires a rack-mounted external storage PC for long-term recording and is intended primarily for use in vehicles.

On the other hand, the lite configuration in Figure 3(b) eliminates the external storage PC so the entire equipment is small enough to fit in a backpack. In this configuration, the received RF signals are first converted to IQ data and saved temporarily in the Universal RF Unit internal random access memory (RAM). The IQ data saved in RAM is then transferred to and saved in the control PC via GbE cable. Although the lite configuration has limited recording time compared to the standard configuration, it cuts the workload when transporting equipment and recording.

Table 1 shows the RF Air Monitor System specifications supporting capture of RF signals from 0.4 to 6 GHz for NR frequency range 1 (FR1) and LTE systems. Bandwidths up to 100 MHz are supported and data can be captured for up to 4 RF ports per Universal RF Unit. The continuous recording time is 120 seconds for the standard configuration and 8 seconds for the lite configuration when capturing 100-MHz bandwidth signals for 4 RF ports.

Table 1 RF Air Monitor System Specifications

Number of RF ports	4
Frequency	0.4 to 6 GHz
Bandwidth (BW)	≤100 MHz
Sampling rate	30.72 Msps for ≤20 MHz BW 61.44 Msps for ≤50 MHz BW 122.88 Msps for ≤100 MHz BW
Recording time	120 s for 100 MHz BW × 4@Standard 8 s for 100 MHz BW × 4@Lite

Figure 4 shows the Log Capture Control Software for capturing IQ data in real-time while checking the power and

frequency spectrum of signals being received by the Universal RF Unit.

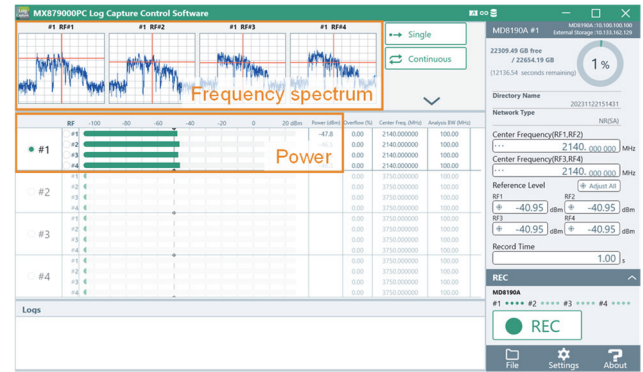


Figure 4 Log Capture Control Software (MX879000PC)

2.3 Analysis and Modeling

At the analysis and modeling step, the IQ data recorded using the RF Air Monitor System described in the previous section is analyzed to generate fading models that characterize the radio propagation environment. This step is carried out through the software FST Studio (MX879020PC) installed on a PC.

Table 2 shows the recorded target signals for analysis and modeling. As shown, FST Studio supports analysis of NR NSA, NR SA, and LTE signals. Specifically, the NR analysis targets are synchronization signal/physical broadcast channel (SS/PBCH) block, physical downlink shared channel (PDSCH), and channel-state information reference signal (CSI-RS)¹⁵. Additionally, the LTE analysis target is cell-specific reference signal (CRS)¹⁶. These target signals are used to estimate the instantaneous responses of the radio propagation channels and are processed while referencing radio resource control (RRC) messages in the UE logs acquired simultaneously with these signals as needed. FST Studio defines the open UE Log Open Interface file format in order to read RRC messages. UE logs captured in the field by users can be used for analysis after conversion to this format.

Table 2 Captured Data for Analysis and Modeling

Network type	NR SA/NR NSA (Option3x)/LTE
Bandwidth	10/15/20/25/30/35/40/45/50/60/70/80/90/100 MHz for NR, 1.4/3/5/10/15/20 MHz for LTE
Channel type	SS/PBCH block/PDSCH/CSI-RS for NR CRS for LTE
SCS	15/30 kHz
Number of layers	1 layer for NR SS/PBCH block 1/2/3/4 layer(s) for NR PDSCH-DMRS/CSI-RS and LTE CRS

Figure 5 shows an example of radio propagation channel analysis results using FST Studio. As shown, the instantaneous impulse response of the radio propagation channel is displayed in the top part of the screen, and the received power is displayed in the lower part. Based on this result, the user chooses the time range of the instantaneous response to generate the fading model. FST Studio adopts the well-known tapped delay line (TDL) model¹⁷⁾ as the fading model. The following parameters are primarily calculated based on the selected instantaneous response time range.

- Power delay profile (PDP): Relationship between multipath delay time and average power in radio propagation channel response
- K factor: Power ratio between line-of-sight (LOS) component and non-line-of-sight (NLOS) component
- Antenna correlation: Correlation of radio propagation channel response between either Tx or Rx antennas that significantly affects quality of multiple-input and multiple-output (MIMO) transmission

Furthermore, FST Studio also has a simple analysis function to quickly check IQ data captured in the field, allowing users to quickly spot abnormalities and reduce the need and costs of recording do-overs.

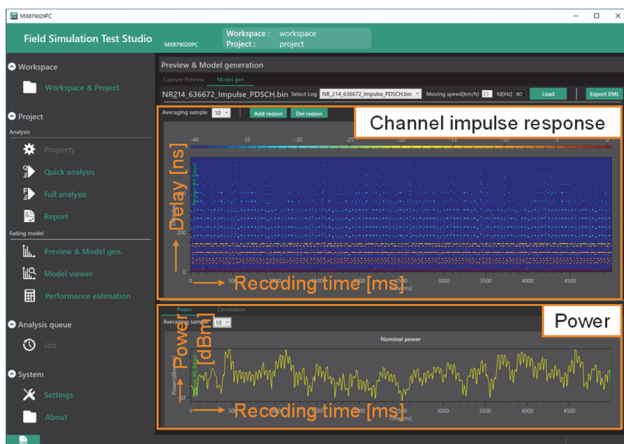


Figure 5 Example of FST Studio (MX879020PC) analysis results

2.4 Testing

Testing using the Radio Communication Test Station (MT8000A) evaluates the device connectivity in accordance with the actual field environment based on the fading model described in the previous section. Figure 6 shows typical device test system configurations. The MT8000A simulates NR and LTE BTS behavior and fading. Figure 6(a) shows an NR SA configuration for 4×4 MIMO NR device testing.

Figure 6(b) shows an NR NSA configuration for both 4×4 MIMO in both NR and LTE device testing. The test system is controlled using the Rapid Test Designer (RTD) installed in the control PC.

By using the above-described test configuration, devices can be tested repeatedly under the same conditions based on actual field-environment characteristics.

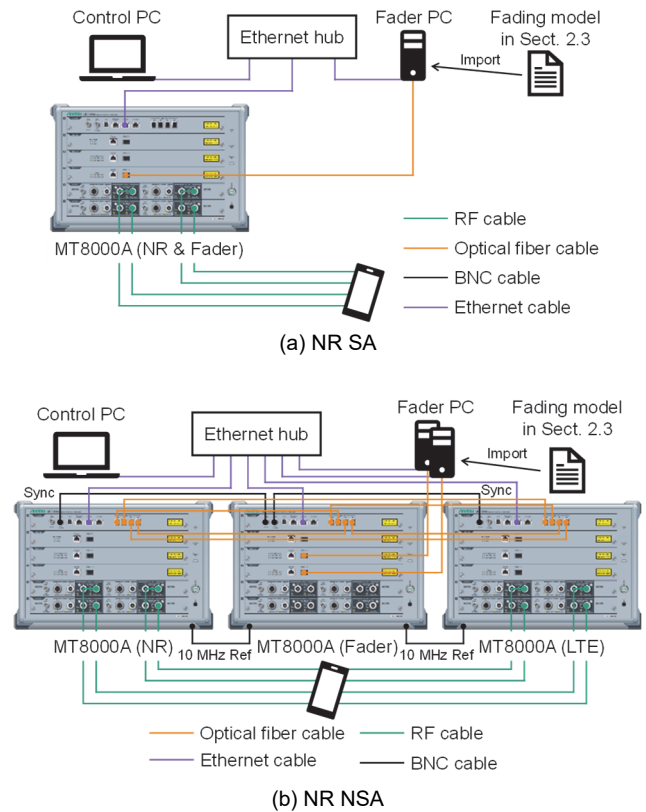


Figure 6 Example of device test systems

3 Demonstration

3.1 Evaluating Fading Model Generation Accuracy

This section describes using an experiment to evaluate the validity of modeling radio propagation characteristics, which is the key to achieving device tests matching actual field conditions.

Figure 7 shows the experimental configuration. The evaluation generates a fading model from signals captured in known fading environments and evaluates its accuracy. Specifically, first, a DL signal that has passed through a known fading channel is output using BTS and fading simulators. Then, that DL signal is recorded as IQ data using the FST solution and a fading model is generated by analyzing the data. Finally, the parameters of the generated model are compared with those of the known fading channel.

This example uses the 3GPP TDL-A model¹⁸⁾ for the NLOS environment known fading with delay spread set to 30.0 ns and antenna correlation set to high (Tx correlation coefficient $\alpha = 0.90$, Rx correlation coefficient $\beta = 0.90$)^{19), 20)}. In addition, the model assumes the BTS simulator band is set to n78 (3.5-GHz center frequency), the bandwidth is 100 MHz, and 4×4 MIMO NR PDSCH signals are output.

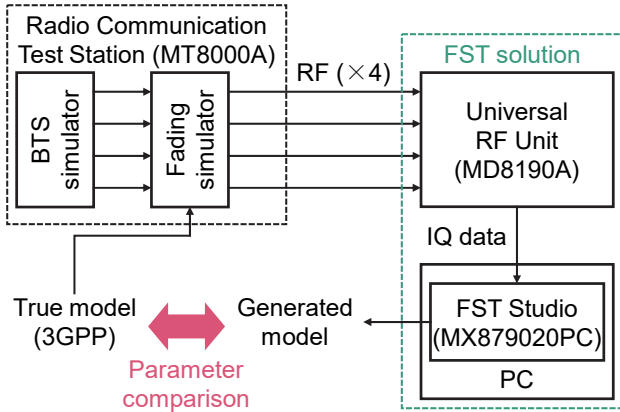


Figure 7 Experimental configuration for evaluating generated fading model accuracy

Table 3 shows the results of fading model generation. In this table, the K factor value of -99 dB represents an NLOS environment. This table shows that the FST-generated fading model K factor, Root Mean Square (RMS) delay spread, and antenna correlation parameters generally match those of the 3GPP TDL-A model.

Table 3 Generated Fading Model Results (TDL-A)

	Generated model (FST solution)	True model (3GPP)
K factor	-99 dB	-99 dB
RMS delay spread	27.2 ns	30.0 ns
Tx correlation α	0.88	0.90
Rx correlation β	0.89	0.90

3.2 On-site Field Usage Example

This section introduces an example FST application for on-site field usage. First, we captured the DL signal from a sub-6 GHz band 5G NR BTS as IQ data in an NLOS environment in a suburban area. Next, the PDSCH signal in that IQ data was analyzed to generate a fading model.

Figure 8 shows the generated PDP based on the captured signal as well as the K factor. This figure shows that the generated-model environment matches NLOS because the K factor value is -99 dB, and the power of the second or third wave is larger than the power of the first wave with zero

delay. A fading model generated in this way can be used in the testing step described in section 2.4, facilitating device testing matching actual on-site field environments. Note that the RMS delay spread is 38.0 ns when calculated from the PDP. This is consistent with the RMS delay spread from 32 to 153 ns defined in the rural macro (RMA) scenario for the sub-6 GHz band in 3GPP TR38.901¹⁸⁾.

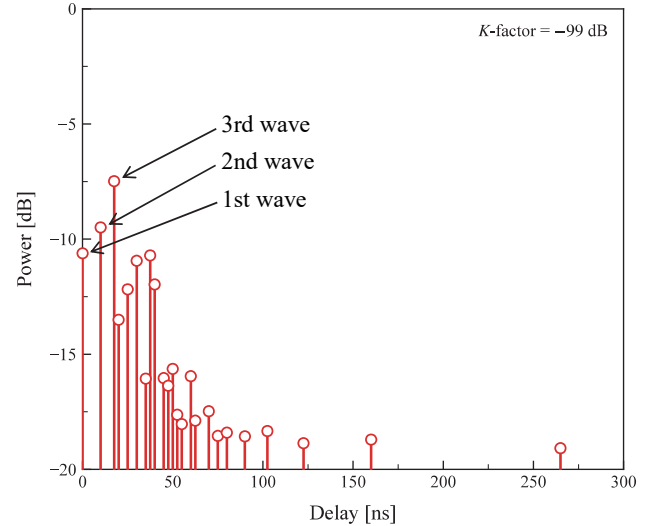


Figure 8 Generated PDP based on signal captured in suburban area

4 Conclusions

This article proposes an FST solution to solve issues such as efficiency and reproducibility at on-site field testing of mobile devices. The FST generates a fading model that characterizes the radio propagation environment by analyzing BTS signals measured on-site, and conducts laboratory device tests while simulating the actual on-site field environment using that model. This facilitates repeated device tests under the same conditions matching actual field environments. Evaluation of the validity of the model generated by this solution in known fading environments gave generally accurate values for K factor, RMS delay spread, and antenna correlation. By applying this solution to an actual on-site sub-6 GHz band 5G NR BTS we could generate an NLOS fading model matching the captured signal environment.

Anritsu is continuing to develop solutions that contribute to easier and accurate field testing, helping widespread adoption and development of mobile communication systems.

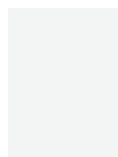
References

- 1) Ericsson, "Ericsson mobility report," June 2023.
- 2) Report ITU-R M.2516-0, "Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond," Nov. 2022.
- 3) C.-X. Wang et al., "On the road to 6G: Visions, requirements, key technologies, and testbeds," *IEEE Commun. Surv. Tut.*, vol. 25, no. 2, pp. 905–974, Feb. 2023.
- 4) Global Certification Forum, "GCF certification," Feb. 2018.
- 5) H. Baba, O. Yamashita, H. Iida, and M. Setsu, "Trends in 5G NR mmWave UE RF conformance test standards", *Anritsu Tech. Rev.*, no. 30, pp. 1–15, Sep. 2022.
- 6) H. Hosoya, K. Tanaka, K. Takahashi, G. Oki, H. Kono, and T. Sakamoto, "Anritsu solution for carrier acceptance inspection tests", *Anritsu Tech. Rev.*, no. 22, pp. 9–13, Sep. 2014.
- 7) A. Prasad, S. Bhatia, L. Duan, F. Zawaideh, C. Chen, J. Wu, M. Mittal, and S. Ramachandran, "Enhanced voice services based VoLTE rate adaptation mechanism to improve quality of experience," *Proc. 2019 IEEE Wireless Commun. Netw. Conf. (WCNC 2019)*, pp. 1–6, Apr. 2019.
- 8) Y. Liu, Y. Deng, A. Nallanathan, and J. Yuan, "Machine learning for 6G enhanced ultra-reliable and low-latency services," *IEEE Wireless Commun.*, vol. 30, no. 2, pp. 48–54, Apr. 2023.
- 9) S. Si-Mohammed, M. Bouaziz, H. Hellaoui, O. Bekkouche, A. Ksentini, T. Taleb, L. Tomaszewski, T. Lutz, G. Srinivasan, T. Jarvet, and P. Montowtt, "Supporting unmanned aerial vehicle services in 5G networks: New high-level architecture integrating 5G with U-space," *IEEE Veh. Technol. Mag.*, vol. 16, no. 1, pp. 57–65, Mar. 2021.
- 10) K. V. Katsaros et al., "Connected and automated mobility services in 5G cross-border environments: Challenges and prospects," *IEEE Intell. Transp. Syst. Mag.*, vol. 15, no. 3, pp. 145–157, May/June 2023.
- 11) A. Mahmood, S. F. Abedin, T. Sauter, M. Gidlund, and K. Landernäs, "Factory 5G: A review of industry-centric features and deployment options," *IEEE Ind. Electron. Mag.*, vol. 16, no. 2, pp. 24–34, June 2023.
- 12) H. N. Qureshi, M. Manalastas, A. Imran, and M. O. Al Kalaa, "Service level agreements for 5G-enabled healthcare systems: Challenges and considerations," *IEEE Netw.*, vol. 36, no. 1, pp. 181–188, Jan./Feb. 2022.
- 13) Y. Ji, W. Fan, M. G. Nilsson, L. Hentilä, K. Karlsson, F. Tufvesson, and G. F. Pedersen, "Virtual drive testing over-the-air for vehicular communications," *IEEE Trans. Veh. Technol.*, vol. 69, no. 2, pp. 1203–1213, Feb. 2020.
- 14) H. Gao, Z. Wang, X. Zhang, P. Kyösti, Y. Jing, W. Wang, Y. Wu, G. F. Pedersen, and W. Fan, "Over-the-air performance testing of 5G new radio user equipment: Standardization and challenges," *IEEE Commun. Standards Mag.*, vol. 6, no. 2, pp. 71–78, June 2022.
- 15) 3GPP TS38.211 v15.2.0, "NR; Physical channels and modulation," June 2018.
- 16) 3GPP TS36.211 v8.3.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation," June 2008.
- 17) A. F. Molisch, *Wireless Communications*, 2nd ed., Wiley, 2011.
- 18) 3GPP TR38.901 v14.2.0, "Study on channel model for frequencies from 0.5 to 100 GHz," Sept. 2017.
- 19) 3GPP TR36.101 v8.2.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception," June 2008.
- 20) 3GPP TR36.104 v8.2.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception," June 2008.

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