



GROUP REPORT

Fifth Generation Fixed Network (F5G); F5G-A Methodology for Hybrid Measurement-Simulation of FTTR

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) Fifth Generation Fixed Network (F5G).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the [ETSI Drafting Rules](#) (Verbal forms for the expression of provisions).

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Executive summary

The present document presents a hybrid measurement-simulation methodology for the performance evaluation of Fiber-to-the-Room (FTTR) wireless devices in residential indoor environments. The methodology combines physical electromagnetic field measurements with numerical simulation techniques in a digital twin representation of the deployment environment.

FTTR systems combine optical access with multiple distributed wireless access points, creating complex indoor propagation conditions that are difficult to characterize using conventional testing approaches alone.

Conventional wireless testing approaches include fully physical measurement setups and purely numerical simulation models. While physical measurements provide traceability and realism, they are often constrained by test environment limitations and measurement effort. Simulation-based approaches offer flexibility and scalability, but their accuracy strongly depends on modelling assumptions. The hybrid methodology introduced in the present document aims to combine the strengths of both approaches by integrating measured field data into electromagnetic simulation workflows. The methodology is designed to facilitate realistic indoor performance evaluation while maintaining traceability and technical repeatability across different test environments.

The proposed framework enables the evaluation of key radio performance indicators such as received signal strength, power density distribution, and spatial coverage under realistic indoor conditions. By leveraging near-field measurement techniques and equivalent source modelling, the methodology allows the extension of physical measurements into representative digital twin environments, improving repeatability and reducing overall test complexity and measurement time.

The present document defines the reference model, data integration flow, validation principles, and a representative test case structure for hybrid measurement-simulation based FTTR performance evaluation. It is intended to support test laboratories, fixed network operators and service providers, and equipment designers in the development and application of consistent and reproducible hybrid testing methodologies.

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1 Scope

The present document describes a hybrid measurement-simulation methodology for evaluating the wireless performance of Fiber-to-the-Room (FTTR) devices in residential indoor environments. The methodology applies to Sub FTTR Units (SFU) and Main FTTR Units (MFU) operating as access points within FTTR deployments.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long-term validity.

The following referenced documents may be useful in implementing an ETSI deliverable or add to the reader's understanding, but are not required for conformance to the present document.

- [i.1] CTIA Certification: "Test Plan for Wireless Device Over-the-Air Performance, Multi-Probe Anechoic Chamber Methodology (CTIA 01.40)", Version 6.0.1.
- [i.2] ETSI TR 137 977 (V19.0.0): "Universal Mobile Telecommunications System (UMTS); LTE; Universal Terrestrial Radio Access (UTRA) and Evolved Universal Terrestrial Radio Access (E-UTRA); Verification of radiated multi-antenna reception performance of User Equipment (UE) (3GPP TR 37.977 version 19.0.0 Release 19)".
- [i.3] IEEE Std 1720™: "IEEE Recommended Practice for Near-Field Antenna Measurements".
- [i.4] IEC 61000-4-21:2011: "Electromagnetic compatibility (EMC) - Part 4-21: Testing and measurement techniques - Reverberation chamber test methods".
- [i.5] S. Gregson, J. McCormick, C. Parini: "Principles of Planar Near-Field Antenna Measurements", IET, 2023.
- [i.6] L.J. Foged et al.: "Antenna measurement systems using multi-probe technology", 2015 IEEE™ Conference on Antenna Measurements & Applications (CAMA).
- [i.7] S.-H. Park, G.-H. Jang, Y.-H. Seo, H.-S. Keum and S.-I. Bang: "High-Speed Antenna Measurement System Using Multi-Probe Array Technique for 5G Applications", Electronics, Vol. 11, No. 21, 2022, Article 3435.
- [i.8] K. Persson and M. Gustafsson: "Reconstruction of equivalent currents using near-field data transformation with radome applications", Progress In Electromagnetics Research, Vol. 54, 2005, pp. 179–198.
- [i.9] R. Bagheriasl et al.: "Toward Standardization of Phasor Near-field OTA Testing for Connected Devices – How RF Phasor Arrays Enable Augmented Measurements", IEEE™ Conference on Antenna Measurements & Applications (CAMA), 2025.
- [i.10] Broadband Forum TR-398 Issue 3 Corrigendum 1: "Wi-Fi Residential & SOHO Performance Testing", May 2025.
- [i.11] IEEE Std 145™-2025: "IEEE Standard for Definitions of Terms for Antennas".

- [i.12] ETSI TS 138 161 (V19.3.0): "5G; NR; User Equipment (UE) TRP (Total Radiated Power) and TRS (Total Radiated Sensitivity) requirements; Range 1 Standalone and Range 1 Interworking operation with other radios (3GPP TS 38.161 version 19.3.0 Release 19) ".
- [i.13] IEEE Std 802.11ax™-2021: "IEEE Standard for Information Technology--Telecommunications and Information Exchange between Systems Local and Metropolitan Area Networks--Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 1: Enhancements for High-Efficiency WLAN".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

digital twin: numerical model of a physical environment used to emulate realistic indoor propagation conditions and enable repeatable simulation of electromagnetic fields in that environment

equivalent electromagnetic source model: numerical representation derived from measured near-field data that reproduces the radiated field behaviour of the device under test in the region outside the equivalent-source region

hybrid measurement: combination of physical field measurement and electromagnetic simulation, where measured data are coupled with numerical computation to determine electromagnetic field distributions and performance metrics across defined test environments

measurement surface: geometrical surface associated with the spatial locations at which complex near-field electromagnetic field samples are acquired

near-field: region in the vicinity of an antenna corresponding to near-field conditions

NOTE: See IEEE Std 145-2025 [i.11] for antenna terminology.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

A_e	effective aperture of the receiving antenna (m ²)
A_{iso}	effective aperture of an isotropic antenna (m ²)
C_T	percentage of evaluation locations with received signal strength greater than or equal to T (%)
$C_{covered}$	percentage of evaluation locations classified as acceptable or strong (%)
C_{strong}	percentage of evaluation locations classified as strong (%)
$C_{acceptable}$	percentage of evaluation locations classified as acceptable (%)
C_{weak}	percentage of evaluation locations classified as weak (%)
C_{req}	minimum required percentage of evaluation locations classified as acceptable or strong for the selected test scenario (%)
G	receiving-antenna gain in linear units, including radiation efficiency and excluding impedance mismatch at the receiver interface
G_{dip}	linear gain of the lossless half-wave dipole receiving antenna
G_{ant}	linear gain of alternative receiving antenna
$I(.)$	indicator function, equal to 1 when its argument is true and 0 otherwise
η_{pol}	polarization mismatch factor between the incident electromagnetic field and the receiving antenna, in linear units, with $0 \leq \eta_{pol} \leq 1$
$\eta_{pol,dip}$	polarization mismatch factor for the lossless half-wave dipole reference antenna
$\eta_{pol,ant}$	polarization mismatch factor for the alternative receiving antenna
η_m	impedance mismatch efficiency between the receiving antenna and the receiver input, in linear units, with $0 \leq \eta_m \leq 1$
$\eta_{m,dip}$	impedance mismatch efficiency of the half-wave dipole reference receiving antenna
$\eta_{m,ant}$	impedance mismatch efficiency of the alternative receiving antenna

N	number of evaluation locations
PD	scalar power density, corresponding to the magnitude of the time-averaged Poynting vector (W/m^2)
P_{av}	available received power from the receiving antenna, defined as the maximum power that can be delivered at the antenna terminals to a conjugate-matched receiver input (W)
P_r	actual received power delivered to the receiver input at the defined receiver reference plane (W)
$P_{r,i}$	actual received power delivered to the receiver input at evaluation location i (W)
$\overline{P_r}$	average power delivered to the receiver input, computed across all evaluation locations (W)
RSS_i	received signal strength at evaluation location i (dBm)
RSS_{avg}	average received signal strength (dBm)
T	received signal strength threshold used for spatial coverage evaluation (dBm)
T_{min}	minimum acceptable RSS boundary for the selected receiving antenna (dBm)
T_{strong}	strong received signal strength boundary for the selected receiving antenna (dBm)
T_{avg}	minimum required linear-power-averaged received signal strength for the selected test scenario and receiving antenna (dBm)
$T_{min,dip}$	minimum acceptable RSS boundary for the lossless half-wave dipole reference antenna (dBm)
$T_{strong,dip}$	strong RSS boundary for the lossless half-wave dipole reference antenna (dBm)
$T_{avg,dip}$	average received signal strength threshold for the half-wave dipole reference receiving antenna (dBm)
$T_{min,ant}$	minimum acceptable RSS boundary adapted to the alternative receiving antenna (dBm)
$T_{strong,ant}$	strong RSS boundary adapted to the alternative receiving antenna (dBm)
$T_{avg,ant}$	average received signal strength threshold adapted to the alternative receiving antenna (dBm)
λ	wavelength (m)

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

LAN	Local Area Network
MCS	Modulation and Coding Scheme
MFU	Main FTTR Unit
OTA	Over-The-Air
PD	Power Density
RF	Radio Frequency
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
SFU	Sub FTTR Unit
TRP	Total Radiated Power
UDP	User Datagram Protocol
UE	User Equipment
WLAN	Wireless Local Area Network

4 Reference Model and Test Environment

4.1 Overview

Clause 4 defines the reference model used for the hybrid measurement-simulation methodology. The reference model describes the roles of the measurement and simulation subsystems and the data integration flow between them.

The framework enables the transformation of measured electromagnetic field data into equivalent numerical excitation sources for use within a digital twin representation of the indoor environment. This approach allows physically measured device behaviour to be propagated into representative deployment scenarios while maintaining consistency with electromagnetic theory.