

# Channel Characterization for Intra-Wagon Communication at 60 and 300 GHz Bands

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**Abstract**—In this paper, the intra-wagon channels at 60 and 300 GHz bands are characterized through measurement-validated ray-tracing (RT) simulations. To begin with, an in-house-developed three-dimensional RT simulator is calibrated and validated by a series of millimeter-wave and Terahertz channel measurements inside a high-speed train wagon. Then, the validated RT simulator is used to conduct extensive simulations with different transmitter (Tx) and receiver deployments. At low frequencies, the channel is strongly influenced by the line of sight (LOS), and therefore, is usually classified into LOS and non-LOS (NLOS) regions. However, the simulation results at 60 and 300 GHz bands show that the first-order reflection also imposes a significant impact on the channel characteristics. This motivates us to further classify the NLOS region into light-NLOS (L-NLOS) and deep-NLOS (D-NLOS) according to the existence of the first-order reflection. Through analyzing the area ratios of LOS, L-NLOS, and D-NLOS regions, we evaluate the Tx deployment strategies and suggest the optimum one. Based on RT simulation results, totally 12 cases (three propagation regions with two Tx deployments at two frequencies) are characterized in terms of path loss, shadow fading, root-mean-square delay spread, Rician  $K$ -factor, azimuth/elevation angular spread of arrival/departure, cross-polarization ratio, and their cross correlations. All these parameters are fed into the 3GPP-like quasi-deterministic radio channel generator (QuaDRiG). The good agreement between QuaDRiG and RT proves that the 13 tables provided in this paper effectively parameterize the intra-wagon scenario for the standard channel model family. These results provide valuable insights into the system design and evaluation for intra-wagon communications.

**Index Terms**—Channel characterization, intra-wagon, mmWave, railway communications, ray-tracing, smart rail mobility, THz.

## I. INTRODUCTION

**I**N THE vision of “smart rail mobility”, railway infrastructure, trains, travelers and goods will be increasingly interconnected [1]. Correspondingly, a seamless high-data-rate wireless connectivity with up to dozens of GHz bandwidth will be required to provide various bandwidth intensive applications, such as on-board and wayside high definition (HD) video surveillance, on-board real-time high-data rate connectivity, train operation information, real-time train dispatching HD video, and journey information [2]. Thus, developing millimeter wave (mmWave) and terahertz (THz) communications for railway is attracting increasingly more attention nowadays [3]. Among the five “smart rail mobility” scenarios [2], the intra-wagon scenario describes the links between access points (APs) in the wagon and the transceivers of passengers’ user equipment (UE) or sensors inside a wagon. Because of the relatively low mobility, this scenario is very suitable for mmWave and THz communications.

In principle, there are two possible methods to realize high-data rate transmission inside a wagon. One is aiming at systems at the 60 GHz band with 7 GHz spectrum dedicated to the mobile applications worldwide. The other is to adopt moderate spectral efficiencies with ultra-high bandwidths beyond 20 GHz, which can be identified only in the THz frequency range, i.e., beyond 300 GHz [4]. Thus, in order to support the design and development of the intra-wagon mmWave and THz communication systems, it is necessary to characterize the intra-wagon channels both at 60 GHz and 300 GHz bands.

In the existing research, most of the efforts were made on various train-to-infrastructure channels [5], such as viaducts [5], cuts [6], crossing bridges [7], tunnels [8], [9], and train stations [10]. However, due to totally incomparable environments, the aforementioned studies can be hardly transferred to the intra-wagon channel. In fact, because of particular geometrical and physical characteristics of a wagon, the intra-wagon channel is even different from other intra-vehicle environments, e.g., intra-car [11], [12], intra-plane [13], [14], intra-ship [15], and intra-container [16]. Thus, it is of importance to characterize the intra-wagon channels through measurements or simulations

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# Communication Channels Characterization

**W. I. Thompson (III.)**



## **Communication Channels Characterization:**

**Communications Channels** Bernard Goldberg, Herbert S. Bennett, 1976  
Goldberg, Herbert S. Bennett, 1976 [Propagation Channel Characterization, Parameter Estimation, and Modeling for Wireless Communications](#) Xuefeng Yin, Xiang Cheng, 2016-09-13 A comprehensive reference giving a thorough explanation of propagation mechanisms channel characteristics results measurement approaches and the modelling of channels Thoroughly covering channel characteristics and parameters this book provides the knowledge needed to design various wireless systems such as cellular communication systems RFID and ad hoc wireless communication systems It gives a detailed introduction to aspects of channels before presenting the novel estimation and modelling techniques which can be used to achieve accurate models To systematically guide readers through the topic the book is organised in three distinct parts The first part covers the fundamentals of the characterization of propagation channels including the conventional single input single output SISO propagation channel characterization as well as its extension to multiple input multiple output MIMO cases Part two focuses on channel measurements and channel data post processing Wideband channel measurements are introduced including the equipment technology and advantages and disadvantages of different data acquisition schemes The channel parameter estimation methods are then presented which include conventional spectral based estimation the specular path model based high resolution method and the newly derived power spectrum estimation methods Measurement results are used to compare the performance of the different estimation methods The third part gives a complete introduction to different modelling approaches Among them both scattering theoretical channel modelling and measurement based channel modelling approaches are detailed This part also approaches how to utilize these two modelling approaches to investigate wireless channels for conventional cellular systems and some new emerging communication systems This three part approach means the book caters for the requirements of the audiences at different levels including readers needing introductory knowledge engineers who are looking for more advanced understanding and expert researchers in wireless system design as a reference Presents technical explanations illustrated with examples of the theory in practice Discusses results applied to 4G communication systems and other emerging communication systems such as relay CoMP and vehicle to vehicle rapid time variant channels Can be used as comprehensive tutorial for students or a complete reference for engineers in industry Includes selected illustrations in color Program downloads available for readers Companion website with program downloads for readers and presentation slides and solution manual for instructors Essential reading for Graduate students and researchers interested in the characteristics of propagation channel or who work in areas related to physical layer architectures air interfaces navigation and wireless sensing

**Channel Characterization and Modeling for Vehicular Communications** Xiang Cheng, Ziwei Huang, Lu Bai, 2023-12-04 This book presents and develops comprehensive knowledge of vehicular channel characteristics and proper vehicular channel models The studied topics contain the propagation

characteristics of vehicular communications such as a time frequency non stationary single input single output SISO vehicle to vehicle V2V non geometry stochastic model NGSM a space time non stationary massive multiple input multiple output MIMO V2V regular shaped geometry based stochastic model RS GBSM and a space time non stationary massive MIMO V2V irregular shaped geometry based stochastic model IS GBSM Each is introduced with characteristics then discussed in detail Finally this book discusses future research directions to inspire further investigation in the field of vehicular channels from three different perspectives

*Channel Characterization and System Design in Wireless Communications* Do-Sik Yoo,2002 We introduce parameters called normalized mean square covariance NMSV normalized mean square correlation NMSR re centered normalized mean square correlation RC NMSR and stochastic degree of freedom SDF to efficiently characterize the correlation properties of L2 stochastic processes We show that these parameters are very useful to characterize wireless communication channels In particular we show that there are very close relationships between the parameters and the performance of various wireless communication systems Due to such close relationship the parameters are very useful to evaluate the quality of wireless communication channels We show that the parameters are very effective in wireless communication system design In particular we can obtain direct relations between the quality of channel and the performance of various wireless communication systems Due to the fundamental nature of the parameters we believe that they will be very helpful in other branches of science and engineering in which stochastic modeling is useful

**Modeling and Characterization of Land Mobile Communication Channels** Abdulkader Sadek Akki,1977 *Advanced Diffraction and Wave Propagation Models for Characterization of Wireless Communication Channels* Il-Suek Koh,2002 *Channel Characterization for Indoor Wireless Communication* Kwok Wai Cheung,1997 *Power Line Communications* Lutz Lampe,Andrea M. Tonello,Theo G. Swart,2016-04-14 This second edition of Power Line Communications will show some adjustments in content including new material on PLC for home and industry PLC for multimedia PLC for smart grid and PLC for vehicles Additional chapters include coverage of Channel Characterization Electromagnetic Compatibility Coupling and Digital Transmission Techniques This book will provide the reader with a wide coverage of the major developments within the field With contributions from some of the most active researchers on PLC the book brings together a wealth of international experts on specific PLC topics

**Broadband Power-line Communications Systems** Justinian Anatory,Nelson Theethayi,2010 This book covers topics that include classification of BPLC systems models for analyses based on TL theory estimation of channel capacity and performance and finally application of modulation coding and media access control techniques for boosting the performance of BPLC systems It will be of interest to graduates and practicing engineers

*Characterization and Modeling of Real Communication Channels* Jean-Pierre A. Adoul,Bruce D. Fritchman,Laveen N. Kanal,LEHIGH UNIV BETHLEHEM PA DEPT OF ELECTRICAL ENGINEERING.,1970 The paper presents new descriptive and generative models for the error cluster and error gap patterns which occur in the binary discrete time stochastic processes

observed as outputs of digital communication channels having memory The slope of the error gap distribution is used to uncover relationships between various channel models One characterizes the memory  $\mu$  of a process of error density  $P_e$  by its relative deviation in average conditional entropy from the discrete memoryless channel  $D M C$  which one proves has maximum entropy for the class of finite and infinite memory length processes of density  $P_e$  One obtains an upper bound for  $\mu$  for real channels derive  $\mu$  for the general discrete renewal process from the error gap probability mass function EGPMF and prove that it is a lower bound for any processes having the same EGPMF One demonstrates some limitations of finite error free state models by showing that their EGPMF is bounded from above by a geometric series To estimate the counting distribution with flexibility we introduce conditional gap distributions and multigap statistics one uses these in implementing a denumerable Markov Chain model which free from finite state model limitations and more general than renewal processes allows the derivation of all classical statistics including entropy Author *Intra-body Communication Channel Characterization and Modeling* Hongjie Zhu,2011 **Bibliography on Ground Vehicle Communication and Control: a KWIC Index. Annual Report. Volume II.** W. I. Thompson (III.),1971 **Advanced Trends in Wireless Communications** Mutamed Khatib,2011-02-17 Physical limitations on wireless communication channels impose huge challenges to reliable communication Bandwidth limitations propagation loss noise and interference make the wireless channel a narrow pipe that does not readily accommodate rapid flow of data Thus researches aim to design systems that are suitable to operate in such channels in order to have high performance quality of service Also the mobility of the communication systems requires further investigations to reduce the complexity and the power consumption of the receiver This book aims to provide highlights of the current research in the field of wireless communications The subjects discussed are very valuable to communication researchers rather than researchers in the wireless related areas The book chapters cover a wide range of wireless communication topics **Antenna Design and Channels Characterization for Body Centric Communication** Zhen Hua Sampson Hu,2007 Ultra-wide Bandwidth Spread-spectrum Techniques for Wireless Multiple-access Communications Moe Z. Win,1998 **The Journal of the Acoustical Society of America** Acoustical Society of America,2006 **Channel Characterization and Wireless Communication Performance in Industrial Environments** ,2014 *The ... IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications* IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications,2001 Transdex Index ,1996 An index to translations issued by the United States Joint Publications Research Service JPRS

## Whispering the Techniques of Language: An Emotional Quest through **Communication Channels Characterization**

In a digitally-driven earth wherever screens reign supreme and quick interaction drowns out the subtleties of language, the profound strategies and mental subtleties hidden within words often go unheard. However, nestled within the pages of **Communication Channels Characterization** a captivating fictional treasure sporting with organic thoughts, lies an exceptional journey waiting to be undertaken. Published by an experienced wordsmith, that enchanting opus encourages viewers on an introspective journey, softly unraveling the veiled truths and profound influence resonating within the fabric of each word. Within the emotional depths of the moving review, we will embark upon a sincere exploration of the book's primary subjects, dissect their captivating writing model, and yield to the effective resonance it evokes serious within the recesses of readers hearts.

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### **Table of Contents Communication Channels Characterization**

1. Understanding the eBook Communication Channels Characterization
  - The Rise of Digital Reading Communication Channels Characterization
  - Advantages of eBooks Over Traditional Books
2. Identifying Communication Channels Characterization
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Communication Channels Characterization
  - User-Friendly Interface
4. Exploring eBook Recommendations from Communication Channels Characterization
  - Personalized Recommendations

- Communication Channels Characterization User Reviews and Ratings
- Communication Channels Characterization and Bestseller Lists
- 5. Accessing Communication Channels Characterization Free and Paid eBooks
  - Communication Channels Characterization Public Domain eBooks
  - Communication Channels Characterization eBook Subscription Services
  - Communication Channels Characterization Budget-Friendly Options
- 6. Navigating Communication Channels Characterization eBook Formats
  - ePub, PDF, MOBI, and More
  - Communication Channels Characterization Compatibility with Devices
  - Communication Channels Characterization Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Communication Channels Characterization
  - Highlighting and Note-Taking Communication Channels Characterization
  - Interactive Elements Communication Channels Characterization
- 8. Staying Engaged with Communication Channels Characterization
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Communication Channels Characterization
- 9. Balancing eBooks and Physical Books Communication Channels Characterization
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Communication Channels Characterization
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Communication Channels Characterization
  - Setting Reading Goals Communication Channels Characterization
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Communication Channels Characterization
  - Fact-Checking eBook Content of Communication Channels Characterization

- Distinguishing Credible Sources
13. Promoting Lifelong Learning
    - Utilizing eBooks for Skill Development
    - Exploring Educational eBooks
  14. Embracing eBook Trends
    - Integration of Multimedia Elements
    - Interactive and Gamified eBooks

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