




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

Ke Guan , *Member, IEEE*, Bile Peng , *Member, IEEE*, Daping He , *Member, IEEE*, Johannes M. Eckhardt ,  
Sebastian Rey, Bo Ai , *Senior Member, IEEE*, Zhangdui Zhong, *Senior Member, IEEE*,  
and Thomas Kürner, *Senior Member, IEEE*

**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

Manuscript received November 7, 2018; revised January 23, 2019; accepted March 10, 2019. Date of publication March 26, 2019; date of current version June 18, 2019. This work was supported in part by the Beijing Natural Science Foundation under Grant L1610099, in part by the National Natural Science Foundation of China under Grants 61771036, U1834210, and 61725101, in part by Fundamental Research Funds for the Central Universities under Grant 2018SC030, in part by State Key Lab of Rail Traffic Control and Safety Project under Grants RCS2018GZ0006 and RCS2017ZT008, and in part by Alexander von Humboldt Foundation. The review of this paper was coordinated by Prof. D. B. da Costa. (Corresponding author: Bile Peng.)

K. Guan, D. He, B. Ai, and Z. Zhong are with the State Key Laboratory of Rail Traffic Control and Safety, Beijing Engineering Research Center of High-speed Railway Broadband Mobile Communications, Beijing Jiaotong University, Beijing 100044, China (e-mail: kguan@bjtu.edu.cn; hezdaping@bjtu.edu.cn; boai@bjtu.edu.cn; zhdzhong@bjtu.edu.cn).

B. Peng is with the Institut für Nachrichtentechnik, Technische Universität Braunschweig, 38106 Braunschweig, Germany. He is now with the Department of Electric Engineering, Chalmers University of Technology, Gothenburg, 41296, Sweden (e-mail: bile.peng@chalmers.se).

J. M. Eckhardt, S. Rey, and T. Kürner are with the Institut für Nachrichtentechnik, Technische Universität Braunschweig, 38106 Braunschweig, Germany (e-mail: eckhardt@ifa.ing.tu-bs.de; rey@ifa.ing.tu-bs.de; kuerner@ifa.ing.tu-bs.de).

Digital Object Identifier 10.1109/TVT.2019.2907606

# Communication Channels Characterization

**Do-Sik Yoo**



## **Communication Channels Characterization:**

The Enthralling World of Kindle Books: A Detailed Guide Unveiling the Pros of Kindle Books: A World of Ease and Flexibility E-book books, with their inherent portability and simplicity of access, have liberated readers from the constraints of hardcopy books. Gone are the days of carrying bulky novels or meticulously searching for specific titles in shops. E-book devices, stylish and portable, effortlessly store an extensive library of books, allowing readers to indulge in their favorite reads anytime, anywhere. Whether commuting on a bustling train, relaxing on a sunny beach, or just cozying up in bed, E-book books provide an unparalleled level of ease. A Literary Universe Unfolded: Discovering the Vast Array of Kindle Communication Channels Characterization Communication Channels Characterization The Kindle Store, a digital treasure trove of bookish gems, boasts an extensive collection of books spanning diverse genres, catering to every reader's preference and preference. From captivating fiction and thought-provoking non-fiction to timeless classics and modern bestsellers, the Kindle Store offers an exceptional abundance of titles to discover. Whether seeking escape through engrossing tales of fantasy and exploration, delving into the depths of historical narratives, or broadening one's understanding with insightful works of science and philosophical, the Kindle Store provides a doorway to a literary world brimming with limitless possibilities. A Game-changing Force in the Bookish Scene: The Persistent Influence of Kindle Books Communication Channels Characterization The advent of E-book books has undoubtedly reshaped the bookish scene, introducing a paradigm shift in the way books are released, disseminated, and read. Traditional publishing houses have embraced the digital revolution, adapting their approaches to accommodate the growing need for e-books. This has led to a rise in the availability of E-book titles, ensuring that readers have entry to a wide array of literary works at their fingertips. Moreover, E-book books have democratized access to literature, breaking down geographical limits and providing readers worldwide with equal opportunities to engage with the written word. Irrespective of their place or socioeconomic background, individuals can now immerse themselves in the intriguing world of literature, fostering a global community of readers. Conclusion: Embracing the Kindle Experience Communication Channels Characterization Kindle books Communication Channels Characterization, with their inherent convenience, versatility, and wide array of titles, have unquestionably transformed the way we experience literature. They offer readers the liberty to discover the boundless realm of written expression, whenever, anywhere. As we continue to navigate the ever-evolving online landscape, Kindle books stand as testament to the enduring power of storytelling, ensuring that the joy of reading remains reachable to all.

[https://enterpriseenrollment.cruiselady.com/About/detail/Download\\_PDFS/bear\\_pit\\_a\\_life\\_in\\_politics.pdf](https://enterpriseenrollment.cruiselady.com/About/detail/Download_PDFS/bear_pit_a_life_in_politics.pdf)

## **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

### **Communication Channels Characterization Introduction**

In today's digital age, the availability of Communication Channels Characterization books and manuals for download has revolutionized the way we access information. Gone are the days of physically flipping through pages and carrying heavy textbooks or manuals. With just a few clicks, we can now access a wealth of knowledge from the comfort of our own homes or on the go. This article will explore the advantages of Communication Channels Characterization books and manuals for download, along with some popular platforms that offer these resources. One of the significant advantages of Communication Channels Characterization books and manuals for download is the cost-saving aspect. Traditional books and manuals can be

costly, especially if you need to purchase several of them for educational or professional purposes. By accessing Communication Channels Characterization versions, you eliminate the need to spend money on physical copies. This not only saves you money but also reduces the environmental impact associated with book production and transportation. Furthermore, Communication Channels Characterization books and manuals for download are incredibly convenient. With just a computer or smartphone and an internet connection, you can access a vast library of resources on any subject imaginable. Whether you're a student looking for textbooks, a professional seeking industry-specific manuals, or someone interested in self-improvement, these digital resources provide an efficient and accessible means of acquiring knowledge. Moreover, PDF books and manuals offer a range of benefits compared to other digital formats. PDF files are designed to retain their formatting regardless of the device used to open them. This ensures that the content appears exactly as intended by the author, with no loss of formatting or missing graphics. Additionally, PDF files can be easily annotated, bookmarked, and searched for specific terms, making them highly practical for studying or referencing. When it comes to accessing Communication Channels Characterization books and manuals, several platforms offer an extensive collection of resources. One such platform is Project Gutenberg, a nonprofit organization that provides over 60,000 free eBooks. These books are primarily in the public domain, meaning they can be freely distributed and downloaded. Project Gutenberg offers a wide range of classic literature, making it an excellent resource for literature enthusiasts. Another popular platform for Communication Channels Characterization books and manuals is Open Library. Open Library is an initiative of the Internet Archive, a non-profit organization dedicated to digitizing cultural artifacts and making them accessible to the public. Open Library hosts millions of books, including both public domain works and contemporary titles. It also allows users to borrow digital copies of certain books for a limited period, similar to a library lending system. Additionally, many universities and educational institutions have their own digital libraries that provide free access to PDF books and manuals. These libraries often offer academic texts, research papers, and technical manuals, making them invaluable resources for students and researchers. Some notable examples include MIT OpenCourseWare, which offers free access to course materials from the Massachusetts Institute of Technology, and the Digital Public Library of America, which provides a vast collection of digitized books and historical documents. In conclusion, Communication Channels Characterization books and manuals for download have transformed the way we access information. They provide a cost-effective and convenient means of acquiring knowledge, offering the ability to access a vast library of resources at our fingertips. With platforms like Project Gutenberg, Open Library, and various digital libraries offered by educational institutions, we have access to an ever-expanding collection of books and manuals. Whether for educational, professional, or personal purposes, these digital resources serve as valuable tools for continuous learning and self-improvement. So why not take advantage of the vast world of Communication Channels Characterization books and manuals for download and embark on your journey of knowledge?

## FAQs About Communication Channels Characterization Books

How do I know which eBook platform is the best for me? Finding the best eBook platform depends on your reading preferences and device compatibility. Research different platforms, read user reviews, and explore their features before making a choice. Are free eBooks of good quality? Yes, many reputable platforms offer high-quality free eBooks, including classics and public domain works. However, make sure to verify the source to ensure the eBook credibility. Can I read eBooks without an eReader? Absolutely! Most eBook platforms offer web-based readers or mobile apps that allow you to read eBooks on your computer, tablet, or smartphone. How do I avoid digital eye strain while reading eBooks? To prevent digital eye strain, take regular breaks, adjust the font size and background color, and ensure proper lighting while reading eBooks. What the advantage of interactive eBooks? Interactive eBooks incorporate multimedia elements, quizzes, and activities, enhancing the reader engagement and providing a more immersive learning experience. Communication Channels Characterization is one of the best book in our library for free trial. We provide copy of Communication Channels Characterization in digital format, so the resources that you find are reliable. There are also many Ebooks of related with Communication Channels Characterization. Where to download Communication Channels Characterization online for free? Are you looking for Communication Channels Characterization PDF? This is definitely going to save you time and cash in something you should think about.

## Find Communication Channels Characterization :

~~bear pit a life in politics~~

**beacon across the prairie**

~~battle to save the houston~~

**bater skip**

*battlefields of canada*

**battleships in transition the creation of the steam battlefleet 1815-1860**

**bathed in blood hunting and mastery in the old south**

**bay area green pages**

~~be still my child 366 devotional readings from the psalms~~

beaches of oahu

~~beads and threads a new technique for fiber jewelry~~

~~bauhaus masters students~~

[bayonets to lhasa](#)

[battle of jericho](#)

*battle of 1900 an official handbook for*

### **Communication Channels Characterization :**

Fundamentos da Biologia Celular F981. Fundamentos da biologia celular [recurso eletrônico] / Bruce. Alberts ... .. livro extenso para estudantes avançados de graduação e de pós-graduação que ... Fundamentos da Biologia Celular Compre online Fundamentos da Biologia Celular, de Alberts, Bruce, Bray, Dennis, Hopkin, Karen, Johnson, Alexander, Lewis, Julian, Raff, Martin, Roberts, ... Fundamentos da Biologia Celular (Alberts & Bray) - 4. ed. ... Faça o download do livro Fundamentos de Biologia Celular dos autores Alberts & Bray 4ª ed. (2017) no formato pdf e de graça! :) \_ livro fundamentos da biologia celular uma introduco a ... 1. \_ livro fundamentos da biologia celular uma introduco a biologia molecular da bruce alberts. Bruce alberts dennis bray julian lewis e outros. Published by ... Fundamentos Da Biologia Celular 3.Ed. Detalhes do livro · ISBN-10. 8536324430 · ISBN-13. 978-8536324432 · Edição. 3ª · Editora. Artmed · Data da publicação. 13 abril 2011 · Idioma. Português · Dimensões. Fundamentos da Biologia Celular de Bruce Alberts - Livro Fundamentos da Biologia Celular. Uma introdução à biologia molecular da célula (Inclui CD-Rom). de Bruce Alberts. editor: Artmed Editora, dezembro de 2006 ... Fundamentos da Biologia Celular 4 ed. Bruce Alberts - Grupo A Livro Fundamentos da Biologia Celular 4 edição, por Bruce Alberts, editora Artmed. Para todas as áreas de biociências. Parcele em até 10x Sem Juros! Livro - Fundamentos Da Biologia Celular Neste livro, os autores descrevem os fundamentos da biologia celular de maneira clara e didática, explicando como uma célula viva funciona e apresentando as ... Fundamentos da Biologia Celular - Bruce Alberts e Outros Bruce Alberts e Outros - Fundamentos da Biologia Celular, Em sua terceira edição, Fundamentos de Biologia Celular destaca-se por apresentar as informações ... Bruce Alberts et al.-Biologia Molecular da Célula-Artmed ( ... - Porto. Alegre : Artmed, 2017. Editado como livro impresso em 2017. ISBN 978-85-8271-423-2. 1. Biologia molecular - Célula. Les Secrets de la casserole by This, Herve This is a great book for cooks, and for chemists. It explains the science of cooking in layman's terms, with the focus on French style cooking, and does so ... Amazon.com: Les secrets de la casserole: nouvelle édition Amazon.com: Les secrets de la casserole: nouvelle édition: 9782701149745: This, Hervé: Books. Les Secrets de la casserole - This, Herve: 9782701115856 Les Secrets de la casserole - Hardcover. This, Herve. 3.75 avg rating • ( 220 ratings by Goodreads ). View all 32 copies of Les Secrets de la casserole from US ... Les Secrets de la casserole Herve This Author. This, Herve ; Book Title. Les Secrets de la casserole Herve This ; Accurate description. 4.9 ; Reasonable shipping cost. 5.0 ; Shipping speed. 5.0. Les Secrets de la casserole Herve This Les Secrets de la casserole Herve This ; Item Number. 394996975267 ; Special Attributes. EX-LIBRARY ; Author. This, Herve ; Accurate description. 4.9 ; Reasonable ... Kitchen mysteries : revealing the

science of cooking = Les ... Kitchen mysteries : revealing the science of cooking = Les secrets de la casserole ; Authors: Hervé. This, Jody Gladding (Translator) ; Edition: View all formats ... Les Secrets De La Casserole by Herve This-Benckhard Les Secrets De La Casserole by Herve This-Benckhard. Nature; London Vol. 368, Iss. 6472, (Apr 14, 1994): 595. Publisher logo. Links to publisher website ... Les secrets de la casserole. VonH. This. Éditions Bélin, ... by P Weyerstahl · 1996 — Les secrets de la casserole. VonH. This. Éditions Bélin, Paris, 1993. 222 S., geb. 110.00 FF. - ISBN 2-7011-1585-X. Révélations Gastronomiques. VonH. This. Les secrets de la casserole (French Edition) Les secrets de la casserole (French Edition). USD\$26.57. Price when purchased online. Image 1 of Les secrets de la casserole (French Edition). Les secrets de la casserole Nouvelle édition - broché Les secrets de la casserole ont été traduits en allemand, en espagnol, en italien, en japonais, en polonais et en portugais (Brésil) et ont reçu le Prix de l' ... Philosophy: A Text With Readings (Available Titles ... Philosophy: A Text With Readings (Available Titles CourseMate). 11th Edition. ISBN-13: 978-0495808756, ISBN-10: 049580875X. 4.4 4.4 out of 5 stars 67 Reviews. Philosophy: A Text with Readings: 9780495812807 ... Philosophy: A Text with Readings. 11th Edition. ISBN-13: 978-0495812807, ISBN-10: 0495812803. 4.4 4.4 out of 5 stars 67 Reviews. 4.1 on Goodreads. (36). Part of ... Here is a link to almost any textbook's free PDF version. : r/unt For those who are unaware, you can download a free copy of the majority of textbooks via the link provided below. Philosophy: A Text with Readings - Manuel Velasquez Jan 1, 2010 — PHILOSOPHY: A TEXT WITH READINGS, Eleventh Edition, covers a wide range of topics such as human nature, reality, truth, ethics, the meaning of ... Philosophy: A Text with Readings by Manuel G. Velasquez This highly engaging text will not only help you explore and understand philosophy-it will also give you an appreciation of how philosophy is relevant to ... Philosophy: A Historical Survey with Essential Readings Get the 11e of Philosophy: A Historical Survey with Essential Readings by Samuel Enoch Stumpf and James Fieser Textbook, eBook, and other options. Philosophy: A Text with Readings, 11th Edition PHILOSOPHY AND LIFE: Is Selflessness Real? 2.2. WHAT IS HUMAN NATURE? 48 51 ... free or determined. • Ethics is the study of our values and moral principles ... Introduction to Philosophy OpenStax provides free, peer-reviewed, openly licensed textbooks for introductory college and Advanced. Placement® courses and low-cost, personalized courseware ... Hurley's A Concise Introduction to Logic, 11th Edition Along with instructions, each new text includes a sheet of red paper so that you can bring the cover to life. This exercise serves as a metaphor for the process ... Sophie's World by J GAARDER · Cited by 716 — “A Novel About the History of Philosophy' was not only a bestseller in France, but for a while Europe's hottest novel.” —The Washington Post Book World. “A ...