論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Antenna De-embedding in Wireless Body Area Network Channel
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出典(和文)	学位:博士（工学）, 学位授与機関:東京工業大学, 報告番号:甲第9793号, 授与年月日:2015年3月26日, 学位の種別:課程博士, 審査員:高田　潤一,高橋　邦夫,山下　幸彦,秋田　大輔,青柳　貴洋
Citation(English)	Degree:, Conferring organization: Tokyo Institute of Technology, Report number:甲第9793号, Conferred date:2015/3/26, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

専攻： Department of	国際開発工学　　専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（工学）
学生氏名： Student's Name	長縄　潤一	指導教員（主）： Academic Advisor(main)	高田 潤一　教授
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The thesis is entitled as "Antenna De-embedding in Wireless Body Area Network Channel" and consists of five chapters.

In chapter 1, the background, motivation, and objective are summarized. The body area network (BAN) is a network among the sensors and actuators attached on the body, which is a promising technology for future health-care. However, its radio propagation channel is severe because of shadowing, absorption, and fluctuation caused by the human body and the body motion, which may result in the degradation of reliability. Therefore, accurate characterization and modeling of the propagation channel is essential for reliable design of the BAN system.

In this context, the importance of antenna de-embedding in channel model is emphasized. The channel responses obtained by simulation and measurement generally include the contribution of various factors such as antennas, body, and surrounding environment. Among the various factors, only antenna is a designable factor. This implies the importance of the antenna optimization for better performance. At the same time, antennas have been arbitrary chosen in different measurement campaigns, being the source of the discrepancies. Therefore, antenna de-embedding, separation of the antennas and the other factors in other word, should be achieved, hence the purpose of this thesis.

In chapter 2, the novel antenna de-embedding approach is proposed. Instead of the conventional plane wave channel modeling, spherical-wave-function (SWF) channel modeling is applied to the BAN channel. This modeling approach separates the antennas and the other factors by means of the spherical wave coefficients (SWCs). To apply the SWF approach into the BAN channel, implementation by finite-difference time-domain (FDTD) method, which is a numerical electromagnetic simulation technique, is proposed.

The proposed implementation consists of three stages: 1) antenna simulation, 2) SW channel simulation, and 3) synthesis of the channel response by combining 1) and 2). In the antenna simulation stage, antenna current distribution in proximity to the human body is firstly obtained. The radiated E-field is reconstructed with the current distribution in free space, which is then further expanded by SWFs. Thus, the antenna characteristic is modeled as the SWCs. In the SW channel simulation stage, SW source and observation spheres are used at the transmitter and receiver positions, respectively, instead of the real antenna structures. The observed E-field at receiver is further expanded by SWFs, producing SWCs of the impinging waves. Thus, this simulation provides the relationship between transmitted SWs and receiving SWs. SW source in the FDTD method is also newly developed for this simulation. In the final stage of the proposed approach, the antenna characteristics and the SW channels are combined in the form of matrix multiplication, generating the channel response.

Furthermore, the simplification of the proposed approach is introduced, where only the fundamental modes of the SWF are involved. The equivalence to the channel modeling using orthogonal dipoles is formulated, which allows the implementation in FDTD method using only a point source and a point observation.

In chapter 3, the proposed approach is evaluated. The SW source used in the SW channel simulation is firstly validated. Specifically, the error between the radiated wave and desired SW mode is confirmed to be sufficiently small. It is also observed that the smaller cell size reduces the error and the source size should be chosen according to the truncation number. Next, the channel responses obtained by the proposed approach are compared to that obtained by the conventional approach. The comparison is performed in three types of environment: free space, body-shadowing channel, and on-body channel. In all the types of the environment, the agreement between the proposed approach and conventional approach was confirmed. Specifically, the average path gain error is 0.45 dB and 3.63 dB in comparison with the embedded FDTD simulation in body-shadowing channel and on-body channel, respectively. Successful embedding and de-embedding of the antenna means the validation of the proposed implementation as well as the SWF approach.

Also, the accuracy of the fundamental mode simplification is investigated in the dynamic body environment. The deviated dipoles, which can radiate the higher modes, are simulated with the walking body model. The error due to the simplification is modeled by the log-normal distribution, the statistics of which are fitted as the function of antenna size or residual power.

In chapter 4, the applications and benefits of the proposed approach are demonstrated. Most important application is the evaluation of the antenna. Specifically, a 3-port dielectric resonator antenna (DRA) and a walking body model are separately simulated with the proposed approach. Combining the SWC of the DRA and SW channel, 3x3 channel matrices during walking motion are obtained, which allow discussing the best polarization combination. The obtained channels are compared with the measurement. After the calibration in free space, the average path gain predicted by the proposed approach successfully agrees with the measurement. In addition, statistical modeling for various body motions and the evaluation of the cooperative transmission scheme are demonstrated.

Finally, the thesis is concluded in chapter 5. The concluding remarks are listed. The future research topics and the potential development of the proposed approach are also described.