Development of a WBAN Channel Model for Capsule Endoscopy

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Introduction

To design the communication systems for wireless body area network (WBAN), an appropriate propagation channel model is required. Our research group has been studying the WBAN channel models. These include one for between body surface and the access point in a room[1], one for inter body surface communications by dipole antenna[2][3], one for wearable and implantable WBAN based on numerical simulations, and the measurement of the propagation loss for implantable WBANs. We contributed these results to the TG6 of IEEE 802.15 (Wireless Personal Area Network) standardization[4][5]. While an internal body propagation scenario is included in WBAN as well as external body, there are only few reports about the implantable WBAN channel model[5][6] due to the difficulty of measurement. in comparison with the body surface WBAN channel model, there are few reports about the implantable WBAN channel model. In this present paper, we constructed an implantable WBAN channel model for capsule endoscopy, specifically used to test small intestines.

Usage Scenario of the Implantable WBAN Channel Model

We aimed to develop a channel model for bidirectional communication between internal and surface of a body. We assumed an inner body communicator (implant node) is a capsule endoscope, which passes through from esophagus to large intestine. The coordinator node is a quarter-wavelength dipole antenna or the printed chip antenna mounted on the surface of the body[5]. The frequency is 403.5 MHz, the center frequency of the medical implant communications service band.

Figure 1 shows the locations of the implants and the coordinator nodes. The implant nodes are located at esophagus (2 points), stomach, duodenum, small intestine, and large intestine (9 points). The coordinator is located over the navel. A distance between the body surface and the coordinator is 1.5 cm.

Path-loss Simulation by using a Numerical Human Model

An electromagnetic wave simulation software (SEMCAD) was used for the calculation of the path-loss between the implant nodes and the coordinator. A numerical

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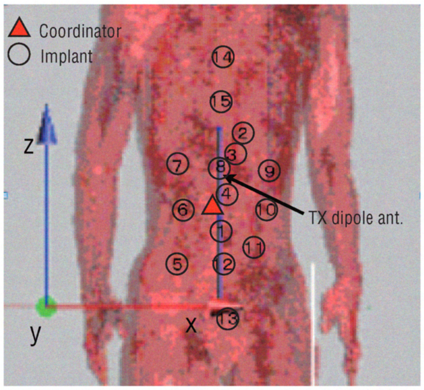

Figure 1: Positions of the implants and the coordinator.

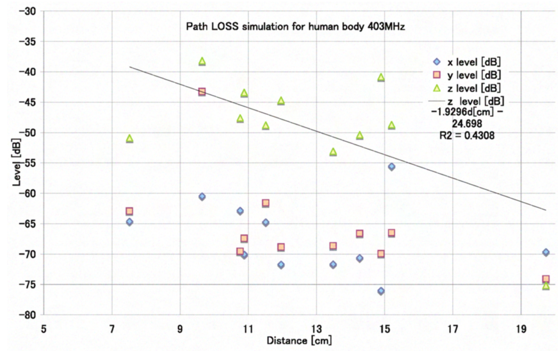

Figure 2: Reception level at each implant position.

human model of a Japanese adult male was used for the simulation[7]. Permittivities and conductivities of each tissue at 403.5 MHz were used for the simulation[8]. The coordinator node was modeled by a quarter-wavelength dipole antenna. The implants are modeled by 5-mm length line element orients to either x, y, or z directions. Figure 2 shows the received electric field level at each receiving positions. The transmitting and the receiving electric field were matched in the case of the z direction. According to Fig. 2, the standard deviation from the regression line was 7.3 dB in the z direction. The average level difference between x or y and z direction was 16.8 dB.

Experimental Validation of Simulation

In general, simulation using the numerical human model well approximate real propagation. However, it is not easy to compare the results for implants with experiments. Propagation loss measurement using liquid human phantom was performed. Figure 3 shows the vessel used both for the measurement and the calculation. The diameter was 300 mm, the height was 300 mm, and the thickness of the vessel was 2 mm. That was made with polycarbonate. The permittivity and the conductivity of liquid was same as average muscle. Gradient of the regression line of the path-loss agreed well with the result of the simulation, as shown in Fig. 4.

Development of an Implantable WBAN Channel Model

We propose the following formula as an implantable WBAN channel model for capsule endoscopy. The channel model includes a stochastic fluctuation caused by the organ arrangement:

$$PL(d, \theta) = a \cdot d + b + P(\theta) + N \, [\text{dB}] \tag{1}$$

where, a: gradient coefficient (dB/cm), b: intercept coefficient (dB), d: distance between the coordinator and the implant (cm), $P(\theta)$: fluctuation caused by the capsule direction (dB), $P(\theta) = -20 \log_{10}(\cos(\theta) \cdot (1.0 - x_c) + x_c)$ (dB), θ: angle between transmitting and receiving antenna, x_c: difference between main (z) and

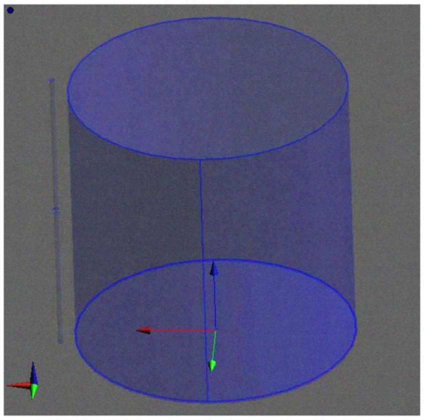

Figure 3: The human-body-simulating vessel.

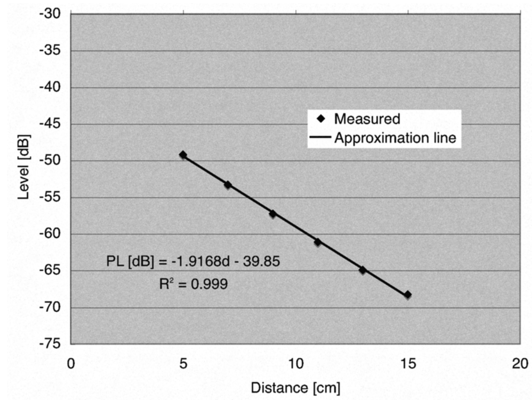

Figure 4: Example of the calculated path-loss in the vessel (403.5 MHz).

cross (x, y) electric field direction, N: stochastic fluctuation (dB, follows normal distribution with mean 0 and standard deviation σ_N).

The channel model was developed by combining the simulation and the experimental estimation. The gradient parameter a is derived from the simulation result of the numerical human model and the simulation result of the human-body-simulating vessel. The intercept parameter b is derived from the vessel experiment and the simulation results. The stochastic fluctuation σ_n and the antenna direction fluctuation x_c are derived from the numerical human model simulation. Table 1 concludes the estimated parameters. When the coordinator antenna is the printed chip antenna, the PL should be decreased by 6.34 dB, the difference in gain between the dipole antenna and the printed chip antenna[5].

Table 1: Estimated parameters of the Implantable WBAN channel model

Parameter	Value	Parameter	Value
a	1.92	b	39.85
σ_N	6.59	x_c	0.145

Conclusion

In this paper, we developed an implantable WBAN channel model for a capsule endoscopy to be used in digestive organs. Followings are left for further study:

- Experimental validation for the channel model.
- Development of dynamic implant WBAN channel models.
- Estimation method of the location and direction of the implant.

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