

# *Finite integration technique based channel modeling on the WBAN receiver performance evaluation*

*(Parkinson's disease monitoring case)*

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**Abstract**—One of the main challenges for wireless body area networks (WBANs) is to evaluate realistic methods to generate channel models for new different purposes and various environments quickly and flexibly. Finite integration technique (FIT) has shown to be promising method for modeling channels characteristics in WBAN deployment scenarios. Applying simulation based channel modeling on the performance evaluations of the concrete use scenarios have not been presented yet in the literature. In this paper, FIT-based channel modeling is applied on the performance evaluation of IEEE 802.15.6 based energy detector (ED) receiver designed for monitoring the symptoms of Parkinson's disease. First aim of this paper is to assess and compare the simulated channel impulse responses (CIRs) with the data from measurement campaign. The second aim is to apply the simulated channel on the performance evaluations of the IEEE 802.15.6 based ED receivers. The obtained bit error rate (BER) performances are compared with BERs obtained using channel measurement data in the simulations. It is shown that performance obtained using FIT-based channel modeling corresponds to performance obtained using channel measurement data based channel modeling. The results of this paper further verify the statements that FIT is well applicable for WBAN channel modeling.

**Keywords**—*finite integration technique; measurement campaign; wireless health monitoring receiver;*

## I. INTRODUCTION

Wireless health monitoring with several directions to be applied have achieved a great interest in the recent years. The aim of both medical and non-medical applications is to improve the user's quality of life. Ubiquitous health care, sport and fitness, military, entertainment, etc. are examples of the areas for wireless monitoring applications. [1]-[3].

There are several demanding challenges in the design and implementation processes of wireless applications targeted for health monitoring. For example, due to the privacy of patient's measured data, transmission must be secure. For successful implementation of health monitoring wireless body area network (WBAN) applications, the IEEE published the standard 802.15 [4] for low-power in-body/on-body node communication. The main technologies for wireless health

monitoring in this standard are narrowband (NB), ultra wideband (UWB) and human body communication (HBC). Amongst them, (UWB) provides several advantages for short-range communication in the close proximity of the human body. [3], [4]

Radio channel captured to the channel model can have considerable impact of the system design. Hence, the channel modeling for WBAN application has also been under intensive research recently [3]-[14]. Several models have been proposed and numerous measurement campaigns have been performed for WBAN applications, and they are representing approximations for certain specific environments. Numerical electromagnetic simulation based channel modeling is one option to generate realistic channel models for new different purposes quickly and flexibly. For that purpose, there are several methods such as Finite-Difference Time-Domain (FDTD), Finite Integration Technique (FIT), Method of Moments (MoM), etc. to simulate the channel characteristics on the human body and at its close proximity [1]. FIT has shown to be promising method for modeling WBAN communication links [11]-[14]. The principle of FIT with advantages over other approaches are explained, e.g., in [12],[15].

Applying FIT based channel modeling on the performance evaluations of the concrete use scenarios have not been presented in the literature. In this paper, we selected to model a scenario for monitoring Parkinson's disease which is a relatively common neurodegenerative disorder. Due to its measurable motor symptoms and fluctuating states, which complicates clinical assessments, it is an interesting target for wireless monitoring applications. The first detailed IEEE 802.15.6 based multisensory application scenario for monitoring Parkinson's disease was presented in [16].

The first receiver performance evaluation on IEEE 802.15.6 based WBAN for monitoring Parkinson's disease was presented in [17]. The study presented BER performances for different node links in the Parkinson's disease monitoring scenario using measurement data based channel modeling.

The aim of this paper is to realize FIT-based channel simulations for the performance evaluation of the WBAN

receiver designed for Parkinson disease monitoring scenario [17]. First, the channel characteristics for different node links in the monitoring scenario are obtained by CST software [18]. The obtained channel impulse responses are compared with the measured impulse responses. Next, bit error rate (BER) performance of the WBAN energy detector is evaluated with MATLAB simulation model [19] using the FIT channel coefficients as the model multipath channel. Then, the correlation of the measured and simulated BER performance is demonstrated.

This paper is organized as follows: The system model description is presented in Section II, numerical results are shown in Section III. Conclusions are given in Section IV.

## II. SYSTEM MODEL

### A. Deployment Scenario for Monitoring Parkinson Disease

The generic block diagram for monitoring Parkinson's disease is represented in Figure 1, which is based on [16]. The monitoring system consists, in total, of five accelerometers placed on each limb. Nodes N1-N4 are used for monitoring patient's activity while N5 is the accelerometer on the fall detector on the waist-worn device. The waist-worn device includes also the central in-body hub (H). More detailed description of the monitoring system is given in [16].

In this work, we focus on the links N1-H and N4-H. The aim is to simulate the channel characteristics for these links using FIT. Next, the obtained channel responses are used for the performance evaluation of WBAN energy detector receivers designed for the Parkinson's monitoring system. Evaluations consider two modulation methods: on-off keying (OOK) and pulse position modulation (PPM), both determined for the WBAN communication by IEEE 802.15.6 [4]. The antennas in this study are planar UWB monopoles designed for the WBAN communications [20]. The detailed description of the signal model and receiver structure is found in [17] and [19].

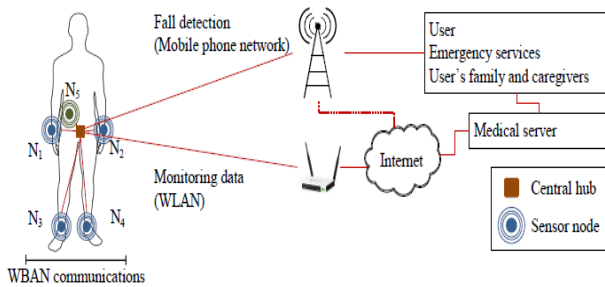


Fig. 1. Block diagram for monitoring Parkinson's disease [17].

### B. Channel models

This study applies finite integration technique based channel model on this link performance evaluation. Figure 2 represents the simulation model for the wrist-waist and ankle-waist links. FIT-simulations are conducted using the same parameters and principles as in [13], from which the details for the simulation model can be studied more precisely.

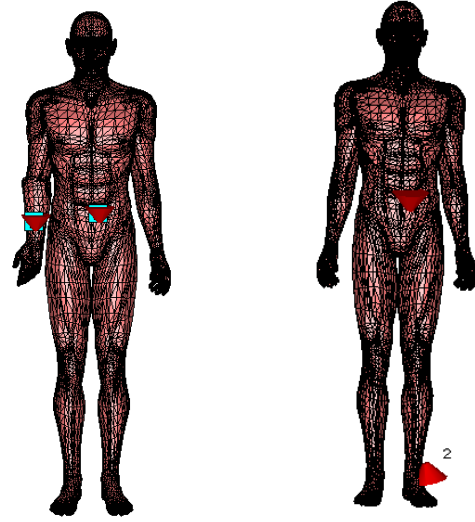


Fig. 2. CST simulation model the wrist-waist link and the ankle-waist link.

The target frequency band for simulations is from 2.0 GHz to 8.0 GHz with 1601 samples. Inverse fast Fourier transform (IFFT) is applied for the simulated data in frequency domain. Respectively with the measurement data [17], only the beginning of the main peak with the following 31 samples appearing during the time period of 5 ns are included due to energy concentration.

Figure 3 illustrates the impulse responses obtained from the simulations for the studied links (dashed lines). For the comparison purposes, mean of the measured impulse responses (solid lines) are included in the results. The impulse responses are shown to have relatively good match for the wrist-waist link but for the ankle-waist link, the difference is greatly notable, even 30 dB difference between the main peaks.

Reason for differences are tilting angles in the antennas in the measurements: a slight tilt in the waist antenna and a greater tilt in the ankle antenna. In the measurements, the unintentional tilting of the antennas occur easily due to the antenna cables. In the realistic user scenarios, there is actually always some tilting in the antennas; they are never exactly perpendicular to the body in practice. To evaluate the impact of antenna tilting on the channel response, the tilting angle was estimated in the measurement scenario. Then the same scenarios were applied on se CST simulation model, as shown in Figure 4. The impulse responses for tilted antennas in wrist-waist and ankle-waist links are shown in Figure 3 with the dotted lines. As visible, the impact of tilt is minor in the wrist-waist link since the tilt of the waist antenna does not change dramatically the link properties. Instead, the impact of the tilt is more significant in the ankle-waist link: the main peak of the impulse response for the tilted antennas' case is almost 15 dB higher compared to that without antenna tilts. With antenna tilts, there is a better match between the simulated and the measured impulse responses in general, which is obvious due to the better correspondence between the measurement and simulation setups.

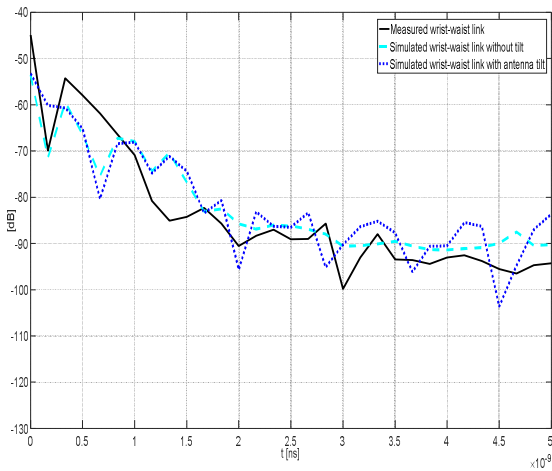
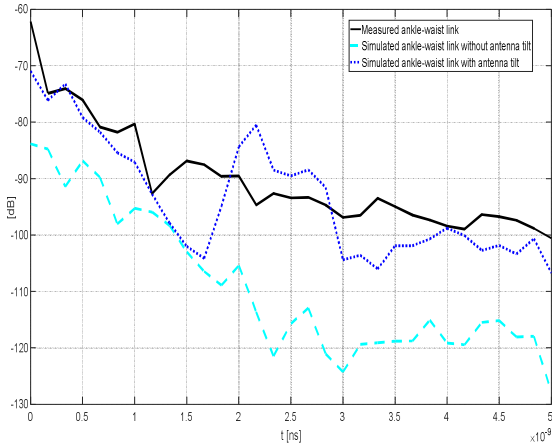


Fig. 3. Simulated and measured impulse responses for a) wrist-waist link and b) ankle-waist link.

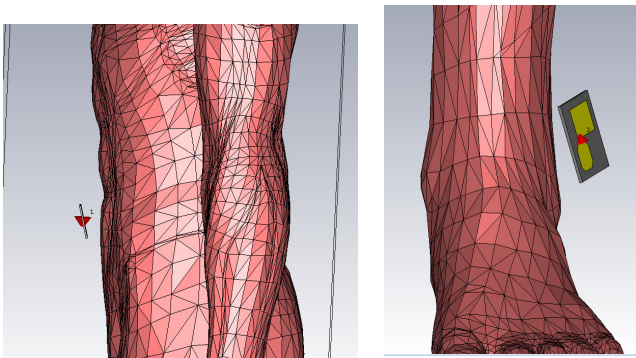


Fig. 4. CST simulation model with tilted antennas a) on the waist, b) on the ankle.

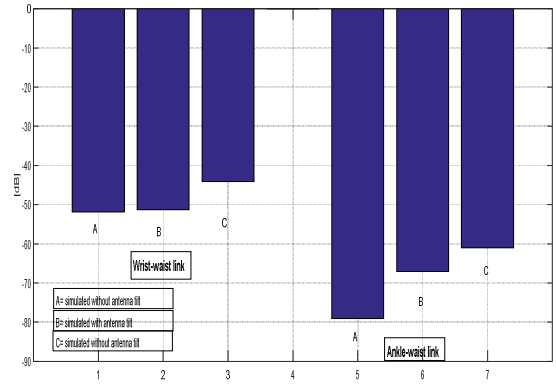


Fig. 5. Channel attenuation for the wrist-waist and ankle-waist links.

Simulated and measured channel responses are compared by studying the mean attenuation for the wrist-waist and ankle-waist links. The attenuation is defined and visualized by a bar chart in Figure 5. The bars A and B correspond to the attenuation for simulated link without and with antenna tilt, respectively. The bar C corresponds to the attenuation on the measured link. Bars on the left side of the figure are related to the wrist-waist link and the bars on the right hand side to the ankle-waist link. As noted, the attenuation in the measured links smaller than in the simulated links. The attenuation difference between the simulated and measured channels is 8 dB without the antenna tilt and 7 dB with the antenna tilt in the wrist-waist link. Instead, in the ankle-waist link, the attenuation differences are higher: 18 dB without the antenna tilt and 12 dB with the antenna tilt. As noted, the impact of tilting is more significant in the ankle-waist link than in the wrist-waist link. The difference in the correlation of measurement data is assumed to be observed at least due to the following factors as the different body morphology in simulations and measurements, different antenna orientation with respect to a body surface, because of cables along a body surface that exist in the measurements. Besides, the simulated antenna tilt may not be exactly same as in the measurement set up, since it is challenging to measure exact tilts on the antennas in the measurement setup with the cables etc. These challenges bring up the advantages of the simulations where different antenna orientations with respect to a body surface can be easily modified and tested. With measurement campaigns, the antenna tilt study would be excessive laborious.

In the next section, the obtained channel responses are used for the performance evaluations of the OOK and PPM based energy detector receivers.

### III. PERFORMANCE EVALUATION RESULTS

In this section, the performance of the WBAN receiver is evaluated in terms of uncoded bit-error-rate versus the bit energy to noise power spectral density ratio ( $E_b/N_0$ ). The FIT-simulated channel responses presented in the previous section are used as multipath channel in the simulations. The performance evaluations are conducted using Matlab

simulation software, which has been developed according to the IEEE 802.15.6 definitions [19]. The evaluation is shown separately with OOK and PPM modulations. The energy of each transmitted burst is normalized to one both with OOK and PPM.

The BER performances in the wrist-waist and ankle-waist links are shown in Figure 6-7, respectively. The BERs obtained using the measured channel are shown for the comparison. As noted, the PPM outperforms the OOK clearly at the higher  $E_b/N_0$  range, the difference is more significant in the ankle-waist link than in the wrist-waist link.

BER performances obtained from simulated and measured channel seem to have an excellent match both for OOK and PPM especially in the  $E_b/N_0$  range below 17 dB. From  $E_b/N_0$  17 dB upwards, the BER performance is better with the measurement channel than with the simulated channel. The BER difference between the simulated channel with antenna tilt and without the antenna tilt is negligible in the ankle-waist link. Instead in the wrist-waist link, the BER difference increases from the  $E_b/N_0$  range upwards. However, the differences is around 3 dB at highest.

The shown BER performance differences when using these three different channels are not related to the differences in the attenuation, since the energy is normalized in the BER simulations. Instead, the shape of the impulse response impacts on the BER performances. As noted from Figure 3, the measured impulse response has the clear main path followed by minor multipaths, which is known to be favorable channel for the simple receivers due to minor impact of inter-symbol-interference (ISI). Thus, the best BER performance is obtained in the measured channel.

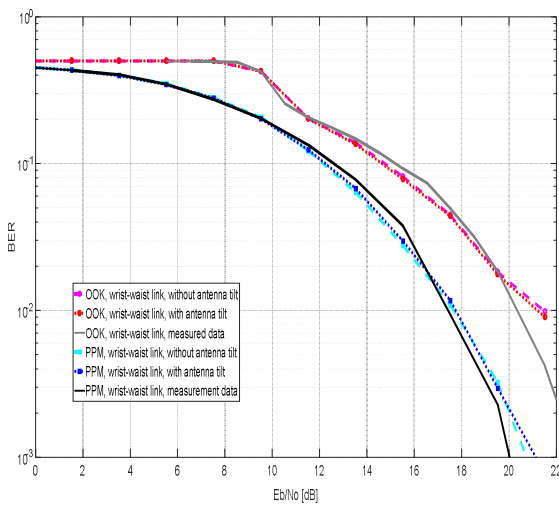


Fig. 6. The BER performance for OOK and PPM modulations in the wrist-waist link.

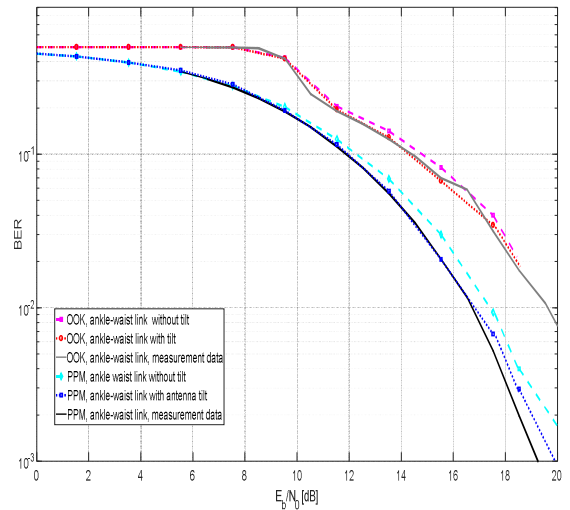


Fig. 7. The BER performance for OOK and PPM modulations in the ankle-waist link.

#### IV. CONCLUSIONS

In this paper, the performance of the IEEE 802.15.6 based ED receiver, designed for Parkinson’s disease monitoring, is evaluated using FIT-based channel modeling in simulations. The evaluation is shown separately with the OOK and PPM modulations. BER performances are compared with the data obtained in the measurement campaign and in simulations. It is shown that performance obtained using FIT based channel modeling corresponds to performance obtained using channel measurement data based channel modeling. The channel characteristics are found to be sensitive on the position of the antenna: small tilt angle may affect even 30 dB on the level of the main peak in the impulse response and almost 20 dB on the overall attenuation of the channel.

The results of this paper further verify the statements presented in the earlier studies that the FIT is well applicable for body area network channel modeling. It is also highlighted that the use of simulation based channel modeling is practical in the performance evaluations of realistic user case scenarios, since the channel model can easily be modified for different setups and purposes. Our next target is to conduct WBAN performance evaluations using FIT-channel model simulated in a more complex environment with different antennas.

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