Dog IoT: Path Loss and Link Budget Analysis for Canine Wireless Body Area Network

J. Goethals[#1], A.-M. Leys[#], G. Vermeeren[#], M. Deruyck[#], L. Martens[#], W. Joseph[#]
[#]Department of Information Technology - WAVES, Ghent University - IMEC, Belgium
[1] jasper.goethals@ugent.be

Abstract— **Internet of Animal Health Things is an upcoming domain in both professional and domestic fields related to animal welfare monitoring including dairy cows, racehorses and domestic dogs. Wireless Body Area Networks represent a large allotment in the realization of these applications. Characterization of the path loss between on-body nodes in various surroundings is required when deploying such network. In this paper, the path loss between various on-body transmitting sensors and an on-body receiver is investigated at 2.45 GHz. Simulations using the Finite-Difference Time-Domain method are performed using a representative, homogeneous canine model on which two half-wavelength dipoles are placed at short distance from the body of the dog. Several combinations of transmitter and receiver locations and orientations are explored and for each transmitter location, the orientation and receiver location resulting in minimal path loss is determined. All path loss results are fitted to a log-normal path loss model with path loss exponent n ranging from 2.7 to 3.5. A link budget is composed with the wireless technologies ZigBee. The battery lifetime for several modules is determined. The ZigBee device XB24CAPIT-001 assures 237 days without recharging when using a battery capacity of 5000 mAh with an awake time period of 25%.**

Keywords— **Internet of Animal Health Things, Link budget, On-body communication, Path loss, Wireless Body Are Network**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) and in particular Wireless Body Area Networks (WBANs) are employed in various fields, including entertainment, travel and home automation [1]. An interesting and critical application domain is medical supervision. Wireless measurements of several vital and bodily functions are enhanced during the recent years with the advances in wireless communication and micro-electro-mechanical systems (MEMS) [2]. Sensors have become smaller, more efficient and cheaper, extending health welfare monitoring from human to animal healthcare [3]. For domestic dogs, the application of WBANs can enhance the effectiveness of training and rehabilitation programs. WBANs can be effectively used to track several parameters such as heart rate, blood pressure and muscle contraction in real time [4]. This way, musculoskeletal abnormalities, diabetes, heart malfunctions or excessive stress levels can be efficiently, and prematurely diagnosed, and the appropriate treatment can be determined and started [2]. The goal of this paper is to characterize the path loss (PL) between a sensor node and an on-body receiver node at 2.45 GHz on a typical canine body. Past studies were focused on humans [5]. Yet, as mentioned above, due to the progress in health monitoring devices, an interest in pet health is growing. As in the case with humans, different sensors are placed on various specific body parts. In this paper, the optimal location for the receiving node on the dog's body is determined so that path loss between the sensor node is minimal for its placement. Additionally, the favorable orientation of the nodes is investigated. For each of these configurations, the path loss is determined by performing simulations. The results are fitted to single slope PL models [2]. An overview of the optimal receiver locations and orientations for each sensor node location is composed. Finally, Link budgets are calculated to investigate the possible battery lifetimes.

Below, Section II-A and II-B present the setup of the simulations performed for on-body communication and the corresponding results and analysis, respectively. In III-A, the obtained results are fitted to the overarching proposed path loss model. Section III-B covers the composed link budget for this network using the constructed PL model in section III-A. Section IV presents a conclusion on the work carried out in regard to this paper and a brief word on future work is appended.

II. PATH LOSS SIMULATIONS ON A CANINE MODEL

In this section, the setup of the simulations is introduced. Afterwards, the obtained results are summarized and analyzed.

A. Simulation setup

To conduct the simulations, a model of a canine is imported into the simulation platform Sim4Life V6.0 [6]. The dog has dimensions of 1.050 m height, 0.960 m width and 0.300 m depth, based on the measurements of a male border collie (Fig. 1.). Body tissue is assigned to the model, with electric conductivity σ and relative permittivity ε_r of 1.7 S/m and 40.0, respectively [7]. These characteristics are based on a weighted average of the parameters for skin, bone, brain, fat and blood. The transmitter (Tx) and receiver (Rx) locations are determined by considering placements of the most commonly used sensors including heart-monitor devices, blood pressure sensors, muscle contacting and temperature measuring nodes. Both transmitter and receiver are modeled as half-wavelength dipoles, consisting of two cylinders with diameter 18mm. The two poles are separated by 1 mm and fed by a line element as source. The dipoles are placed on the canine's body at a distance of 8 mm. The length of the dipole is optimized at 2.45 GHz to match the presence of the canine body, which

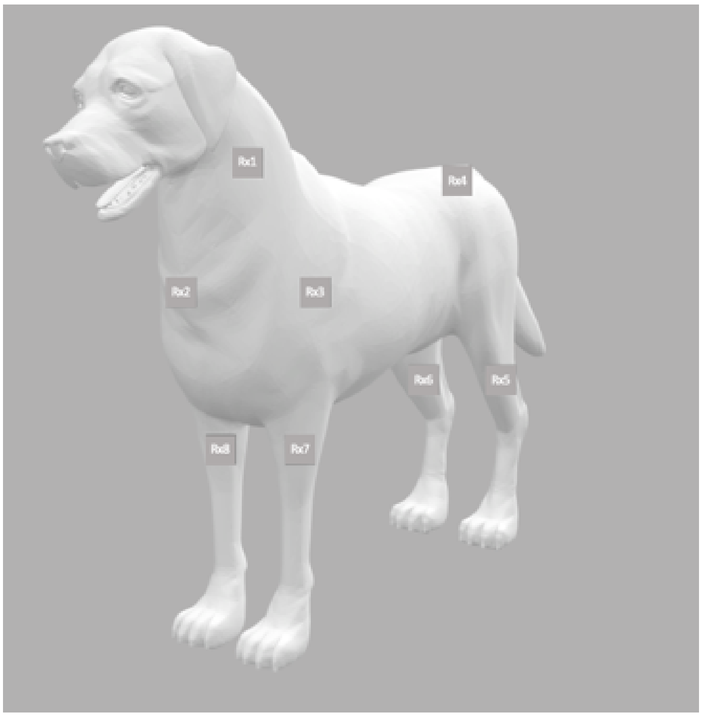

Figure 1. The 3D dog model with the different node locations denoted with squares.

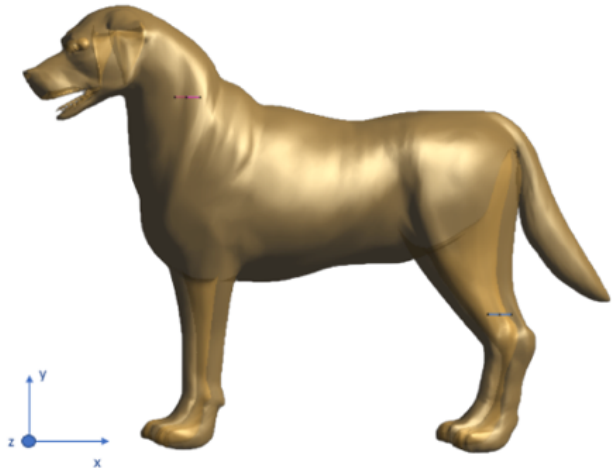

Figure 2. The mentioned orientations with respect to the canine model.

resulted in a dipole arm length of 2.6 cm. The simulations are performed for all possible configurations of the transmitter and receiver locations. Thus, for each of the 8 transmitter locations, 7 receiver locations are investigated. Furthermore, three orientations of both antennas are conducted for each configuration, x-, y- and z-aligned according to the usual coordinate system. The orientations with respect to the canine are shown in Fig. 2. In total, $8 \times 7 \times 3 = 168$ simulations are performed.

Table 1. Path loss results for best configuration for each transmitter location.

Location T_x	**Location R_x**	**Orientation**	**Path Loss [dB]**
Neck	Thorax	Z	32.65
Breast	Left front leg	X	39.32
Thorax	Left front leg	Z	24.56
Pelvis	Neck	Y	44.0226
Left hind leg	Left front leg	Z	38.31
Right hind leg	Right front leg	Z	39.42
Left front leg	Thorax	Z	24.4862
Right front leg	Right hind leg	Z	39.48

B. *Results and Analysis*

Table 1 shows the orientation and receiver location for each transmitter placement in which the minimal path loss for all investigated configurations occurs. Placing the transmitter at the height of the dog's neck is associated with placing the receiver at the thorax. The distance between both is relatively small and they are located in a Line-of-Sight (LOS). The z-orientation is explicable due to the fact that the maximum gain for this orientation is achieved in the XY-plane, in which both antennas are located. Placing the transmitter on the breast and receiver on the left front leg, both in the x-alignment, results in the minimal path loss for this Tx placement. The antennas are not at minimal distance as the neck and breast are separated by 21.94 cm and breast and left front leg by 35.75 cm. Despite this, the transmitted signal experiences the least energy loss for the receiver at this location due to the minimal body tissue that has to be crossed between the two devices. The x-orientation is also expected as the two antennas are approximately situated in the YZ-plane in which the gain for this antenna orientation is maximal. Placement of Tx on the thorax and Rx on the left front leg results in the smallest path loss, again due to the minimal distance, the LOS situation, and the maximum gain in the XY-plane. For Tx on the canine's neck (Table 1), it is advised to place the receiver on the neck and align both with the y-axis, despite the larger separation of 67.84 cm. The fact that they are in LOS results in minimal path loss. When placing the transmitter at the left front leg, path loss is minimal when the Rx is placed on the left front leg and both antennas along the z-axis. The distance between these two placements is far from minimal but they are again in LOS. A similar scenario is achieved when placing the transmitter on the right hind leg, for which Rx on the right front leg results in minimal PL.

III. PATH LOSS MODEL AND LINK BUDGET CALCULATIONS

In this section, the results from section II.B are used to construct a PL model. From this PL model, a link budget can be calculated after choosing a RF technology.

A. *Path Loss Model*

A commonly used model for on-body application is a log-normal relation between path loss and distance, the single slope PL model [5],[8]:

Table 2. Path loss model to fit simulations results for x-, y- and z-orientation of the antennas

Orientation	**PL(d_0)**	**n**	σ
X	11.8656	3.90	10.30
Y	17.0318	2.70	13.0
Z	11.98443	3.50	5.10

$$PL(d) = PL(d_0) + 10 \cdot n \cdot log(\frac{d}{d_0}) + X_\sigma \qquad (1)$$

With PL(d) the path loss measured for a distance d between transmitter and receiver. Distance d_0 is a reference distance at which the initial path loss is measured, n is the path loss exponent and X_σ represents a Gaussian distributed parameter with a mean of zero and deviation σ incorporating the slow fading of the channel in dB. The model is drawn up for all path loss results at each antenna orientation. Table 2 summarizes the model characteristics for each alignment. The fitted models have path loss exponents ranging from 2.7 to 3.9. The spreading ranges from 5.1 dB to 10.30 dB. The PL exponent is similar to the values found in the work of Benaissa et al. [2], which studies on-body PL on cows, where the total body PL exponent was 3.11. Yet the spreading is smaller in [2] because the model averages over less node locations. Also the work of Reusens et al. [5] reports a exponents of 3.11 for the complete human body at 2.45 GHz. The values of our study are thus in line with the literature on on-body communication.

B. Link Budget and Battery Lifetime Calculations

1) Battery Lifetime

Battery lifetime is an important factor to account for when designing wireless networks. Recharging or replacing batteries is a tiresome and inconvenient task, and in some cases impossible. For health monitoring during training and rehabilitation programs, the durability of the system should at least 6 months as within this span of time, as most programs can be completed [9]. The considered wireless technology is ZigBee. ZigBee is specifically designed for low power consuming applications [10]. They operate according to the IEEE 802.15.4 standard at the industrial, scientific and medical (ISM) bands including 868MHz, 915MHz and 2.4GHz. The lower consumption come at the cost of the data rates, which are usually only 250kbps for Zigbee devices. However, modules up to 2Mbps exist. Due to this, ZigBee is a qualified technology to operate wireless on-body networks. The battery lifetime in hours of the sensor is dependent on its the battery capacity and the sensor's activity:

$$\text{Battery lifetime} = \frac{BC}{I_t T_t + I_s T_s}(T_t + T_s) \qquad (2)$$

In which BC represents the battery capacity in mAh, I_t and I_s the current the sensor requires in respectively the transmit and sleep mode. The percentage T_t and T_s represent the ratio of total time for which the sensor is in transmit and sleep mode. The battery lifetime for capacities between 5000 mAh are considered for transmit times T_t of 5%, 10%, 25%, 50%, 75% and 100%. We selected the XB24CAPIT-001 [11] module as it proofs to assure the longest battery lifetime. A durability of up to 237 days can be achieved by employing this device with a battery capacity of 5000mAh and 25% transmit time. This means around 8 months with 8 hours of daily monitoring can be accomplished. This battery lifetime is mostly attained due to the very low required transmit power of only 6.3 mW. With its sensitivity of -102dBm and maximum data rate of 1Mbps, the XB24CAPIT-001 makes an excellent fit for on-body communication applications in regards of animal welfare monitoring.

IV. CONCLUSION AND FUTURE WORK

In this paper, the path loss between an on-body transmitter and receiver node for canine welfare monitoring applications is characterized. The favorable receiver location and orientation for several transmitter locations is determined so that path loss between both antennas is minimal. It is found that path loss does not only significantly depend on the distance between both nodes but is also highly dependent on the LOS or NLOS body-blocked scenarios. The orientation of the antennas proved to be an important factor to achieve minimal path loss. The orientations which aligns the radiation intensity of the RX and the Tx provides the best results in terms of PL. The path loss results are fitted to a log-normal model, which proves to deviate strongly dependent on the transmitting orientation. However, the proposed model shows good agreement with the literature. With the developed PL models and the link budget calculations, it was calculated that a device type XB24CAPIT-001 assures a durability of 237 days with battery with a capacity of 5000 mAh and with a transmit duty cycle of 25%.

In future work, real life experiments with canines will be proposed. The use of a heterogeneous model will then be advised. Furthermore, due to the use of swimming pools in the rehabilitation of canines, the models will be updated in water environments, which will again be verified with real measurement campaigns on canines. Also other frequencies in the ISM band will be explored to extend the lifetime of the nodes even more.

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