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Internet of animals: characterisation of LoRa sub-GHz off-body wireless channel in dairy barns — Source link

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Internet of animals: characterization of LoRa sub-GHz off-body wireless channel in dairy barns

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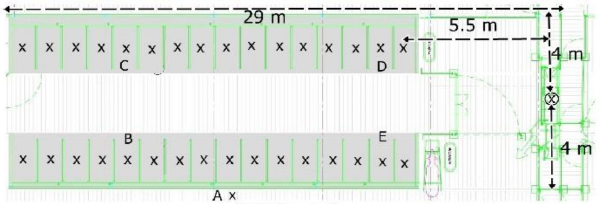
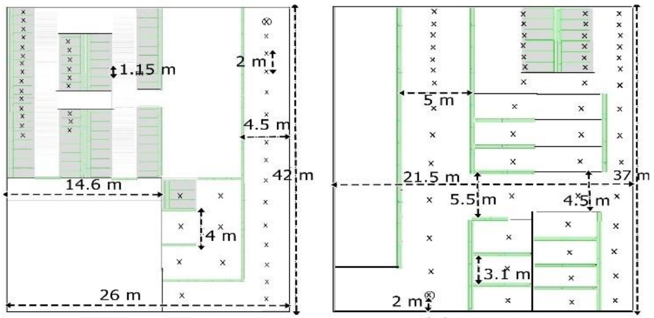
Advances in wireless sensor technologies and micro-electro-mechanical systems (MEMS) have made it possible to automatically monitor the health status of dairy cows using internet-of-things (IoT) and wireless body area networks (WBANs). Since on-cow measuring devices are energy-constrained, a proper characterization of the off-body wireless channel between the on-cow sensor nodes and the back-end base station is required for an optimized deployment of these networks in barns. In this letter, the LoRa (long range) off-body wireless channel has been characterized at 868 MHz, a typical IoT frequency. Both path loss and temporal fading were investigated using LoRa motes. Based on this characterization, network planning and energy consumption optimization of the on-body nodes could be performed, which enables the deployment of reliable dairy cow monitoring systems.

Introduction: The size of dairy farms and the number of animals per stockperson are increasing. With larger herds, detecting the health problems of individual cows in time becomes a challenging and costly task. Growing dairy farms could optimize their economic management by monitoring health indicators in real time using sensors. Wireless body area networks (WBANs) and internet-of-things (IoT) can be effectively used in health tracking of dairy cows to facilitate herd management and enhance the cow welfare (IoA, internet of Animals). Several studies have been published for monitoring dairy cattle with wireless sensors (see review in [1]). However, sub-GHz WBANs for cows have not yet been investigated up to now. Moreover, since on-cow measuring devices are energy-constrained, it is likely that new energy-efficient IoT technologies such as sub-GHz LoRa (Long Range) and Sigfox will find their use in animal monitoring. The aim of this letter was to characterize the off-body wireless channel in indoor (barns) environments at 868 MHz using LoRa nodes. Both path loss and temporal fading were investigated. Based on this characterization, network planning and energy consumption optimization of the on-body nodes could be performed, which enables the deployment of reliable dairy cow monitoring systems.

Path loss measurements: Measurements were conducted in three barns in the region of Melle, Belgium. A barn of the Institute for Agricultural and Fisheries Research (barn 1), and two barns of UGent- Biocentrum Agrivet (barns 2 and 3).



(a)Barn 1



(b)Barn 2 ⊗RX × TX (c)Barn 3

Fig. 1 *Measurement environments and positions of the transmitter (TX) and the receiver (RX).*

Path loss measurements were performed with a LoRaMote (PCB PIFA, 0 dBi) and LoRa gateway (monopole antenna, 2.1 dBi) for three different scenarios, namely: barn without cows, barn with one cow (i.e., one cow wearing LoRaMote and no other cows in the barn), and barn with 17 cows. (i.e., one cow wearing the mote and 16 other cows moving freely in the barn).

In the first scenario, the LoRaMote (TX) was configured to transmit two packets each second at 868.3 MHz with a constant power of 14 dBm. The LoRaMote was mounted on a plastic mast with antenna vertically polarized at a height of 1 m above the ground, a height comparable to that of a cow's neck. The receiver (RX) was a LoRa gateway (iC880A connected to Raspberry Pi B+) configured as a sniffer to capture the transmitted packets. The Raspberry Pi B+ was connected to a laptop via an Ethernet connection to log the captured packets containing the received signal strength indicator (RSSI) values using ExpLoRa studio software. The receiver was placed at a fixed position with the antenna vertically polarized at a height of 4.5 m, a typical access point height. Then, the position of the transmitter was set inside the cubicles as illustrated in Fig. 1 a-c.

In the second scenario, the transmitter side was replaced with one cow wearing the LoRaMote on the collar. In this scenario, no other cows were present in the measurement area. The same TX positions in the barn 1 as scenario 1 were investigated. After attachment, the antenna of the LoRaMote mote was vertically polarized (with respect to the ground) with a separation of 5 cm above the cow's body (node attached on the collar). We note that the influence of the body is limited in this case and the free space gain is used for the path loss calculation. In case the antenna is too close to the body, the gain near the body should be calculated and used instead of the free space gain as performed in [2].

In the third scenario, the same TX and RX setup was used as scenario 2. However, in addition to the cow wearing the LoRaMote, 16 cows were moving freely in the measurement area.

RSSI calibration: A calibration experiment of the RSSI has been conducted beforehand using a spectrum analyzer as performed in [3] to determine the relation between the RSSI values and the real radio-frequency (RF) power P_{RX}. A constant shift of 6 dB has been found between the RSSI reported by LoRaMote and the RF power measured by the spectrum analyzer.

Path loss modelling: After estimating a local average received power for each transmitter-receiver constellation, the path loss should be calculated and modelled. From the measured average received power P_{RX}, the path loss $PL(dB)$ is calculated as follows:

$$PL = P_{TX} + G_{TX} - L_{TX} + G_{RX} - L_{RX} - P_{RX} \tag{1}$$

where P_{TX} is the transmitter power (dBm), G_{TX} the transmitter antenna gain (dBi), L_{RX} the transmitter cable losses (dB), G_{RX} the receiver antenna gain (dBi) and L_{RX} the receiver cable losses (dB).

It is well known that the average received signal decreases logarithmically with distance. Therefore, the path loss can be modelled as a linear function of the logarithmic distance between transmitter and receiver as explained in [3]:

$$PL(d) = PL(d_0) + 10n \log\left(\frac{d}{d_0}\right) + X_\sigma \tag{2}$$

with $PL(d_0)$ is the path loss at reference distance $d_0 = 1$ m , n the path loss exponent, d the separation distance between TX and RX, and X_σ a zero-mean Gaussian distributed variable (in dB) with standard deviation σ, also in dB. $PL(d_0)$ and n are obtained from the measured data by the method of linear regression (LR) analysis.

Characterization of temporal fading: To determine temporal fading properties, measurements were performed at five different TX-RX configurations within the barn 1 (i.e., A, B, C, D, and E in Fig. 1a). For each case, the transmitter and receiver were set in stationary positions, while the cows were moving freely in the measurement environment. These scenarios were set to allow the recording of received signal power variations due to the movements of the cows. At each TX location, RSSI values were recorded in a time interval of 10 minutes, at a rate of 2 samples per second. Consequently, a total of 1200 RSSI samples of received power were recorded per temporal fading measurement run. The Rician distribution, described in terms of the K-factor (Rician factor), was adopted to characterize the temporal fading [4]. This assumption was validated by comparing the theoretical Rice distribution to the distribution of the measured temporal fading samples.

Results: Fig. 2a shows the measured path loss values and the fitted models versus log-distance (TX-RX separation) for the first scenario (i.e., barns without cows). The markers indicate the individual measurements, while the lines represent the path loss models obtained through fitting of the measurement data.

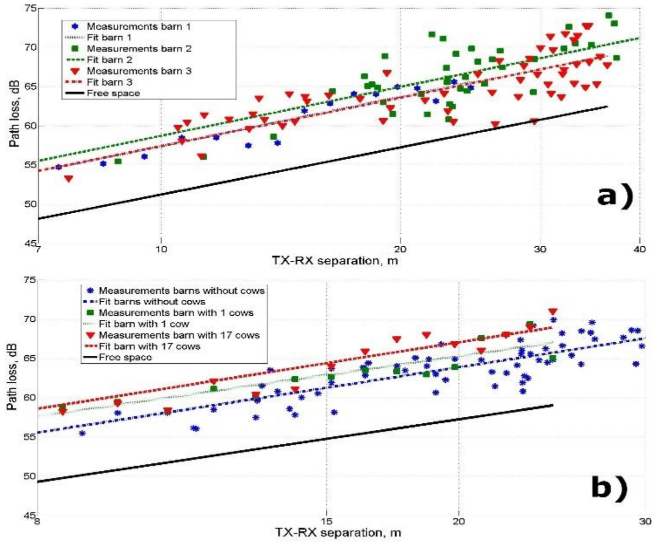


Fig. 2 *Path loss models for scenario 1 (a), and for scenarios 2 and 3 (b).*

As expected, the path loss inside the barns is higher than the free space path loss because of the influence of obstacles inside the barn. Moreover, excellent agreement is achieved between the path loss models of the three barns. This result is shown in Table 1, where the parameter values of the path loss models (see equation (2)) are listed. Similar path loss at reference distance ($PL(d_0)$ ≈37 dB) and path loss exponent ($n \approx 2$) are obtained for the three barns. Standard deviations (σ) around 3 dB are obtained for all models, indicating a relatively low shadow fading effect.

Table 1: Parameters of the path loss models ($d_0 = 1\ m$)

	$PL(d_0)\ (dB)$	$n(-)$	$\sigma(dB)$	$R^2(-)$
Barn 1 without cows	36.45	2.09	2.22	0.89
Barn 2 without cows	37.44	2.11	3.69	0.72
Barn 3 without cows	36.91	2.04	3.36	0.71
Barns without cows	36.67	2.08	3.17	0.80
Barn 1 with 1 cow	40.03	1.92	2.37	0.84
Barn 1 with 17 cows	40.36	2.04	2.52	0.87

After obtaining a path loss model for each barn separately, an equivalent model (i.e., barns without cows) is considered to represent the barns for scenario 1 and compared it to the other scenarios. Fig. 2b shows the obtained path loss models for the three investigated scenarios. The path loss increased (around 4 dB) in scenarios 2 and 3 in comparison to scenario 1, which is expected due to the influence of the cows. As listed in Table 1, although the models have relatively similar path loss exponents ($n \approx 2$), the path loss at reference distance ($PL(d_0)$) increased from 36.67 dB in scenario 1 to 40.03 dB in scenario 2, and 40.37 dB in scenario 3. This means that the body of the cow wearing the node is the main reason of the path loss increase (around 3 dB). The difference between scenarios 2 and 3 is limited (around 1 dB) due to the high height of the base station (4.5 m), which makes the communication between the on-cow node and the base station either in line-of-sight (LOS) conditions or obscured just by the body of the cow wearing the node.

For the temporal fading, the Rician K-factor is estimated based on the moment method presented in [5]. For each K-factor. As listed in Table 2, the K-factor varies between 6.4 dB for location A and 10.2 dB for location C, with an average value of 8.2 dB. The difference in K-factors could be explained by the amount of motion made by the cows when temporal fading measurements are performed. These large values indicate a strong specular path LOS component in our measurements due to the RX height (4.5 m). Based on the obtained K-factors, fade margin are calculated for an outage probability of 1%. The fade margin varies between 6 and 10.8 dB. An average fade margin of 8.3 dB should be considered in barns environments.

Table 2: K-factors and the corresponding fade margins for an outage probability of 1%.

Locations	A	B	C	D	E	Mean
K-factors (dB)	6.4	6.8	10.2	8.3	9.5	8.2
Fade margin (dB)	10.8	10.1	6.0	7.9	6.6	8.3

Conclusion: In this letter, the sub-GHz off-body wireless channel for dairy cows in barns has been characterized for sub-GHz IoT technologies at 868 MHz. Three different barns have been investigated. Measurements of large-scale fading and temporal fading have been performed with LoRa nodes. Results show that the large-scale fading can be well described by a one-slope log-normal path loss model. The highest path loss increase resulted from the body of the cow wearing the sensor node (4 dB). Other cows had less influence (1 dB). The temporal fading was statistically described by Rician distributions with an average K-factor of 8 dB. These results enable the deployment of reliable IoT dairy cow monitoring systems with optimized network planning and energy consumption.

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