of the topology is discussed and practical insights are given on how to instantiate a real-life BAN with respect to the application demands and propagation context. Furthermore, throughout this entire manuscript the indoor and the outdoor environments are treated separately and properly compared.

The remainder of this paper is organized as follows. In Section II, the propagation mechanisms are introduced and characterized. In Section III, the conditional success probability of a link transmission for a node, given the transmitter-receiver and interferers-receiver distances, is derived. In the same section, the minimum required transmit power, over a given link, in the absence of any interfering node is computed in both indoor and outdoor environments. Then, in Section IV the tree topologies analyzed in this paper are presented and the traffic model is discussed. Finally, in Section V, an extensive performance analysis, in terms of network throughput and energy consumption, is performed. Section VI concludes the paper.

II. PROPAGATION MECHANISMS

In order to build an accurate model for the on-body propagation, a Rohde & Schwartz ZVA-24 vector network analyzer was used to capture the complex-valued frequency-domain transfer function between 3 GHz and 7 GHz, with a frequency step of 50 MHz. Omnidirectional Skycross SMT-3T010M ultra-wide band (UWB) antennas were used during the entire measurement campaign. Their small-size (13.6 mm x 16 mm x 3 mm) and low profile characteristics precisely match the body sensor requirements. These antennas were separated from the body skin by about 5 mm in order to ensure a return loss value $S_{11} \leq 9$ dB. Finally, low-loss and phase-stable cables interconnect all components and the IF-bandwidth was set to 100 Hz in order to enlarge the dynamic range to about 120 dB.

The experimental scenario is presented in Fig 1 and can be described as follows. The measurements were carried out around the 94 cm of the waist of a man (1m87, 83kg) whose body is in a standing position, arms hanging along the side. The transmit antenna is placed around the body at a distance $d$ from the receive antenna, which is located at the middle axis of the torso.

A. Measurements

First, the diffraction mechanism is analyzed by gradually shifting the transmitter around the body. The spatial values of the power are extracted from 7 different sites separated by 4 cm each. For each level, the transmitter is also shifted one level below and one level above and the observed measures are averaged. Second, the impact of the reflections off the surrounding environment was investigated for 5 positions of the transmitter around the body. Repeated measures are taken by positioning the human body on a rectangular grid of $7 \times 7$ position, each separated by 4 cm. This procedure is performed for a set of 20 locations in a standard office room with a surface of about 20 m$^2$.

The baseband frequency response at the receiver was then converted into the delay domain using an inverse discrete Fourier transform (IDFT) \cite{30}. Next, a Hamming window was applied to reduce the side lobes up to $43$ dB for the second lobe. The resulting complex impulse response allows a description of the BAN channel with a delay resolution of up to $0.25$ ns. As shown in Fig. 2 and Fig. 3, the different multipath and scattering mechanisms are well distinguished as a function of time. More precisely, the diffraction around the body is followed by the reflections off the environment. Both propagation mechanisms can be efficiently separated by applying a rectangular time gating at 7 ns. Finally, the narrowband power of the two distinct contributions mechanism is estimated by integrating the complex values of the temporal taps over each sub-channel.

The conclusions of this extensive measurement campaign, also highlighted in \cite{13}, can be summarized in three points. Firstly, there is propagation through the body. However, when high transmission frequencies are considered, the attenuation undergone by these waves is relevant and the corresponding contribution can be neglected.

A second mechanism corresponds to guided diffraction around the body. This mechanism is consistent with a surface wave propagation and its properties depend on the body specific characteristics.

Finally, the last propagation contribution comes from the surrounding environment. More precisely, the third propagation mechanism originates from reflections off the body limbs (arms and legs) and the surrounding objects (walls, floor, and ceiling). Obviously, this mechanism is observed only in an