to 10 dB, $\mu_{\text{dB}}$ is the average path loss on the link (dimension: [dB]). Since the loss is accounted for by the term $L(d)$, it follows that $\mu_{\text{dB}} = 0$ dB and the cumulative distribution function (cdf) of $X$ reduces to the following:

$$F_X(x; 0, \sigma) = \frac{1}{2} - \frac{1}{2} \text{erf}\left(\frac{-10 \log_{10} x}{\sigma \sqrt{2}}\right)$$

with the following corresponding probability density function (pdf):

$$f_X(x; 0, \sigma) = \frac{10}{(\ln 10) x \sqrt{2\pi}\sigma} \exp\left(-\frac{(10 \log_{10} x)^2}{2\sigma^2}\right). \quad (5)$$

C. Reflections off the Environment

The second significant propagation mechanism originates from the multiple reflections off the environment. A substantial measurement campaign has shown that the contribution of the environment can be considered, on average, as an additive, constant power when the transmission distance is significant (i.e., when $d > 25$ cm). The obtained results are shown in Fig. 4 (b), the power received by means of reflections from the surrounding environment is shown as a function of the distance. It can be observed that when $d > 25$ cm, the value of the loss is, on average, around $-78$ dB. More precisely, for $d > 25$ cm the average value of the received power can be expressed, in logarithmic scale, as follows:

$$\mathbb{E}[P_{\text{env}}] = P_{\text{env}} \triangleq P + L_{\text{dB}}^{\text{env}} \quad (6)$$

where $P$ is the transmit power and $L_{\text{dB}}^{\text{env}} \simeq -78$ dB. Alternatively, the average received power can be expressed in linear scale as

$$\mathbb{E}[P_{\text{env}}] = P_{\text{env}} \triangleq P \cdot L^{\text{env}} \quad (7)$$

where $L^{\text{env}} = 10^{L_{\text{env}}/10}$.

Our measurement campaign has shown that the propagation channel can be accurately characterized as narrowband Rayleigh block fading. Therefore, the instantaneous received power $P_{\text{env}}$ has the following exponential distribution [33]:

$$f_{P_{\text{env}}}(x) = \frac{1}{P_{\text{env}}} \exp\left\{-\frac{x}{P_{\text{env}}}\right\}. \quad (8)$$

D. A Unified BAN Propagation Model

The combination of the two propagation mechanisms presented in Subsection II-B and Subsection II-C allows to derive a unified propagation model for a generic BAN. It can be observed that the degree of importance of each mechanism depends on the distance between transmitter and receiver. More precisely, in close proximity, the dominant propagation mechanism is the on-body propagation described in Subsection II-B. Above the cross-over distance $d_{\text{cross}} \approx 25$ cm, the contribution of the environment becomes dominant and the second propagation mechanism, presented in Subsection II-C, is the only relevant one. Therefore, a unified propagation model can be characterized as follows:

- in an outdoor environment, the average received power can be computed using (4) (i.e., $\mathbb{E}[P(d)] \propto P 10^{\gamma d}$) and
- in an indoor environment:
  - if $d \leq d_{\text{cross}}$, the average received power can be computed using (4) (i.e., $\mathbb{E}[P(d)] \propto P 10^{\gamma d}$) and the log-normal fading in (5) is used;
  - if $d > d_{\text{cross}}$, the average received power is approximately constant (i.e., $\mathbb{E}[P(d)] = P L^{\text{env}}$) and the instantaneous received power, owing to a Rayleigh faded channel model, has the distribution given by (8).

In Fig. 5, the average path loss is shown as a function of the distance. In particular, the overall (unified) path loss can be expressed as follows:

$$L^{\text{indoor}}(d) = \max\{L_0 10^{\gamma d}, L^{\text{env}}\}$$

$$L^{\text{outdoor}}(d) = L_0 10^{\gamma d}.$$