A New Look to THz Wireless Links: Fading Modeling and Capacity Assessment

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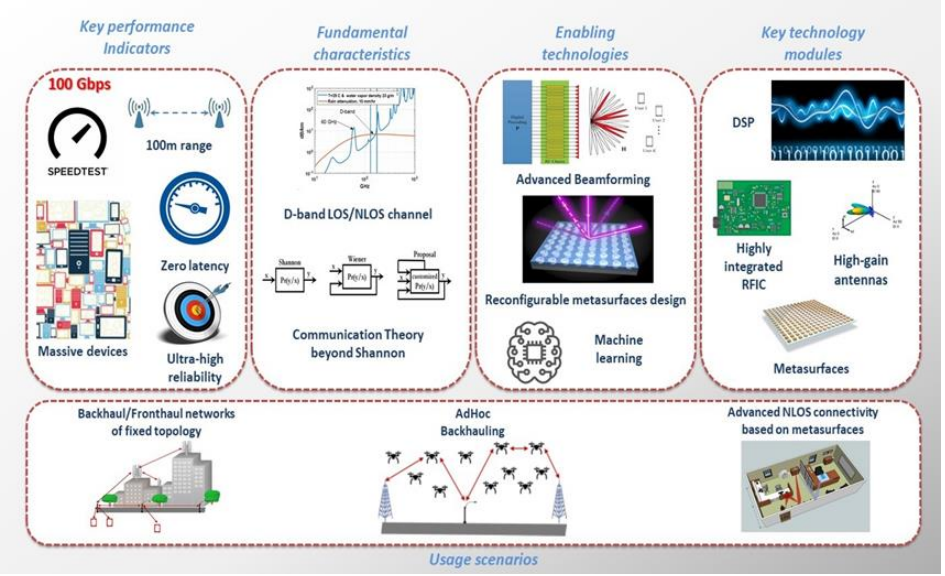
Motivation

Systems beyond 5G are expected to:

- Provide unprecented performance excellence, in the 100 Gbps regime.
- Support novel usage scenarios combining extreme data rates with agility, reliability and zero response time.
- Exploit frequencies above 100 GHz.



- The THz band (0.1-10 THz) offers a vast amount of unallocated bandwidth.
- Is envisioned to sustain flexible and ubiquitously available networks for backhaul and access applications.

Objective

- To investigate the small-scale fading statistics of THz wireless channels.
- Perceive a fading distribution that is not only analytically tractable, but also accurately describes the THz channels.
- Examine the suitability of $\alpha - \mu$ distribution to model the small-scale fading of THz channels.
- Verify the accuracy of $\alpha - \mu$ fitting to the empirical channel gain distributions of various indoor links measured at 142 GHz.
- Present the ergodic capacity performance of THz links under different levels of small-scale fading intensity.

The $\alpha - \mu$ fading distribution

- The $\alpha - \mu$ is a well-known fading distribution.
- It includes many well-known distributions, by appropriately setting α and μ values.
- The probability density function (PDF) of $\alpha - \mu$ is expressed as

$$f(x) = \frac{\alpha\, \mu^{\mu} \left(\frac{x}{\beta}\right)^{\alpha\,\mu-1} exp\left(-\mu\left(\frac{x}{\beta}\right)^{\alpha}\right)}{\beta\, \Gamma(\mu)}$$

- For a random variable X following $\alpha - \mu$

$$\beta = \sqrt[\alpha]{\mathrm{E}(X^{\alpha})}$$

$$\mu = \frac{\mathrm{E}^2(X^{\alpha})}{\mathrm{V}(X^{\alpha})}$$

Capacity of $\alpha - \mu$ fading channels

- For a single-input-single-output (SISO) THz wireless system by assuming $\alpha - \mu$ small-scale fading, the ergodic capacity is expressed as

$$C = \frac{\alpha\, \mu^{\mu} \left(\frac{\sqrt{1/\kappa}}{\beta}\right)^{\alpha\, \mu}}{2\, ln(2)\Gamma(\mu)} H_{3,4}^{4,1}\left[\mu \left(\frac{\sqrt{1/\kappa}}{\beta}\right)^{\alpha} \middle| \begin{matrix} \left(-\frac{\alpha\, \mu}{4}, \frac{\alpha}{4}\right), \left(1 - \frac{\alpha\, \mu}{4}\right), & (1,1) \\ (0,1), & (1,1) \end{matrix} \begin{matrix} \\ \left(-\frac{\alpha\, \mu}{4}, \frac{\alpha}{4}\right), \left(-\frac{\alpha\, \mu}{4}, \frac{\alpha}{4}\right) \end{matrix}\right]$$

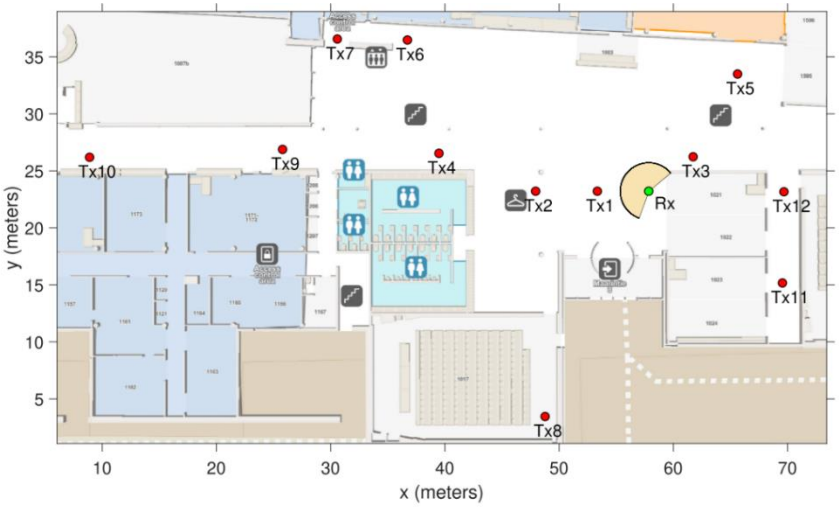
$$\kappa = \frac{P_t}{N_o} \frac{c G_t G_r}{16\pi^2 f^2 d^2} \tau(f, d)$$

- Where $H_{3,4}^{4,1}[\cdot]$ is the Fox-H function.

A. A. Boulogeorgos, E. N. Papasotiriou and A. Alexiou, "Analytical Performance Assessment of THz Wireless Systems," in IEEE Access, vol. 7, pp. 11436-11453, 2019, doi: 10.1109/ACCESS.2019.2892198.

Experimental Setup

- Indoor multipath measurements in the premises of a university.
- Two line-of-sight (LoS) links.
- Ten non-line-of-sight (NLoS) links.
- The transmitter (TX) and the receiver (RX) were static.



- No people were present during the measurements.
- A different link was defined by changing the TX position.

Preprocessing of the measurement data

- The channel sounding yields power-angular-delay-profiles (PADP) for each TX-RX link.

$$PADP(\phi, t) = \sum_{i=1}^{I} G_a P_i \delta(\phi - \phi_i)\delta(t - t_i)$$

- To investigate the stochastic behavior of the THz channels, the deterministic pathloss must be omitted.

$$\zeta_i^2 = \frac{P_i}{\frac{\sum_{i=1}^{I} P_i}{I}}$$

- Where ζ_i is the normalized path amplitude.

Generation of different channel realizations

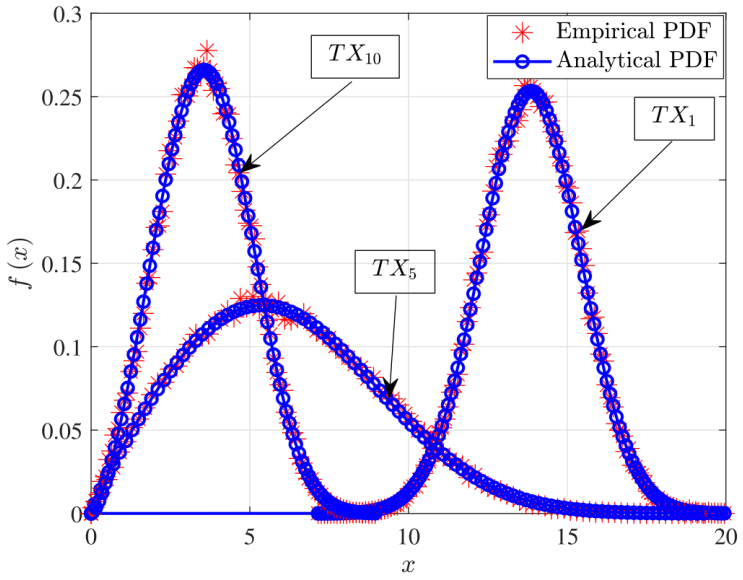
- The THz wavelengths are much smaller compared to the size of objects.
- The multipath richness is reduced.
- Different transfer function realizations can be generated by changing the phases of the multipath components.

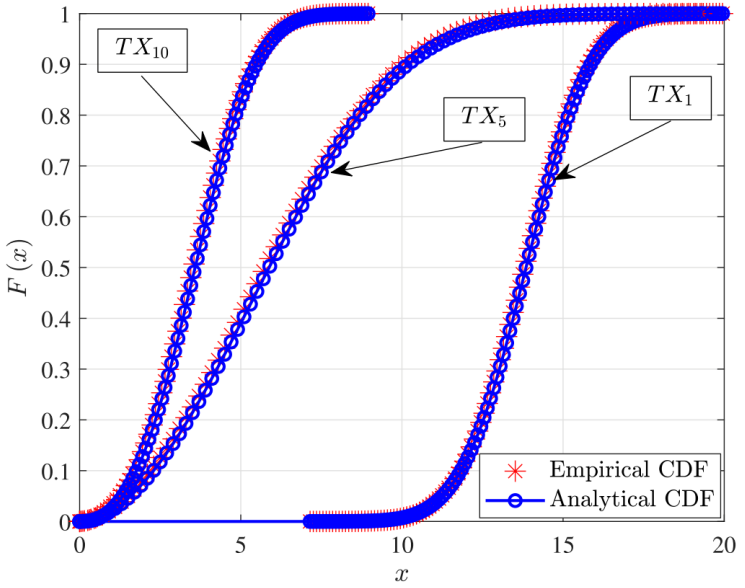
$$h = \sum_{i=1} \zeta_i exp(-j\,2\pi f t_i) exp(j\psi_i)$$

- By assuming a flat-fading channel, $t_i = 0$.

Fitting of $\alpha - \mu$ to the empirical channel gain distributions (1/2)

- The $\alpha - \mu$ fading distribution was found to adequately fit the empirical channel gain distributions of the measured links.
- The goodness of fit was evaluated in terms of the Kolmogorov-Smirnov test with a significance level of 5%.





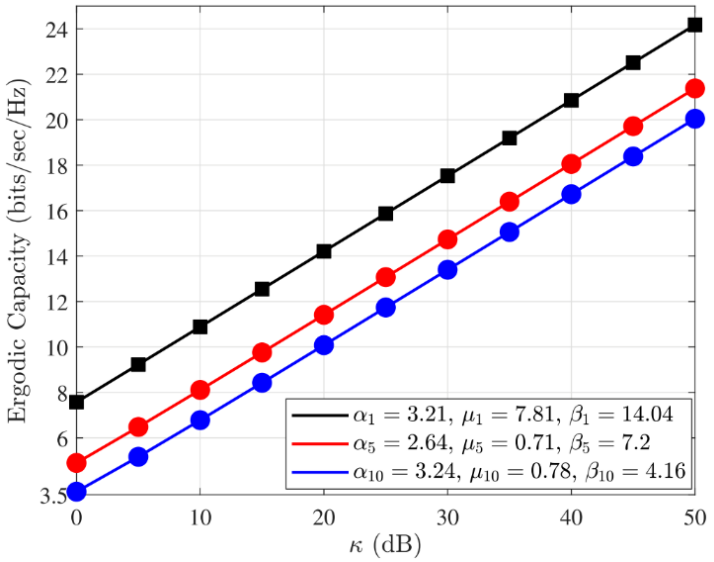
Fitting of $\alpha - \mu$ to the empirical channel gain distributions (2/2)

- $\alpha - \mu$ accurately fits the empirical channel gain distributions of both LoS and NLoS links.
- For the LoS links $\mu > 1$, while for the NLoS links $\mu < 1$.
- For both LoS and NLoS $\alpha \in [2 - 3.25]$ except for link 4.

TX	d (m)	α	μ	β	KS–test	LOS
1	4.35	3.21	7.81	14.04	✓	✓
2	9.82	3.13	3.76	11.36	✓	✓
3	3.3	3	0.66	10.77	✓	✗
4	17.01	8.55	0.23	8.5	✓	✗
5	11.24	2.64	0.71	7.2	✓	✗
6	23.31	2.48	0.78	7.27	✓	✗
7	28.71	2.48	0.77	3.65	✓	✗
8	20.16	-	-	-	✗	✗
9	30.65	2.29	0.85	6.35	✓	✗
10	47.44	3.24	0.78	4.16	✓	✗
11	12.59	-	-	-	✗	✗
12	10.19	3.25	0.72	3.05	✓	✗

Capacity Evaluation

- The ergodic capacity of a SISO THz wireless link is evaluated for different values of α, μ and β.
- For a given set of values, as κ increases the ergodic capacity improves.
- The increase of κ leads to pathgain and received power improvement.



- The ergodic capacity of link 1 is greater compared to links 5 and 10.
- Because μ_5 and μ_{10} have similar values while μ_1 is greater.
- Also, $\beta_1 > \beta_5 > \beta_{10}$.

Conclusions

- The small-scale fading statistics of THz wireless channels was investigated.
- For the first time the $\alpha - \mu$ was fitted to experimentally obtained THz channel gain measurements.
- The $\alpha - \mu$ achieves an adequate fit to the empirical channel gain distributions.
- More channel measurements are needed to identify the range of $\alpha - \mu$ parameters to describe different indoor environments.

Thank You!

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- Site: https://www.ict-ariadne.eu/