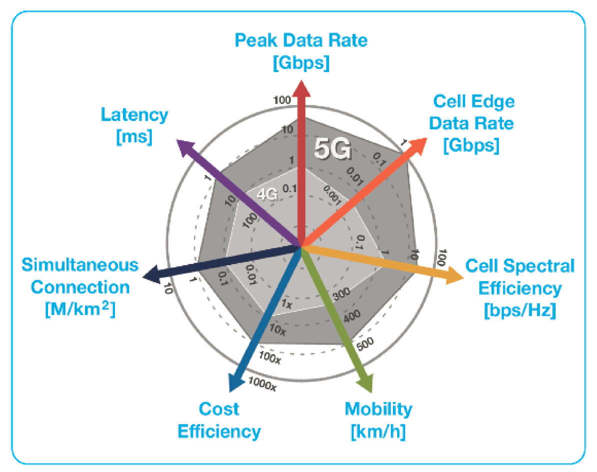
A PROBABILISTIC INTERFERENCE DISTRIBUTION MODEL ENCOMPASSING CELLULAR LOS AND NLOS MMWAVE PROPAGATION

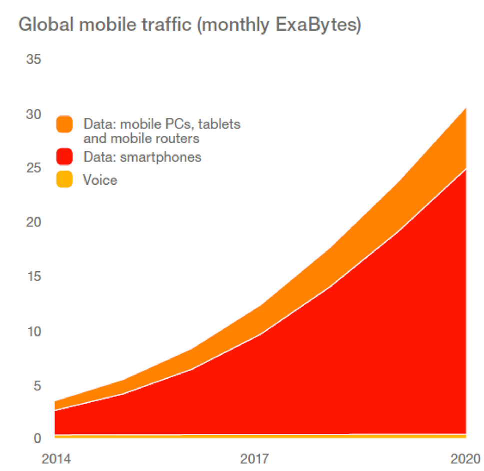
Tufts UNIVERSITY
Department of Electrical and Computer Engineering

Hussain Elkotby and Mai Vu

Introduction and Motivation



Samsung 5G Rainbow Requirements



Ericsson Mobility Report, 2015

- Scarce spectrum at the microwave band.
- Migration to mmWave (massive increase in bandwidth)
- Smaller cell radii leading to dense network deployments.
- Cellular networks are interference rather than noise limited.

mmWave Channel Model and Features

- Channel propagation model:

$$\mathbf{H} = \sqrt{l(r)}\tilde{\mathbf{H}}$$

- Small-scale fading: non-parametric or parametric models.
- Probabilistic large-scale fading model

$$l(r) = \mathbb{B}\big(p(r)\big)\, L_l \beta_l r^{-\alpha_l} + \Big(1 - \mathbb{B}\big(p(r)\big)\Big)\, L_n \beta_n r^{-\alpha_n}$$

$\mathbb{B}(\cdot)$: Bernoulli random variable, $L_i \sim \mathcal{N}(0, \sigma_i)\ \forall i \in \{l, n\}$

Floating intercept model: β_i floating intercept, α_i linear slope
Close-in model: β_i is free space path loss
α_i is path loss exponent

- The probability that a link of length r is LOS

$$p(r) = \left[\min\left(\frac{r_{BP}}{r}, 1\right)\left(1 - e^{-\frac{r}{\alpha}}\right) + e^{-\frac{r}{\alpha}}\right]^2$$

r_{BP}: Breakpoint distance, α: decay parameter

- Separate measurements/models for LOS and NLOS.

Cellular Model based on Stochastic Geometry

- A multi-antenna cellular system.
- No intra-cell interference.
- Interferers distributed outside a cell of nominal radius R_0.
- LOS interferers distributed as a p.p.p. Φ_L with intensity $p(r)\lambda_1$.
- NLOS interferers distributed as a p.p.p. Φ_N with intensity $(1 - p(r))\lambda_1$.

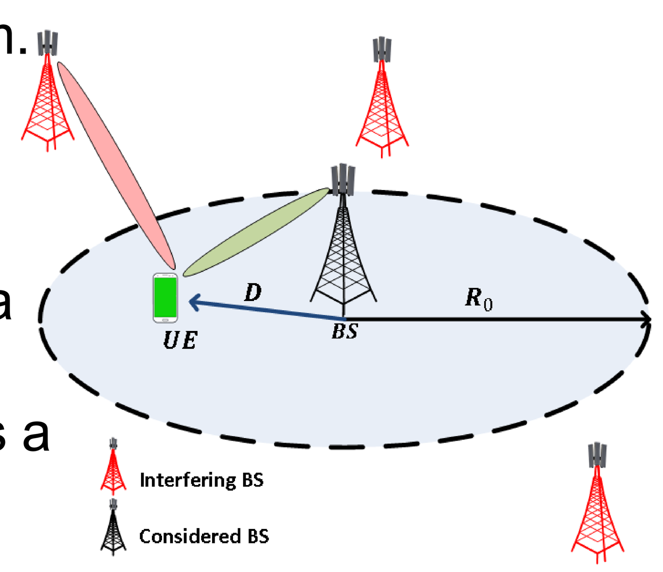


Fig. 1: System Model.

Interference Modeling

- The interference vector $\mathbf{v}_0$ at a UE at distance D from BS:

$$\mathbf{v}_0 = \sum_{z_k} \mathbf{H}_k \mathbf{w}_k x_k = \sum_{z_k} \sqrt{P_k l(\|\mathbf{z}_k - \mathbf{t}_0\|_2)}\tilde{\mathbf{h}}_k U_k$$

$\mathbf{w}_k$: unit-norm beamforming vector independent of $\mathbf{H}_k$
$x_k = \sqrt{P_k} U_k$ is the transmitted signal with power P_k
$\mathbf{t}_0$: the 2-D location of the considered UE

- For a fixed fading and spatial realization, $\mathbf{v}_0$ is $\mathcal{CN}(\mathbf{0}, \mathbf{Q}_0)$.
- The covariance matrix $\mathbf{Q}_0$ is random.
- Diagonal elements q_0 represent interference power.
- Assuming LOS probability independence, we separate the LOS and NLOS interference power modeling

$$q_0 = \sum_{z_k \in \Phi_L} l(\|\mathbf{z}_k - \mathbf{t}_0\|_2)\, g_k P_k + \sum_{z_k \in \Phi_N} l(\|\mathbf{z}_k - \mathbf{t}_0\|_2)\, g_k P_k$$

g_k: the small-scale fading power gain from k^{th} interferer.

- Analytical expressions available for LOS and NLOS first two moments when the elements of $\tilde{\mathbf{H}}$ are i.i.d. $\mathcal{CN}(0,1)$.

Interference Power Candidate Distributions

- Consider 2-parameter candidates {Gamma (G), Inverse Gaussian (IG), and Inverse Weibull (IW)}.
  - ➢ Characterized by shape and scale parameters.
  - ➢ Few parameters to estimate.

LOS Model as a Mixed Distribution

- The probability $p(r)$ is a decreasing function of r.
- Only interferers in a limited area contribute to LOS part.
- Consider probability density function (PDF) as

$$\gamma_G(D) = \begin{cases} 0 & \text{with probability } p_0(D) \\ \tilde{\gamma}_G(D) & \text{with probability } 1 - p_0(D) \end{cases}$$

$p_0(D)$: probability that LOS interference power is 0.
$\tilde{\gamma}_G(D)$: Gamma distributed random variable

NLOS Model as a Mixture Distribution

- The increasing function $1 - p(r)$ suggests very low probability of NLOS interference power components around 0.
- Consider as a weighted mixture of IG and IW distributions.

$$f_Y(y|\theta) = w_1 f_{Y_{IG}}(y|\lambda) + w_2 f_{Y_{IW}}(y|c)$$

- After moment matching, only 3 parameters to estimate:
  - ➢ The distribution mixing weight, and
  - ➢ Shape parameter in each individual distribution.

Models Parameters Estimation Approaches:

- Gamma moment matching (MM):
  - ➢ Match the first two moments analytically.
- Gamma Maximum Likelihood Estimation (MLE):
- Mixture distribution MLE:
  - ➢ Match the first moment, then develop an Expectation Maximization algorithm to estimate the parameters.

Interference Models Evaluation

Visual verification:

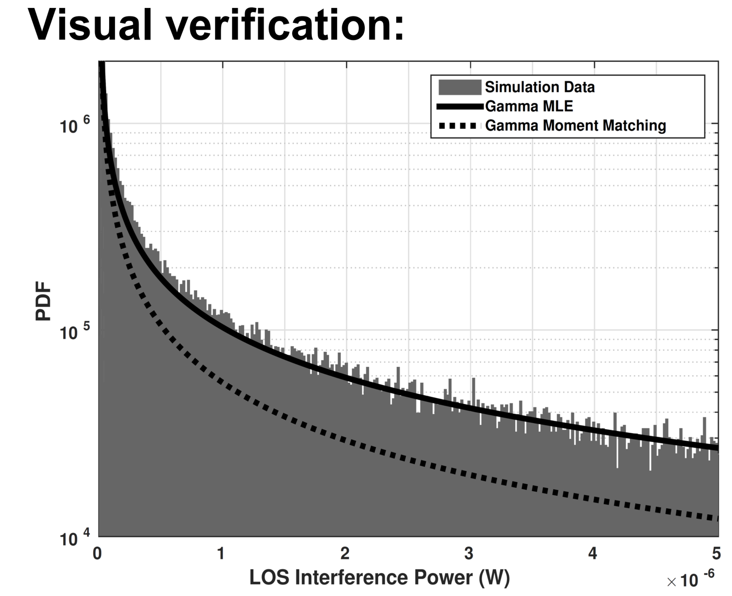


Fig. 3: LOS interference power PDF, $\alpha_l = 3.5, \sigma_l = 4\text{dB}, (P_{max} = 30\text{dBm}, D = 75\text{m})$.

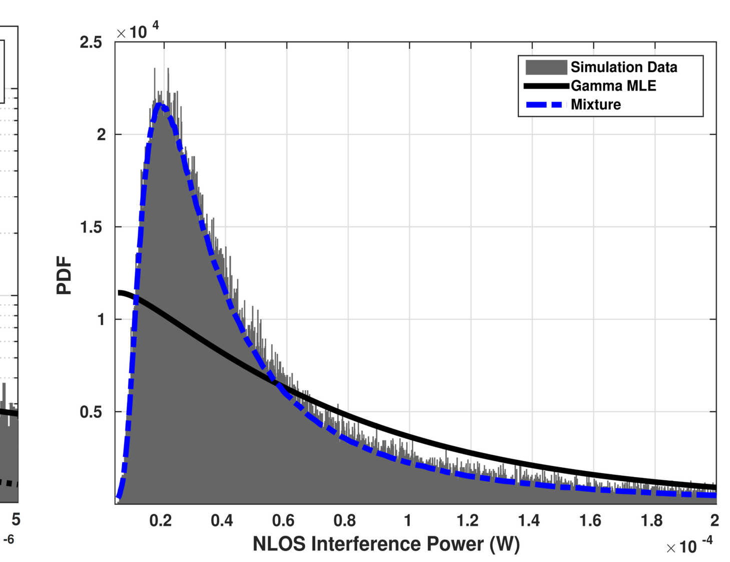


Fig. 4: NLOS interference power PDF, $\alpha_n = 3.5,\ \sigma_n = 4\text{dB}, (P_{max} = 30\text{dBm}, D = 75\text{m})$.

Kullback–Leibler (KL) divergence metric:

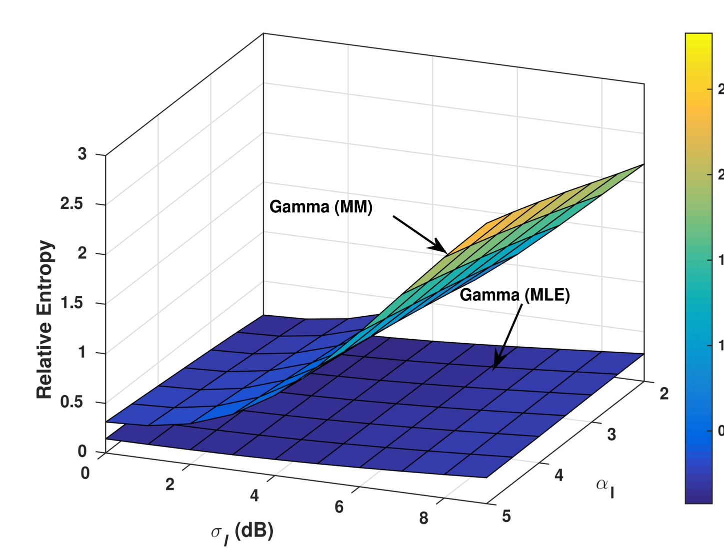


Fig. 5: KL metric of LOS models, $D = 75$m.

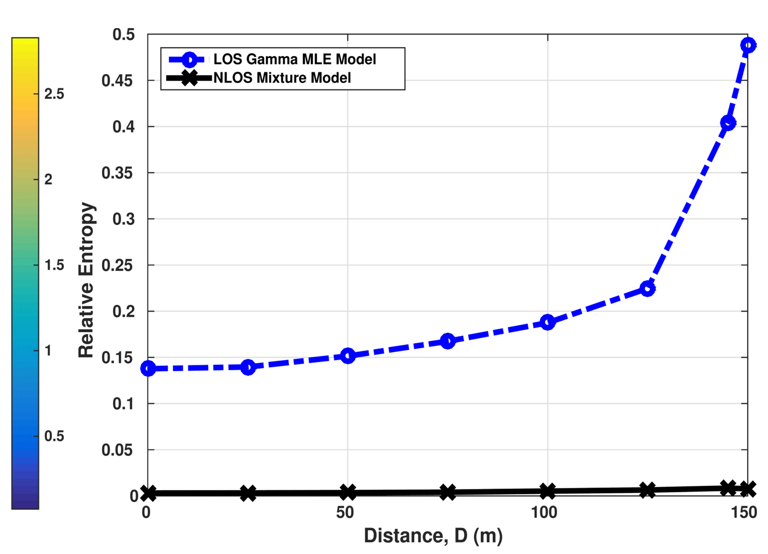


Fig. 6: KL metric versus distance D m, $(\alpha_l = \alpha_n = 3.5, \sigma_l = \sigma_n = 4\text{dB})$.

Conclusion and Future Work

- LOS MM model represents the simplest approach but fails to capture interference at high shadowing.
- Gamma MLE provides a good model for LOS interference power, but fails to model NLOS interference.
- Mixture MLE NLOS interference power model offers the best and most accurate fit.
- Future work:
  - ➢ Functional fitting as a simple way of modeling the mmWave interference directly.
  - ➢ Study models fitness under mmWave parametric channel model.