Assume that the Alice-Eve distance $d_{\mathrm{H_e}}$ obeys a uniform distribution on $[d_1, d_2]$ and the IRS-Eve distance $d_{\mathrm{G_e}}$ obeys a uniform distribution on $[d_3, d_4]$. Then we have

$$\mathbb{E}\left[\beta_d\right] = \frac{\ln d_2 - \ln d_1}{d_2 - d_1}$$

$$\mathbb{E}\left[\beta_r\right] = \frac{\ln d_4 - \ln d_3}{d_4 - d_3}$$

$$\mathbb{E}\left[\beta_d^2\right] = \frac{1}{d_1 d_2} = \alpha_1$$

$$\mathbb{E}\left[\beta_r^2\right] = \frac{1}{d_3 d_4} = \alpha_2$$

$$\mathbb{E}\left[\beta_d^4\right] = \frac{1}{3\left(d_2 - d_1\right)} \cdot \left(\frac{1}{d_1^3} - \frac{1}{d_2^3}\right) = \gamma_1$$

$$\mathbb{E}\left[\beta_r^4\right] = \frac{1}{3\left(d_4 - d_3\right)} \cdot \left(\frac{1}{d_3^3} - \frac{1}{d_4^3}\right) = \gamma_2$$

The auxiliary random variable X is given by

$$X = \left\| \left(\mathbf{H}_e + \mathbf{G}_e \boldsymbol{\Theta} \mathbf{H}\right) \mathbf{b} \right\|^2$$
$$= \left\| \beta_d \mathbf{a} + \beta_r \mathbf{C} \boldsymbol{\Theta} \mathbf{H} \mathbf{b} \right\|^2$$
$$= \left\| \beta_d \mathbf{a} + \beta_r \mathbf{C} \mathbf{u} \right\|^2$$

The mean of X is expressed as

$$\mathbb{E}[X] = \mathbb{E}\left[\left|\beta_d \mathbf{a}\right|^2\right] + \mathbb{E}\left[\left|\beta_r \mathbf{C} \mathbf{u}\right|^2\right]$$
$$= \mathbb{E}\left[\beta_d^2\right] \cdot \mathbb{E}\left[\left|\mathbf{a}\right|^2\right] + \mathbb{E}\left[\beta_r^2\right] \cdot \mathbb{E}\left[\left|\mathbf{u}\right|^2\right]$$
$$= \left(\alpha_1 + \alpha_2 \left|\mathbf{u}\right|^2\right) N_e$$

The variance of X is given by

$$\mathrm{Var}(X) = \left(\gamma_1 + \left|\mathbf{u}\right|^4 \gamma_2 - \alpha_1^2 - \left|\mathbf{u}\right|^4 \alpha_2^2\right) N_e^2 + \left(\gamma_1 + \left|\mathbf{u}\right|^4 \gamma_2 + 2\alpha_1 \alpha_2 \left|\mathbf{u}\right|^2\right) N_e$$

Hence, the shape and scale of the Gamma distribution can be given by

$$k = \frac{\left|\mathbb{E}[X]\right|^2}{\mathrm{Var}(X)} = \frac{\left(\alpha_1^2 + \left|\mathbf{u}\right|^4 \alpha_2^2 + 2\alpha_1 \alpha_2 \left|\mathbf{u}\right|^2\right) N_e^2}{\left(\gamma_1 + \left|\mathbf{u}\right|^4 \gamma_2 - \alpha_1^2 - \left|\mathbf{u}\right|^4 \alpha_2^2\right) N_e^2 + \left(\gamma_1 + \left|\mathbf{u}\right|^4 \gamma_2 + 2\alpha_1 \alpha_2 \left|\mathbf{u}\right|^2\right) N_e}$$

$$w = \frac{\mathrm{Var}(X)}{\mathbb{E}[X]} = \frac{\left(\gamma_1 + \left|\mathbf{u}\right|^4 \gamma_2 - \alpha_1^2 - \left|\mathbf{u}\right|^4 \alpha_2^2\right) N_e^2 + \left(\gamma_1 + \left|\mathbf{u}\right|^4 \gamma_2 + 2\alpha_1 \alpha_2 \left|\mathbf{u}\right|^2\right) N_e}{\left(\alpha_1 + \alpha_2 \left|\mathbf{u}\right|^2\right) N_e}$$