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

$$\begin{aligned}
\mathbb{E}\left[\beta_d\right] &= \frac{\ln d_2 - \ln d_1}{d_2 - d_1} \\
\mathbb{E}\left[\beta_r\right] &= \frac{\ln d_4 - \ln d_3}{d_4 - d_3} \\
\mathbb{E}\left[\beta_d^2\right] &= \frac{1}{d_1 d_2} = \alpha_1 \\
\mathbb{E}\left[\beta_r^2\right] &= \frac{1}{d_3 d_4} = \alpha_2 \\
\mathbb{E}\left[\beta_d^4\right] &= \frac{1}{3\left(d_2 - d_1\right)} \cdot \left(\frac{1}{d_1^3} - \frac{1}{d_2^3}\right) = \gamma_1 \\
\mathbb{E}\left[\beta_r^4\right] &= \frac{1}{3\left(d_4 - d_3\right)} \cdot \left(\frac{1}{d_3^3} - \frac{1}{d_4^3}\right) = \gamma_2
\end{aligned}$$

The auxiliary random variable X is given by

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

The mean of X is expressed as

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

The variance of X is given by

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

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

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

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

When $d_{\mathrm{H_e}}$ and $d_{\mathrm{G_e}}$ are fixed, then β_d as well as β_r can be determined, the k and w can be simplified as

$$\begin{aligned}
k &= \frac{|\mathbb{E}[X]|^2}{\mathrm{Var}[X]} = N_e, \\
w &= \frac{\mathrm{Var}[X]}{\mathbb{E}[X]} = \beta_d^2 + \beta_r^2 \|\boldsymbol{\Theta} \mathbf{H} \mathbf{b}\|^2.
\end{aligned}$$