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Coverage performance of the multilayer UAV-terrestrial HetNet with CoMP transmission scheme

Key words: Unmanned aerial vehicle; Poisson point process; Coordinated multipoint (CoMP); Statistics of interference; Coverage performance

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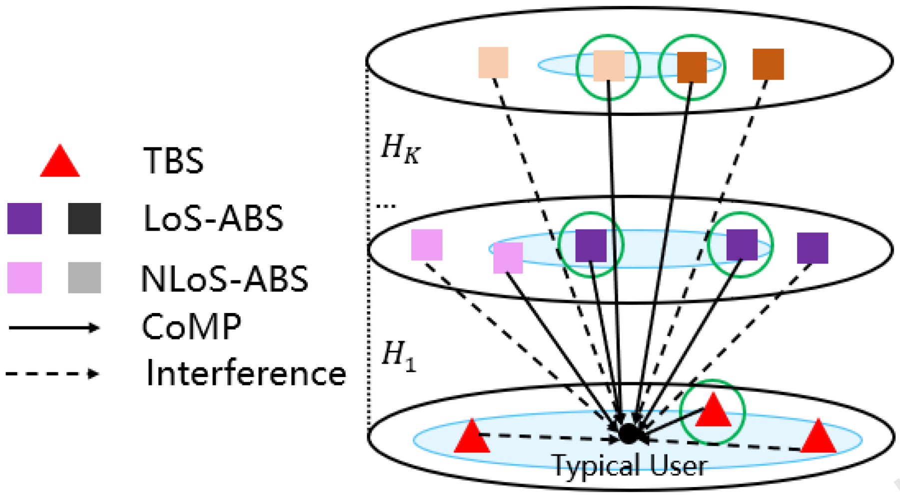
Motivation

- Owing to the flexibility and high mobility of unmanned aerial vehicles (UAVs), the multilayer drone-cell heterogeneous network (HetNet) can serve diversified communication demands and support broad connectivity, which plays a vital role in future networks.
- The management of interference is one major challenge to be addressed in multilayer drone-cell HetNet, where the coordinated multipoint (CoMP) technology is regarded as an effective technique to mitigate the interference.
- The analysis of a CoMP-enabled drone-cell network is important, since it helps understand the impact of key system parameters and shed light on network design.

System model



System model

- System model
  - K layers of UAVs: the location of UAVs on each layer is modeled as an independent homogeneous Poisson point process (HPPP)
  - The location of terrestrial base stations (TBSs) is modeled as an independent HPPP
  - A2G channel model: probabilistic transmission model

- CoMP transmission scheme
  - Step 1: select the candidate BSs for CoMP transmission
    - Condition: The average received signal strength is larger than the threshold

$$\mathcal{B}_{k,\iota} \triangleq \left\{ y_{k,j,\iota} \mid \|y_{k,j,\iota}\| \le D_{k,\iota} \triangleq \left(\frac{\Theta_{k,\iota}}{P_{\mathrm{t},k} K_{\mathrm{r}} \eta_\iota} \right)^{-\frac{1}{\alpha_\iota}} \right\}$$

- Step 2: select the BSs among candidate BSs to perform coordinated transmission
  - Condition: Instantaneous received signal strength is larger

$$\mathcal{B}_{\mathrm{a},k,\iota} \triangleq \left\{ y_{k,j,\iota} \in \mathcal{B}_{k,\iota} \mid \|y_{k,j,\iota}\| \le W_{k,\iota}(g_{k,j,\iota}) \triangleq \left(\frac{\tilde{\Theta}_{k,\iota}}{P_{\mathrm{t},k} K_{\mathrm{r}} \eta_\iota g_{k,j,\iota}} \right)^{-\frac{1}{\alpha_\iota}} \right\},$$

Statistic of aggregate interference

☐ Aggregate interference

$$I_{\text{agg}} = \sum_{y_{0,j,\text{T}} \in \overline{\mathcal{B}}_{\text{a},0,\text{T}} \cup \overline{\mathcal{B}}_{0,\text{T}}} P_{\text{t},0} K_{\text{r}} \eta_{\text{T}} g_{0,j,\text{T}} \|y_{0,j,\text{T}}\|^{-\alpha_{\text{T}}} + \sum_{k=1}^{K} \sum_{\iota \in \{\text{L},\text{N}\}} \sum_{y_{k,j,\iota} \in \overline{\mathcal{B}}_{\text{a},k,\iota} \cup \overline{\mathcal{B}}_{k,\iota}} P_{\text{t},k} K_{\text{r}} \eta_{\iota} g_{k,j,\iota} \|y_{k,j,\iota}\|^{-\alpha_{\iota}}$$

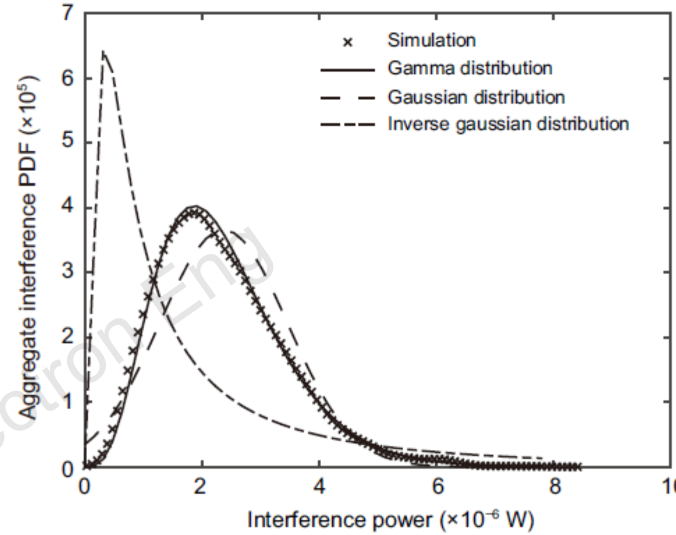


Fig. 1 Comparison of the probability density function (PDF) of several distributions and the result of simulation of interference

☐ n^{th} cumulant of aggregate interference

$$\text{Cum}_{I_{\text{agg}}}(n) = \frac{\text{d}^n}{\text{d}s^n} \Bigg(-E_{g_{0,\text{T}}} \left[\int_{\min\{D_{0,\text{T}}, W_{0,\text{T}}(g_{0,\text{T}})\}}^{D_{0,\text{T}}} \left(1 - \exp\left(sP_{\text{t},0} K_{\text{r}} \eta_{\text{T}} g_{0,\text{T}} z^{-\alpha_{\text{T}}}\right)\right) 2\pi\lambda_{\text{T}} z \text{d}z \right]$$

$$- \int_{D_{0,\text{T}}}^{\infty} \left(1 - \mathcal{F}_{0,\text{T}}\left(sP_{\text{t},0} K_{\text{r}} \eta_{\text{T}} z^{-\alpha_{\text{T}}}\right)\right) 2\pi\lambda_{\text{T}} z \text{d}z - \sum_{k=1}^{K} \sum_{\iota \in \{\text{L},\text{N}\}} \Bigg(E_{g_{k,\iota}} \Bigg[\int_{\min\left\{\sqrt{D_{k,\iota}^2 - H_k^2}, \sqrt{W_{k,\iota}^2(g_{k,\iota}) - H_k^2}\right\}}^{\sqrt{D_{k,\iota}^2 - H_k^2}} \Bigg(1$$

$$- \exp\left(\frac{sP_{\text{t},k} K_{\text{r}} \eta_{\iota} g_{k,\iota}}{\left(\sqrt{z^2 + H_k^2}\right)^{\alpha_{\iota}}} \right) \Bigg) 2\pi\lambda_{\text{A},k} p_{\iota}(z, H_k) z \text{d}z \Bigg]$$

$$+ \int_{\sqrt{D_{k,\iota}^2 - H_k^2}}^{\infty} \left(1 - \mathcal{F}_{k,\iota}\left(sP_{\text{t},k} K_{\text{r}} \eta_{\iota} (z^2 + H_k^2)^{-\frac{\alpha_{\text{L}}}{2}}\right)\right) 2\pi\lambda_{\text{A},k} p_{\iota}(z, H_k) z \text{d}z \Bigg) \Bigg) \Bigg|_{s=0}.$$

$$\mathcal{F}_{k,\iota}(x) \triangleq \left(1 - \frac{x}{m_{\iota}}\right)^{-m_{\iota}}$$

Gamma distribution is a good approximation for the distribution of the aggregate interference of the multilayer UAV-terrestrial HetNet with CoMP.

Coverage probability analysis

- MGF of the received signal from ComP BSs on the k^{th} layer with link state ι

$$\mathcal{M}_{S_{k,\iota}}(s)=\begin{cases}\exp\Bigg(-\pi\lambda_0 E_{g_{0,T}}\Big[\max\left\{D_{0,T}^2, W_{0,T}(g_{0,T})^2\right\} \\ \times\left(1-\exp\left(sP_{t,0}K_r\eta_T g_{0,T}\min\left\{D_{0,T},W_{0,T}(g_{0,T})\right\}^{-\alpha}\right)\right) \\ +\left(-sP_{t,0}K_r\eta_T g_{0,T} g_{0,T}\right)^{\frac{2}{\alpha_T}} \\ \times\gamma\left(1-\frac{2}{\alpha_T},-sP_{t,0}K_r\eta_T g_{0,T}\min\left\{D_{0,T},W_{0,T}(g_{0,T})\right\}^{-\alpha}\right)\Big]\Bigg), & k=0,\iota=T; \\ \exp\Bigg(-E_{g_{k,\iota}}\Big[\int_0^{\min\left\{\sqrt{D_{k,\iota}^2-H_k^2},\sqrt{W_{k,\iota}(g_{k,\iota})^2-H_k^2}\right\}} 2\pi\lambda_{A,\iota}p_\iota(z,H_k)\,z \\ \times\left(1-\exp\left(sP_{t,k}K_r\eta_\iota g_{k,\iota}\left(z^2+H_k^2\right)^{-\alpha_\iota}\right)\right)\mathrm{d}z\Big]\Bigg), & k=1,\ldots,K,\iota=L,N.\end{cases}$$

- The approximate expression for the coverage probability of a typical user

$$P_{\text{cov}}\approx 1-\sum_{n=0}^{\lfloor\alpha\rfloor-1}\frac{(\beta\tau)^{-n}}{n!}\frac{\partial^n}{\partial s^n}\left[\mathcal{M}_{S_{0,N}}(s)\prod_{k=1}^{K}\prod_{\iota\in\{L,N\}}\mathcal{M}_{S_{k,\iota}}(s)\right]_{s=-\frac{1}{\beta\tau}}$$
$$-(\alpha-\lfloor\alpha\rfloor)\frac{(\beta\tau)^{-\lceil\alpha\rceil+1}}{(\lceil\alpha\rceil-1)!}\frac{\partial^{\lceil\alpha\rceil-1}}{\partial s^{\lceil\alpha\rceil-1}}\left[\mathcal{M}_{S_{0,N}}(s)\prod_{k=1}^{K}\prod_{\iota\in\{L,N\}}\mathcal{M}_{S_{k,\iota}}(s)\right]_{s=-\frac{1}{\beta\tau}}.$$

CoMP performance comparison

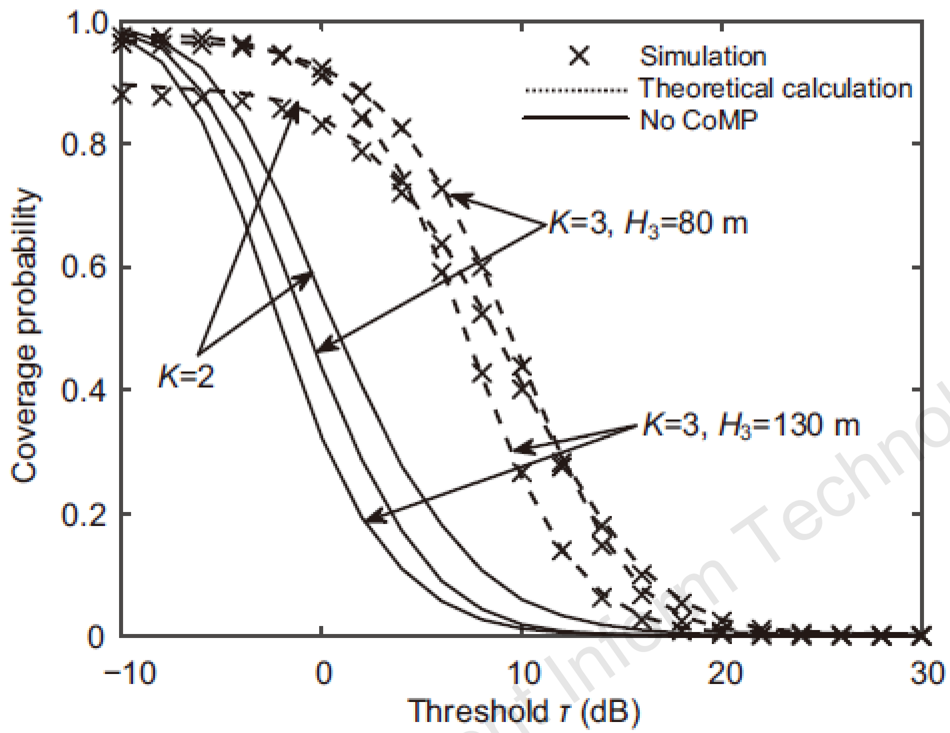


Fig. 3 Coverage probability v.s SIR threshold τ when $K = 2$ and $K = 3$ ($H_1 = 50$ m, $H_2 = 100$ m)

- The simulation results fit the analytical results closely.
- The CoMP scheme achieves an obvious performance gain compared to the no-CoMP scenario.
- CoMP effectively reduces co-channel interference, which is beneficial for improving the coverage performance in the case of dense deployment of BSs.

Influence of ABS height

- The height of the higher-altitude ABS influences mainly the coverage performance.

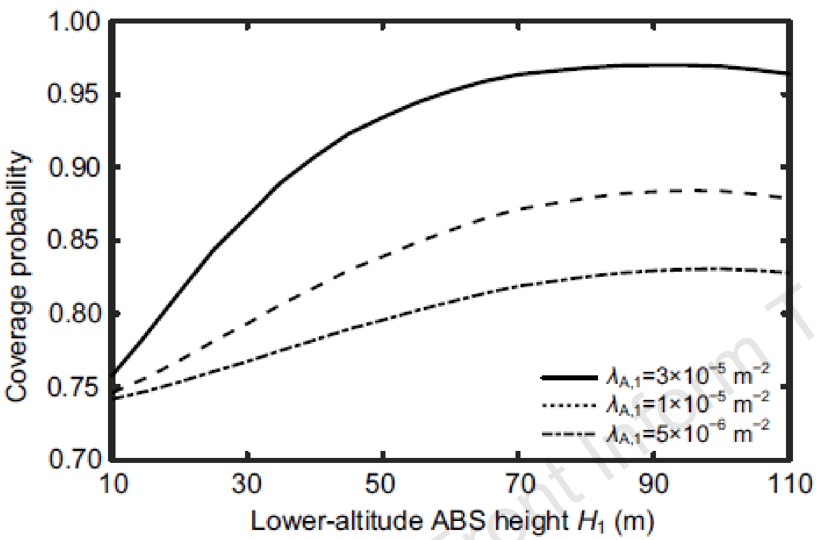


Fig. 4 Coverage probability under different lower-altitude ABS densities v.s lower-altitude ABS height H_1 ($H_2 = 110$ m, $\lambda_{A,2} = 10^{-5}$ m^{-2})

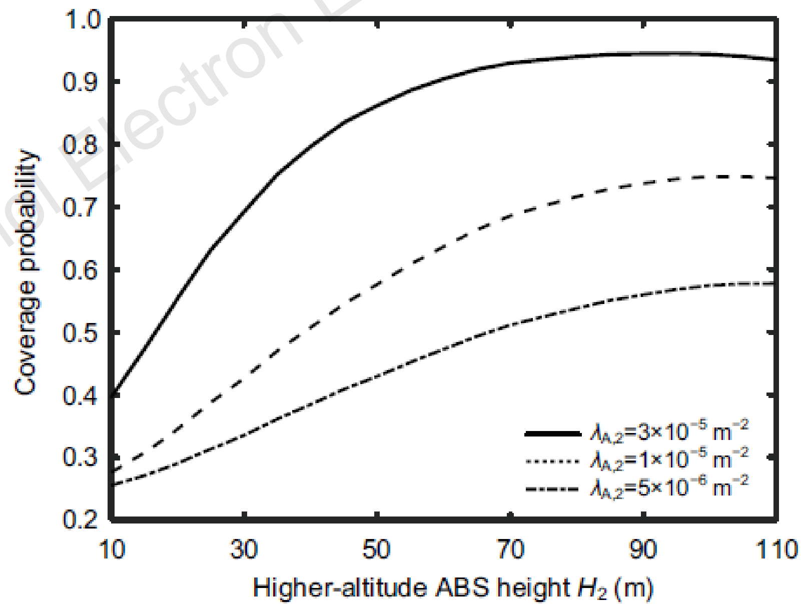


Fig. 5 Coverage probability under different higher-altitude ABS densities v.s higher-altitude ABS height H_2 ($H_1 = 10$ m, $\lambda_{A,1} = 10^{-5}$ m^{-2})

Influence of BS density

- The density of higher-altitude ABSs is a more important factor affecting the coverage probability.
- When the CoMP is used, a larger BS density is beneficial to the improvement of network coverage performance.

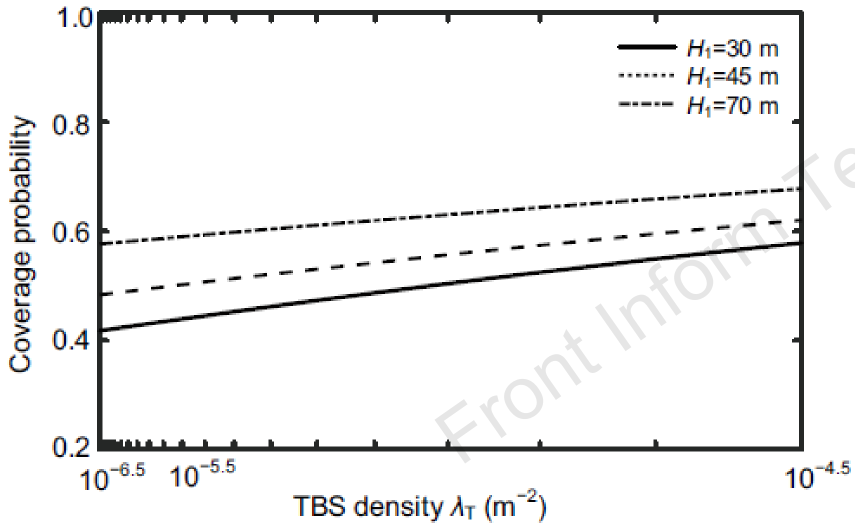


Fig. 6 Coverage probability v.s the density of the TBSs λ_T at different heights ($\lambda_{A,1} = \lambda_{A,2} = 10^{-5}$ m^{-2}, $H_2 = 50$ m)

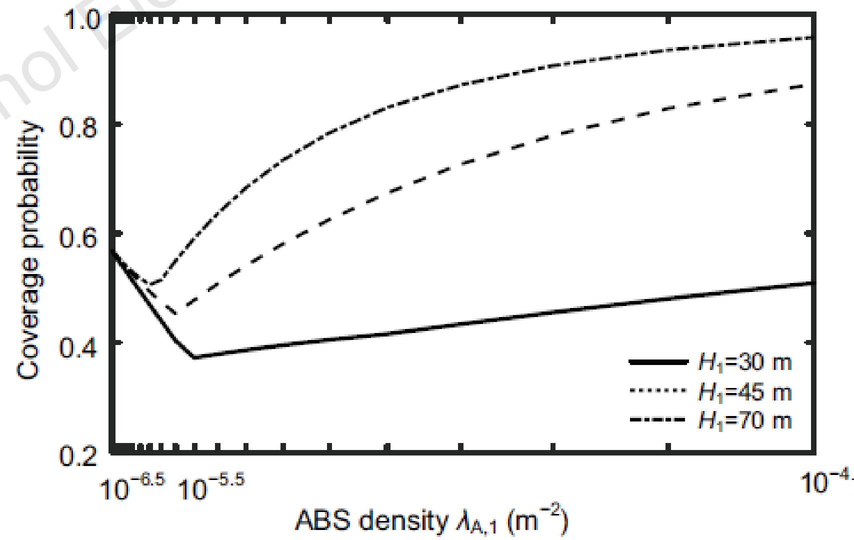


Fig. 7 Coverage probability at different heights v.s the density of ABSs $\lambda_{A,1}$ ($\lambda_T = \lambda_{A,2} = 10^{-5}$ m^{-2}, $H_2 = 50$ m)

Conclusions

- Using stochastic geometry, the mathematical framework to characterize the aggregate interference and evaluate the coverage performance of the considered HetNet has been developed.
- The CoMP scheme can reduce the interference in the considered 3D HetNet under dense environments. A larger BS density is beneficial to the improvement of network coverage performance.
- The system parameters of the higher-altitude ABS influence mainly the coverage performance.

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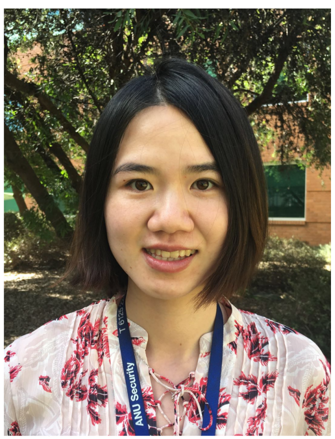

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