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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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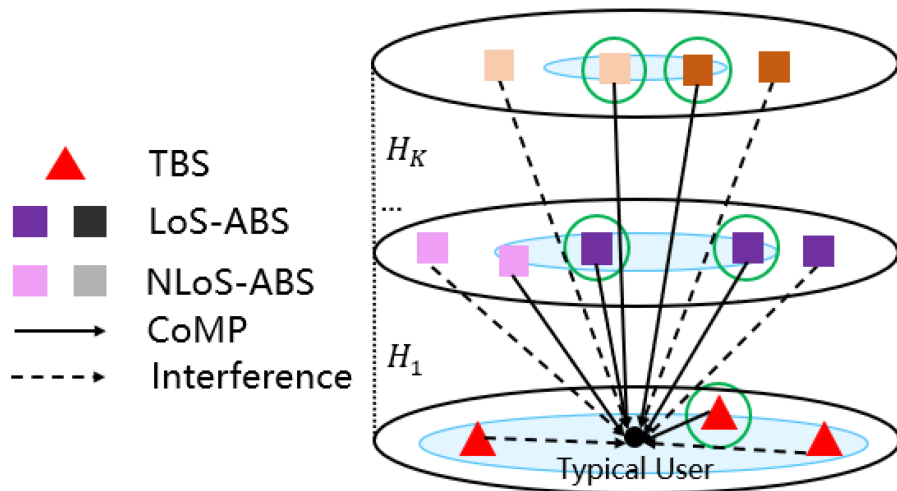
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Motivation

- ❑ 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

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

- Step 2: select the BSs among candidate BSs to perform coordinated transmission

- Condition: Instantaneous received signal strength is larger

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

Statistic of aggregate interference

Aggregate interference

$$I_{\text{agg}} = \sum_{y_{0,j,T} \in \bar{B}_{a,0,T} \cup \bar{B}_{0,T}} P_{t,0} K_r \eta_T g_{0,j,T} \|y_{0,j,T}\|^{-\alpha_T}$$

$$+ \sum_{k=1}^K \sum_{\ell \in \{L,N\}} \sum_{y_{k,j,\ell} \in \bar{B}_{a,k,\ell} \cup \bar{B}_{k,\ell}} P_{t,k} K_r \eta_\ell g_{k,j,\ell} \|y_{k,j,\ell}\|^{-\alpha_\ell}$$

n^{th} cumulant of aggregate interference

$$\text{Cum}_{I_{\text{agg}}}(n) = \frac{d^n}{ds^n} \left(-E_{g_{0,T}} \left[\int_{\min\{D_{0,T}, W_{0,T}(g_{0,T})\}}^{D_{0,T}} (1 - \exp(s P_{t,0} K_r \eta_T g_{0,T} z^{-\alpha_T})) 2\pi \lambda_T z dz \right] \right.$$

$$- \int_{D_{0,T}}^{\infty} (1 - \mathcal{F}_{0,T}(s P_{t,0} K_r \eta_T z^{-\alpha_T})) 2\pi \lambda_T z dz - \sum_{k=1}^K \sum_{\ell \in \{L,N\}} \left(E_{g_{k,\ell}} \left[\int_{\min\{\sqrt{D_{k,\ell}^2 - H_k^2}, \sqrt{W_{k,\ell}^2(g_{k,\ell}) - H_k^2}\}}^{\sqrt{D_{k,\ell}^2 - H_k^2}} (1 - \exp\left(\frac{s P_{t,k} K_r \eta_\ell g_{k,\ell}}{(\sqrt{z^2 + H_k^2})^{\alpha_\ell}}\right)) 2\pi \lambda_{A,k} p_\ell(z, H_k) z dz \right] \right.$$

$$\left. \left. + \int_{\sqrt{D_{k,\ell}^2 - H_k^2}}^{\infty} (1 - \mathcal{F}_{k,\ell}(s P_{t,k} K_r \eta_\ell (z^2 + H_k^2)^{-\frac{\alpha_\ell}{2}})) 2\pi \lambda_{A,k} p_\ell(z, H_k) z dz \right) \right) \Big|_{s=0}$$

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

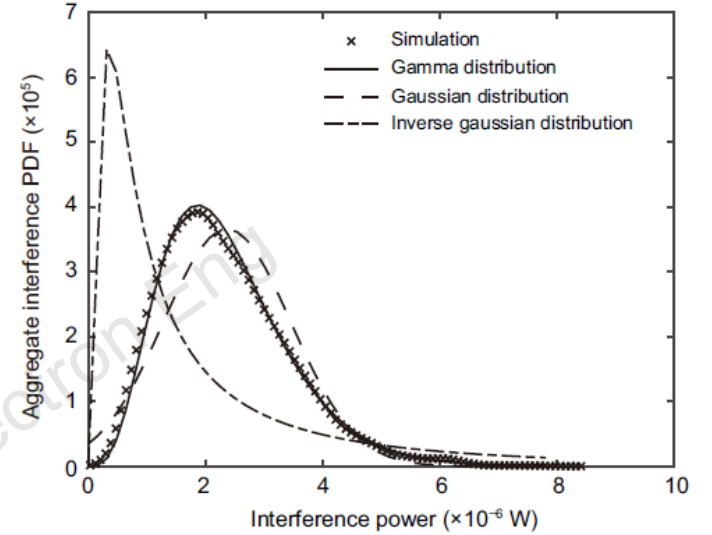


Fig. 1 Comparison of the probability density function (PDF) of several distributions and the result of simulation of interference

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

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

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

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

CoMP performance comparison

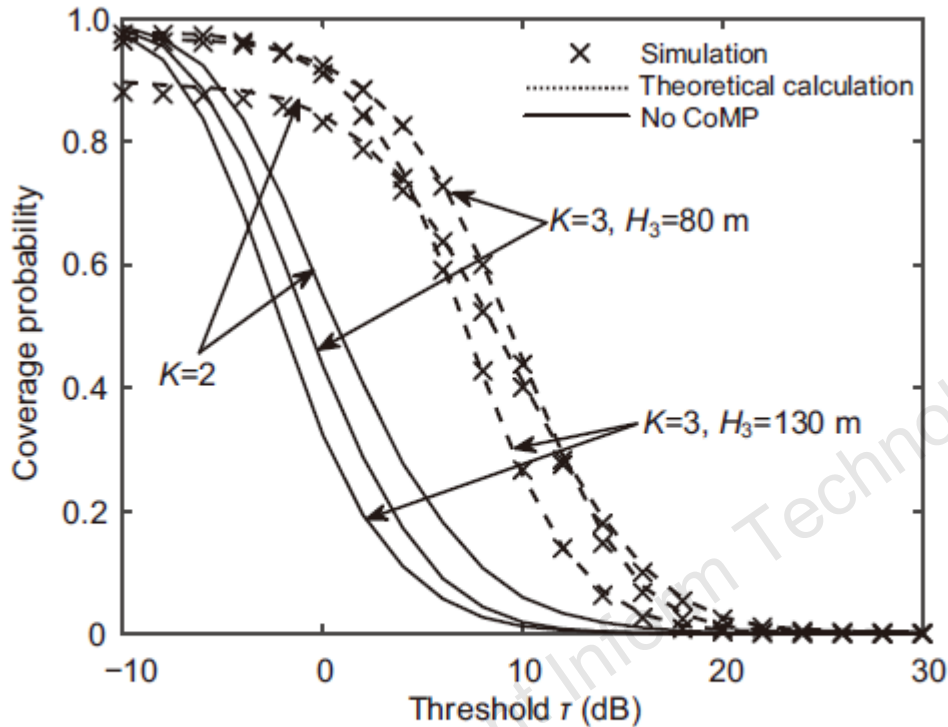


Fig. 3 Coverage probability v.s SIR threshold τ when $K = 2$ and $K = 3$ ($H_1 = 50$ m, $H_2 = 100$ m)

- ❑ 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.

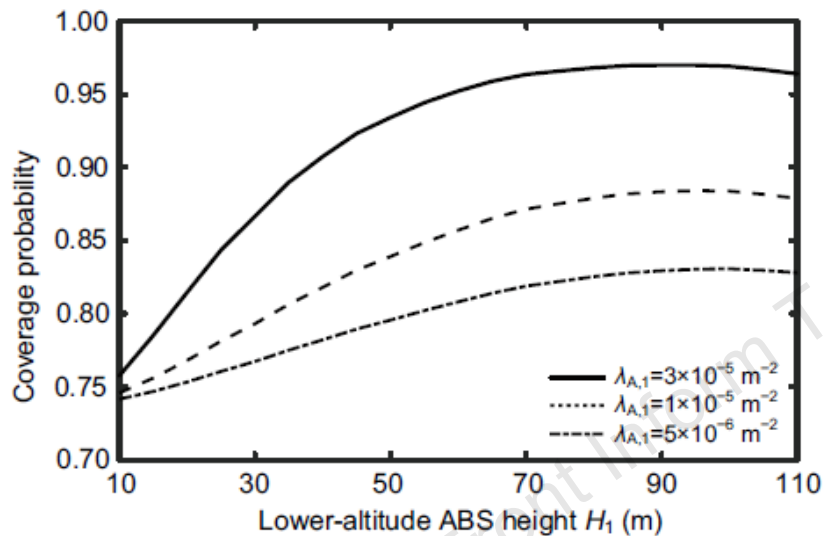


Fig. 4 Coverage probability under different lower-altitude ABS densities v.s lower-altitude ABS height H_1 ($H_2 = 110$ m, $\lambda_{A,2} = 10^{-5} \text{ m}^{-2}$)

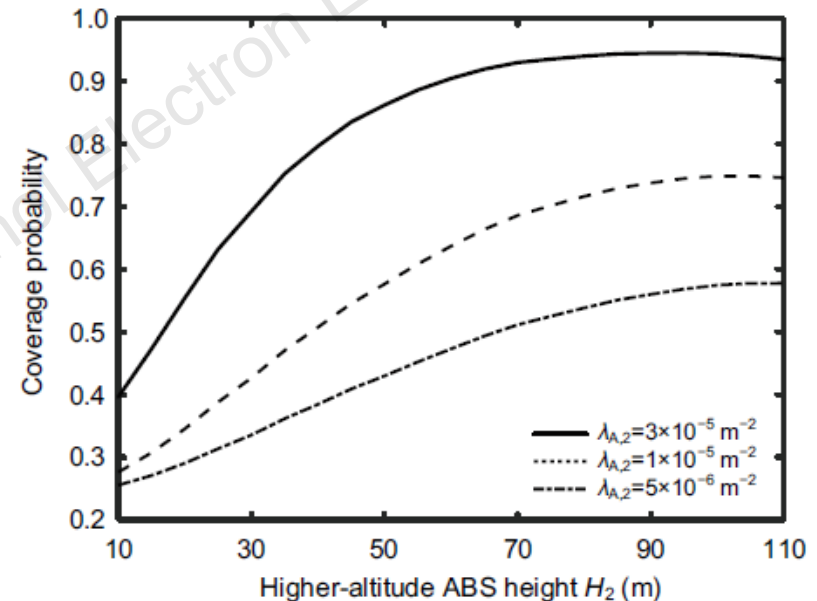


Fig. 5 Coverage probability under different higher-altitude ABS densities v.s higher-altitude ABS height H_2 ($H_1 = 10$ m, $\lambda_{A,1} = 10^{-5} \text{ m}^{-2}$)

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.

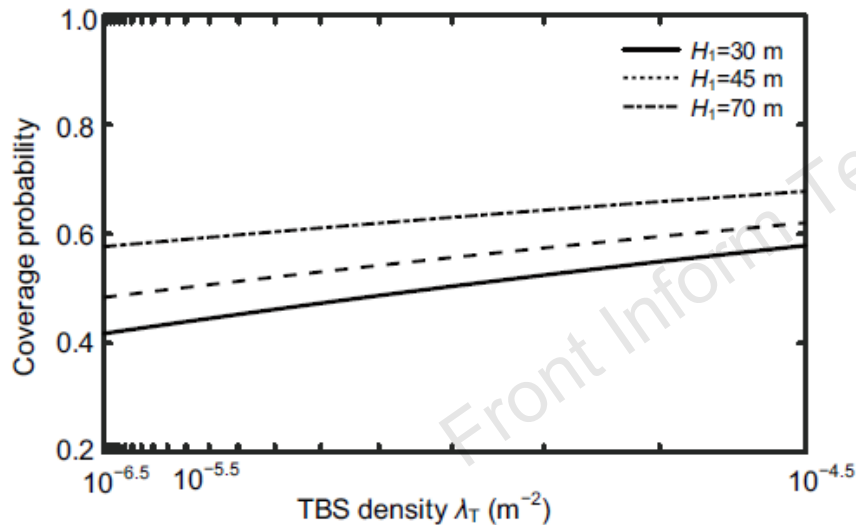


Fig. 6 Coverage probability v.s the density of the TBSs λ_T at different heights ($\lambda_{A,1} = \lambda_{A,2} = 10^{-5}$ m⁻², $H_2 = 50$ m)

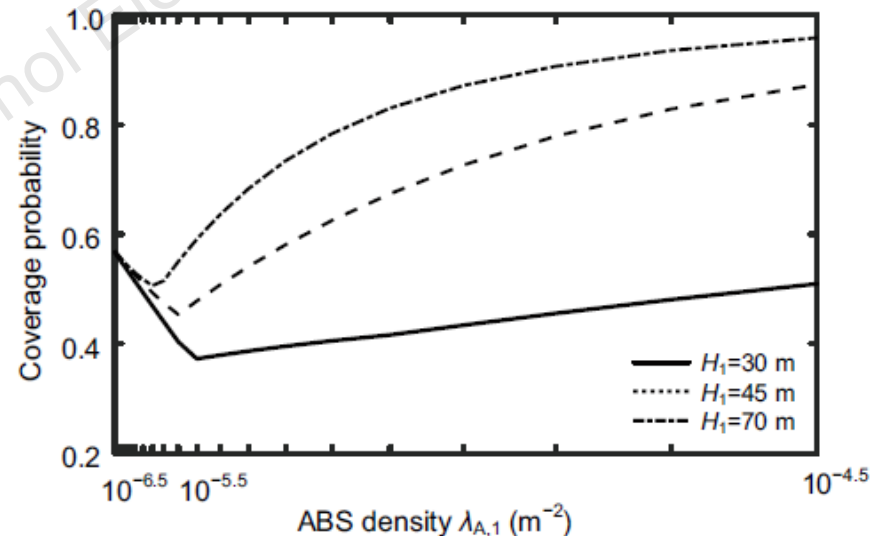


Fig. 7 Coverage probability at different heights v.s the density of ABSs $\lambda_{A,1}$ ($\lambda_T = \lambda_{A,2} = 10^{-5}$ m⁻², $H_2 = 50$ m)

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.



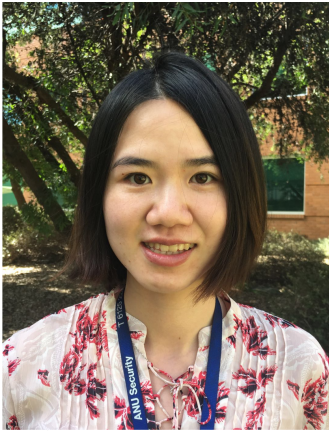
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