Base Station Antenna Tilt Angle Designed for UAV Networks

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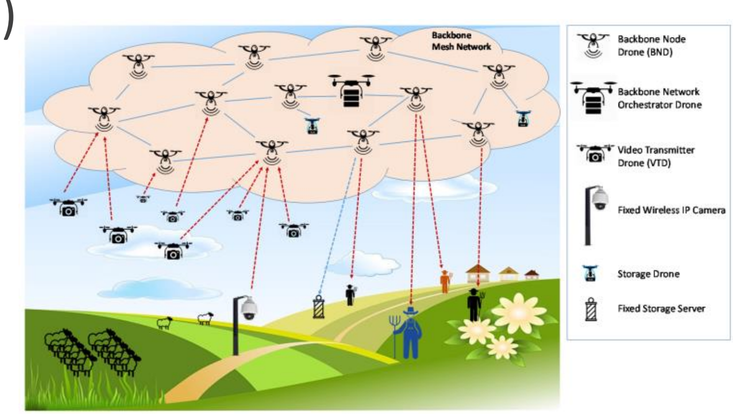
Group Meeting

Outline

- **Introduction**
  - Unmanned Aerial Vehicles Communication
  - Related Work & Object
  - Contributions
- **System Model**
  - Network Model
  - Vertical Antenna Gain
  - Base Station Association Rule
  - Channel Model
- **Problem Formulation**
- **Simulation Analysis**

Unmanned Aerial Vehicle Communication

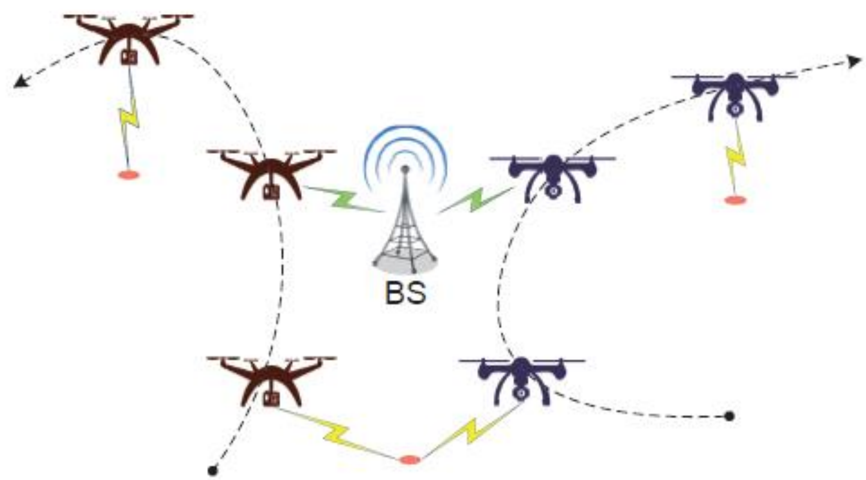
- **Advantages of unmanned aerial vehicle (UAV) communication**
  - **Line-of-sight (LoS) environment**
    - Strong received signal power
      - Better channel fading (Rician fading)
      - Smaller path loss exponent
  - **Flexible mobility**
- **Usage of UAV for communication**[Zen:16]
  - **Data collection** and remote location **sensing** in internet-of-things (IoT)
  - Diverse mission (e.g., search, rescue mission)



[Zen:16] Y. Zeng, R. Zhang, and T. J. Lim, "Wireless communications with unmanned aerial vehicles: opportunities and challenges," *IEEE Commun. Mag.*, vol. 54, no. 5, pp. 36–42, May 2016.

Unmanned Aerial Vehicle Communication

- **Requirement of UAV for communication**
  - **A fast and reliable connection** between the UAV and controller
  - A cost effective way of satisfying the requirements for reliability is by **using an already existing and accessible technology**
    - Such as the ground cellular network
    - But cellular network is set to optimize performance of ground users

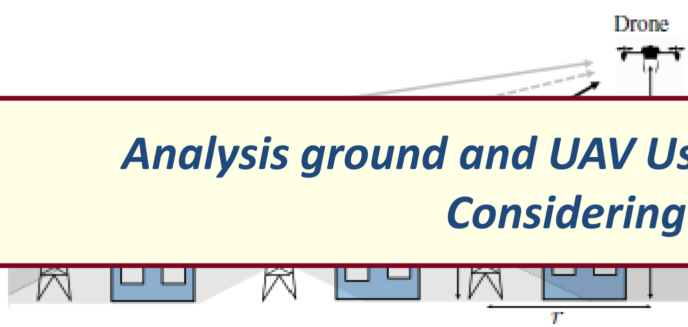


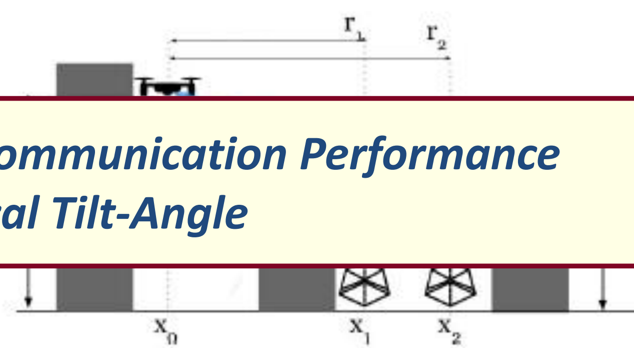
[Shu:18] S.Zhang, H.Zhang, B.Di and L.Song, "Cooperative sensing and transmission for cellular network controlled unmanned aerial vehicle", in Proc IEEE Global Communications Conference (GLOBECOM)

Related Work & Objective

- **Recent paper for UAV integrating to cellular network**
  - To serve *aerial users* **using terrestrial cellular networks** is studied
  - Especially, **vertical antenna tilt** and **beam width** is considered

- **Limitations**
  - These papers did not provide **the mathematical analysis related to tilt angle**[Aza:18]
  - **Consider** only **aerial users**[Gal:18]





Analysis ground and UAV User's Communication Performance Considering Vertical Tilt-Angle

[Aza:17]M.M.Azari and F.Rosas, "Coexistence of Terrestrial and Aerial Users in Cellular Networks", in Proc IEEE Gobecom Workshops (GC wkshps)

[Gal:18]B.Galkin,J,Kibilda, and L.DaSilva, "Backhaul For Low-Altitude UAVs in Urban Environments"" in Proc IEEE Int. Conf. Commun. (ICC), 2018

Contributions

- **Propose the network model that serves both UAV users and ground mobile users**
- **Suggest the channel model affected by the BS antenna tilt angle and the elevation angle between BS and user**
- **Analyze the tendency of the optimal tilt value according to the environmental parameter and the tendency of the optimal ratio of BS for ground users and BS for UAV users**

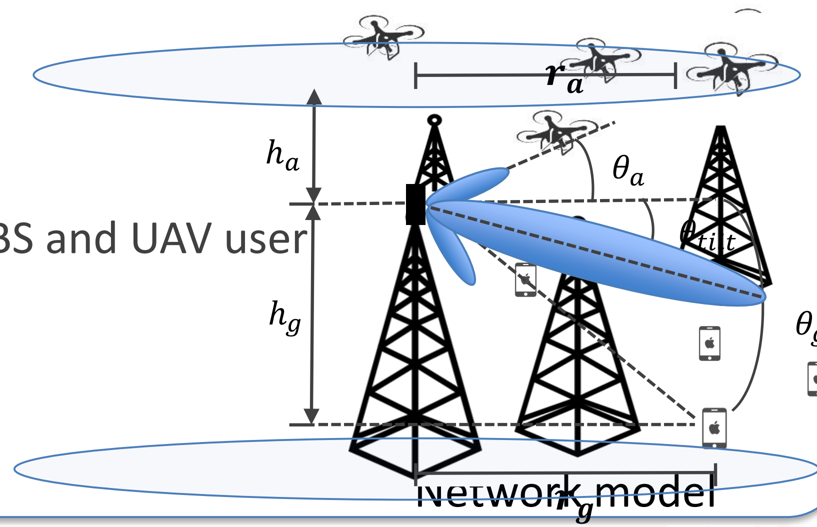
System Model

- **Network model**
  - There are **two types of user :** Ground user & UAV user
  - Users are equipped **omnidirectional receiving antenna**
  - **Ground user**
    - h_g : height of base station (BS)
    - r_g : horizontal distance between service BS and ground user
    - θ_g : elevation angle of ground user

$$\theta_g = -tan^{-1}\left(\frac{h_g}{r_g}\right)$$

  - **Aerial user**
    - h_{uav} : altitude of UAV , $h_a = \left|h_{uav} - h_g\right|$
    - r_a : horizontal distance between service BS and UAV user
    - θ_a : elevation angle of UAV user

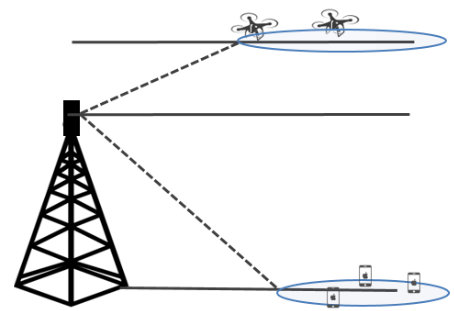
$$\theta_a = tan^{-1}\left(\frac{h_a}{r_a}\right)$$



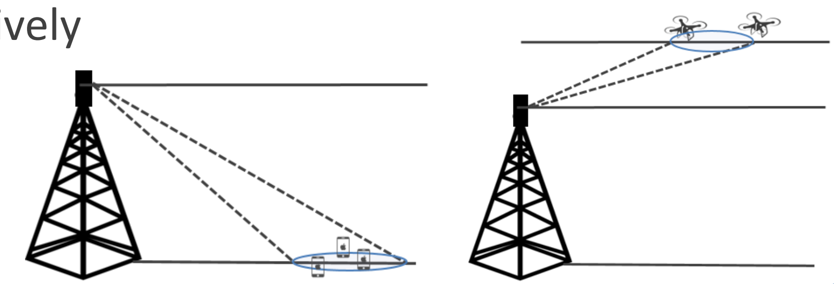
Network model

System Model

- **Network model**
  - BS distribution scenario 1
    - There is **one type of BS**
      - The BSs for ground users & UAV users
    - The ground BSs are randomly distributed according to a Poisson point process (PPP) with density λ_{BS}



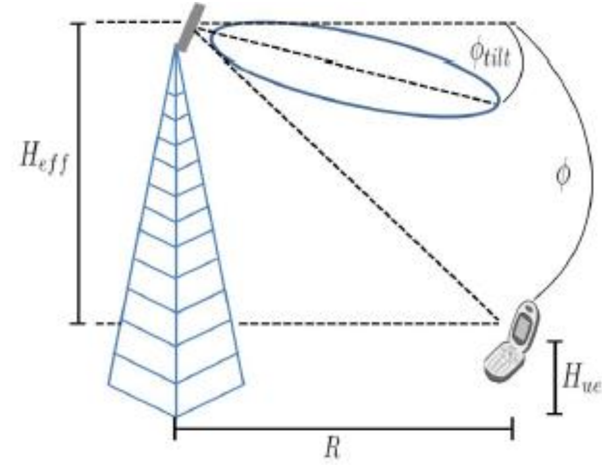
  - BS distribution scenario 2
    - There are **two types of BS** ($\lambda_{BS} = \lambda_{up} + \lambda_{down}$)
      - The down-tilted BSs for ground users
      - The up-tilted BSs for UAV users
    - The down-tilted BSs and up-tilted BSs are randomly distributed according to a PPP with density λ_{down} & λ_{up} respectively



Vertical Antenna Gain

- **Antenna radiation pattern**
  - **3GPP vertical antenna gain**[Rau:15]

$$G(R,\phi_{tilt}) = 10^{-\min\left(12\left(\frac{-\tan^{-1}\left(\frac{H_{eff}}{R}\right)+\phi_{tilt}}{\phi_{3dB}}\right)^2, A_{dB}\right)/10}.$$

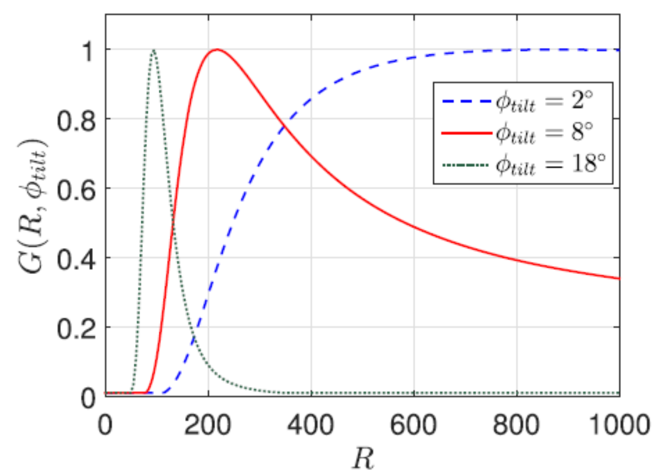


for $\phi_{tilt} < \sqrt{A_{dB}/12}\ \phi_{3dB}$

$$G(R,\phi_{tilt}) = \begin{cases} A & \text{if } R < r_{th1} \\ 10^{-1.2\left(\frac{-\tan^{-1}\left(\frac{H_{eff}}{R}\right)+\phi_{tilt}}{\phi_{3dB}}\right)^2} & \text{if } R \geq r_{th1} \end{cases}$$

for $\phi_{tilt} \geq \sqrt{A_{dB}/12}\ \phi_{3dB}$

$$G(R,\phi_{tilt}) = \begin{cases} A & \text{if } R < r_{th1} \\ 10^{-1.2\left(\frac{-\tan^{-1}\left(\frac{H_{eff}}{R}\right)+\phi_{tilt}}{\phi_{3dB}}\right)^2} & \text{if } r_{th1} \leq R < r_{th2} \\ A & \text{if } R \geq r_{th2} \end{cases}$$



[Rau:15] R.Hernandez-Aquino, S.A.R.Zaidi, D.McLernon, M.Ghogho, and A. Imran, "Tilt angle optimization in two-tier cellular networks a stochastic-geometry approach," IEEE Trans. Commun. Vol. 63. no. 12. Dec. 2015.

Vertical Antenna Gain

- **Modified vertical antenna gain**

$$G_i\left(\theta_{tilt}, r_i\right) = 10^{-min\left(12\left(\frac{-\arctan\left(\frac{h_i}{r_i}\right)+\theta_{tilt}}{\theta_{3dB}}\right)^2, A_{dB}\right)}$$

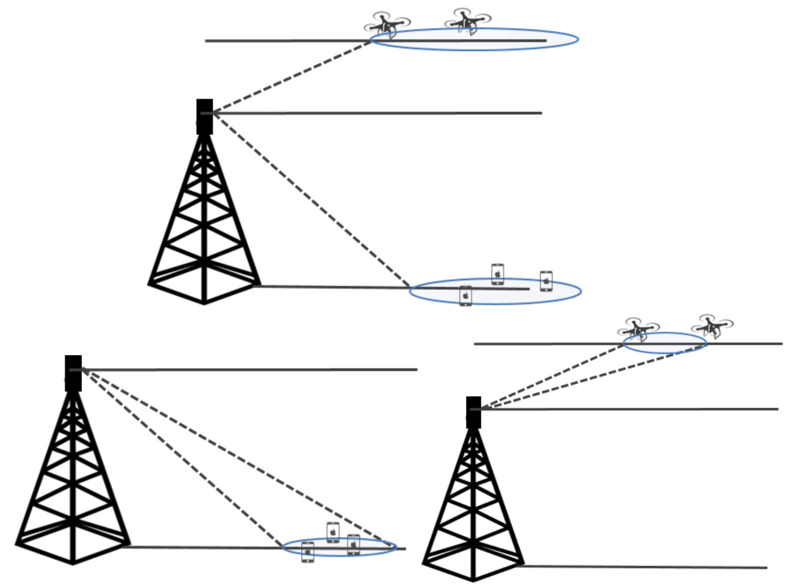
$$G_i\left(\theta_{tilt}, r_i\right) = \begin{cases} 10^{-12\left(\frac{-\arctan\left(\frac{h_i}{r_i}\right)+\theta_{tilt}}{\theta_{3dB}}\right)^2} & R_{i,L} \le r_i \le R_{i,U} \\ 0 & \text{otherise} \end{cases}$$

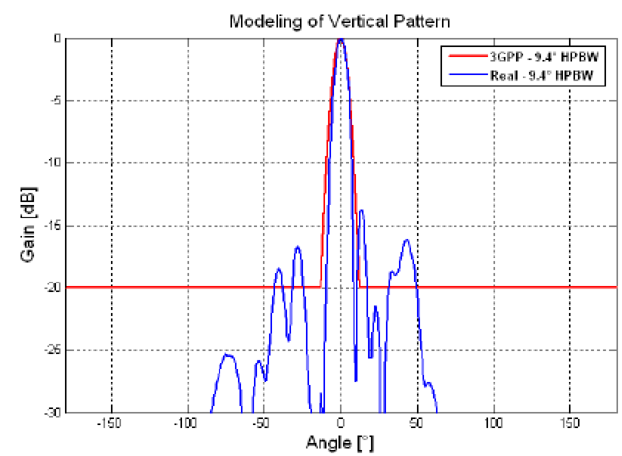
  - **Lower bound** service coverage of BS

$$R_{i,L} = \frac{h_i}{\tan((\theta_{th} + \theta_{tilt})\,\pi/180)}$$

  - **Upper bound** service coverage of BS

$$R_{i,U} = \begin{cases} \frac{h_i}{\tan((-\theta_{th} + \theta_{tilt})\,\pi/180)} & \theta_{tilt} > \theta_{th} \\ \infty & \text{otherise} \end{cases}$$

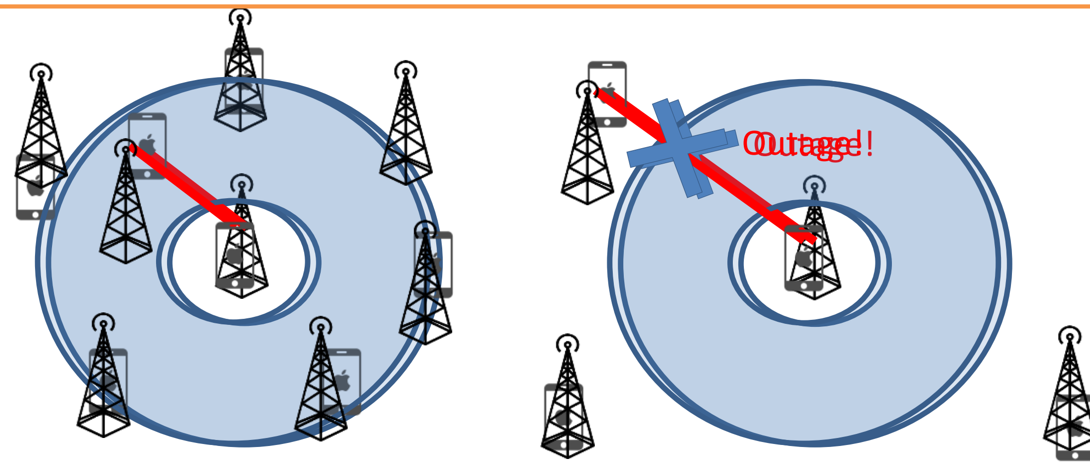




[Yil:09] H.O.N.C. Yilmaz, Seppo and H.Jyri "Comparison of remote electrical and mechanical antenna downtilt performance for 3GPP LTE" in Proc.VCT2009 Fall – 70th IEEE Vehicular Technology Conference. Sep. 2009.

BS Association Rule

- **Nearest serviceable BS association**
  - Associate with the nearest BS among the BSs that have a typical user in the coverage range
    - If the distance between user and closest BS is $R_{i,L} \le r_i \le R_{i,U}$
      - **The user receives service from the closest BS**
    - Else if $r_i \ge R_{i,U}$
      - **The communication** between the BS and the user will be **an outage**
    - The pdf of horizontal distance between user and BS
      - $\boxed{f_r(r_i) = 2\pi\lambda_t r_i exp\left(-\lambda_t \pi\left(r_i^2 - R_{i,L}^2\right)\right)\ r_i > R_{i,L}\text{ , t} \in \{BS, up, down\}}$



Channel Model

- **Channel model**
  - **Consider LoS probability**
    - Ground user
      - $P_{g,L}(r_g) = \frac{1}{1+a_1 exp\left\{-b_1\left(tan^{-1}\left(\frac{h_g}{r_g}\right)-a_1\right)\right\}}$ [Akr:14]
    - UAV user
      - $P_{a,L}(r_a) = \left(1 - \frac{\sqrt{2\pi}c}{|h_a|}\left|Q\left(\frac{h_{uav}}{c}\right) - Q\left(\frac{h_g}{c}\right)\right|\right)^{\sqrt{a_2 b_2} r_a}$ [Zhy:18]
  - **Channel fading & pathloss exponent**
    - LoS channel
      - Rician fading
      - Smaller pathloss exponent α_L(3.5)
    - NLoS channel
      - Rayleigh fading
      - Larger pathloss exponent α_N(2)

$$f_L(h) = \frac{1+K(\theta)}{\overline{H_L}} \exp\left(-K(\theta) - \frac{1+K(\theta)}{\overline{H_L}}h\right) \times I_0\left(2\sqrt{\frac{K(\theta)(1+K(\theta))}{\overline{H_L}}h}\right) = \frac{1}{2}\exp\left(-K(\theta) - \frac{h}{2}\right) I_0\left(\sqrt{2K(\theta)h}\right)$$

$$f_N(h) = \frac{1}{\overline{H_N}} \exp\left(-\frac{h}{\overline{H_N}}\right) = \exp(-h)$$

[Akr:14]A.AI-Hourani,S. Kandeepan,S.Lardner, “Optimal LAP Altitude for Maximum Coverage”, Dec 2014, IEEE WIRELESS COMM.LETTER
[Zhy:18]Z.Yang,L.Zhou,G.Zhao,S.Zhou “Blockage Modeling for Inter-layer UAVs Communications in Urban Environments”, May 2018

Problem Formulation [1/3]

- **Communication Performance**
  - **Signal to noise ratio (SNR)**

$$\boxed{SNR_i = \frac{P_t h_i l_i^{-\alpha}(r_i) G(r_i, \theta_{tilt})}{N_0}}$$

P_t : BS transmit power

h_i : the fading gains of the channel

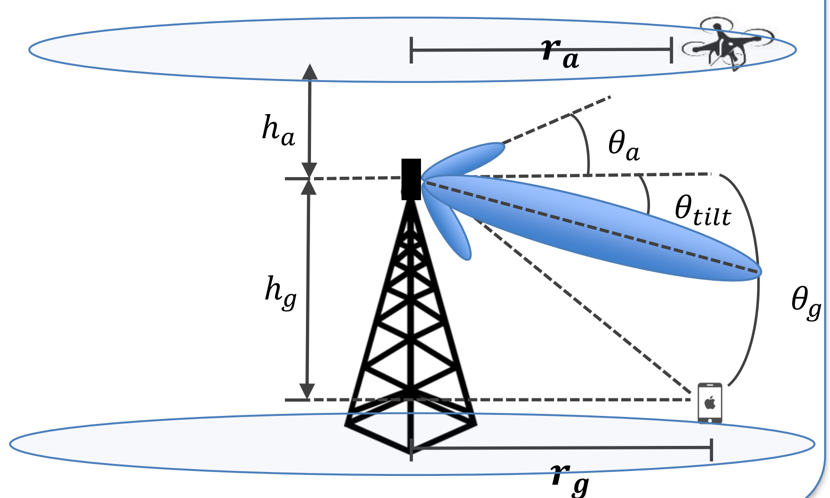
l_i : the link distance $\sqrt{r_i^2 + h_i^2}$

α : path loss exponent

$G(r_i, \theta_{tilt})$: vertical antenna gain

$$G_i(\theta_{tilt}, r_i) = 10^{-min\left(12\left(\frac{-\arctan\left(\frac{h_i}{r_i}\right)+\theta_{tilt}}{\theta_{3dB}}\right)^2, A_{dB}\right)}$$

N_0 : The noise power



Problem Formulation [2/3]

- **Communication Performance**
  - **Outage probability**

$$\mathbb{P}[SNR_i < \gamma]$$

$$= \mathbb{P}\left[\frac{P_t h_i l_i^{-\alpha}(r_i)G(r_i)}{N_0} < \gamma\right]$$

$$= \mathbb{E}_{r_i}\left[\mathbb{P}\left[h_i < \frac{\gamma l_i^{\alpha}(r_i)N_0}{P_t G(r_i)}\right] \mid r_i\right]$$

$$= \mathbb{E}_{r_i}\left[P_{i,L}\mathbb{P}\left[h_i < \frac{\gamma l_i^{\alpha_L}(r_i)N_0}{P_t G(r_i)}\right] + P_{i,N}\mathbb{P}\left[h_i < \frac{\gamma l_i^{\alpha_N}(r_i)N_0}{P_t G(r_i)}\right] \mid r_i\right]$$

$$= \boxed{\begin{aligned} &\int_{R_{i,L}}^{\infty}\left[P_{i,L}\left\{1 - Q\left(\sqrt{2K(r_i)}, \sqrt{\frac{l_i^{\alpha_L}(r_i)\gamma N_0}{P_t G(r_i)}}\right)\right\}\right] f_r(r_i)dr_i \\ &+ \int_{R_{i,L}}^{\infty}\left[P_{i,N}\left\{1 - \exp\left(-\frac{l_i^{\alpha_N}(r_i)\gamma N_0}{P_t G(r_i)}\right)\right\}\right] f_r(r_i)dr_i \end{aligned}}$$

Problem Formulation [3/3]

- **Communication Performance**
  - **Outage probability**

$$P_{g,out}(\theta_{tilt}) = \int_{R_{g,L}}^{\infty}\left[P_{g,L}\left\{1 - Q\left(\sqrt{2K(r_g)}, \sqrt{\frac{l_g{}^{\alpha_L}(r_g)\gamma N_0}{P_t G(r_g, \theta_{tilt})}}\right)\right\}\right] f_r(r_g)dr_g$$
$$+ \int_{R_{g,L}}^{\infty}\left[P_{g,L}\left\{1 - Q\left(\sqrt{2K(r_g)}, \sqrt{\frac{l_g{}^{\alpha_L}(r_g)\gamma N_0}{P_t G(r_g, \theta_{tilt})}}\right)\right\}\right] f_r(r_g)dr_g$$

$$P_{a,out}(\theta_{tilt}) = \int_{R_{a,L}}^{\infty}\left[P_{a,L}\left\{1 - Q\left(\sqrt{2K(r_a)}, \sqrt{\frac{l_g{}^{\alpha_L}(r_g)\gamma N_0}{P_t G(r_a, \theta_{tilt})}}\right)\right\}\right] f_r(r_a)dr_a$$
$$+ \int_{R_{a,L}}^{\infty}\left[P_{a,L}\left\{1 - Q\left(\sqrt{2K(r_a)}, \sqrt{\frac{l_g{}^{\alpha_L}(r_g)\gamma N_0}{P_t G\left(r_{a,\theta_{tilt}}\right)}}\right)\right\}\right] f_r(r_a)dr_a$$

  - **Network outage probability**
    - $\boxed{\boldsymbol{P_{out} = \rho P_{g,out} + (1-\rho)\, P_{a,out}}}$
    - $\boldsymbol{\rho}$ **: The ratio of ground users to total users** $(\mathbf{0} \leq \boldsymbol{\rho} \leq \mathbf{1})$

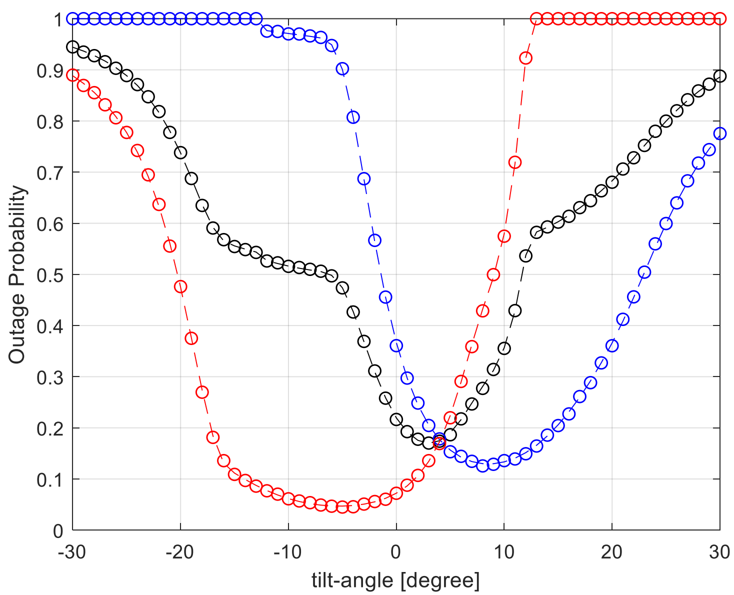
Simulation Parameter

- **Effect of total BS density**

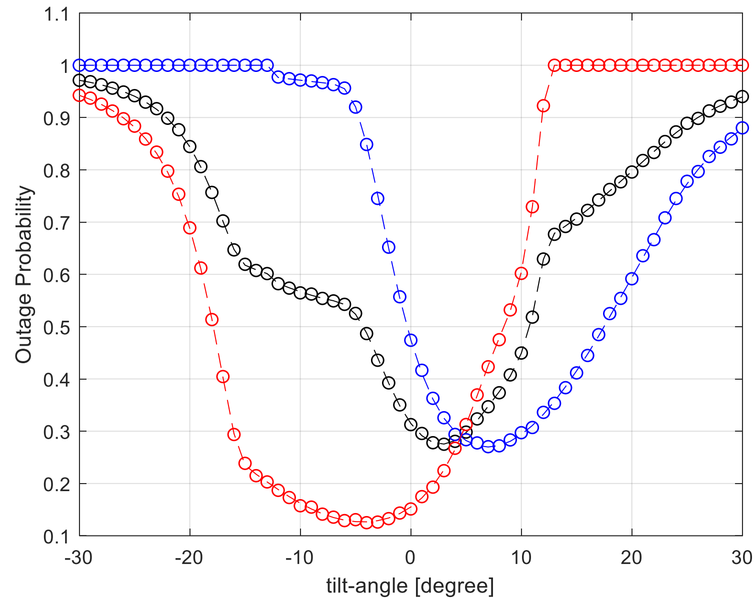
Parameter	Value	Description
P_t	10^{-11}[W]	Transmitter Power
N_0	10^{-20}[W]	Noise Power
γ	1	SNR threshold
$K(0)$	1	Rician factor
$K(\pi/_2)$	15	Rician factor
α_L	3.5	LoS Pathloss exponent
α_N	2	NLoS Pathloss exponent
h_{uav}	50 [m]	Altitude of UAV
h_g	30 [m]	Height of BS
θ_{3dB}	10 [°]	3dB beamwidth
A	0	Minimum power of side lobe

Simulation Result

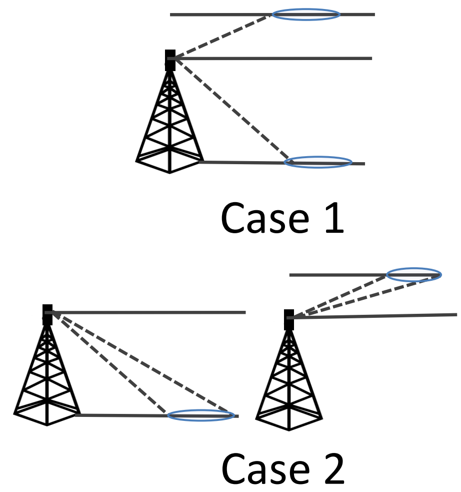
- **Effect of antenna tilt angle**



Case1



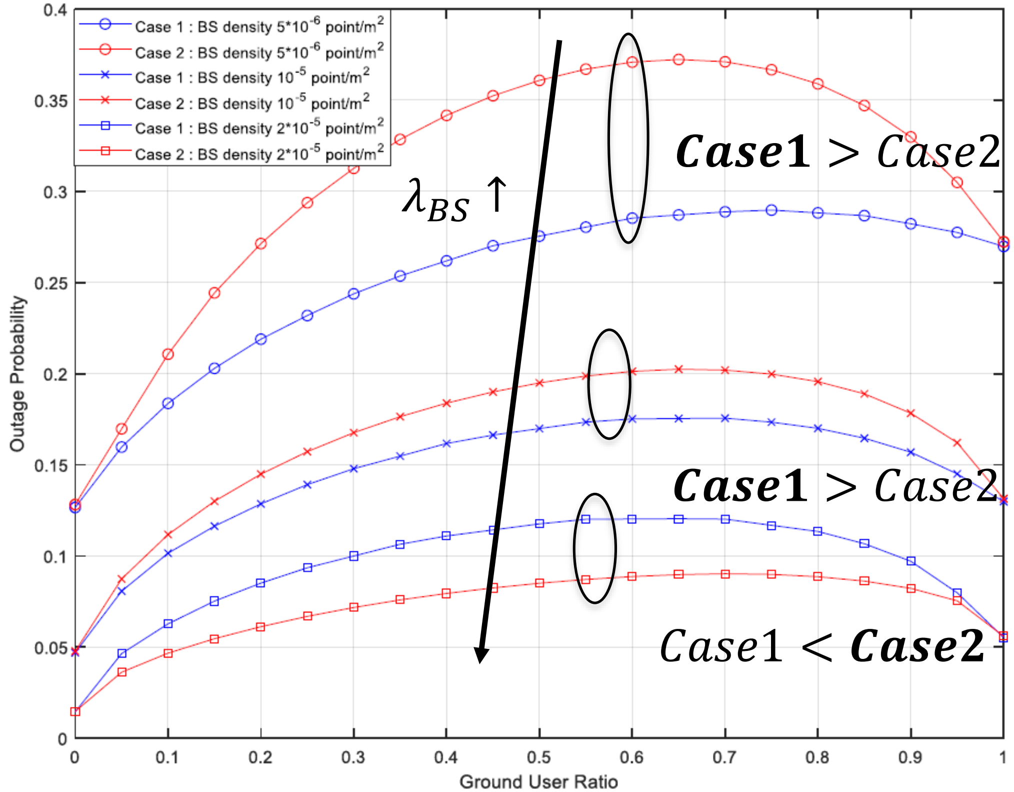
Case2

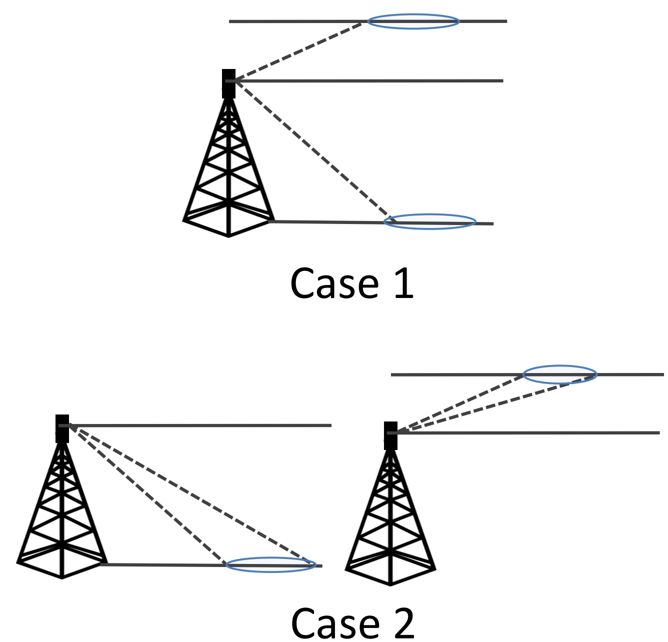


- ✓ **The results of the simulation and the numerical integration are the same**
- ✓ **The performance is determined by the difference between the elevation angle of the user and the BS an the antenna tilt angle**

Simulation Result

- **Effect of total BS density – network outage probability**

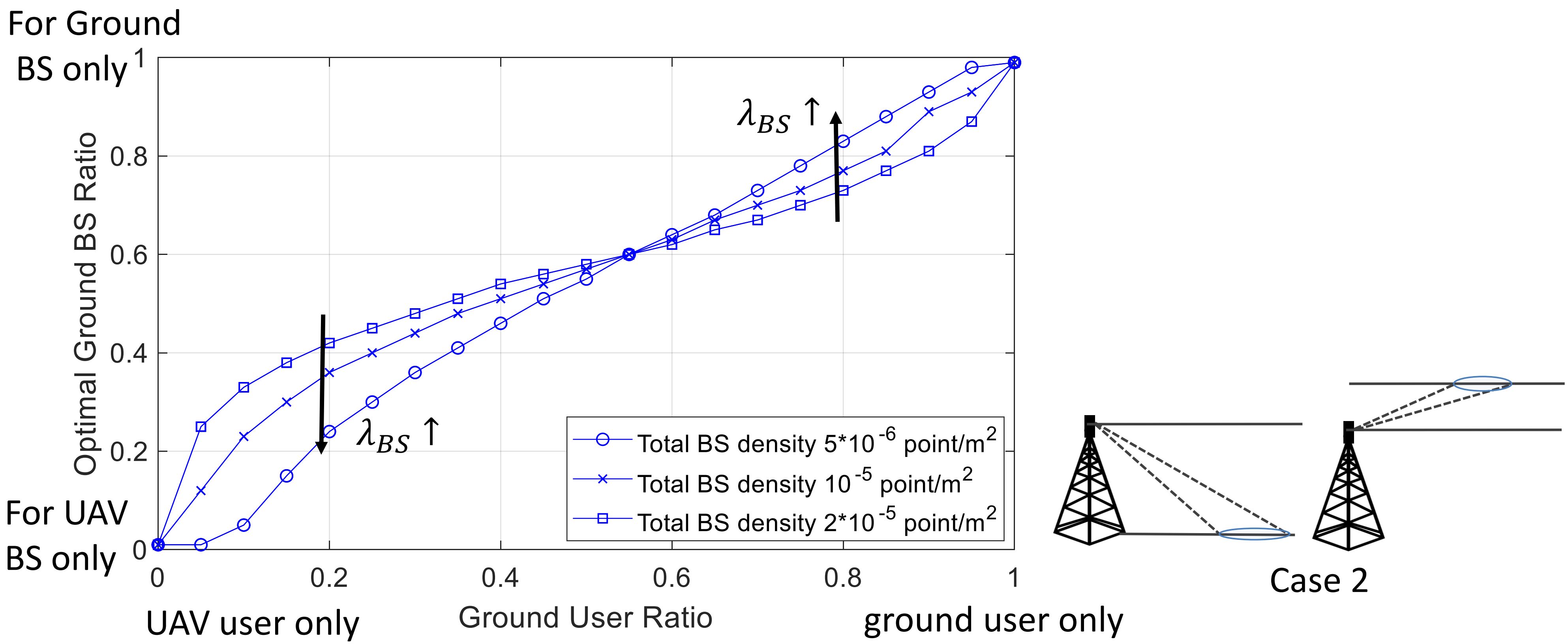




✓ **The smaller the total BS density, the better the network performance of Case 1**
-> As the total # of BS becomes smaller, # of BS that can provide services increases relatively

Simulation Result

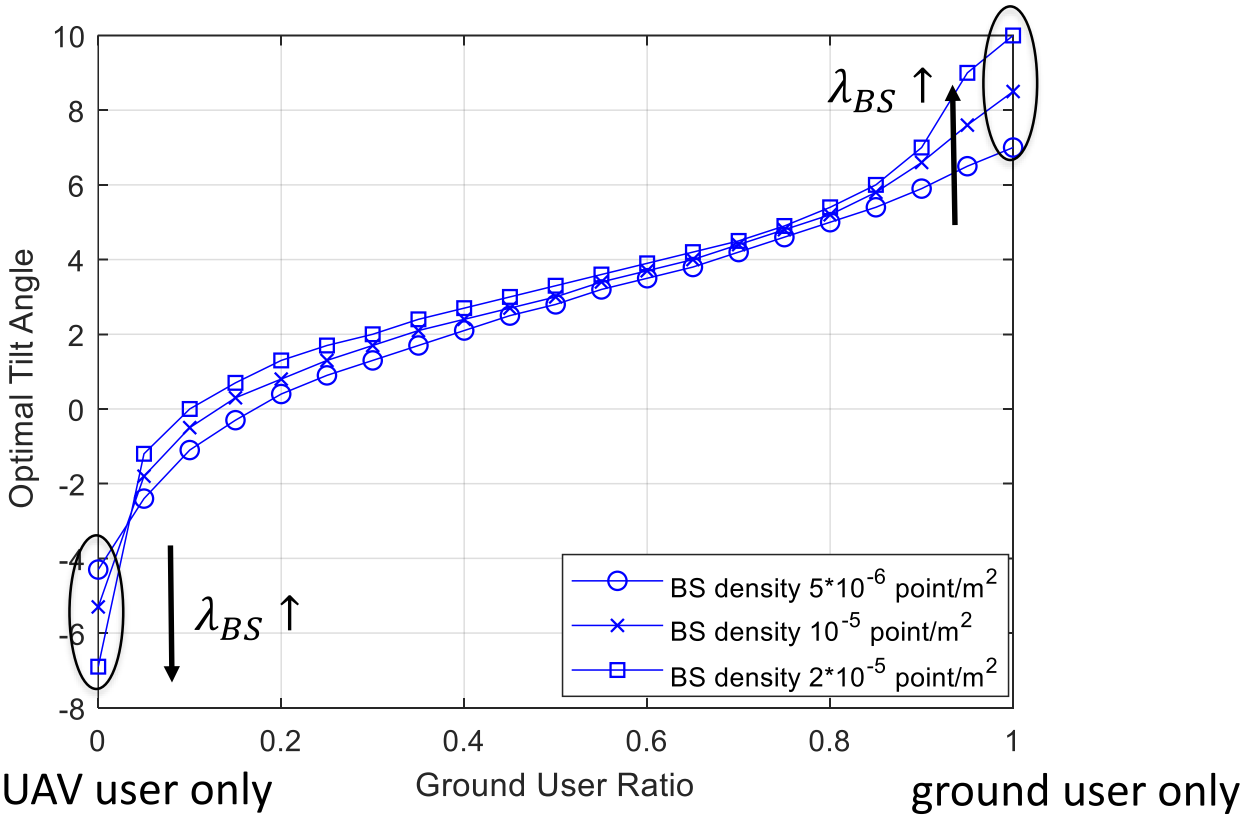
- **Effect of total BS density – optimal ground BS density (Case 2)**

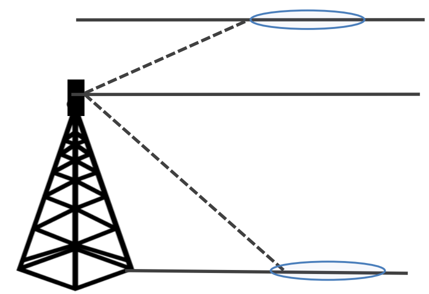


- ✓ **As the ground user ratio increases, the optimal ground BS ratio increases**
- ✓ **Based on the crosspoint, the optimal ground BS ratio trend changes**

Simulation Result

- **Effect of total BS density – optimal tilt angle (Case 1)**





Case 1

> ✓ **As the ground user ratio increases, the optimum tilt angle correspondingly increases**

Research Plan - Seongjun

- **Schedule**

Progress \ Month	6	7	8	9	10	11	12
Simulation analysis & Write a draft of paper							
Summer Vacation Study							
Survey papers & Study For new topic							
System modeling & Performance analysis							

- **Future Work**
  - **UAV communication + α**

Any Questions?

THANK YOU

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