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Backhaul-aware Robust 3D Drone Placement in 5G+ Wireless Networks

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Why Drone Base Stations?

Terrestrial base stations' locations is determined based on the **long term average traffic**.

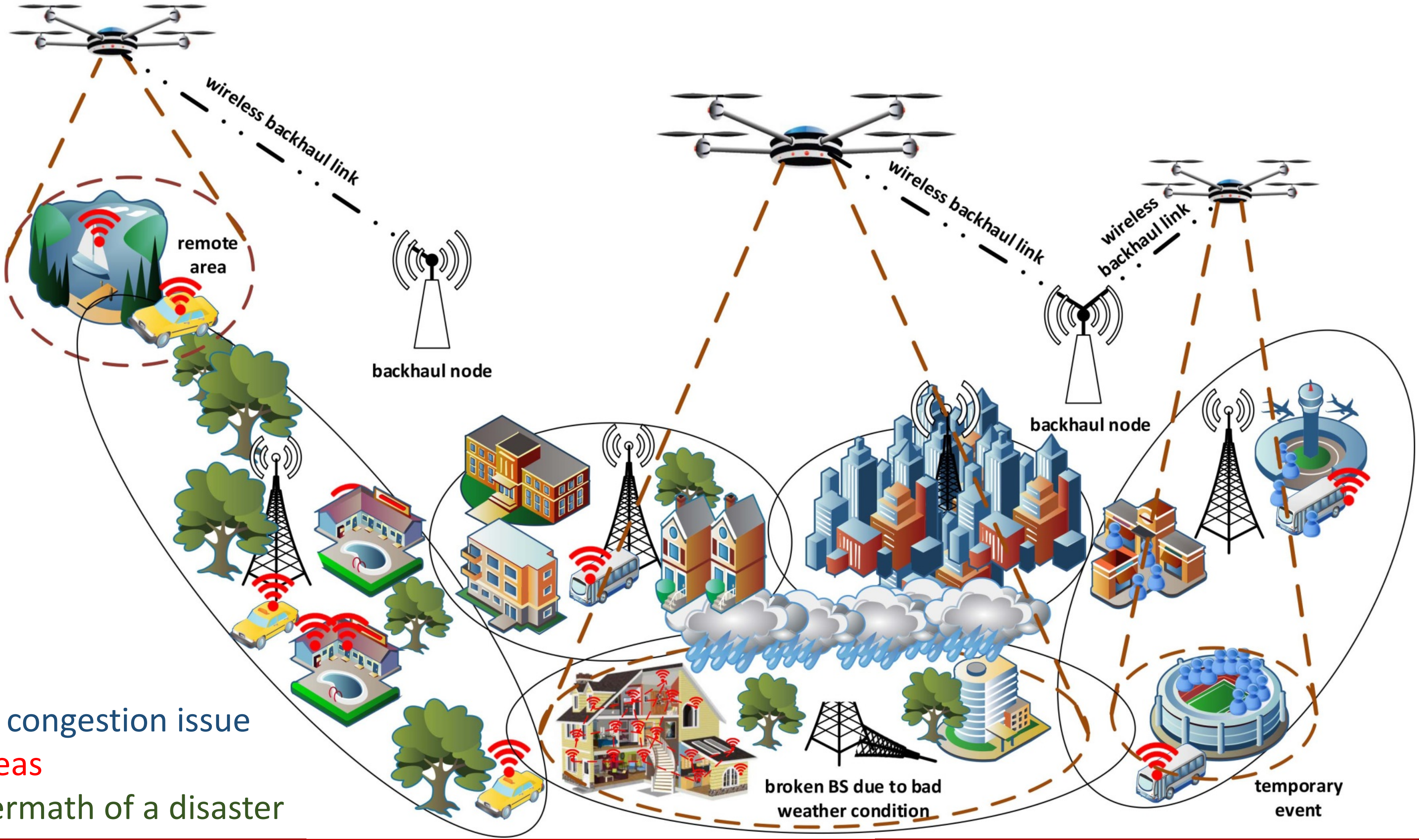
However temporal and spatial variations in user densities and user application rates are expected to result in **difficult-to-predict traffic patterns**.

supply and demand mismatch.

How to satisfy the users who expect unlimited capacity everywhere and all the time?
Solution: deploy a very dense network of BSs.
Drawback: infeasible in terms of expenses, many of them are lightly loaded at a given time.

Solution: Bring supply wherever and whenever the demand is by using drone base stations.

Various Use Cases for Integration of Drone-BSs in Cellular Networks



- Temporary congestion issue
- Remote areas
- During aftermath of a disaster

Previous work

- Find the minimum number of drone-BSs and their 3D placement so that users with high data rates are served. *

$$\min_{x_j, y_j, h_j} \sum_{j=1}^{N_{BS}} \epsilon_j$$

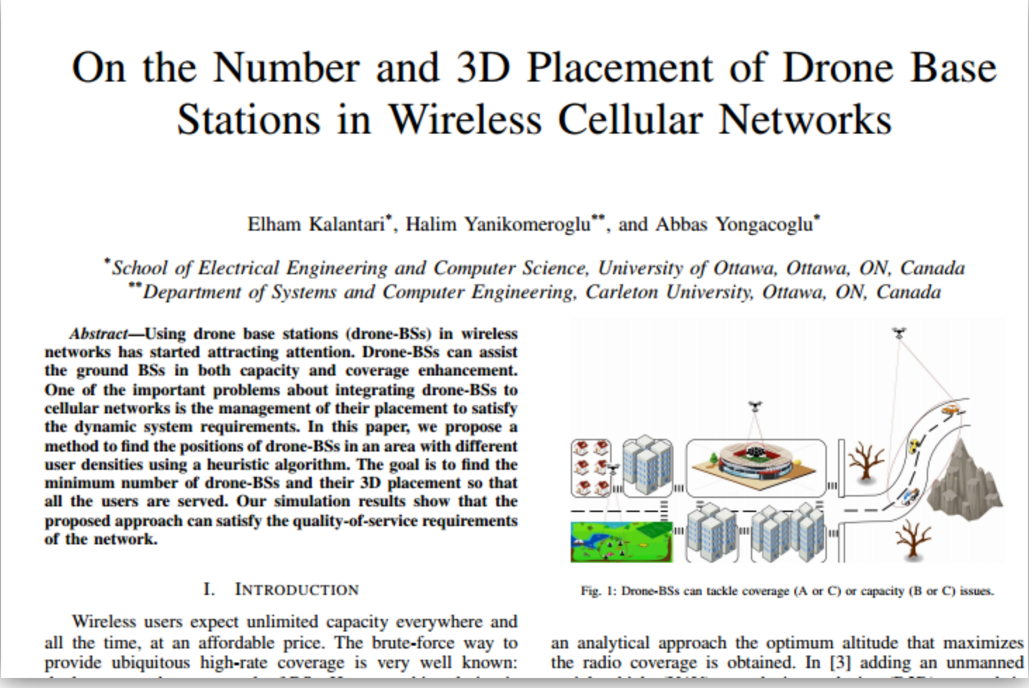
Subject to:

$$\sum_{j=1}^{N_{BS}} N_{U_{BS}} \rho_{j,k} \geq D_k S_k, \forall k = 1, ..., N_{subarea}$$

$$\sum_{i=1}^{N_U} \gamma_i \geq \zeta N_U$$

$$\frac{1}{\mathsf{E}\{\frac{1}{\eta_i}\}} \geq \eta$$

$$\epsilon_j = \begin{cases} 1, & \text{if drone-BS } j \text{ is used}, \\ 0, & \text{if drone-BS } j \text{ is redundant}. \end{cases}$$



On the Number and 3D Placement of Drone Base Stations in Wireless Cellular Networks

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***Abstract*—Using drone base stations (drone-BSs) in wireless networks has started attracting attention. Drone-BSs can assist the ground BSs in both capacity and coverage enhancement. One of the important problems about integrating drone-BSs to cellular networks is the management of their placement to satisfy the dynamic system requirements. In this paper, we propose a method to find the positions of drone-BSs in an area with different user densities using a heuristic algorithm. The goal is to find the minimum number of drone-BSs and their 3D placement so that all the users are served. Our simulation results show that the proposed approach can satisfy the quality-of-service requirements of the network.**

Fig. 1: Drone-BSs can tackle coverage (A or C) or capacity (B or C) issues.

I. Introduction

Wireless users expect unlimited capacity everywhere and all the time, at an affordable price. The brute-force way to provide ubiquitous high-rate coverage is very well known:

an analytical approach the optimum altitude that maximizes the radio coverage is obtained. In [3] adding an unmanned

* Elham Kalantari, Halim Yanikomeroglu, and Abbas Yongacoglu, "On the number and 3D placement of drone base stations in wireless cellular networks", *IEEE Vehicular Technology Conference* (*VTC2016-Fall*), 18–21 September 2016, Montreal, QC, Canada.

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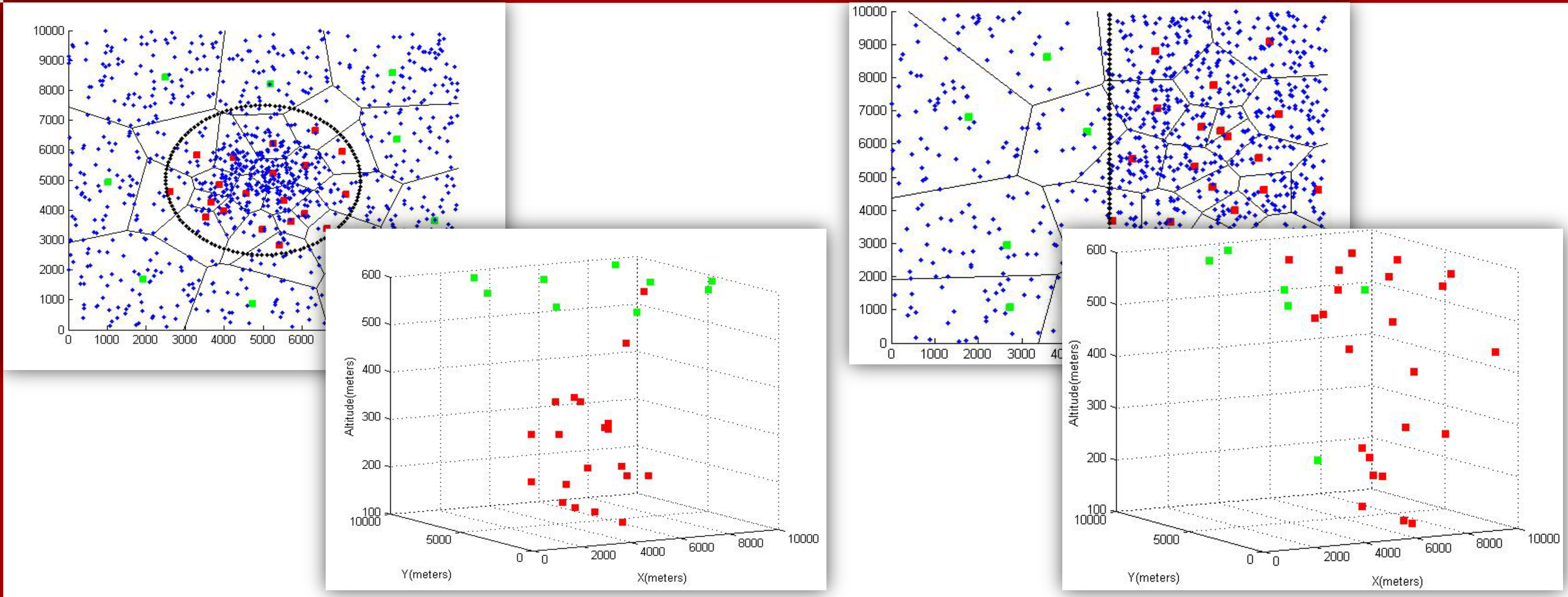
Previous work



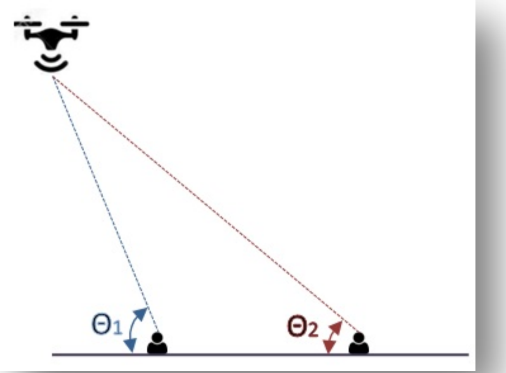
- Number of drones are proportional with the user density of the area.
- Drone-BSs can change their altitudes in order to tackle coverage and capacity issues. A drone-BS decreases its altitude in a dense area to reduce interference to the users that are not served by it and increases its altitude to cover a large area in a low density region.

Air-to-Ground Channel Model

$$\text{PL (dB)} = \text{FSPL} + \boxed{\psi_i}$$

$$\psi_i = \mathcal{N}(\eta_i, \sigma_i^2)$$

Excessive pathloss due to LoS or NLoS channel between TX and RX

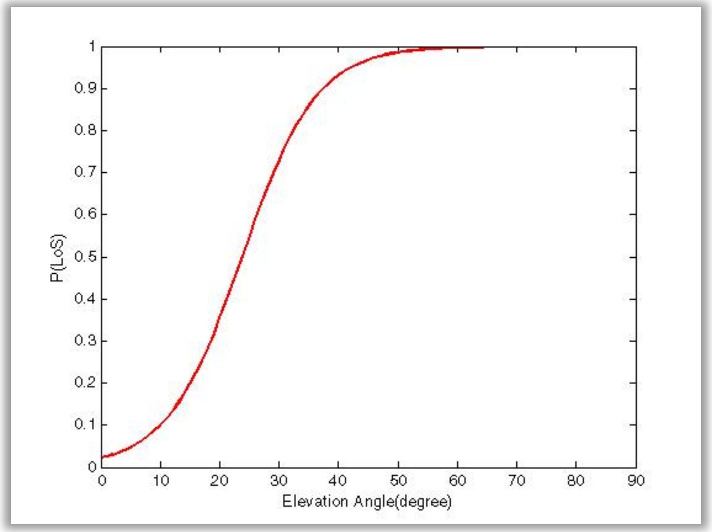


$$\theta_1 \geq \theta_2 \Rightarrow P(\text{LoS})_{\theta_1} \geq P(\text{LoS})_{\theta_2}$$

Probability of LoS:

$$P(\text{LoS}) = \frac{1}{1 + a\exp(-b(\theta - a))}$$

- P(LoS) increases as the elevation angle is increased.



- A. Al-Hourani, S. Kandeepan, and A. Jamalipour, “Modeling air-to-ground path loss for low altitude platforms in urban environments,” in IEEE Global Communications Conference (GLOBECOM), Dec 2014,pp. 2898–2904.
- A. Al-Hourani, S. Kandeepan, and S. Lardner, “Optimal LAP altitude for maximum coverage,” IEEE Wireless Communications Letters, vol. 3,no. 6, pp. 569–572, Dec 2014.

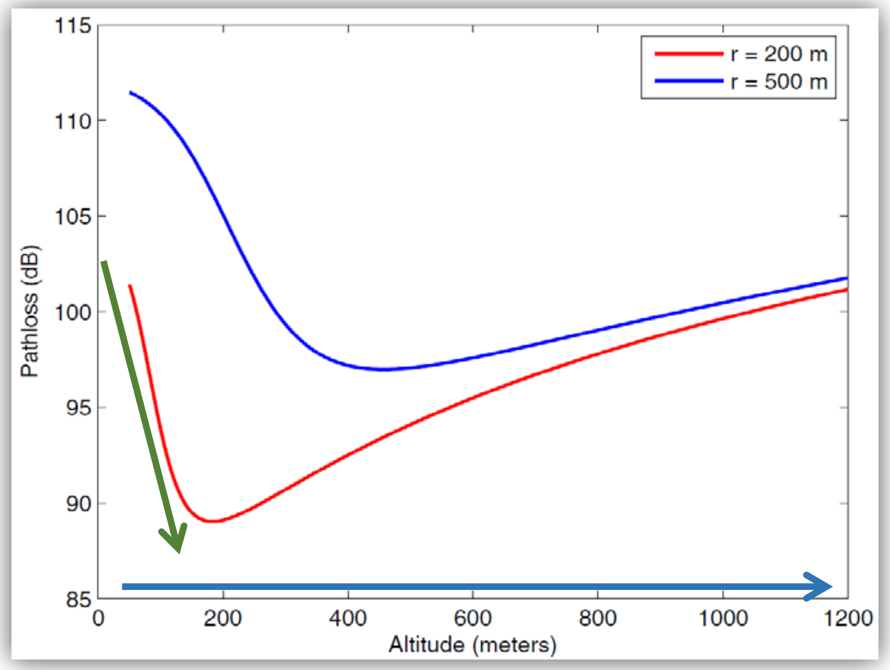
Air-to-Ground Channel Model

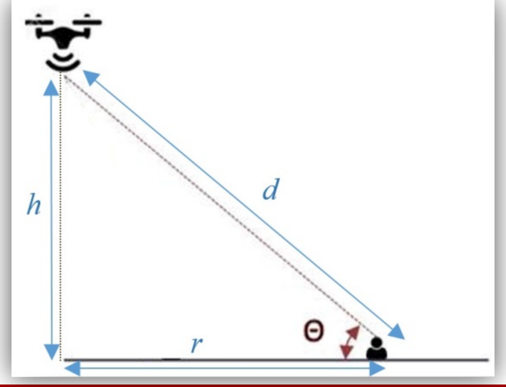
$$\mathrm{PL(dB)} = \boxed{20\log(\frac{4\pi f_c d}{c})} \quad \text{Free Space Pathloss}$$

$$+ \quad P(\mathrm{LoS})\boxed{\eta_{LoS}} + P(\mathrm{NLoS})\boxed{\eta_{NLoS}}$$

LoS Loss   NLoS Loss

By **increasing the altitude** of a drone-BS, the **pathloss first decreases** and **then increases**.





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Air-to-Ground Channel Model

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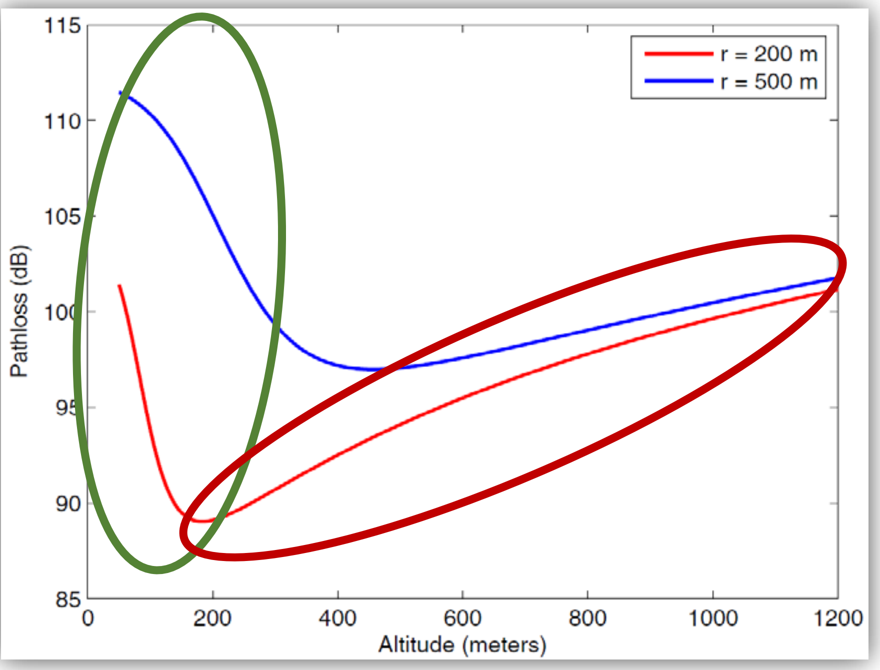
$$\mathrm{PL(dB)} = 20\log(\frac{4\pi f_c d}{c}) + P(\mathrm{LoS})\eta_{LoS} + P(\mathrm{NLoS})\eta_{NLoS}$$

By **increasing the altitude** of a drone-BS, the **pathloss first decreases** and **then increases**.

- In low altitudes, the probability of NLoS is much higher than LoS. By increasing the altitude, NLoS probability decreases and path loss will decrease, too.
- The pathloss is also dependent on the distance between the transmitter and the receiver, so after a specific height, this factor dominates and by increasing the altitude, the pathloss will increase again.



Drone-BS: A new tier in multi-tier cellular networks (HetNets)

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Optimization Problem

- Backhaul constraint is an important limitation in drone-BSs deployment.
- A drone-BS should have a wireless backhaul; therefore, the peak data rate a drone-BS can support is limited and it may dramatically decrease due to inclement weather conditions especially if the link is based on the FSO or mmWave technology.
- It is important to consider the limitations and requirements of the wireless backhaul link as one of the constraints in designing and deploying drone-BSs in future 5G+ networks.
- Here, we try to find the maximum number of weighted users so that the bandwidth, backhaul, and coverage constraints are satisfied for different rate requirements in a clustered user distribution.

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Problem constraints

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Backhaul constraint

$$\sum_{i=1}^{N_U} r_i \cdot I_i \leq R$$

$R =$ the peak wireless backhaul rate of a drone-BS,
$N_U =$ the total number of users,
$r_i =$ the data rate required by user i,
$$I_i = \begin{cases} 1, & \text{if user } i \text{ is served by the drone-BS,} \\ 0, & \text{otherwise.} \end{cases}$$

Available spectrum constraint

$$\sum_{i=1}^{N_U} b_i \cdot I_i \leq B$$

$B =$ the total bandwidth of the drone-BS,
$b_i =$ the bandwidth required by user i,
$b_i = \frac{r_i}{\zeta_i}$, $\zeta_i = \log_2(1+\gamma_i)$, $\gamma_i =$ SNR of user i.

Coverage constraint

$$\mathsf{PL}_i \cdot I_i \leq \mathsf{PL}_{\mathsf{max}}, \forall i$$

$PL_i =$ the pathloss when the signal is received by user i
$PL_{max} =$ the maximum pathloss that a user can tolerate.

Optimization problem

$$\max_{x,y,h,\{I_i\}} \sum_{i=1}^{N_U} \boxed{\alpha_i} \cdot I_i$$

Determined based on the system, whether it is network centric or user centric.

Subject to:

$$\begin{aligned}
\sum_{i=1}^{N_U} r_i \cdot I_i &\leq R \\
\sum_{i=1}^{N_U} b_i \cdot I_i &\leq B \\
\mathrm{PL}_i \cdot I_i &\leq \mathrm{PL}_{\mathrm{max}}, \quad \forall i \\
x_{min} \leq\ & x \leq x_{max} \\
y_{min} \leq\ & y \leq y_{max} \\
h_{min} \leq\ & h \leq h_{max} \\
I_i &\in \{0, 1\}, \quad \forall i
\end{aligned}$$

- Too complicated,
- Use exhaustive search.

Optimization problem

$$\max_{\{I_i\}} \sum_{i=1}^{N_U} \alpha_i \cdot I_i$$

Subject to:

$$\begin{aligned} \sum_{i=1}^{N_U} r_i \cdot I_i &\leq R \\ \sum_{i=1}^{N_U} b_i \cdot I_i &\leq B \\ \mathsf{PL}_i \cdot I_i &\leq \mathsf{PL}_{\mathsf{max}}, \quad \forall i \\ I_i &\in \{0,1\}, \quad \forall i \end{aligned}$$

In each candidate coordinates of the drone-BS, the problem can be transformed to a binary integer linear programming (BILP).

Solve via **Branch and Bound (B&B)** method.

Network centric vs. user centric

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- Network-centric: $\alpha_i = 1$

- User-centric: α_i changes based on the priority of the users.

  Different metrics to identify priority:
  - Sum-rate
  - Price differentiation
  - Signal strength
  - Content demand

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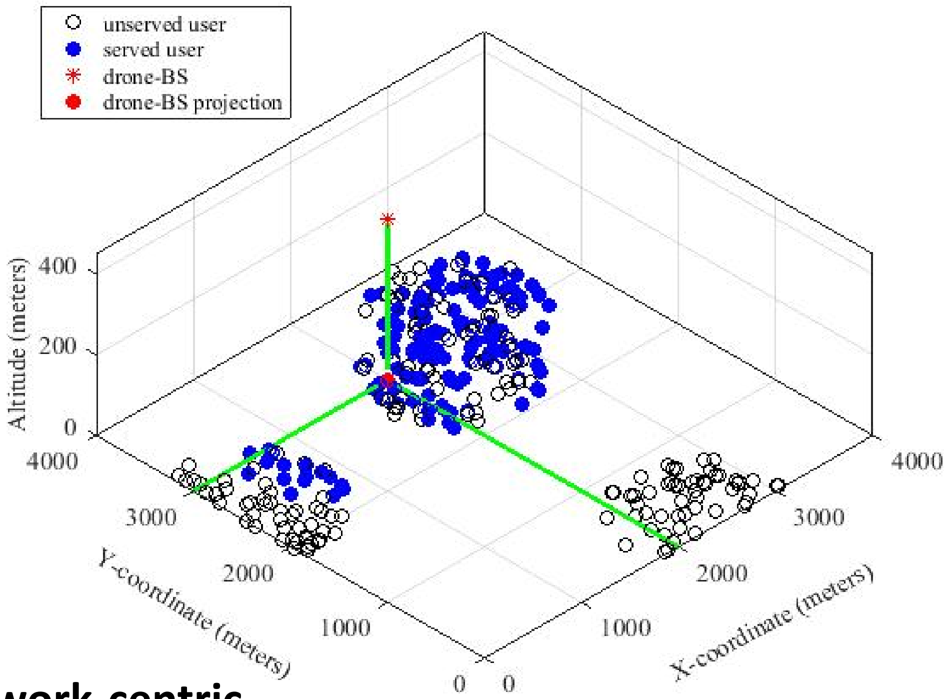
Simulation parameters

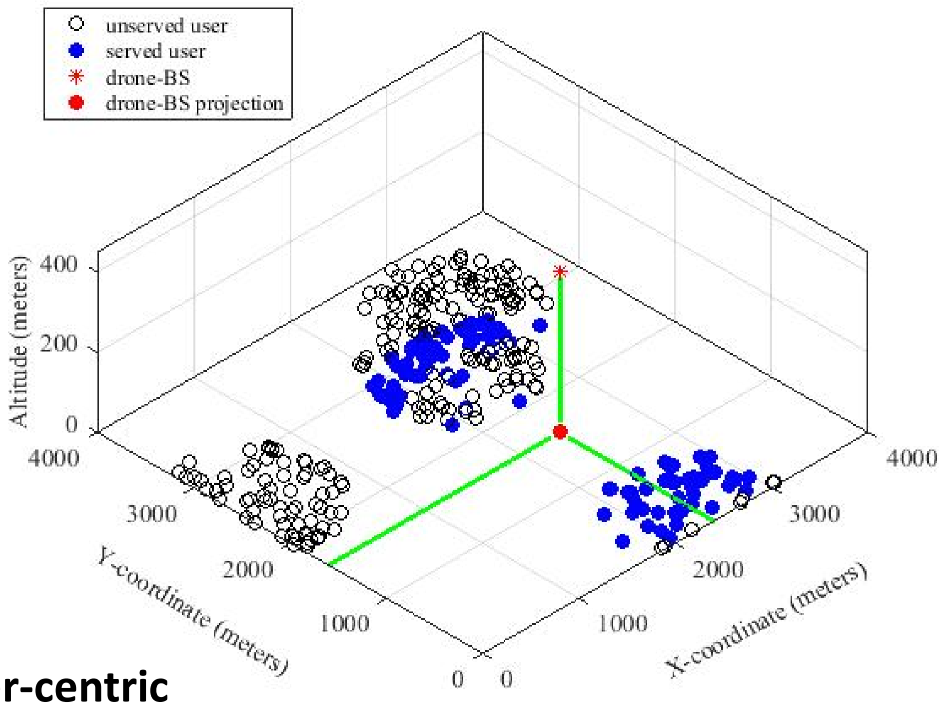
urban area, 16 km^2
Matern cluster process for user distribution
Downlink
$a = 9.61, b = 0.16$ (urban environment parameters)
$\eta_{LoS} = 1$ (LoS loss)
$\eta_{NLoS} = 20$ (NLoS loss)

$f_c = 2$ GHz
$\mathsf{PL}_{\mathsf{max}} = 120$ dB
$h_{max} = 400$ m
$B = 15$ MHz
$R = 80$ Mbps
$P_t = 5$ Watts
$\mathcal{R} = \{0.1, 0.5, 1, 1.5, 2\}$ Mbps
$r_i \in \mathcal{R}$

User Distribution and 3D Drone-BS Placement



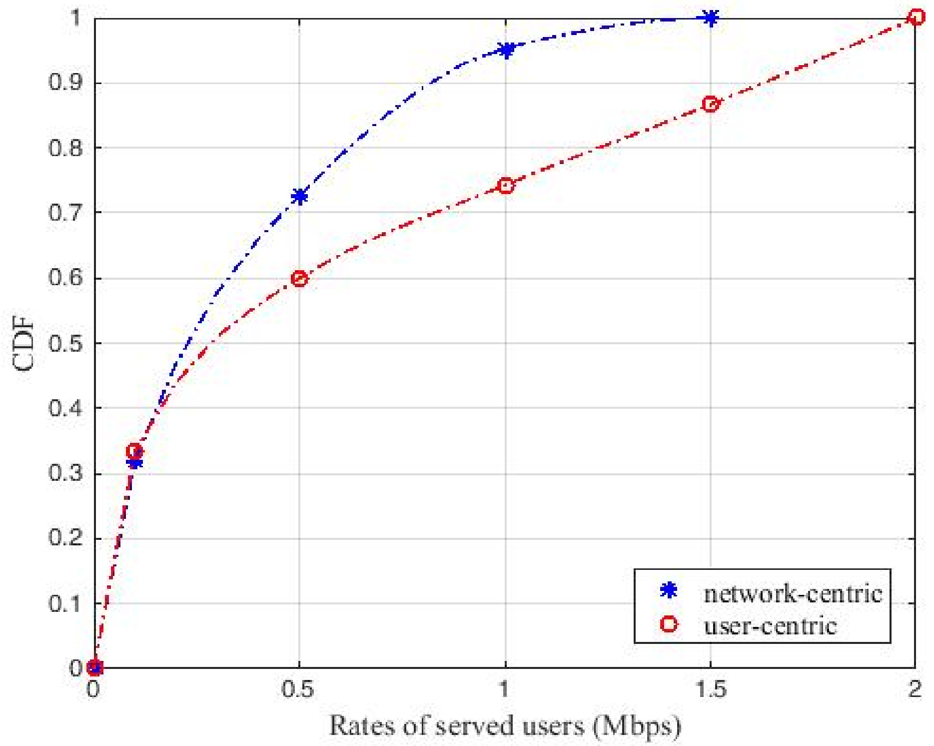
Network-centric



User-centric

In both approaches the drone-BS moves to the highest possible altitude to cover a larger area.
In the network-centric approach, more users are served compared to the user-centric approach.
There is a license fee related to spectrum usage that a service provider has to pay which is based on how much bandwidth per person is utilized over a geographical area. Therefore the network-centric approach may be a more favorable option for a service provider as it pays less for the spectrum usage.

CDF Comparison for User-Centric and Network-Centric Approaches



More probable to serve users with lower rate requirement in network-centric approach.

→ Higher number of total served users in this approach.

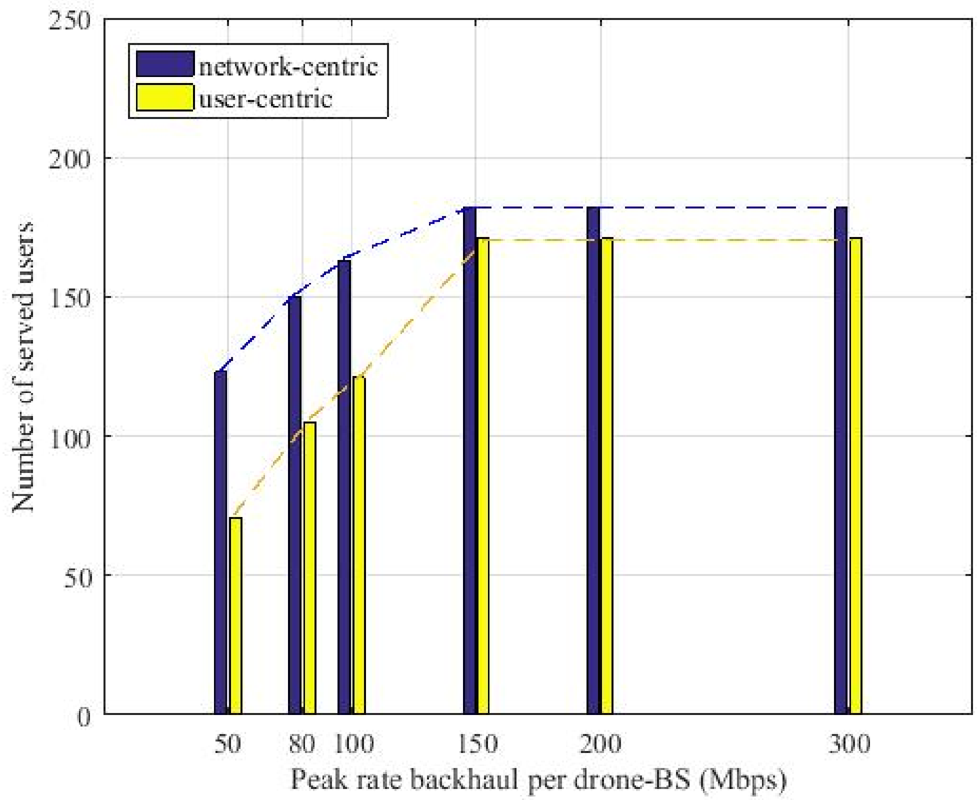
Backhaul Limitation

➢ Dedicated Backhaul:

can be a FSO or mmWave link between access and core networks. Such links can provide very high backhaul capacity, but they are very sensitive to weather conditions; in foggy or rainy weather, the peak rate may dramatically decrease.

➢ In-band Backhaul:

Microwave backhaul can be deployed very quickly at a relatively low cost. By using RF for backhaul, the same spectrum is used in both the access and backhaul links, so it causes interference and the capacity of the backhaul connection is affected.



Low backhaul rates can severely limit the number of served users.
By increasing the backhaul capacity, the number of served users is increased differently in two scenarios. It will stop increasing when the backhaul capacity is around 150 Mbps as there is no more spectrum resource in the access side of the drone-BS.

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Robustness

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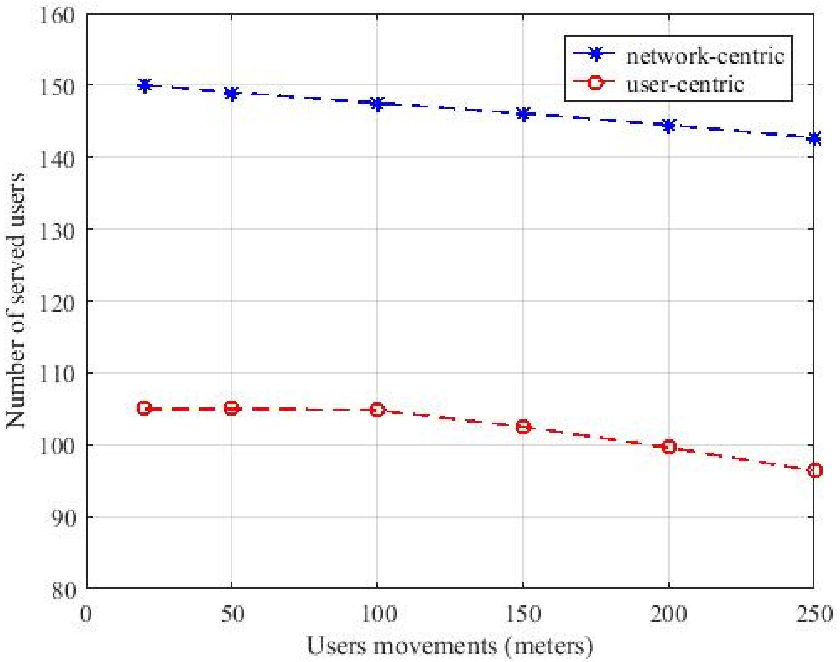

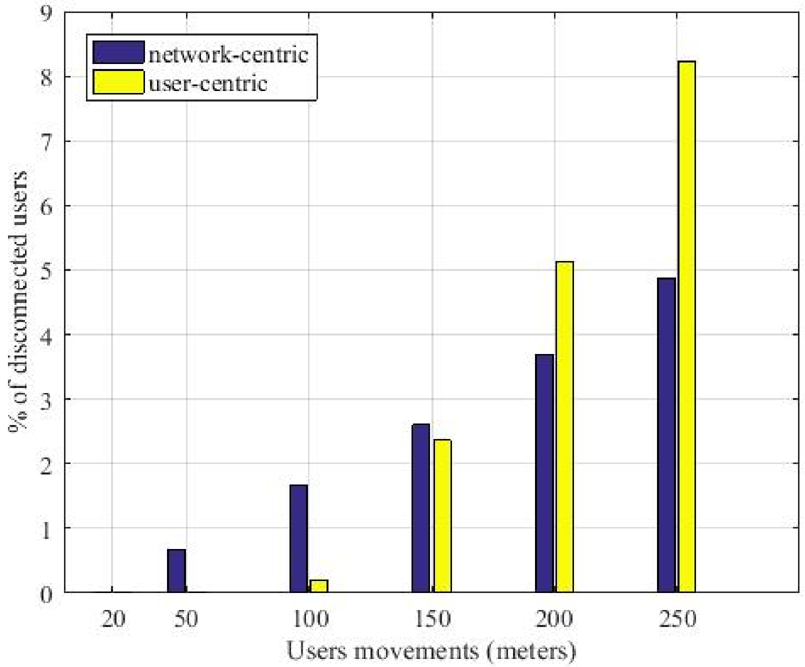

By increasing the movement distance, number of the served users will decrease, but this reduction is not significant.
Therefore, if a drone-BS flies to a predetermined good position, it is not required to change its place constantly due to users movements. This will result in savings in energy and reduction in complexity.

Conclusion

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- The optimal 3D placement of a drone-BS was found over an urban area with users having different rate requirements
- The network-centric approach maximizes the total number of served users regardless of their required rates.
- The user-centric approach maximizes their sum-rate.
- Only a small percentage of the total served users would be in outage when the users move. It suggests the robustness of the proposed algorithm against the modest movement of users.

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Thank you!