uOttawa Carleton UNIVERSITY

IEEE 84th Vehicular Technology Conference

VTC 2016

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

Elham Kalantari*, Halim Yanikomeroglu**, and Abbas Yongacoglu*

*School of Electrical Engineering and Computer Science, University of Ottawa
**Department of Systems and Computer Engineering, Carleton University

September 18-21, 2016

Outline

IEEE 84th Vehicular Technology Conference

VTC 2016

- Introduction
- System model
- Proposed algorithm
- Simulation results
- Conclusion

Why drone base stations?

uOttawa Carleton UNIVERSITY

IEEE 84th Vehicular Technology Conference

VTC 2016

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.

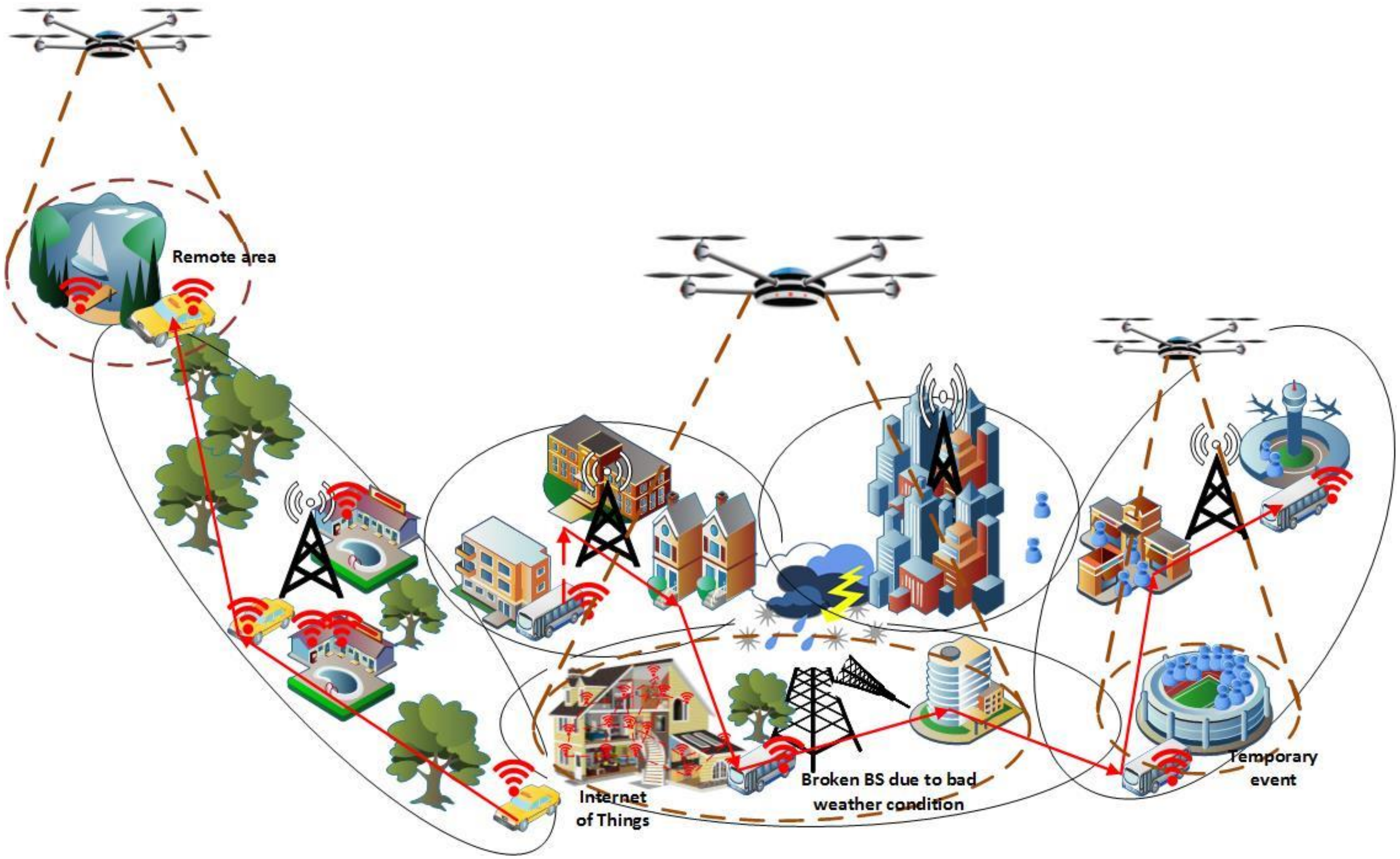
Solution: Bring supply wherever and whenever the demand is ⟶ Use drone base stations

uOttawa Carleton UNIVERSITY

Different use cases of drone-BSs

IEEE 84th Vehicular Technology Conference

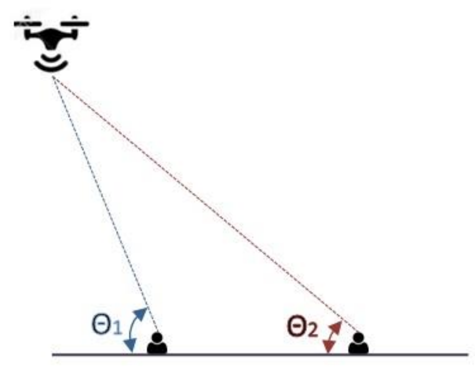
VTC 2016



Air-to-Ground Channel Model

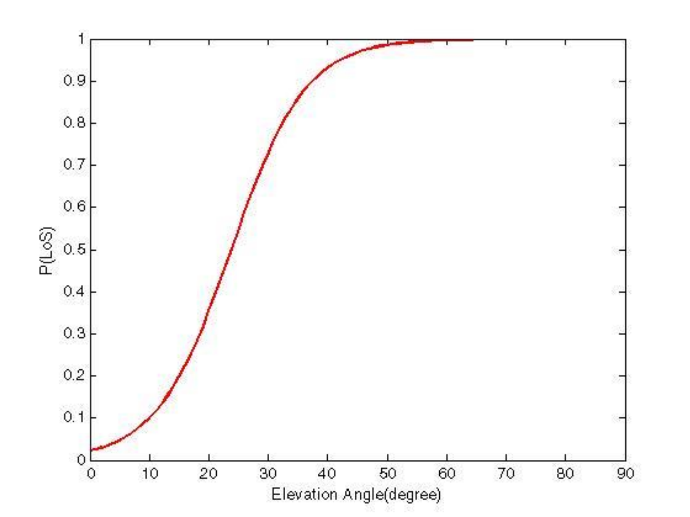
Probability of LoS is an important factor.

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



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

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



* A. Al-Hourani, S. Kandeepan, and S. Lardner, "Optimal LAP altitude for maximum coverage," *IEEE Wireless Communications Letters*, vol. 3, no. 6, Dec 2014.

Air-to-Ground Channel Model

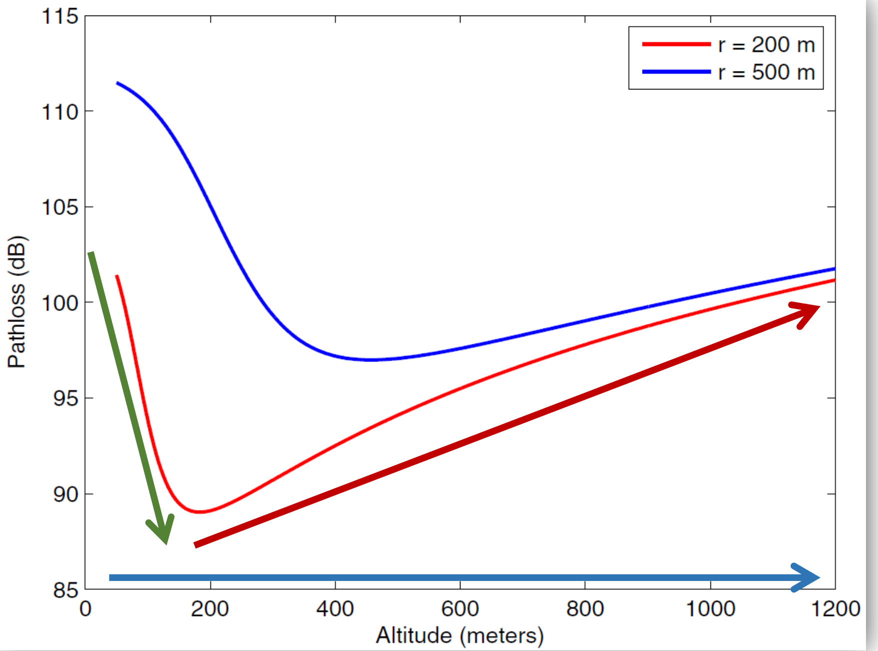
$$\mathrm{PL(dB)} = \boxed{20\log(\frac{4\pi f_c d}{c})} + P(\mathrm{LoS})\boxed{\eta_{LoS}} + P(\mathrm{NLoS})\boxed{\eta_{NLoS}}$$

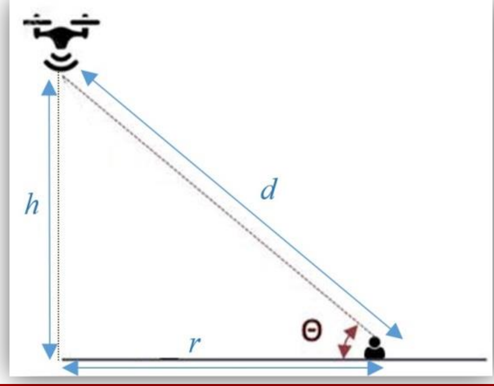
Free Space Pathloss

LoS Loss

NLoS Loss

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





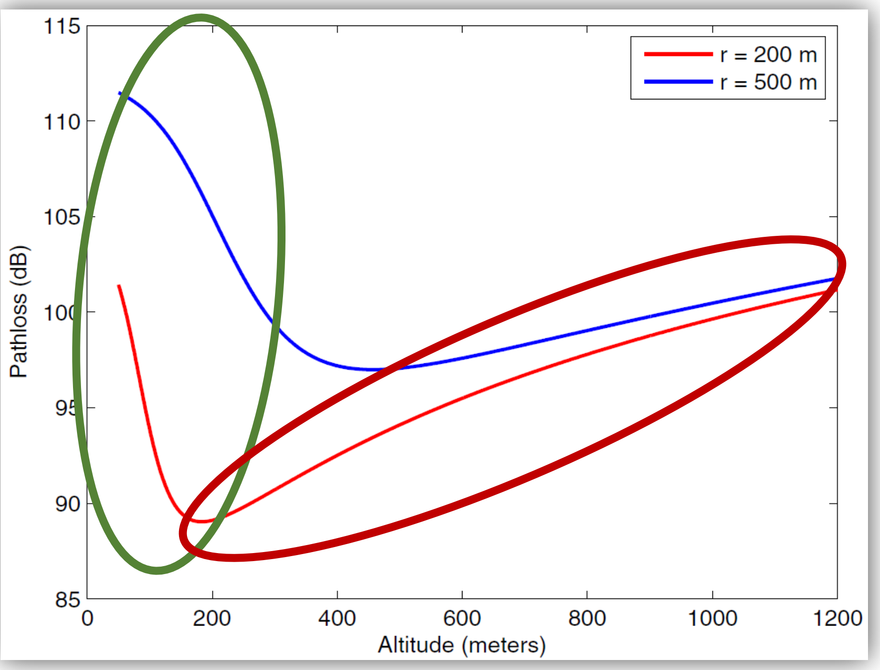
uOttawa Carleton UNIVERSITY

Air-to-Ground Channel Model

IEEE 84th Vehicular Technology Conference

VTC 2016

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



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 the cellular communication systems.

Changing the coverage area by changing the altitude of a drone-BS.

Optimization problem

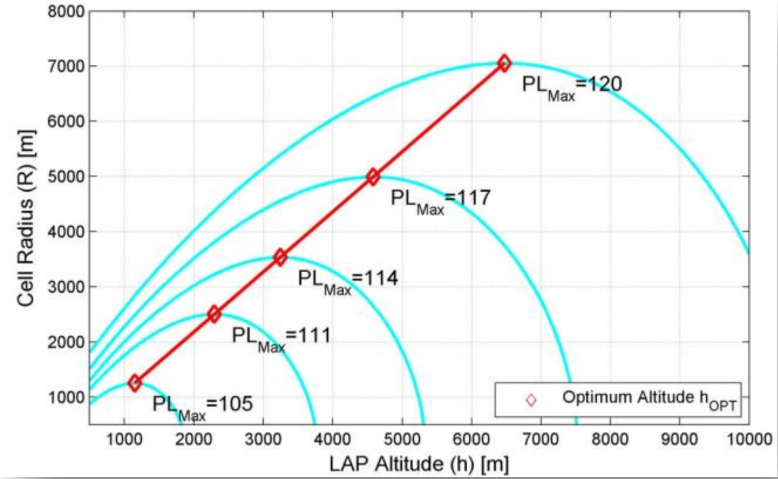
Find the required number of drone-BSs and their 3D placement so that users with high data rates are served.

To do so:

- Initial estimation of the number of drone-BSs,
- Find 3D placements of the drone-BSs, in a way that both coverage and capacity constraints are satisfied.
- Remove redundant drone-BSs.

Initial Estimation of the Number of Drone-BSs

- Coverage Dimensioning



*

- Cell Capacity Dimensioning

$$N_{U_{BS}} = \lfloor \frac{C_{BS}}{r} \rfloor = \lfloor \frac{B \times \eta}{r} \rfloor$$

$N_{U_{BS}}$: maximum number of users that a drone-BS can serve.

$$N_{BS} = \lceil \frac{N_U}{N_{U_{BS}}} \rceil$$

N_{BS} : An estimation for number of drone-BSs
N_U : total number of users

* A. Al-Hourani, S. Kandeepan, and S. Lardner, "Optimal LAP altitude for maximum coverage," *IEEE Wireless Communications Letters*, vol. 3, no. 6, Dec 2014.

Optimization problem constraints

Coverage Constraint

$$P\{\sigma_{ij^*} > \gamma_{th}\} \geq \zeta, \forall i = 1, ..., N_U$$

σ_{ij^*} = SINR user i receiving service from drone-BS j^*
γ_{th} = minimum SINR that a user needs to be covered by a BS
ζ = the minimum percentage of users that are covered by a drone-BS

Capacity Constraint

$$\rho_{j,k} = \frac{a_{j,k}}{A_j}$$

$a_{j,k}$ = mutual area between BS j and sub-area i
A_j = total area of BS j

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

D_k = user density function in sub-area k
S_k = total area of sub-area k

Optimization problem

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

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

Subject to:

$$\begin{aligned} \sum_{j=1}^{N_{BS}} N_{U_{BS}} \rho_{j,k} &\geq D_k S_k, \forall k = 1, ..., N_{subarea} \\ \sum_{i=1}^{N_U} \gamma_i &\geq \zeta N_U \\ \frac{1}{\mathrm{E}\{\frac{1}{\eta_i}\}} &\geq \eta \end{aligned}$$

$$\gamma_i = \begin{cases} 1, & \text{if user } i \text{ is under the coverage of a drone-BS,} \\ 0, & \text{otherwise.} \end{cases}$$

PSO(Particle Swarm Optimization) algorithm

- The algorithm starts with a population of random solutions,
- Iteratively tries to improve the candidate solutions with regards to a given measure of quality.
- The best experience of each candidate as well as the best global experience of all the candidates in all iterations are recorded and the next movement of the candidates is influenced by these items.

$$\boxed{U_1 = \sum_{k=1}^{N_{subarea}} \sum_{j=1}^{N_{BS}} \{N_{U_{BS}} \rho_{j,k} - D_k S_k\}}$$

Satisfying capacity constraint

$$\boxed{U_2 = \begin{cases} -\sum_{i=1}^{N_U} \gamma_i, & \text{if (1) holds,} \\ 0, & \text{otherwise.} \end{cases}}$$

Satisfying coverage constraint

$$\boxed{U_3 = \begin{cases} -N_U + \eta - \frac{1}{\mathsf{E}\{\frac{1}{\eta_i}\}}, & \text{if (1) holds,} \\ 0, & \text{otherwise.} \end{cases}}$$

Satisfying SE in the initial estimation part

uOttawa Carleton UNIVERSITY

Proposed algorithm

Algorithm 1 PSO algorithm for 3D placement of drone-BSs

Generate an initial population including L random particles $W^{(l)}(0), l = 1, ..., L$. Each particle has size $3 \times N_{BS}$. Set $t = 1$, $U = U_1$, $U^{(global)} = \min\{U^{(l)}(0), \forall l = 1, ..., L\}$ and $U^{(l,local)} = U^{(l)}(0)$.
while $U^{(global)} > -N_U$ **do**
  for l = 1, ..., L **do**
    Compute $V^{(l)}(t), W^{(l)}(t), U^{(l)}(t)$.
    if $U^{(l)}(t) < U^{(l,local)}$ **then**
      $W^{(l,local)} = W^{(l)}(t), U^{(l,local)} = U^{(l)}(t)$.
      if $U^{(l,local)} < U^{(global)}$ **then**
        $W^{(global)} = W^{(l,local)}, U^{(global)} = U^{(l,local)}$.
      end if
    end if
  end for
  if $U^{(global)} \leq 0$ **then**
    $U = U_2$.
  end if
  if $U^{(global)} \leq -\zeta N_U$ **then**
    $U = U3$.
  end if
  $t = t + 1$.
end while

H. Ghazzai, E. Yaacoub, M.S. Alouini, Z. Dawy, and A. Abu-Dayya, “Optimized LTE cell planning with varying spatial and temporal user densities,” IEEE Transactions on Vehicular Technology, vol. 65, no. 3, pp. 1575–1589, March 2016.

Remove Redundant Drone-BSs

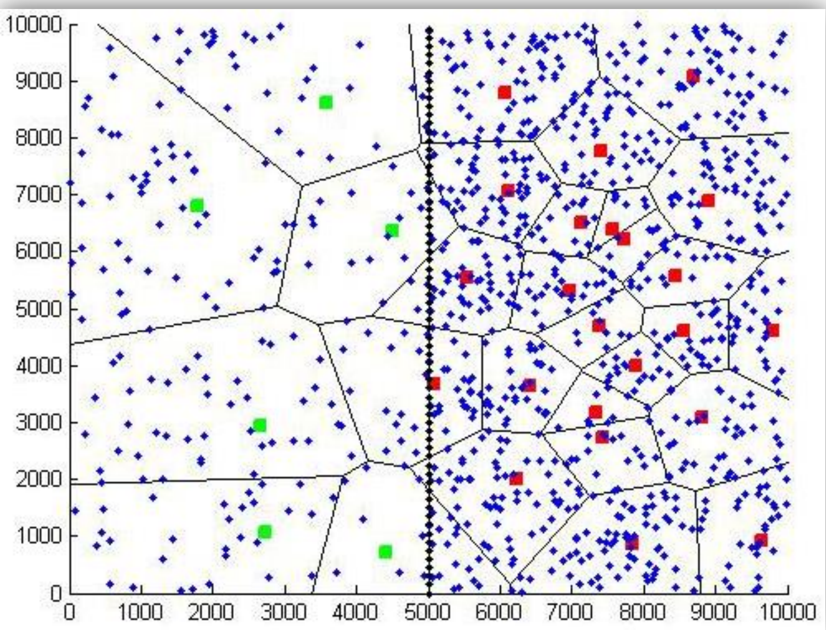
- **Minimize the number of drone-BSs** by removing the ones whose elimination do not affect the quality of the network.
- **Remove one drone-BS in each iteration and check the constraints**. If they hold, that BS can be removed without violating the constraints. If **more than one BS** can be removed based on this algorithm, at first step **the one which makes less users disconnect** of the system will be selected as the redundant BS. After removing this one, the algorithm is repeated again until finally no redundant BS will remain.

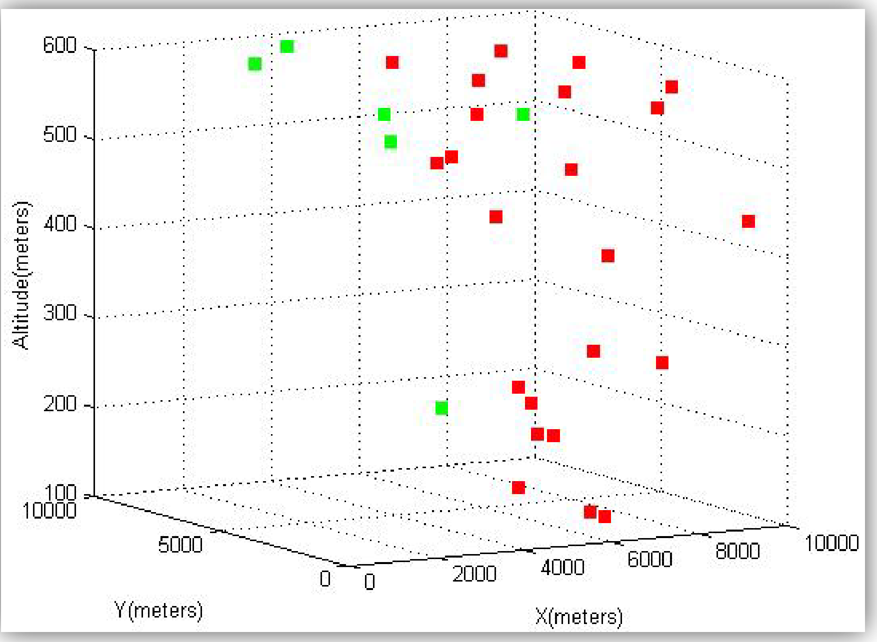
Simulation assumptions

urban area, $100\ \text{km}^2$
1000 users
Downlink
$a = 9.61, b = 0.16$ (urban environment parameters)
$\eta_{LoS} = 1$ (LoS loss)
$\eta_{NLoS} = 20$ (NLoS loss)

$f_c = 2$ GHz
$B = 20$ MHz
$\eta = 1.7$ bps/Hz
$\zeta = 95$
$r = 1$ Mbps
$P_t = 5$ Watts
$\gamma_{th} = -7$ dB

Scenario I

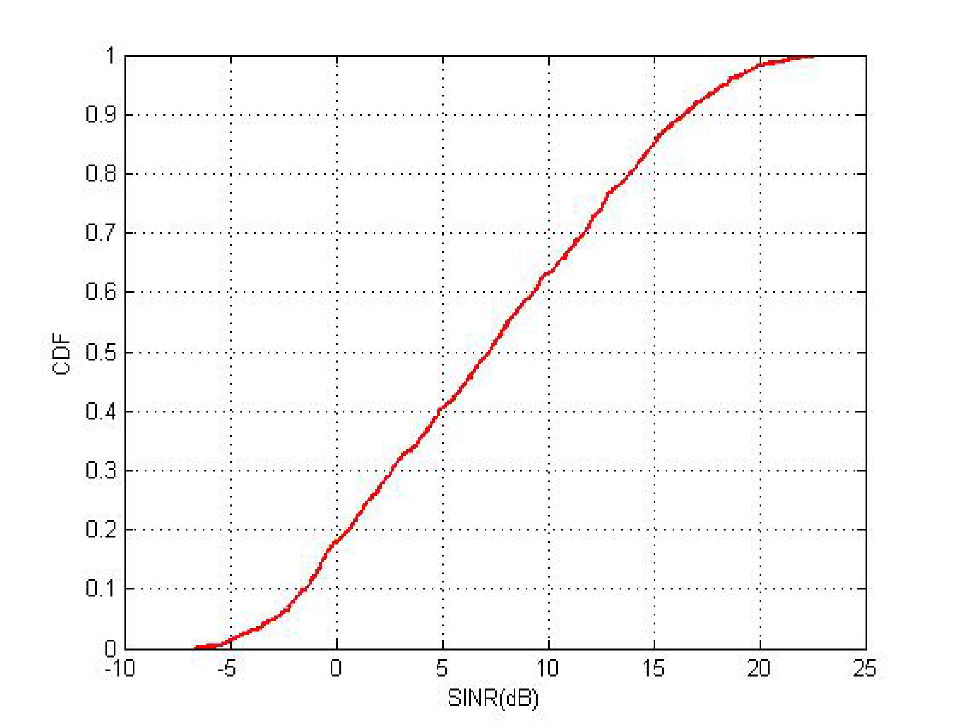


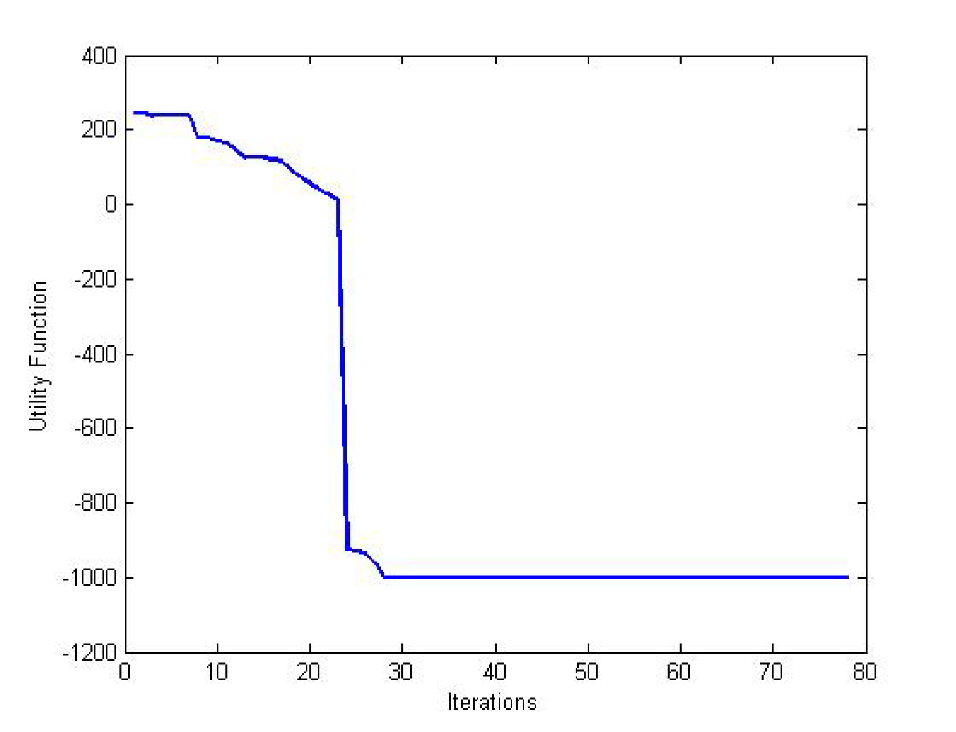


20 and 80 percent of the users are uniformly distributed in left and right part of the region, respectively.

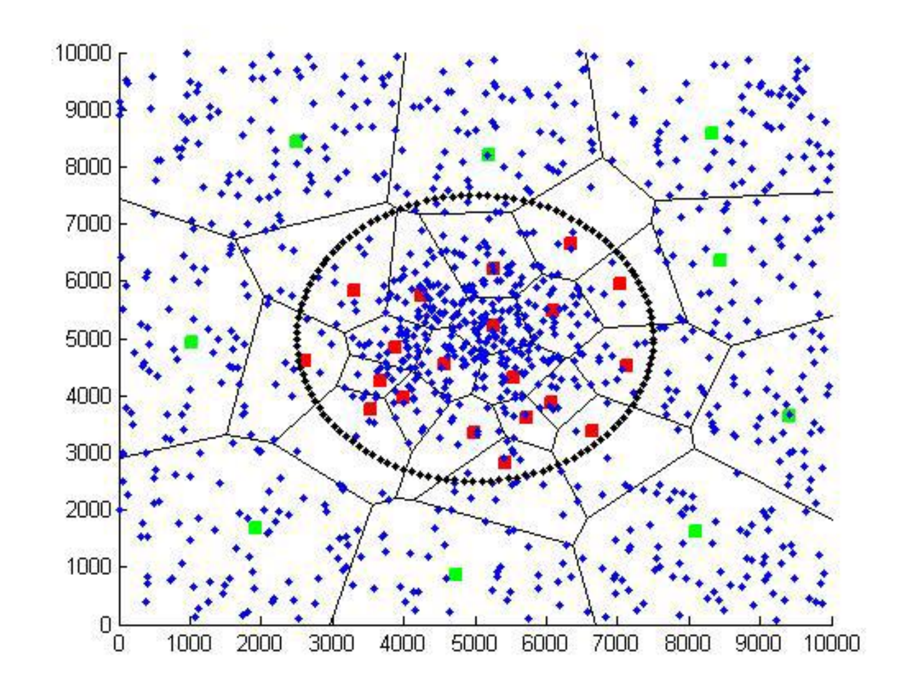
- Less drone-BSs in left, higher altitudes to decrease PL and increase coverage radius.
- More drone-BS in higher user densities area. Lower altitudes to decrease interference.

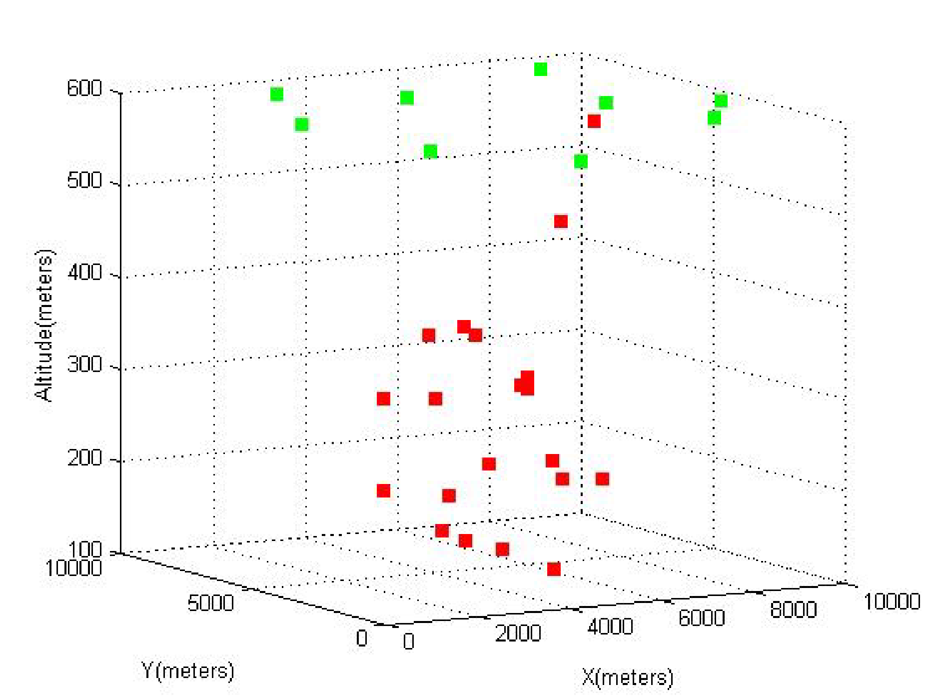
Scenario I


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
CDF
-10
-5
0
5
10
15
20
25
SINR(dB)


400
200
0
-200
-400
-600
-800
-1000
-1200
Utility Function
0
10
20
30
40
50
60
70
80
Iterations

Scenario II





40 percent of the users are normally distributed with standard deviation 1000 meters in central part of the region.

60 percent of the users are uniformly distributed in the remaining area.

uOttawa Carleton UNIVERSITY

Scenario II

IEEE 84th Vehicular Technology Conference

VTC 2016

Outline

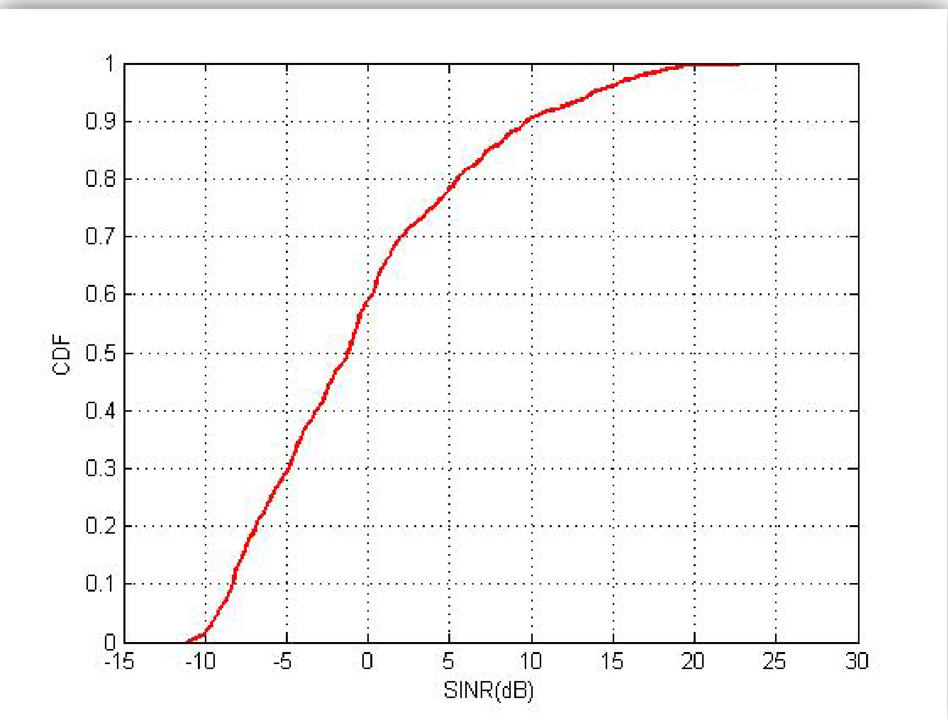
Introduction

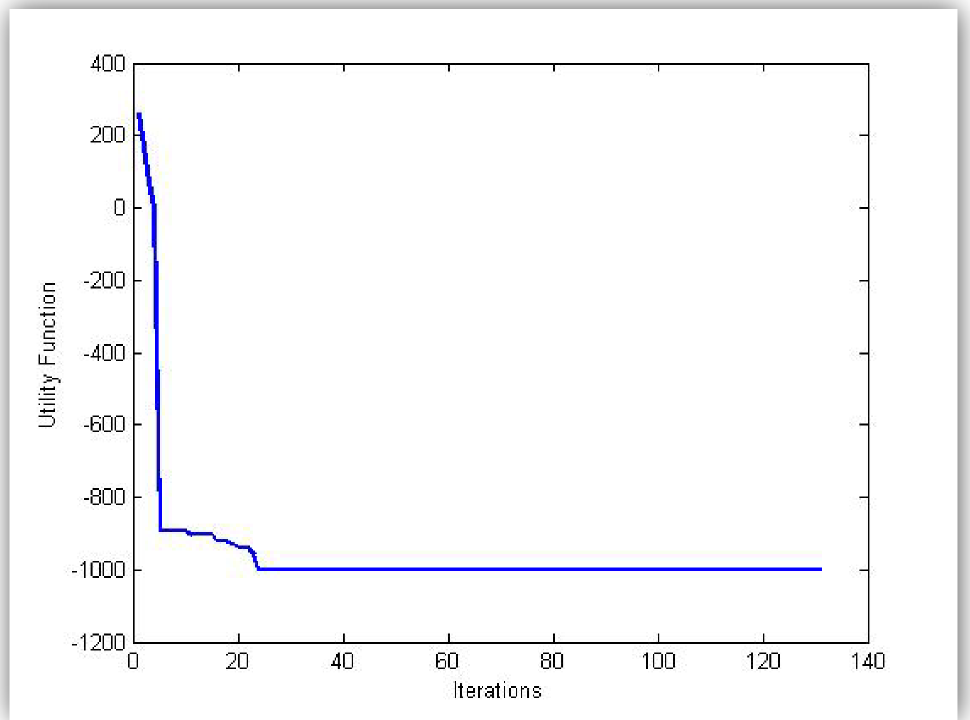
System model

Proposed algorithm

Simulation results

Conclusion





uOttawa Carleton UNIVERSITY

Conclusion and future work

IEEE 84th Vehicular Technology Conference

VTC 2016

Conclusion

- Found 3D placements of drone-BSs to satisfy both capacity and coverage constraint via meta-heuristic PSO algorithm,
- Number of drones are proportional with the user density of the area,
- By changing the altitude of a drone-BS, coverage or capacity issues can be addressed.

Future Work

- Consider backhaul constraint

Thank you!