A Predictive On-Demand Placement of UAV Base Stations Using Echo State Networks

IEEE/CIC ICCC

Aug 12th 2019

Haoran Peng, Chao Chen, Li-Chun Wang,

National Chiao Tung University

Zhu Han,

University of Houston

Background

- ***The UAV- BSs have a great potential in providing on-demand communications services for dynamic flash crowds in marathon, outdoor activities.***
- ***The movements of user equipments (UEs) are inevitable, which pose a challenge in UAV-assisted communications systems.***

Fig. 1. Marathon.

Fig. 2. Crowded place.

Problem Statement

➢ ***How can UAV-BSs be repositioned dynamically to provide seamless services for flash crowds, while minimizing the energy consumption in UAV-BSs' trajectories?***

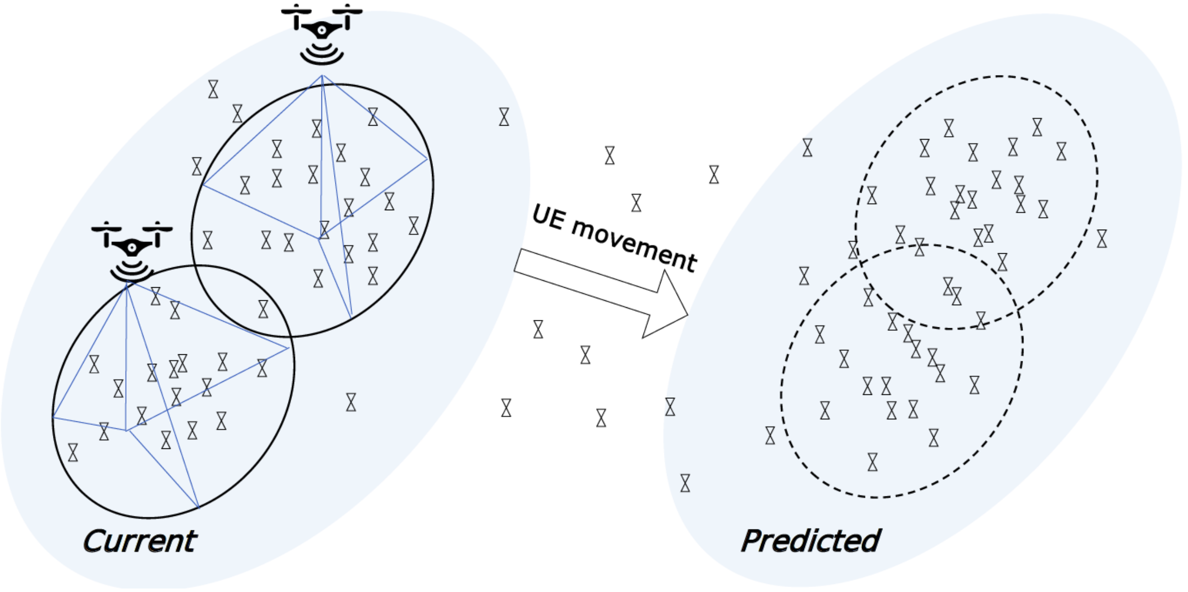


Fig. 3. The considered dynamic application scenario.

The limitation of current solutions?

	Contribution	Limitation
Fotouhi, et. al, [1]	Finding the optimal placement of the UAV-BSs while serving the UEs in the target area.	Reposition actions are performed after the movement of UEs.
Alzenad, et. al, [2]	Maximizing the number of served users with the minimum transmit power.	Do not take dynamic movement scenarios into consideration.
Bayerlein, et al. [3]	Finding the optimal trajectory of an UAV-BS to serve multiple users.	Do not consider the energy cost of UAV-BS's repositioning.

[1] A. Fotouhi, M. Ding, and M. Hassan, "Dynamic base station repositioning to improve performance of drone small cells," in IEEE Global Communications Conference Workshops (GLOBECOM Wkshps), San Diego, CA, Dec. 2016.
[2] M. Alzenad, A. El-Keyi, F. Lagum, and H. Yanikomeroglu, "3-Dplacement of an unmanned aerial vehicle base station (uav-bs) for energyefficient maximal coverage," IEEE Wireless Communications Letters, vol. 6, no. 4, pp. 434–437, Aug. 2017.
[3] H. Bayerlein, P. De Kerret, and D. Gesbert, "Trajectory optimization for autonomous flying base station via reinforcement learning," in IEEE 19th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC), Kalamata, Greece, Jun. 2018.

Why is ESN chosen for Crowd Movement Estimation?

- ***Short computation time* and *low energy cost*.**

  1) containing a large number of neurons;

  2) the connection between neurons is generated randomly;

  3) the links between neurons are sparsity.

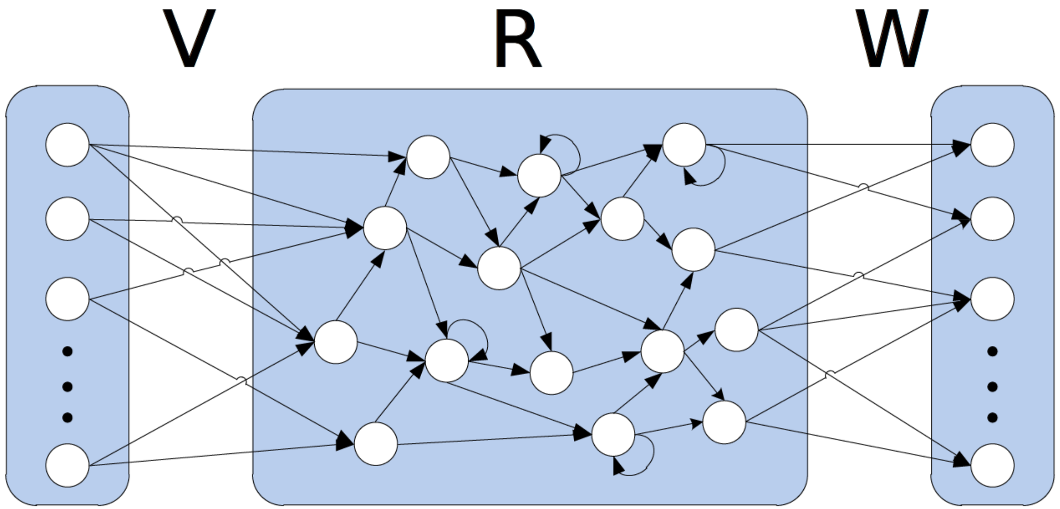


Fig. 4. The framework of an echo state network.

- ***V* represents the *input weight matrix*,**
- ***R* is the *reservoir weight matrix***
- ***W* is the *output weight matrix*.**

[4] http://www.scholarpedia.org/article/Echo_state_network

Proposed scheme

*An **ESN-based algorithm** to predict the future trajectories of the UEs*

*A **Kuhn-Munkres based algorithm** to find the minimum energy cost reposition scheme*

Proposed Algorithm

1) Cluster the UEs by using the K-means algorithm

2) Find the local optimal positions to deploy UAV-BSs

3) Collect the real-time latitude and longitude information of each UE's

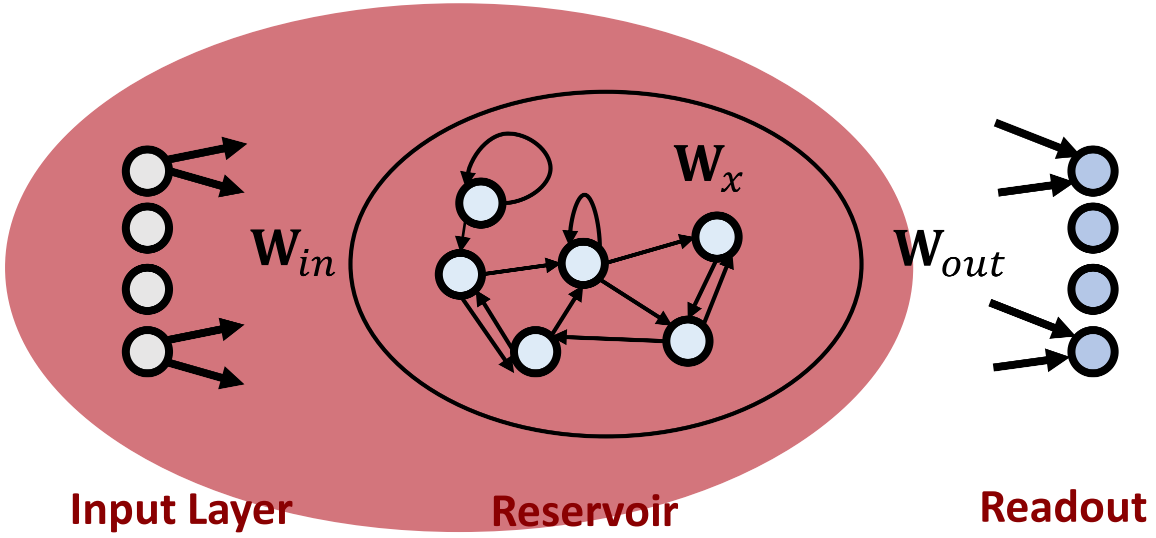
4) Predicting the UE's positions

5) Calculating the optimal positions of UAV-BSs in the next time slot

6) Find the energy-efficient trajectories of UAV-BSs

ESN-based Prediction Algorithm

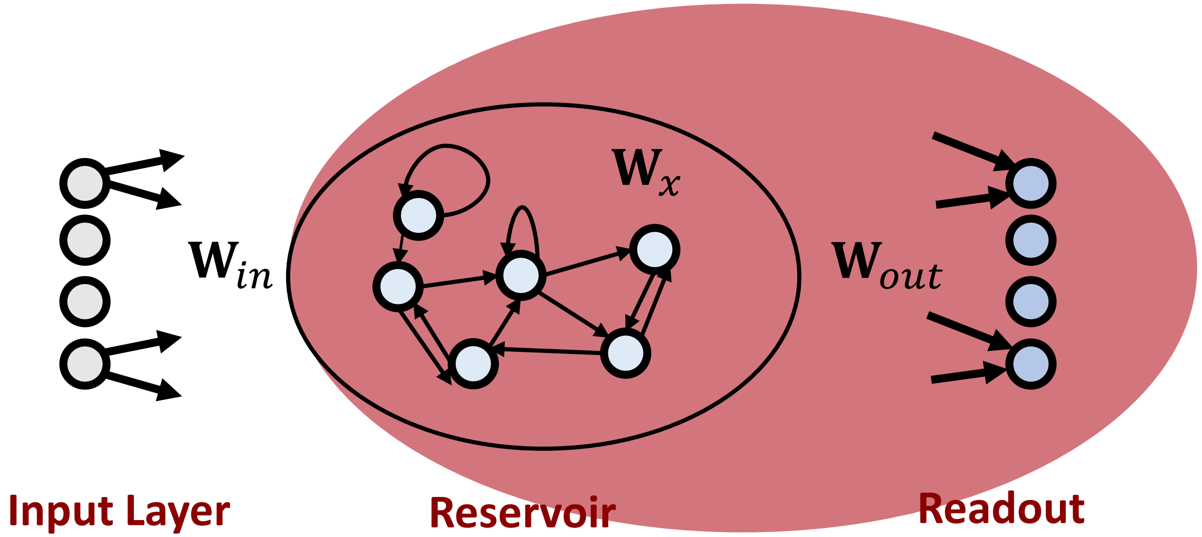
- ***Reservoir Initialization***



- W_{in} *is the connection weight matrices between input layer and reservoir pool, and* W_x *is the recurrent weight matrices.*
- *Use the trajectories information of each UE as the input data.*

ESN-based Prediction Algorithm

- ***Training Phase***



- ***W_{out} is the connection weight matrices between reservoir pool and output layer.***
- ***UE's prediction positions are the output data.***

ESN-based Prediction Algorithm

- ***In the reservoir pool, the typical update equation is written as***

$$\mathbf{x}^{m\times 1}(n) = \tanh(\mathbf{W}_{m\times n}^{in}\mathbf{u}^{n\times 1}(n) + \mathbf{W}_{x}^{m\times 1}(n-1))$$

- ***The output vector***

$$\mathbf{y}(n) = \mathbf{W}_{out}^{n\times m}\mathbf{x}^{m\times 1}(n)$$

- ***We use root mean square error (RMSE) to evaluate the quality of this model. The expected value is $\hat{y}_i$ and the actual result is y_i .***

$$\mathrm{RMSE} = \sqrt{\frac{1}{M}\sum_{i=1}^{M} w_i(\mathbf{y}_i - \hat{\mathbf{y}}_i)^2}, \quad \sum_{i=1}^{M}\omega_i=1$$

Kuhn-Munkres based Matching Algorithm

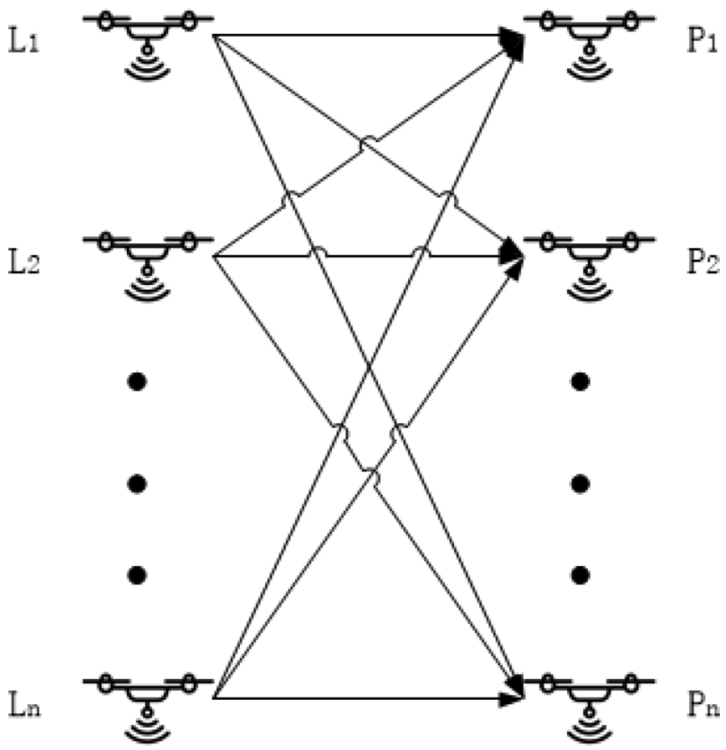


Fig. 5. Reposition matching of multiple UAV-BSs.

- ***The summation of all UAV-BSs' moving distance is smaller, the energy will be consumed less.***
- ***It can be reduced from a well-known problem——Minimum Weighted Bipartite Matching.***

Kuhn-Munkres based Matching Algorithm

- ***The total energy cost of the UAV-BSs' displacements can be optimized by:***

$$\min \sum_{\forall i,j \in [1,n]} w_{i,j} x_{i,j}$$

$$\text{s.t.} \quad \sum_{i=1}^{n} x_{i,j} = 1, \qquad \forall j = 1, 2, \ldots, n,$$

$$\sum_{j=1}^{n} x_{i,j} = 1, \qquad \forall i = 1, 2, \ldots, n,$$

$$x_{i,j} \in \{0, 1\}.$$

- ***n*** is the number of UAV-BSs;
- $\omega_{\mathrm{i},j}$ is the energy cost for a UAV to fly from position $\mathrm{L_i}$ to position P_j;

Experimental Environment

➢ ***The predicted trajectory is very close to the actual trajectory.***

Actual is red & predication is blue

Fig. 6. The comparison of predicted and actual trajectories of a UE.

The performance of prediction RMSE

- ***The RMSE value of each model is no more than 0.030***
- ***The ESN model has a high prediction accuracy.***

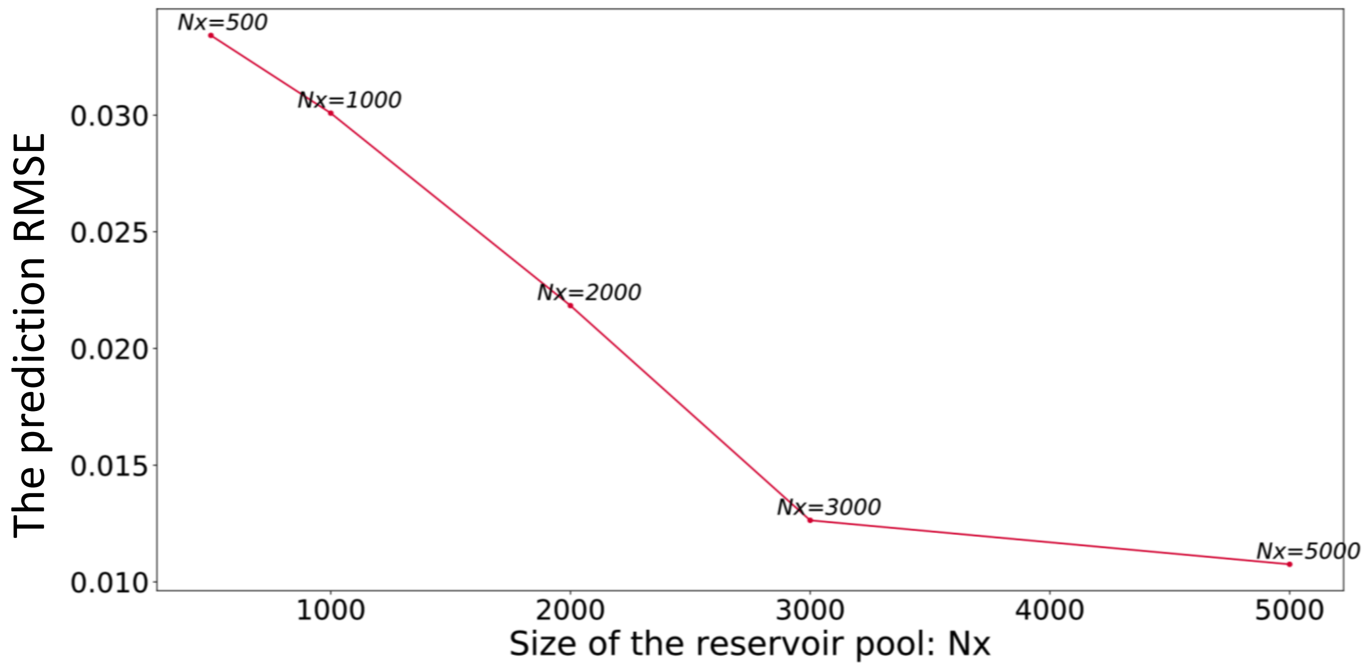


Fig. 7. The performance of prediction RMSE.

- ***N_x is the size of reservoir pool.***

Impact of the sizes of the reservoir pool

- ***When Nx is set to 5000, the predicted value is closest to the actual value.***

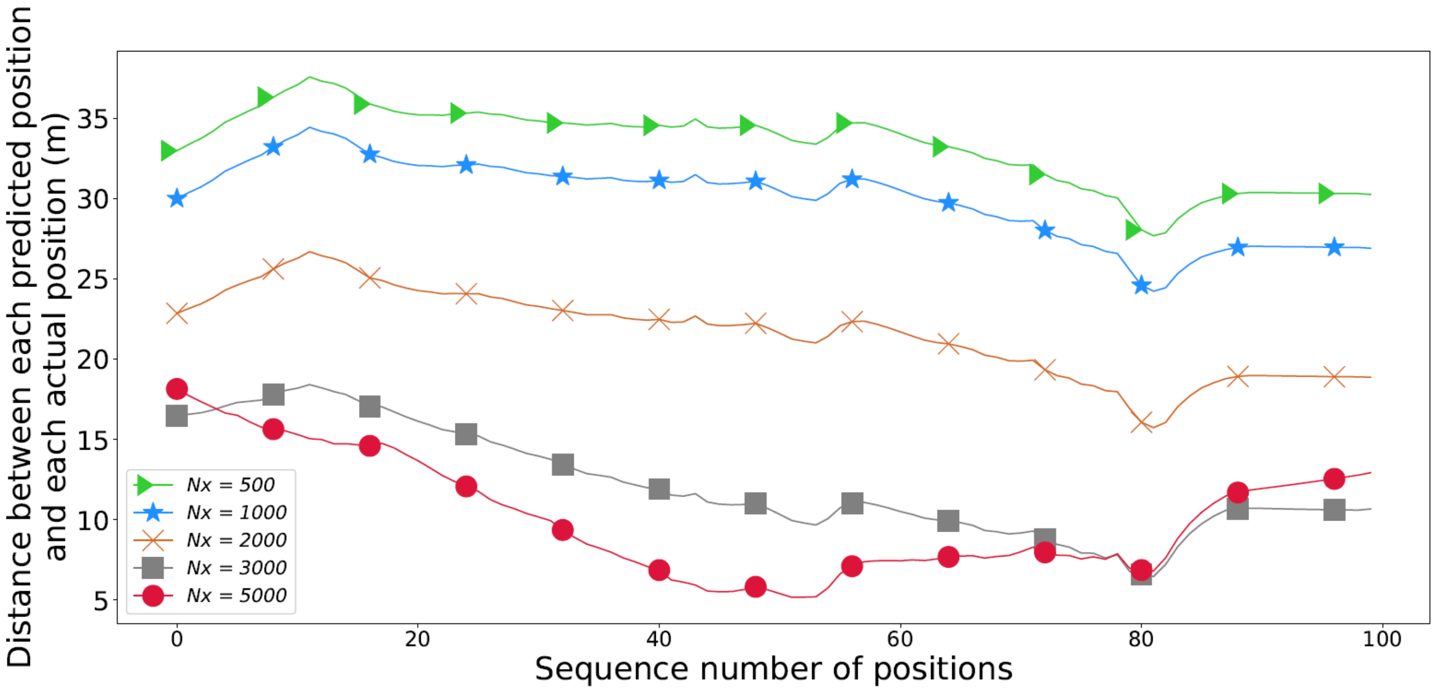


Fig. 8. The performance comparisons of the ESN model using different sizes of the reservoir pool.

Performance of matching

TABLE I
THE DISTANCE OF ALL THE POSSIBLE MATCHING SCHEMES

Reposition matching scheme	Sum of distance (in meters)
$A \rightarrow \alpha, B \rightarrow \beta, C \rightarrow \gamma$	1452
$A \rightarrow \alpha, B \rightarrow \gamma, C \rightarrow \beta$	1471
$A \rightarrow \beta, B \rightarrow \alpha, C \rightarrow \gamma$	1362
$A \rightarrow \beta, B \rightarrow \gamma, C \rightarrow \alpha$	1400
$A \rightarrow \gamma, B \rightarrow \alpha, C \rightarrow \beta$	1256 (minimal)
$A \rightarrow \gamma, B \rightarrow \beta, C \rightarrow \alpha$	1275

- ***The Kuhn-Munkres based matching algorithm can find the energy-efficient trajectories of multiple UAV-BSs when reposition.***

Conclusion and Future work

- ***The dynamic placement problem of UAV-BSs is studied in this paper.***
  - ***The ESN-based algorithm has high accuracy on predicting the next 5 minutes trajectories of the UEs.***
  - ***The KM-based algorithm satisfies the energy-efficient requirement of UAV-BSs reposition trajectories.***
- ***Future work.***
  - ***Studying how to predict non-straight trajectory to improve the performance of prediction.***

Thanks