Multi-Target Tracking Using a Swarm of UAVs by Q-learning Algorithm

Wenwu Wang, Pei Xiao, L. Mihaylova, Shidrokh Goudarzi, X. Liu, Ahmad Soleymani

Abstract

We proposed an algorithm for controlling multiple Unmanned Aerial Vehicles (UAVs) to track multiple targets in challenging 3-D environments in the presence of obstacles and occlusions.

A Q-Learning (QL) algorithm is used to improve the intelligence of UAVs on how to navigate autonomously and avoid obstacle collisions. The proposed QL-based controller selects the optimal joint control actions to achieve high tracking performance and obstacle avoidance.

The proposed method:

1. maximizes a novel reward efficiency function with joint consideration for computation time and energy consumption and obstacle avoidance.
2. learns the environment and its dynamics.

Our simulation results show that the proposed QL-based UAV controller provides a highly accurate target-tracking solution with low energy and delay costs.

Introduction

UAVs have become a promising technological platform offering high mobility, flexible deployment, and low cost [1]. UAVs have a higher chance of Line-of-Sight (LoS) links to ground users, compared to ground Base Stations (BSs). UAVs are able to provide fast, reliable, and cost-effective network access to regions poorly covered by terrestrial networks [2].

The Edge Computing (EC) technique can emerge as a promising solution to address the challenges imposed on UAVs [3]. The UAV-enabled EC is envisioned and developed as a viable option to improve the target tracking process.

We presented a new approach to RSSI-based multi-target tracking. We focused on a tracking environment where sensor nodes and UAVs are equipped with mobile RSSI sensors. We used RSSI because it has low cost, lower power consumption, intrinsic simplicity in hardware, and simpler receivers; furthermore, there is no need to have highly calibrated timing and synchronization between nodes.

We developed an algorithm based on Q-Learning (QL) to decide the control actions of UAVs in order to achieve accurate target tracking.

Key Contributions

The following are the key contributions of this study

- We propose a QL-based algorithm to control multiple UAVs in such a way that multiple targets are being optimally tracked in challenging 3-D environments in the presence of both LoS and NLoS conditions.
- We design a novel reward function to maximize reward efficiency function with joint consideration for computation time and energy consumption and obstacle avoidance.
- We verify the proposed approach through extensive simulation experiments and compare it with existing solutions.

Network Model

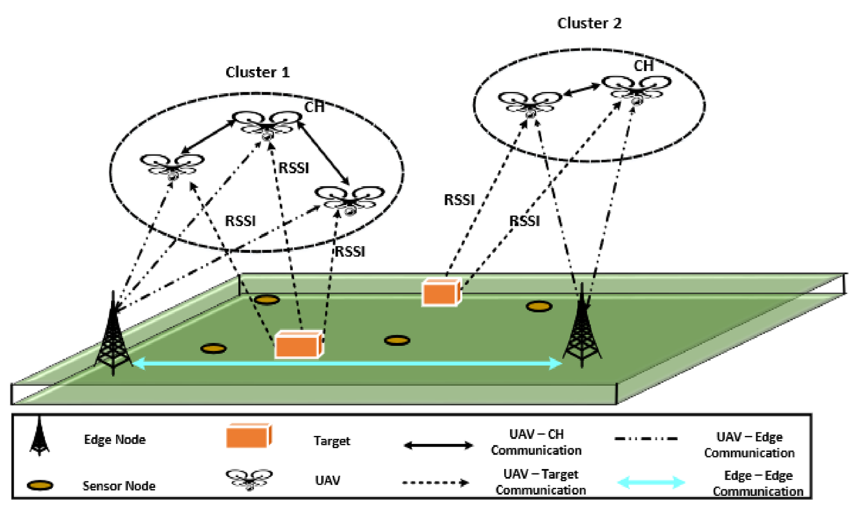

Figure 1. Network model.

Methods

We considered a swarm of UAVs. Once the position of the detected target is estimated, the Edge Node (EN) selects a swarm of nearby UAVs for tracking the target.

These UAVs make a cluster that consists of a Cluster Head (CH) and other UAVs that directly and wirelessly are connected to CH.

Since each UAV is limited by its battery capacity, EN selects a UAV with the highest battery as CH.

Since the Q-learning algorithm utilized in UAVs is a state-action algorithm, we considered some allowable control actions for UAVs that can be taken by them at each state. In this work, the number of actions is equal to 8.

Each UAV by performing the Q-learning algorithm and reward function included in the algorithm selects the best state among the 8 existing states and flies toward this state.

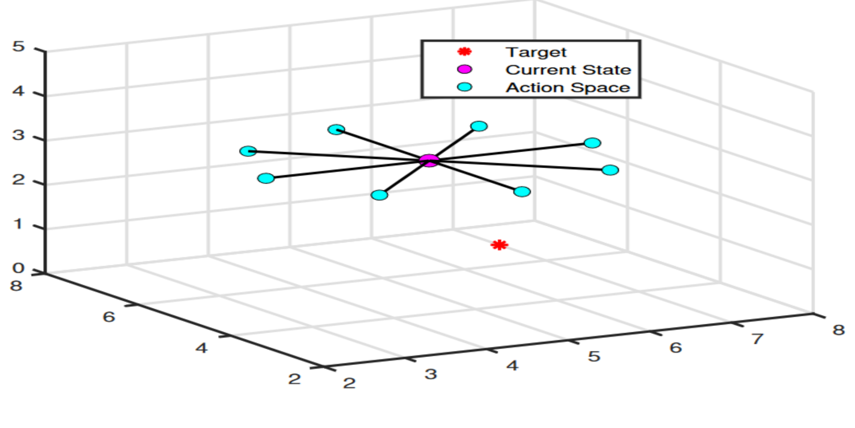

Figure 1. Allowable control actions, where the number of actions = 8.

UAV (UAV_n)	Cluster Head (UAV_{CH})
1- Run Q-learning	1- Run Q-learning
2- Choose the best next state Pos_n^{uav}	2- Choose the best next state Pos_{CH}^{uav}
3- Fly toward the next state	3- Fly toward the next state
4- Measure the RSSI from the power level of a received signal from the target $rssi_n$	4- Measure the RSSI from the power level of a received signal from the target $rssi_{CH}$
5- Send current position Pos_n^{uav} and $rssi_n$ to UAV_{CH}	
$\xrightarrow{\{Pos_n^{uav}, rssi_n\}}$	
	5- Run Multilateration function ($\{Pos_i^{uav}$ and $rssi_i$ for All i in the Cluster$\}$, Pos_{CH}^{uav}, $rssi_{CH}$)
	6- Send the output (Pos_m^{tar}) to UAV_n
	$\xleftarrow{Pos_m^{tar}}$
6- Go to Step 1	7- Go to Step 1

Figure 2. Process of our algorithm and data communication between UAVs and their cluster head.

UAV (UAV_n)	Cluster Head (UAV_{CH})
1- If the power of battery < Thrsld_1	
2- Send a warning message to EN	
3- Turn off unnecessary functions	
4- Send a request message to cluster head	
$\xrightarrow{\{Pos_n^{uav}, Req_n\}}$	
	5- Run the Multilateration function
	6- Send the output (Pos_m^{tar}) to UAV_n
	$\xleftarrow{Pos_m^{tar}}$
6- If the power of battery < Thrsld_2	
7- Send an error message to EN and cluster head	
8- Run the Landing function	

Figure 3. Process of UAV battery power monitoring.

Results

We evaluated our algorithm in terms of the task failure rate and searching time. The objective of numerical analysis is to investigate whether the proposed algorithm results in less task failure rate and less searching time compared to other state-of-the-art solutions.

We used MATLAB as the simulation platform for our algorithm evaluation. We created an environment with obstacles by creating a matrix that represents the environment and some cylinders and cones to represent the obstacles. In this environment, there are 2 targets and 5 UAVs for tracking targets.

We defined three scenarios to evaluate and analyze our model:

1. Scenario 1: Grouping three UAVs into a cluster and electing a UAV as a cluster head (CH)
2. Scenario 2: Grouping two UAVs into a cluster and electing a UAV as a cluster head (CH)
3. Scenario 3: non- clustered UAVs

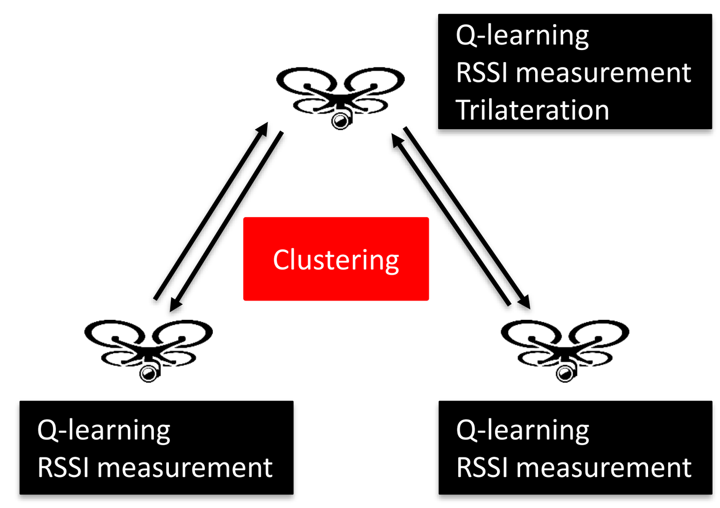

Figure 4. Target tracking based on clustering strategy.

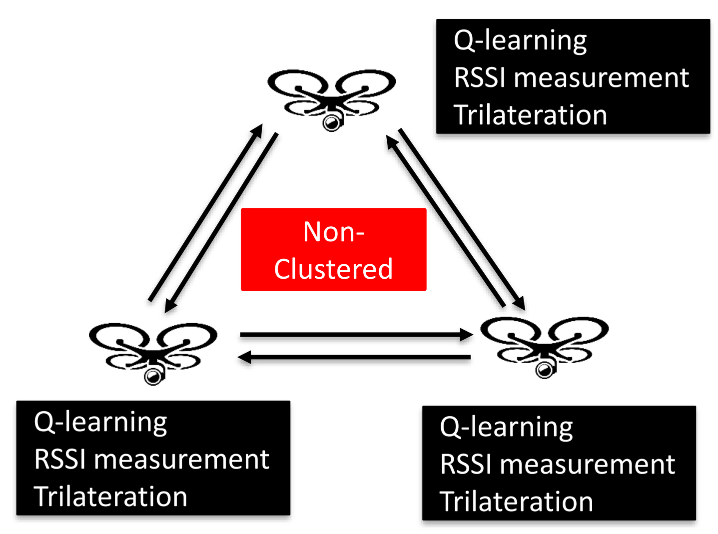

Figure 5. Target tracking based on the non-clustered strategy.

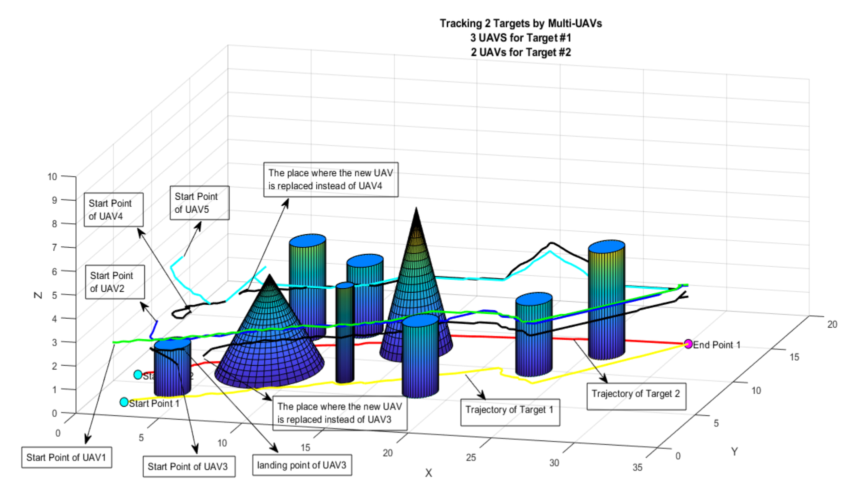

Figure 6. Tracking 2 targets by multi-UAVs (3 UAVs for target #1 and 2 UAVs for target #2).

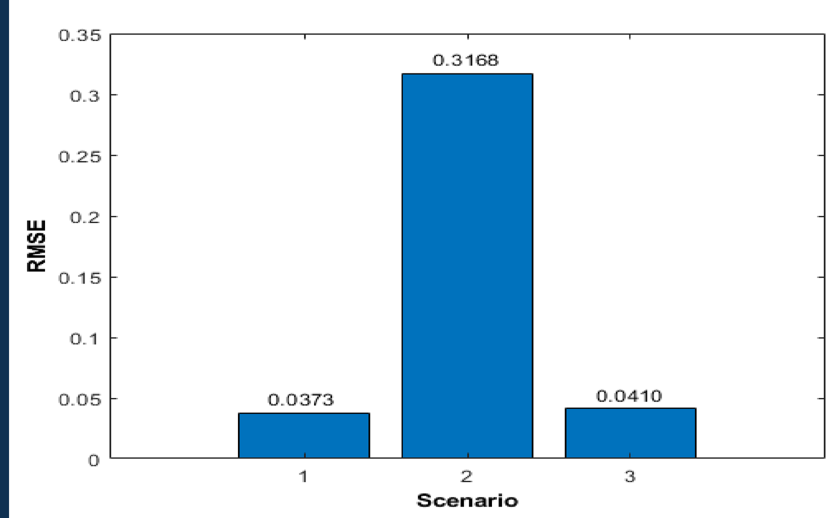

Figure 7. Comparison between 3 scenarios in terms of RMSE.

Results Cont.

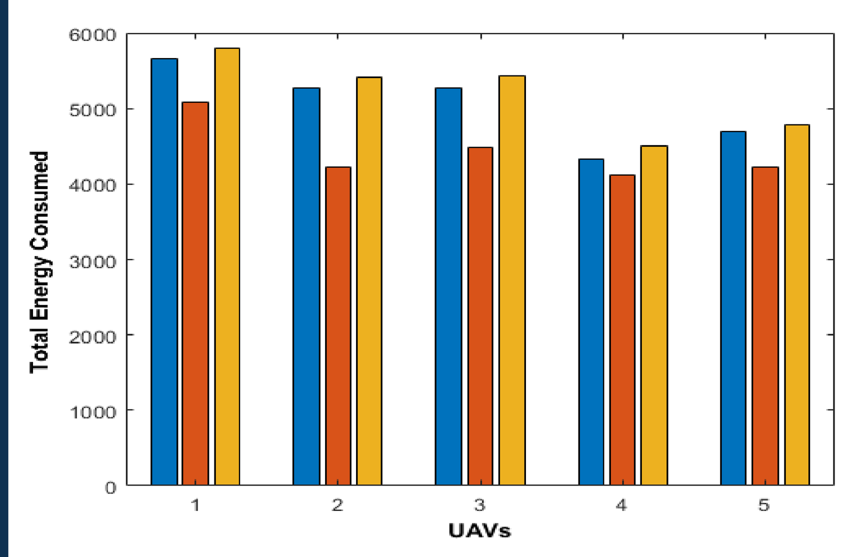

Figure 8. Comparison 3 scenarios in terms of total energy consumed by UAVs during the target tracking

Conclusion and Future Directions

- In this study, a Q-learning algorithm has been developed to track the target. The reward function developed in this algorithm is based on accuracy, energy consumption, and delay.
- The power of the received signals from the target has been used as input for the multilateration algorithm for estimating the position of the target.
- Our simulation results indicated that our algorithm for tracking multi-targets is effective and accurate.
- In the future, we will focus on the multi-agent Q-learning algorithm. We also intend to employ ToA and AoA instead of RSSI and compare these techniques in different environments and conditions.

References

1. Y. Zeng, R. Zhang, and T. J. Lim, "Wireless communications with unmanned aerial vehicles: Opportunities and challenges," IEEE Communications Magazine, vol. 54, no. 5, pp. 36–42, 2016.
2. S. Goudarzi, S.A., Soleymani, W. Wenwu, and X., Pei, "UAV-Enabled Mobile Edge Computing for Resource Allocation Using Cooperative Evolutionary Computation." IEEE Transactions on Aerospace and Electronic Systems, 2023.
3. Y. Mao, C. You, J. Zhang, K. Huang, and K. B. Letaief, "A survey on mobile edge computing: The communication perspective," IEEE communications surveys & tutorials, vol. 19, no. 4, pp. 2322–2358, 2017.

Acknowledgment

This research is sponsored by the US Army Research Laboratory and the UK MOD University Defence Research Collaboration (UDRC) in Signal Processing under the SIGNeTS project. It is accomplished under Cooperative Agreement Number W911NF-20-2-0225.

Contacts

Wenwu, Wang, CVSSP, University of Surrey.

Email: w.wang@surrey.ac.uk

Pei, Xiao, 5GICS, University of Surrey.

Email: p.xiao@surrey.ac.uk

L. Mihaylova, University of Sheffield.

Email: l.s.mihaylova@sheffield.ac.uk

Shidrokh Goudarzi, University of West London.

Email: shidrokh.goudarzi@uwl.ac.uk

X. Liu, University of Sheffield.

Email: xingchi.liu@sheffield.ac.uk

Ahmad Soleymani, CVSSP, University of Surrey.

Email: s.soleymani@surrey.ac.uk; a.soleymani@sheffield.ac.uk