Information Sciences 418–419 (2017) 74–90

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

QUAT-DEM: Quaternion-DEMATEL based neural model for mutual coordination between UAVs

Vishal Sharma*, Ravinder Kumar, Rajesh Kumar

Computer Science and Engineering Department, Thapar University, Patiala, Punjab 147004, India

ARTICLE INFO

Article history:
Received 17 February 2016
Revised 17 April 2017
Accepted 2 August 2017
Available online 2 August 2017

Keywords:
UAVs
Control
Drones
DEMATEL
Neural model

ABSTRACT

Networking between autonomously flying aerial vehicles requires efficient control and sustainable path for data transmission. Aerial nodes are extremely dynamic and provide a vast range of applications especially focusing on surveillance and data acquisition. However, these dynamic nodes are prone to unstable connectivity which hinders network operations, and also decreases the network lifetime. Such issues directly influence the control and relaying over aerial vehicles. Thus, it becomes essential to have an efficient strategy for controller selection and autonomous relaying. In this paper, a quaternion based neural model is proposed, which uses Decision Making Trial and Evaluation Laboratory Technique (DEMATEL) for the selection of network controllers and relays. The proposed algorithms are capable of selecting controller with a complexity $O(n)$, and provide cooperative relaying with a complexity $O(n \times k)$. The effectiveness of the proposed model is demonstrated by using simulations. The results show that the proposed approach reduces delays by 25% during the selection of controller, and increases the transfer speed by 20% compared to existing approaches.

1. Introduction

Unmanned aerial vehicles (UAVs), in a cooperative mode, are able to solve complex tasks more efficiently. These vehicles can form a homogeneous as well as heterogeneous type of networks which establish an interaction not only between each other but also with ground stations. Another aspect of networking with these aerial vehicles is ad hoc formation [20]. Ad hoc formation with UAVs involves enhanced configuration and control over the aerial vehicles [1]. Using multiple UAVs for mission-oriented applications can prevent the loss of pilot that might have incurred by flying under crucial circumstances. Ad hoc formation is not limited to connectivity between the nodes; rather, it also involves configuring the nodes with certain capabilities that provide efficient maneuvers to attain complex tasks. With the evolution of networked UAVs, other aspects to be addressed are fault tolerance, system failures, external intervention, stability, and control [29,32]. All these aspects are listed under controller selection and cooperative relaying. Efficient selection of controller refers to the choice of UAV which helps in stabilization of entire UAV network with the capability to decide their maneuvers based on the configurations and mission requirements [11]. This stabilization is determined with a consistent utilization of network resources so as to

* Corresponding author.
E-mail addresses: vishal_sharma2012@hotmail.com, vishal.sharma@thapar.edu (V. Sharma), ravinder@thapar.edu (R. Kumar), rajeshkumar_nagdev@hotmail.com (R. Kumar).

http://dx.doi.org/10.1016/j.ins.2017.08.005
0020-0255/

enhance the overall lifetime of the aerial network. The primary focus of controller selection is the choice of best possible UAVs for relaying and distribution of load on the basis of available resources such that network failures are minimized; and fault tolerance is maximized. The control and decision can be attained through Decision Making Trial and Evaluation Laboratory (DEMATEL) approach [30,31].

DEMATEL allows convergence at a solution for controller selection and cooperative relaying at any instance of time during whole network connectivity. DEMATEL helps in identifying those UAVs which have values of certain parameters greater than the threshold values so as to allow the best possible combination of UAVs to be selected for solving complex tasks. However, DEMATEL alone cannot provide stability to a network. Network stability can be attained using a neural model which senses the learning of system and helps to attain the state of equilibrium. This equilibrium state is the best possible configured mode of a network. The neural model helps in maintaining a stable state which is capable of providing a cooperative solution to complex problems along with the efficient handling of resources. This neural model keeps on learning with each iteration and converges towards an ideal state with maximized fault tolerance and zero failures. Practically, this ideal state is not possible to attain, however, it is used as a benchmark to analyze the efficiency of the proposed approach. This can be further explained by considering the following example: Let N be the number of UAVs configured for a particular mission. Assume that the minimum number of UAVs to be active at time instance t be $\frac{N}{4}$. Therefore, it is the responsibility of the neural model to maintain such stabilization over the network so that the required number of minimum UAVs is always active to provide constant connectivity throughout the mission.

In practical environments, network failures are liable to occur. It is not possible to keep network aloof from uncertain failures, thus, a neural model should be capable of adjusting its learning and feedback rate so as to enhance the performance of the entire network. Also, the network should maximize its lifetime for supporting extensive utilization of network resources. This neural formation is supported by quaternion model over the network. These quaternions identify the network controlling parameters and form the stabilization equations to control the network. Therefore, the proposed model has been termed as "QUAT-DEM: Quaternion-DEMATEL based neural model". Another controlling feature for network formation with UAVs is cooperative relaying. A network must be capable of providing a continuous path based on the available resources to allow transmission without any hindrance. Also, the number of active connections available at any given time must be greater than the certain threshold value to provide effective transmission. Cooperative relaying prevents any loopbacks and delays that might occur if the selected UAVs are unable to relay as intermediate nodes. In a nutshell, cooperative relaying provides a network with a set of active UAVs which are capable of coordinating and disseminating information for efficient transmission.

The presented work focuses on the selection of a controller and cooperative relaying over the networked UAVs. A quaternion model is proposed which is integrated with DEMATEL to converge at a solution for selection of efficient UAVs. Further, this quaternion-DEMATEL model has been used to design a weight based neural model which is capable of stabilizing the whole network. The model also incorporates the learning and feedback model to converge network towards the stabilized state for maximizing its lifetime. The key features of this work are:

- Selection of a controller and cooperative relaying between the UAVs.
- Stabilized network formation with minimized network failures.
- Maximized network lifetime with efficient utilization of network resources.
- Selection of appropriate UAVs for efficient data transmission.

1.1. Problem definition and contribution of this work

The selection of UAVs as a controller for a mission depending upon available resources and requirements is really a tedious task. Thus, for finding a suitable solution, the entire problem has been divided into two parts. The first part of the problem deals with the selection of best possible UAVs and optimally computes their precedence on the basis of available resources. These resources can be evaluated on the basis of pre-configured or dynamically assigned mission. The proposed approach follows a pre-configured mechanism to evaluate the defined strategy. The second part provides best possible relay paths using link connectivity between the active UAVs. Here, 'active' refers to those UAVS which satisfy all the threshold conditions defined for network coordination. The selection of the best possible controller and relays helps in the formation of a self-sustainable network which can take a decision on its own in case of failures or interruptions.

The paper contributes significantly by developing a novel neural model using Quaternion-based DEMATEL approach. To the best of our knowledge, till date, these two methods have never been integrated for defining an algorithmic solution in the selection of controllers and cooperative relaying. Quantitative, as well as robust simulations presented in the manuscript, prove the novelty of the model. The proposed approach is highly dynamic, and the number of parameters can be easily scaled by their simple inclusion in the initial quaternion model. This feature makes the proposed approach an efficient and unique way of handling the UAVs network. Currently, five sets of parameters are used for defining the system equations; however, this can be scaled to as many parameters as required for taking a decision on the selection of a controller as well as the relays. Further, the major advantage of adopting the proposed approach is its lesser dependency on algorithms and higher on equations. Since these equations can be solved in a constant time, the overall running complexity of the proposed approach is very low. This can be used to replace the next hop selection in most of the existing routing protocols that target