Distributed SDN Based Network State Aware Architecture for Flying Ad-hoc Network

Muhammad Saqib [1], Asif Mehmood [2], Adeel Rafiq [3], Afaq Muhammad [4], Wang-Cheol SONG [5, *]

Department of Computer Engineering, Jeju National University, Jeju-si, South Korea

em.saqb@gmail.com, asif@jejunu.ac.kr, adeel.rafiq@jejunu.ac.kr, afaq@jejunu.ac.kr, kingiron@gmail.com

Abstract - Flying networks are resource constraints while the nature of nodes' mobility is very dynamic and unpredicted. Therefore, these networks are very prone to link failure and performance degradation. By considering the existing limitations, this work proposes a new approach consists of proactive and reactive network failure mitigation techniques that have been named as a hybrid approach. In the proposed architecture, the SDN controllers are distributed where each one controls its local domain nodes. The controller node continuously monitors the network state information and proactively adjusts the near-future changes to the topology. Each local domain also contains a sink node that directly connects to the controller. The sink node is used to forward the network state information to the controller and keep the controller defined flow rules for local domain nodes. The sink node can also request a new path in case of any link failure or any topology updates cause by nodes' movement. Besides, a distributed routing protocol also runs on domain nodes to establish connectivity toward the sink node.

Keywords: Distributed SDN, UAV, Routing, Flying Network

I. INTRODUCTION

The network properties do not remain stable in the aerospace network but change constantly due to the dynamic nature of networks. These high dynamics cause multi-interconnections in the network, which pose a challenge of the instability of network links and lead to network performance degradation. The problem cannot be treated in a conventional way such as adding redundant links in the network, which can lead to inefficient use of resources. The network availability and performance can be considerably affected by the random movement of Unmanned Aerial Vehicles (UAVs). The possible solution is to continually monitor the network state information [1]. To be more specific, the UAV mobility can be measured which can assist the optimal proactive routing decision in the network. Hence, a central control unit can be placed in the network to perform intelligent decision making for the nodes' routing, based on overall network-level knowledge.

Software-Defined Networking (SDN) is a preferable solution with innovative applications and adaptive control aspects. SDN is the most widely used approach for central control of the network, which eases network management and offers a promising approach toward proactive configuration in the network [2-4]. Although the SDN based approaches have been used as optimal solutions for various applications, it also raises scalability and reliability challenges. Such challenges have been addressed with the decentralization of the control plane [5]. Moreover, the physically distributed and logically centralized approaches introduce an additional set of challenges that have been further categorized as centralized and distributed solutions [6].

The SDN based designs are largely used for ground network applications. Later, an effort has been made to replicate this success in the flying network. For instance, the SDN controller integrated with the load balancing module results in considerable power saving in the flying network [7]. The problem of robust migration service is addressed in a high mobility network such as a UAV swarm [2]. The UAV location planning problem is addressed for Quality of Service (QoS) improvement in real-time applications such as real-time video monitoring [8]. The SDN based central approach is designed for UAV-assisted infrastructure-less vehicular networks with the realization of efficient data processing by using computation task offloading [9]. Another work introduced software-defined flight ubiquitous sensor network (FUSN) to play a role of the SDN controller and suggested that routing and sensing modules should be deployed in different UAVs [10]. Moreover, the SDN solution is also deployed to maximize UAV network performance [11]. Another study has been conducted to control the communication overhead with the optimal placement strategy of the SDN controller [12]. Also, the controller placement was studied to reduce the hope counts of control packets in the network [13]. There is no single approach that can address the failure prediction/recovery and joint optimization between network performance and scalability. We mainly define three UAV research challenges that SDN can ideally handle:

a) Failure prediction: due to the dynamic nature of network topology, the nodes appear and disappear very simultaneously. Therefore, link failures are unpredictable. It is highly desirable to predict the link failure based on nodes' mobility and network state information.
b) Failure recovery: in case of unpredicted link failure at flying nodes, the longer time delay may result in socket closures for connection-oriented protocol flow. A solution is needed to provide the fastest link recovery in case of unpredicted ink failure.
c) Network Scalability: to provide an acceptable level of service to the packets even in the presence of a large number of nodes in the network.

In the following section, a detailed architecture is presented for highlighting the control plan functionalities. The basic testbed and experimental results have been shown in Section III. Concluding remarks and future work insights are discussed in section IV.

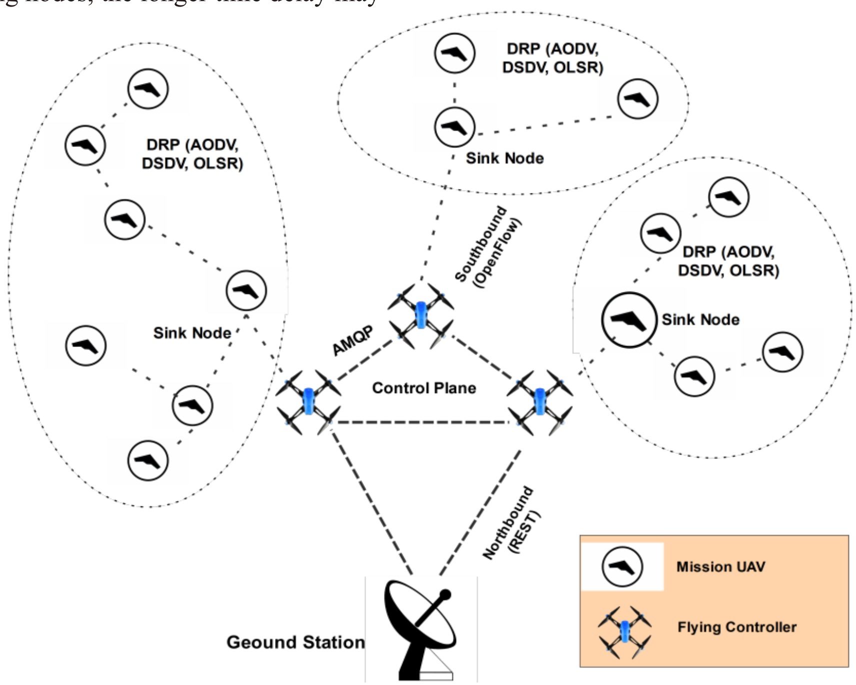

Figure 1. Detailed diagram of the proposed network architecture

II. PROPOSED ARCHITECTURE

A network state aware and scalable architecture is highly desirable to timely predict the link failure in the network. Many approaches can be used to achieve these objectives. For instance, a central SDN controller can be used to monitor underlying network resources and install the corresponding flow rules to the network switches. By doing so, the network resource utilization can be achieved which can lead to improved performance.

Although the central SDN control plan can fulfill the requirements of next-generation networks, but there are several problems associated with it. For instance, a single control can be a single point of failure. Also, the huge control traffic overhead can put an extra load on the controller, which can be resulted in performance degradation. Therefore, we consider the fully distributed SDN control plan by dividing the network into multiple different zones, each zone has a local domain controller. The domain controller is responsible to control its local domain nodes and exchange its topology updates with neighboring controllers to form the global network view.

Moreover, we also used the distributed routing protocol on network nodes to establish connectivity with the sink node in case of unpredicted failure. Hence, we further subdivided our system into network architecture, controller architecture, pro-active/re-active configuration.

A. Network Architecture

The proposed architecture is designed based on SDN, broadly divided into three plans: application, control and data plan. The ground station is logically centralized residing on the application layer, responsible to monitor and control the whole network. The central ground station may have connected to at least two flying SDN controllers and can send desired commands to the mission UAVs. The control layer is composed of physically distributed domain controllers. Some flying UAV nodes with considerable resources are dedicated for controlling purpose, where each one controls its local domain and share its local topology information with neighboring controller nodes using coordinator module to form a wide network view on each controller. The protocol called AMQP is chosen for messages exchange between controllers. AMQP is the most appropriate one due to its publish/subscribe nature. The data plan is where all the mission UAVs are residing. Due to the random unpredicted movement of UAV, the controller may beyond line-of-sight for some UAVs. Therefore, the UAV nodes follow ad-hoc network principles, where the nodes can be controlled directly or using multi-hopes. The detailed diagram of network architecture is shown in Figure 1.

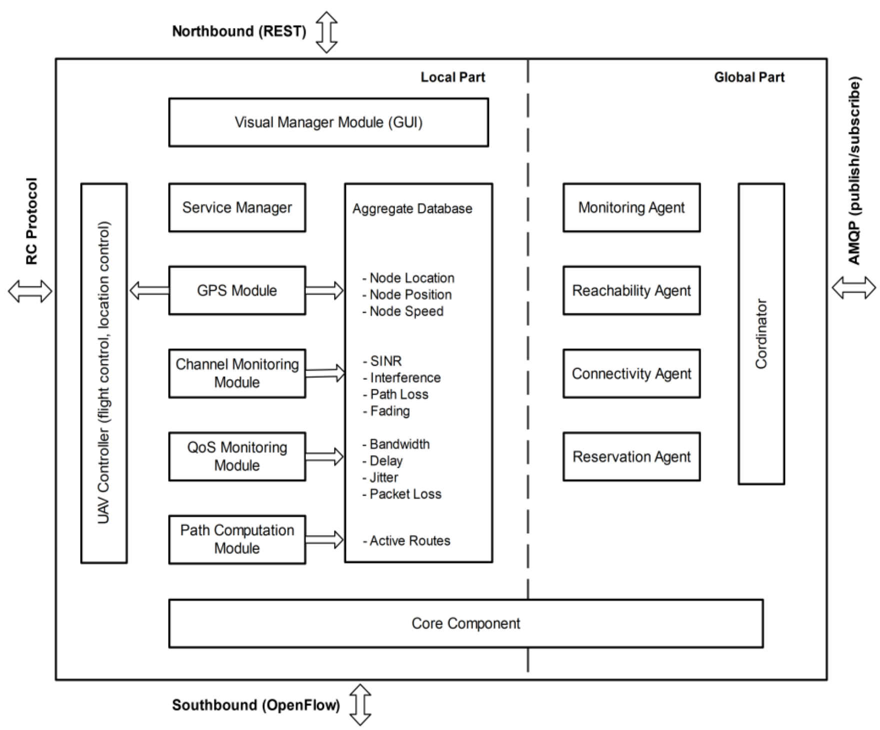

Figure 2. SDN Controller Functionalities Diagram

B. Controller Design

With the realization of autonomous decision making at the network, our proposed SDN controller is consisting of UAV control and network control part. The flight controller part is responsible for UAV path planning while the SDN control part is responsible for the communication channel control, power allocation and optimal flow rules installation of the network switches. The SDN controller can make intelligent decisions based on network-level knowledge, such as nodes' location, channel capacity, the signal strength of wireless links and network delay. All this information is used to collect periodically from the data plan. Moreover, the relationship is collaborative between the SDN controller and the UAV controller. The control function is further divided into two levels: the local level, where the main functionalities (aggregated DB, QoS monitoring, path computation & GPS coordinates) of a local domain are performed; and the global level, which make a global network view by sharing local domain information with neighboring controllers using coordinator module. Each controller is adequately intelligent and it can control its local domain independently. The controllers which are in the range of ground station may periodically share the summarized network data to the ground station. The detailed diagram of the distributed controller is illustrated in Figure 2.

C. Hybrid path establishment approach

SDN controller is responsible to proactively adjust the network structure based on the network state information and nodes' mobility behavior. Whereas, sufficient intelligence is also embedded into UAV nodes to re-actively configure the links in case of unpredicted link failure. Both mechanisms are combined as a hybrid approach. A detailed sequence diagram is presented in Figure 3.

The mission UAVs resides on the bottom layer to perform different application tasks. It collects various types of information (e.g., channel properties and node mobility information) to help the SDN controller for making optimal decisions. The network links are very prone to failure due to the random movement of nodes. Therefore, the establishment and maintenance of optimal network topology are tightly coupled with the establishment and maintenance of an optimal packet routing or switching solution, the use of a centralized controller for SDN style forwarding is not strictly required. An alternative is to embed sufficient intelligence into network nodes. Therefore, the reactive distributed protocol called AODV [14] is chosen to use, to make connectivity by following an alternate path in case of unpredicted link failure.

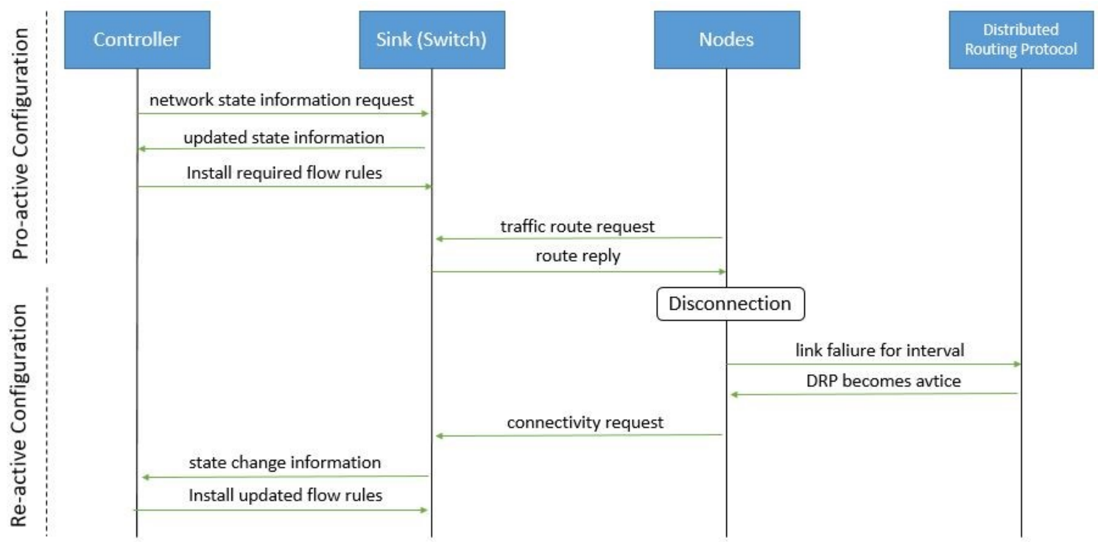

Figure 3. Sequence diagram of hybrid approach

III. RESULTS & DISCUSSION

In the first part of this section, we evaluate the system performance in a proactive state where the SDN controller early predicts link failure based on network state information and proactively adjust the network topology. After this, we evaluated the system performance in the reactive phase, where a single UAV node lost its connectivity with the network due to unpredicted link failure and the reactive routing protocol is used to establish a connection by using nearby neighboring nodes.

A. Collection of topology information

In the underlying network, some nodes may not directly have connection with the controller. Therefore, each node must learn a path to reach the controller. To achieve this, the controller periodically broadcasts beacon packets for network nodes. The network packet has entries for numbers of hop count (distance from the controller) and battery level of the node. Upon receiving a packet, each node overwrites its current battery level information and increase the value of the current distance from the controller, and forward the packet. Moreover, each node also measures the RSSI value in the link towards the nodes that have just transmitted the beacon. Each node has a neighbor table and stores a RSSI value of the directly connected node's link. All nodes periodically share their neighboring nodes' information with the controller as a report packet, and thus the controller can form a global topology [15].

The network nodes can identify the best next hop toward the sink node by looking at the beacon packet contained information and measured RSSI value. To be more specific, first priority will be given to the lowest distance toward the sink node; secondly, the nodes will be chosen with the longest priority while the node toward which the highest RSSI value will be chosen last.

B. Proactive topology configuration

Since, we are only interested in estimating the link failure probability, by using nodes' wireless link properties and mobility information, so the exact future location of UAV is not required. Each node is configured to observe fast mobility of its neighboring node by using the RSSI value, as there is a negative correlation between signal strength and distance coverage, therefore each node measures the signal strength of its connected links against a specified threshold. When the signal strength of a particular node goes below from the defined threshold, the node generates a notification toward the controller. The controller node then collects the GPS data of that particular node to verify the mobility. The controller tries to find expected changes in the network topology based on node position and velocity. Based on the estimation of future expected location, the controller installs flow rules to that area nodes, so that a UAV can have new path connectivity thorough newly installed rules at neighboring nodes without any delay. Currently, the system performance has been evaluated in a simulating environment where the performance metric has been set to network throughput. In the experimental phase, we first predicted the nodes' mobility in the network using velocity and position information. Secondly, by using the ONOS controller and Mininet-WiFi, we installed the desired flow rules to the sink node and generated 1MB data rate traffic from H1 node to H2, H3 and H4. Meanwhile, the H3 and H4 have changed their location but the network throughput remained better as shown in Figure 4.

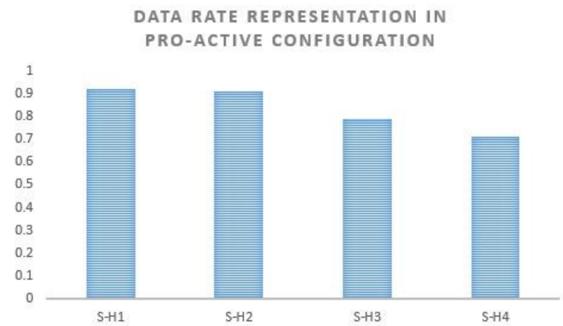

Figure 4. Network throughput and delay in proactive mode

C. Reactive connectivity establishment

The distributed routing protocol called AODV runs at the network nodes in sleep mode. When a node loses its connectivity for a specific time interval, its routing mode switch to reactive and the AODV becomes active to find a nearby node and establish connectivity with the network. For the system performance testing in reactive phase, we generated data traffic between two nodes residing at the same domain. During transmission, we manually disconnected a specific node and after a defined interval, the concerning node establishes its connectivity to the network and starts data transmission. Due to this connection establishment process, some packets get lost and the network throughput between H3 and H4 has been compromised as shown in Figure 5. Although the network performance has been decreased in this phase, but we assumed the reactive approach just for unexpected failure, while normally we predict the near future changes to proactively install the expected flow rules to the switches.

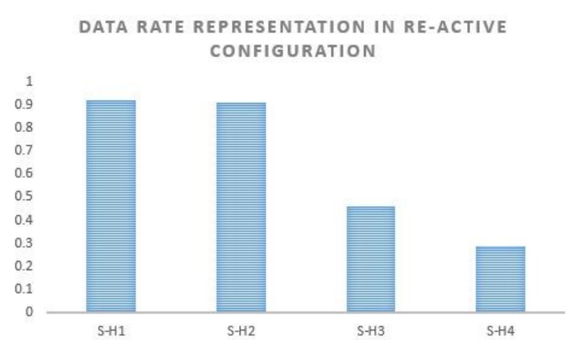

Figure 5. Network throughput and delay in case of connectivity re-establishment

IV. CONCLUSION & FUTURE WORK

The proposed architecture uses a hybrid network configuration approach to completely mitigate the network failure or reduce the failure time by combining the proactive and reactive configuration methods. The detailed design of the system has been presented and the performance of the proposed system has been evaluated in a simulated environment. It has been noticed that the proactive approach is far better from reactive in terms of achieving better network throughput as well as lower delay time. Although, it creates extra network overhead, but it still acceptable in a critical communication environment.

Soon, we plan to target the scalability issue and test the system performance in a highly dense network. We also plan to perform inter controller communication with a focus on the best synchronization strategy for sharing network updates. Last but not least, we are trying to go ahead toward the real-time implementation of this proposed architecture.

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