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Research on Multi-UAV Networks in Disaster Emergency Communication

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Abstract. Unmanned Aerial Vehicles (UAVs) are an emerging technology that can be used in military, public, and civilian applications. Military use of UAVs is more than 25 years old, mainly for border surveillance, reconnaissance and so on. UAVs can do the job more efficiently and cost-effectively than with a single UAV system. In disaster emergency communications system, UAVs system can be deployed rapidly and its coverage can be dynamically adjusted. It provides network support for disaster site rescue in a timely and efficient manner, and real-time information of disaster scene can be returned to the Rescue center to better rescue the affected people. This dissertation proposed SDN-based disaster emergency UAVs networks to realize the flexible deployment and management of high dynamic dis-aster area networks. Meanwhile, it has a significantly improvement in network lifetime and node switching time comparing with Optimized Link State Routing protocol (OLSR) and Ad hoc On-demand Distance Vector Routing protocol (AODV).

1. Introduction

Large-scale natural disasters often test the most basic survival instinct of human beings by causing huge and unpredictable losses of human life and property. Various types of natural disasters, such as geological disasters (earthquakes, volcanic eruptions, landslides and avalanches), hydrological disasters (floods, river dam breaks and mine intakes) and meteorological disasters (tropical storms, hurricanes, dust storms and heavy rain), result in many deaths [1]. Many people are trying to figure out how to respond to a natural disaster in a timely and effective way from the beginning, so as to quickly reduce the loss, to solve problems such as the rescue of victims and restore normal conditions as soon as possible.

Other When a disaster occurs, people tend to organize themselves to build a disaster relief command center and a real-time disaster observation platform to effectively direct disaster relief workers to carry out disaster relief work in real time according to the dis-aster situation. Thus, the communication between the disaster relief command center and the rescue personnel is particularly important in the whole process of disaster relief, and the commercial network (such as network operators) in the disaster area is often destroyed by the disaster.

When ground communications are not possible (such as earthquake recovery, forest fires, etc.), the use of UAV networks, also known as Unmanned Aeronautical Ad-hoc Network (UAANET) [2]. The UAV network could be deployed in disaster scenes and other critical scenarios to provide communications services to ground nodes that could be people carrying portable equipment such as smartphones and personal computers. In addition, a UAV network can be deployed at the object location to monitor the disaster zone, so that rescuers can search and track people or animals in need. Moreover, the UAV network can span multiple square kilometres and be able to adapt to changes on the ground. Since the UAV can move around the region on demand, the use of UAV networks in emergency situations is flexible and scalable.

Recently, more and more unmanned aerial vehicle (UAV) network display and application show that it can provide a wire-less network set up quickly and large coverage, but the survival time of UAV network nodes generally shorter, especially small rotary-wing UAV system, low prices for rapid deployment of emergency communication much lower costs UAV network has brought certain difficulties, and making it easier for the network backbone nodes drops due to run out of battery, and make the network topology changes frequently and make the network coverage unstable.

In order to enhance the network stability and stabilize the coverage of emergency networks for disaster area in the front of disaster area and the rear of the command, this paper proposes an emergency communication multi-UAV network scheme based on SDN. In our method, UAV creates a backbone network with variable topology, which has strong advantages in network lifetime time, service response time, etc., and can provide long-term stable network coverage service in disaster emergency communication network construction. To this end, the rest of this article is organized as follows. Section 2 discusses and proposes an emergency communication multi-UAV network scheme based on SDN. Section 3 presents the proposed scheme and performance evaluation of two common routing protocols. Finally, section 4 summarizes and prospect of the future work.

2. Multi-UAV Network Architecture Based on SDN

At present, the research on integrating SDN into the network of drones is still underway, and many of the most critical new network architectures have been proposed. In the control layer, application layer and data layer, the deployment of the three layers is mostly the same. The biggest difference is the key deployment in the control layer. In the early days, the east-west interface in the SDN controller has not been carefully studied, which has deployed on the ground station.

NOCC (Network Operation Control Centre) is the application layer of SDN. It is mainly responsible for route calculation and service-driven policy generation. The controller is deployed on the ground, transforming instructions from the upper NOCC into simple data structures (such Open Flow’s flow table) and sending them to the underlying infrastructure layer [3]. Many drones organize the infrastructure layer of the network architecture, and have their network coverage areas, in which ground nodes and other drones can directly interact with the drone network. The UAV network architecture distributes routing policies through ISLs, or configuration instructions for network devices.

To achieve real-time and flexible central control of the UAV network, routing tables and configuration policies are uploaded to all UAVs via single-sided ISL forwarding or broadcast. At the same time, the agent on the drone continuously collects the link information of the UAV coverage area, including the remaining link bandwidth, power status and payload status, and sends it to the control layer drone above it. The control layer drone (same as the high altitude drone) then sends status information directly to the ground. All information obtained will eventually be processed on the NOCC.

For single-layer ISL forwarding, we can reduce the cost of redundant broadcast packets by using the shortest path tree and the multicast tree. These trees are included in the snapshot routing table obtained in the last update. The UAVs in the middle and low altitudes are constantly rotating and moving, and the UAV links and the UAV-to-Ground links also change. These changes require an update to the configuration, but there will be some delay in the update [4]. It is therefore difficult to decide the correct time to switch to the updated routing table and configuration of the entire network. Therefore, in this architecture, the control layer drone is used to broadcast the entire network for network update. By taking advantage of the wide coverage of the control layer drones, only three control layer drones can coverage almost 12 square kilometres of, so updates can be sent to the control layer drones. After the current control layer drone receives the update information, it sends it to the other two control layer drones and then sends them all to the covered medium/low altitude drone. We found that control layer drone broadcast updates are significantly faster and easier than ISLs forwarding. However, when we only need to update a small number of drones, the broadcast properties of the control layer drone will interfere with many other drones at the same time, because these work waste bandwidth [5]. Therefore, the control layer drone is responsible for broadcasting

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large-scale updates, while the small-scale configuration update is more suitable for single-layer drones' link forwarding. The hybrid control of the control layer drone and the medium/low altitude drones greatly reduces the update time and reduces the dependence on the ground nodes [6].

2.1. NOCC: Application Layer

NOCC acts as an application layer, running a large number of computing and control applications. The track of the drone is predictable. The NOCC can calculate the routing strategy of the UAV network and the configuration strategy of the network device by using the predicted data and collecting the link state information transmitted from the UAV. As the most important part, the routing method uses a simple and controllable snapshot routing method. This method divides the operating cycle of the system into a number of small time segments, and each time segment corresponds to changes in the network topology, particularly the destruction or reconstruction of the inter-UAVs link caused by the drone motion. During the divided time period, the network topology can be considered as unchangeable, and each time period becomes a snapshot. Based on the topology information, the NOCC calculates the entire network routing path using the current network traffic status information and then uploads it to the drone through the ground node.

2.2. Ground node: Control Layer

The ground node acts as a controller in the SDN framework and is separate from the NOCC for a clearer and simpler hierarchy. The configuration strategy calculated by the NOCC cannot be directly used for the underlying physical device, and needs to be converted into a data structure in the OpenFlow protocol through the ground node. The transformation is critical to the open interface design of the infrastructure layer, so drones can provide great flexibility and complex functional structures through simple implementation. However, various protocol conversions and open interface design make the controller more complex than the other two layers. The motion state of the drone can be monitored by the ground node, combined with the UAV network status information received from the drone. This information is very important for NOCC to construct a global network view and calculate the transmission rules, but the information must transform from ground nodes. The controller is deployed on multiple ground nodes and runs a coherent protocol to avoid single node fault and to ensure a consistent global network view between these nodes.

2.3. Drone: Infrastructure Layer

In traditional drone networks, drones are the most expensive to develop and the most complex facility. In the SDN-based UAV architecture, the functionality of the UAV in the architecture can be simplified. They receive user management policies, hardware configuration information and updated new routing tables from the ground station to enable NOCC deployment on the UAV network. During the operation of the network, the drone transmits the UAV data and network status information collected in real time back to the NOCC, so that the NOCC constructs the topology of the UAV network. Simplification on drones reduces drone development and production costs, saving resources. The software-defined mode simplifies management and makes the network more flexible and controllable.

Due to the development of the east-west interface of SDN control, the controller deployment is gradually enriched. It is proposed that the controller is mainly deployed in the cluster on the high-level UAV and ground nodes. On the basis of the single-controller UAV network, the controller cluster UAV network architecture is shown in Figure 1.

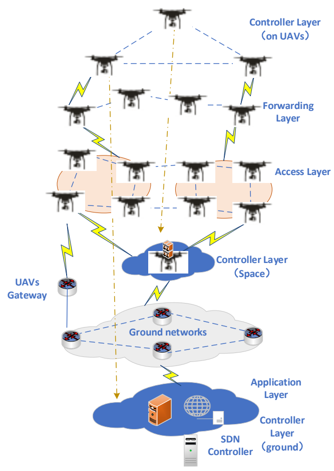


Figure 1. Multi-controller cluster drone network architecture.

2.4. Application Layer
Due to the limited processing power of the drone, the application layer is responsible for routing policy calculation, security and resource management strategies. In other words, it is the coordinator of the entire network. The application layer formulates policies based on the drone network conditions collected by the control layer drones and user needs. These policies are sent to the control layer drone to direct traffic between the drones.

2.5. Control Layer
Considering the global view of the entire network and the reliability of the link, the control layer is divided into three layers: drone, space, and ground control layer. That is, the controller cluster is deployed on the high-altitude drone, and the space drone (such as an airship), and ground stations within the coverage of high altitude drones. The high-altitude drone collects the link state information between the drones. Through the consistency protocol, the information is synchronized on the space and the ground controller, and is managed by the application layer. At the same time, the indication of the application layer is controlled by the ground controller, which is synchronized to the control layer drone and then sent to other drones. When the application layer instructions interact with the ground controller, they are converted to OpenFlow flow tables and distributed to medium altitude drones. Therefore, the transmission of drone data is controlled by a high altitude drone.

2.6. Forwarding Layer
The control decision part and the forwarding hardware are separated, and only the forwarding function is reserved on the medium altitude drone. The flow table of the medium altitude drone is configured by the dynamic controller. When data from a medium altitude drone/low altitude drone arrives, the mid-elevation drone searches the flow table to match forwarding information. These packets are then forwarded to the next drone and the flow table is used to reserve network resources for flow table. This can greatly reduce the processing burden of the mid-elevation drone.

2.7. Access Layer
Compared with the high-altitude drone/middle-altitude drone, the processing burden on the low-altitude drone is not too great, and the low-altitude drone is less difficult to develop and cheaper [7]. Only the basic access function and partial forwarding function are left on the low altitude drone. If the transmission distance is short, the data is forwarded between the low altitude drones via the ISL.

3. Disaster Emergency Multi-UAV network simulation
This simulation experiment is aimed at emergency UAVs communication network based on common task scenario building simulation model, with KVM virtual machine + entity SDN switches in the

form of the semi-physical simulation platform of real business simulation, and build SDN-based network architecture and traditional routing based respectively, on the basis of this to the entire communication process to make a detailed performance test and evaluation, and compared the performance differences between different implementations.

3.1. Simulation Environment Construction

The structure diagram of the simulation system is shown in Figure 2. The following describes the hardware and software environment required by the system according to different layers.

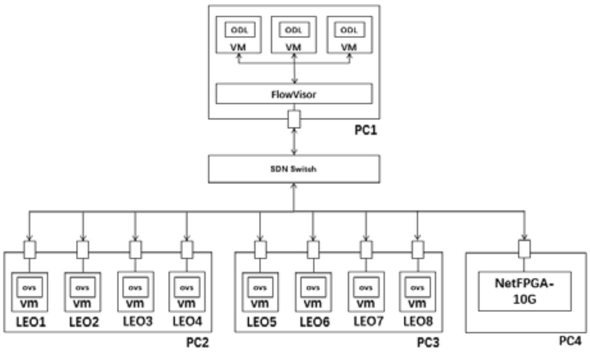


Figure 2. Simulation system block diagram.

Table 1. Computing Environment Description Table.

Computing environment description				
	CPU	RAM	hard disk	Network card
Server 1	Intel Core i7 quad-core and above	24 g-DDR3	240GSSD	Intel E1G44ET2
Server 2	Intel Core i7 quad-core and above	24 g-DDR3	240G SSD	4 x1000base PCI - E - T
Server 3	Intel Core i7 quad-core and above	24 g-DDR3	240G SSD	4 x1000base PCI - E - T
Server 4	Intel ® Pentinum ® G620	8 g - DDR3	240G SSD	Realtek PCIe GBE Family Controller

Table 2. Network Environment Description Table.

Network environment description		
	Introduction	Performance parameter
SDN switches	Shengke V350 cost-effective high-performance SDN /OpenFlow switch	240Gbps (8x1GE+12x10GE) forwarding capability with rich Open Flow features
Ordinary switch	TP-LINK TL - WR842N	4 10/100M adaptive LAN ports, 1 10/100M adaptive WAN port, auto flip (Auto MDI/MDIX)
NETFPGA	Xilinx XC5VTX240TFFG1759 Virtex - 5	Support SFP+ 10Gbps interface

Table 3. Software Environment Description Table.

Software environment description		
	Introduction	Version
OpenVswitch	Distributed high quality multi-layer virtual switch supporting multiple physical machines	2.5.0
Flowvisor	Network virtualization tool based on OpenFlow	2.1
Opendaylight	JAVA-based open source SDN controller	Be 0.4.1
Iperf	Mainstream network performance testing tools	0.2
VLC player	Is an open source cross-platform multimedia player and framework for playing most multimedia files	1.1.9
KVM	Open source system virtual machine based on Linux platform	0.12
Ubuntu Kylin	Ubuntu-based Chinese customized operating system	14.04

3.2. Simulation Scene Description
This scenario simulates a wireless communication network composed of multiple airship nodes covering a large area, and using an instance of remote video on demand service to realize uninterrupted data flow. The diagram of simulation scenario is shown in Figure 3.

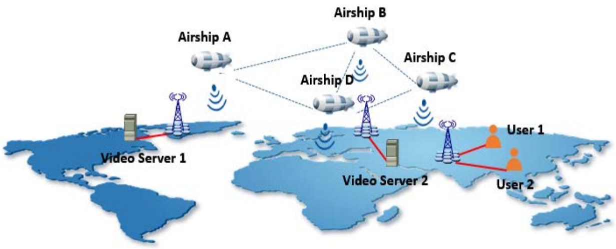


Figure 3. Schematic diagram of simulation scene.

User 1 initiates video server 1 to the video on demand service request, smooth playback of video to start a business after a successful build, followed by user 2 initiate a video-on-demand to video service 2, we use the schemes of traditional distributed routing and SDN-based centralized control to test separately. And evaluate the performance of the two schemes in network traffic scheduling.

3.3. Contrast Test Plan

3.3.1. Traditional routing scheme.
The network topology of this test solution is shown in Figure 4. Two traffic flows 1 and 2 are constructed in the figure, from server 1 to user 1 and server 2 to user 2.

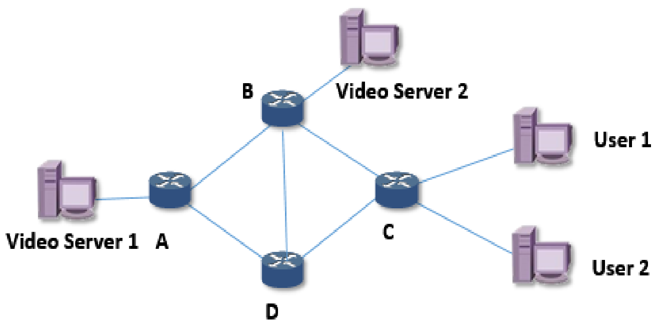


Figure 4. Traditional routing test solution topology.

Now the AODV routing protocol and OLSR routing protocol are respectively used to test the traditional routing solution:

First of all, AODV(on-demand distance vector routing protocol), as a kind of optional driven routing protocol, is an algorithm based on distance vector, and only needs to maintain the required route, without requiring the node to maintain the route of the inactive destination node during the communication process. Therefore, in this scenario, two traffic flows are always kept using the two paths with the shortest distance. (Even if the link is severely congested.)

For OLSR proactive table driven routing protocol, it is different from AODV routing protocol in that it periodically broadcasts routing information grouping, exchanges routing information and actively discovers routing. Its routing standard is to analyse the link status, including the delay, hop count and other indicators are finally weighted, and the cost of cutting the route is large. In the transmission of the second service flow, the test is the same as the AODV routing protocol. In the OLSR protocol test, B-->C is also selected as the transmission path.

3.3.2. SDN solution

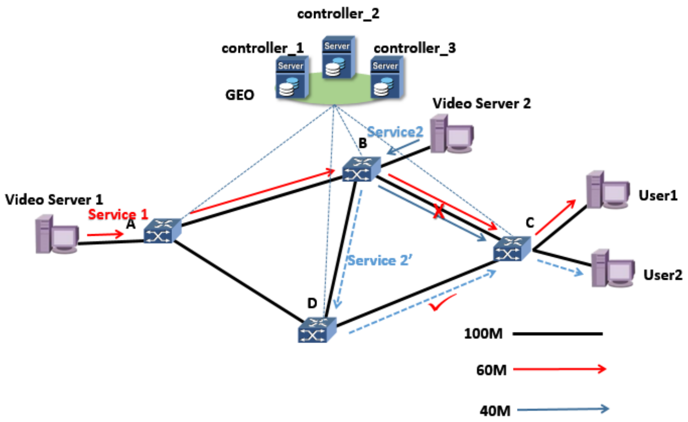


Figure 5. SDN test plan topology.

SDN solution test topology as shown in Figure 5, A, B, C, D for four SDN switch nodes, both belong to the control domain of the ODL controller cluster. First, we assume that the communication link bandwidth between the airships is 100M. User 1 initiates a video on demand service to the video server 1, assuming that the service needs to occupy 60 M bandwidth resources. According to the traditional routing protocols, this data flow will be along A --> B --> C flow path to video server 1, due to the whole link resources are more abundant, after the success of the service building, the video playback is clear and smooth.

Then the user 1 to the video server 2 launched a second video on demand service, under the assumption that the service need to 40M bandwidth resources, in the traditional network, according to the traditional routing protocol choice B - -> C for the shortest path, and set up along the path B --> C the business flow, at this point, the link B --> C because carries two business flow at the same time, the bandwidth load of close to 100%, the link quality serious decline, a more obvious delay and packet loss, reflected in service QOS is that the user's viewing experience of the video is degraded, and the video has obvious flower screen and stagnation. The main reason for this situation is that the traditional routing protocol is distributed and lacks the control of the whole network view, so it is difficult to optimize the whole forwarding path from a global perspective. As a result, some links are overloaded, while some links are idle for a long time.

However, in the SDN- based spatial information network architecture, we can send flow table to the SDN switch deployed on the airship to perform traffic scheduling by deploying an SDN controller deployed on the airship .See Figure 4,switch the data stream of service 2 to the relatively idle path of B -->D --> C to relieve the bandwidth load on the path of B --> C, so as to ensure the smooth establishment of both services and enable both user 1 and user 2 to watch the clear and smooth video program.

3.4. Test Result Analysis

Table 4. UAV resource consumption comparison table.

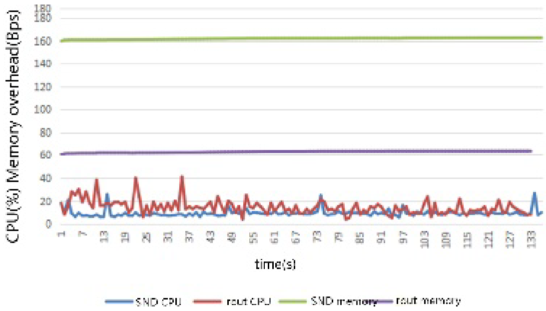
	Average CPU usage	Averagememory consumption
SDN solution	9.32%	162 Bps
Traditional routing scheme	14.52%	63 Bps
Contrast curve		
conclusion	The SDN solution reduces the CPU consumption by about 35% compared to the traditional routing scheme.	

Table 5. Comparison table of signaling overhead.

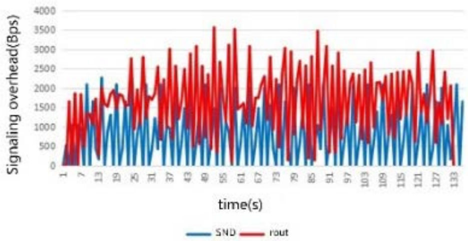
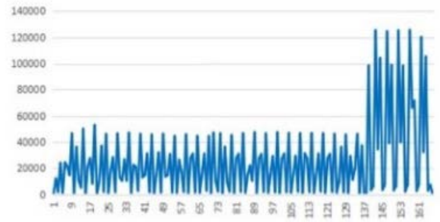
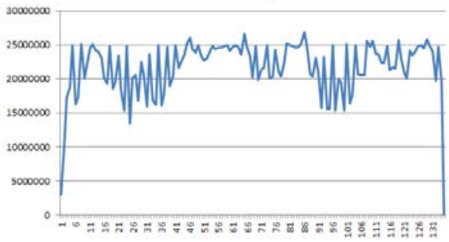
	Mean signaling overhead
SDN solution	810.9416
Traditional routing scheme	1655.91
Contrast curve	
Conclusion	Compared with the routing scenario, the signaling overhead of SDN is reduced by about 51.03%
Controller-Switch Signal overhead	
Controller- Controller Signal overhead	
Conclusion	Signaling between controller clusters is expensive and requires a lot of communication resources

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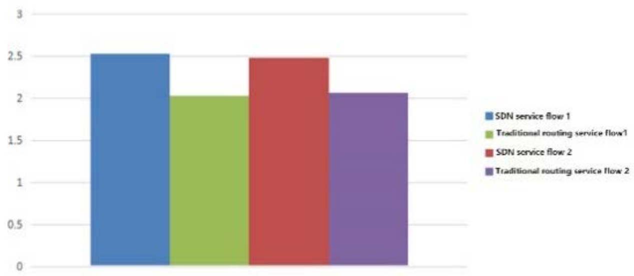
Table 6. Comparison table of business responsiveness.

	Business response speed	
	Business flow 1	Business flow 2
SDN solution	2.53 seconds	2.48 seconds
Traditional routing scheme	2.027 seconds	2.07 seconds
Contrast curve		
Conclusion	Compared with the routing scenario, SDN service response speed is slightly slower	

4. Conclusion

In this paper, we focus on the performance analysis of multi-UAV system based on software-defined network in disaster emergency communication. Simulation results show that, compared with AODV and OLSR, the method proposed in this paper can save 30%-50% energy consumption for the entire network, at the same time, it can also provide a relatively stable business responsiveness, and significantly improve the network lifetime on the basis of meeting business requirements. The following work intends to start from reducing the signalling overhead between controllers to further save system resources and improve the lifetime of the emergency disaster rescue UAV network. Our goal is to conceive the future of emergency communications systems, as well as solve emergency communication system can quickly build, long and stable operation of the problems and challenges, and thus a step forward in communications disaster rescue command information systems.

5. Acknowledgment

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6. References

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