Software Defined Mobile Sensor Network for Micro UAV Swarm

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***Abstract*—This paper introduces novel mobile sensor networking architecture for a swarm of micro unmanned vehicles (MAVs) using software defined network (SDN) technology. The proposed architecture aims to enhance the performance of user/control plane data transmission between MAVs. SDN technique for mobile network is adopted to release the computation burden of MAV nodes and improve the wireless channel resource utilization by moving the complex network management operations to cloud-based SDN controller.**

Keywords-mobile sensor network; UAV; swarm; SDN

I. INTRODUCTION

Micro Unmanned Aerial Vehicles refer to aerial vehicles small enough to be carried by people and typical MAVs include fixed wings, flapping wings (i.e. for insect flight) or rotor crafts (e.g. helicopter, quadcopter, hexacopter). Depending on the targeted service, MAVs collect and store or distribute information using communication units. A swarm of MAVs proved to be capable of handling highly complex tasks that single MAV cannot do. Communications in a MAV swarm can be performed by employing mobile ad hoc network (MANET) [1] protocols. However, traditional MANET protocols are designed for ordinary ground mobile terminals and do not take into account MAV specific characteristics such as dynamic altitude, fast variable routing topology, etc. Research in [2] reviews techniques and challenges of multiple-MAV coordination and communications in tactical edge networks, which are highly dynamic and uncertain in nature. Research has also explored optimized networking policies for MAV swarms regarding speed- and altitude-aware routing algorithms [3] [4].

Cooperation between UAVs relies on flocking algorithms and data distribution mechanisms of user and control plane (e.g. routing, topology information, multimedia sensor data, etc). Performance of the cooperation between a swarm of UAVs depends on reliability of communication and networking schemes [5] [6]. Key technologies involved in swarm communication and networking include routing protocols, clock synchronization, low delay media channel access, anti-interference, data security, etc. Routing protocol is the core technique for UAV swarm communication in terms of user and control plane data distribution.

Traditional mobile sensor networking technologies like mobile ad hoc network (MANET) and vehicular ad hoc network (VANET) have been provide reliable communication theories and practical experiences for UAV swarm networking. However, MANET and VANET networks cannot be directly applied to UAV-based mobile sensor network due to many factors such as fast mobility, limited computing resources and poor wireless channel qualities. For instance, typical MANET network was designed for mobile sensor network where nodes are moving at low speed (<2m/s) while VANET-based mobile sensor network were developed for vehicle nodes with higher speed (20-30m/s). Additionally, VANET network generally provides the node with external vehicle power system for energy usage the data communication computation tasks are completed by high performance platform. However, the mobile sensor network consists of UAVs include nodes with very high speed (0-100m/s). Meanwhile, data computation of single UAV is quite limited, since most of the CPU and memory resources needed to be reserved for flight control system. Furthermore, environmental factors such as wind, obstacle and magnetics bring additional negative impacts on the stability of UAV swarm. Along with the increasing density of UAV swarm, the available wireless channel resources become bottleneck as well due to the strong signal interference.

Software defined networking (SDN) [7] technologies have been attracting lots of attentions by both academic institutions and industrial partners. SDN aims to optimize and simplify the management of both wired and wireless networks. SDN-based networks allows unified programmable interfaces for all nodes (e.g. routing/relay nodes). Centralized or distributed SDN controller instances are used to manage all the networking equipment. The principle idea of SDN technology is to decouple the user and control plane data and enable adaptive data communications and improve network bandwidth utilization.

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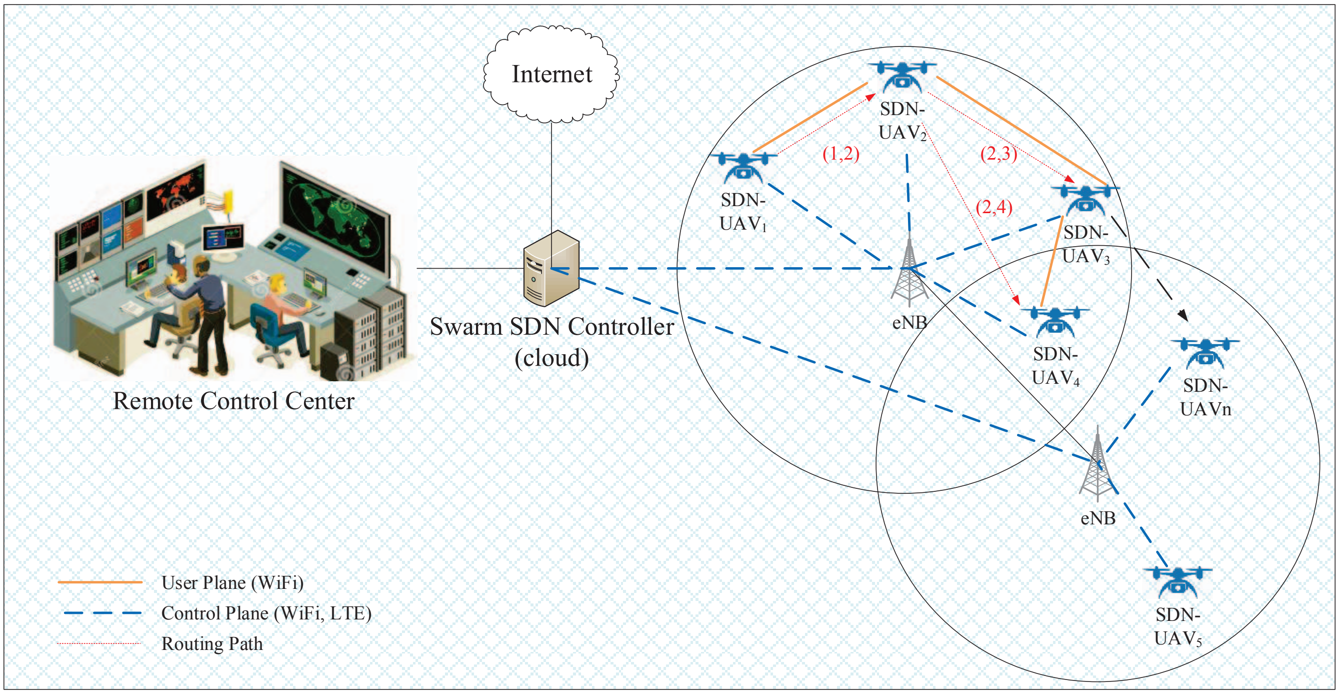

Figure 1. Topology of UAV swarm control based on SDN

TABLE I. ROUTING TABLE OF SWARM

ID	MAV_ID	SRC_IP	DST_IP	NEXT_HOP	HOPS
j	m	src_m	dst_m	$next_m$	HOP_m
j+1	n	src_n	dst_n	$next_n$	HOP_n
..	..	..	..	..	..

SDN was firstly deployed at centralized large scale data center and provide flexible adaptation polices for network devices using standard Openflow communication protocols [8]. Recently, the feasibility of SDN for mobile sensor network has been discussed, in particular, how to enhance network management efficiency.

This paper introduces novel mobile sensor networking architecture for a swarm of MAVs using software defined network (SDN) technology. Additionally, the proposed networking architecture provides potential application for advanced routing policies for a swarm of MAVs with highly dynamic topology. Simulation and real life field test-bed for deploying the novel mobile sensor networks are shown.

II. SOLUTION ARCHITECTURE

Since existing mobile sensor network technologies cannot provide reliable data communications for UAV swarms, a novel SDN-based mobile sensor network architecture is thus proposed.

Figure 1 presents the topology of the proposed swarm MAV management based on SDN. Remote Control Center deploys specific tasks of swarm such as reconnaissance, search and rescue, emergency communication, etc. The Swarm SDN Controller manages communication and networking operation such routing policies. The Software Defined MAVs monitor the wireless link status as well as flight statistics and report back to the Swarm SDN Controller, meanwhile, forward data packets to other MAVs. Each SDN MAV is equipped with both LTE and WiFi interfaces. Communication of control plane data between the Swarm SDN Controller and SDN MAV is enabled via LTE link while user plane data communication between MAVs is offered by WiFi link. The multipath communication aims to improve the overall throughput of user plane of swarm and increase the controlling coverage of the remote control center.

The core of the proposed system is the Swarm SDN Controller which maintains global routing table for a swarm of MAV as shown in Table I. The routing table include identifier of MAV (MAV_ID), source and destination of IP addresses of the packet (SRC_IP and DST_IP), the number of hops (HOPS) from the source MAV to the destination MAV, and the next MAV to be forwarded (NEXT_HOP).

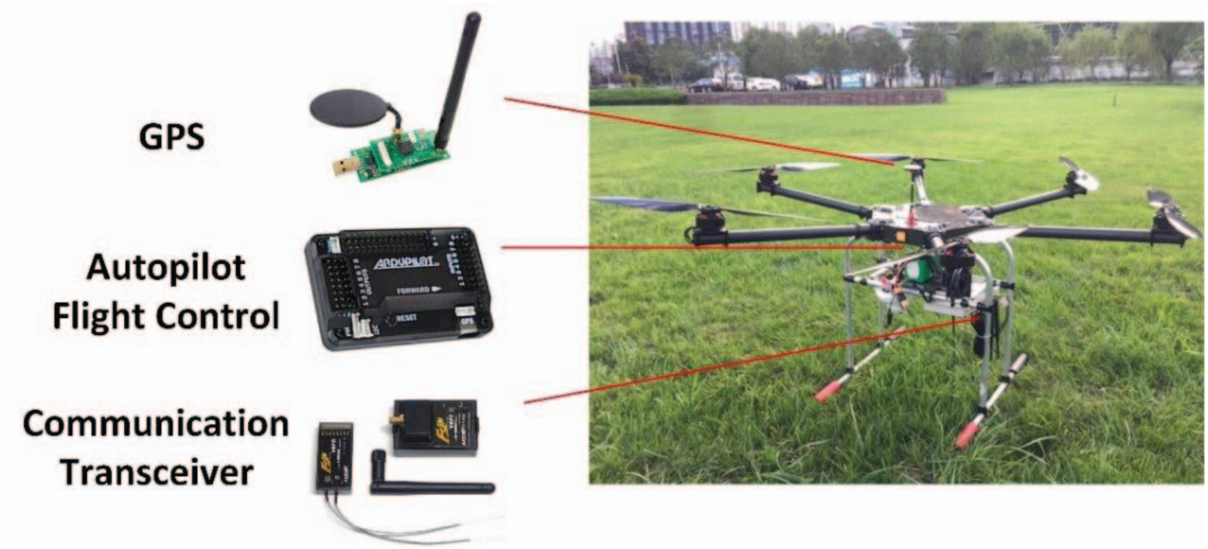

Figure 2. Hexacopter developed by the Drone Research Group (http://drgroup.hdu.edu.cn) at Hangzhou Dianzi University and RobSense Co.Ltd (http://www.robsense.com).

Besides, the Swarm SDN Controller maintains link status table for further routing algorithms, Link Quality-based routing, and update the routing table in react to topology change of the swarm.

The SDN MAV contains link status monitoring module and flight statistics monitoring module. Link status (e.g. RSSI, delay, bit error rate) and flight statistics (e.g. speed, GPS data, IMU data) are collected and report back to the swarm SDN controller periodically. SDN MAV performs routing update actions distributed from the SDN controller enabling fast and flexible routing policies.

The proposed SDN-based mobile sensor network architecture aims to overcome the limited computing and channel resources of traditional mobile networks. Complex routing algorithm are moved to centralized cloud based server and the computation burden of MAVs are largely reduced. MAVs are responsible for topology change monitoring and data forwarding only.

III. HARDWARE EQUIPMENT

A typical MAV system includes three fundamental modules: Autopilot Flight Controller, Navigation Module and Communication and Networking *Unit, as illustrated in Figure 2*. A critical part of MAV, the Autopilot Flight Controller supports the complex cooperation between hardware and software computing resources, while monitoring the flight status and environmental conditions using multiple onboard micro- electro-mechanical system (MEMS) sensors. Among these, the inertial measurement unit (IMU) sensor measures the angular velocity, orientation, and gravitational forces, the optical flow sensor performs distance estimation, the ultrasound wave sensor is employed for obstacle avoidance and the gyroscope and accelerometer sensors enable movement balance, etc. The Navigation Module provides location and trajectory information to the Autopilot Flight Controller.

Heterogeneous data is generated and exchanged between MAVs and between MAVs and ground control station. Most MAVs rely on peer-to-peer short-range wireless links. In general, 433MHz frequency is adopted for uplink transmission of UAV flight control signals (in non-autonomous flight mode), 2.4GHz frequency is used for downlink transmission of telemetry data and 5.8GHz frequency is used for downlink transmission of multi-sensorial data. Alternatively, the cellular network technology (i.e. LTE) is considered in some MAV products in order to support much wider range of data transmission.

IV. RELATED WORKS

Bernardos [9] introduces the strengths of applying SDN technology for mobile networks and analyzes typical business cases deployed by operators such as QoE-aware mobility management. The authors in [9] designed 3GPP-based SDN architecture and adopt different SDN controllers at the core network for variable access technologies including LTE，UMTS and IEEE 802.11. Abolhasan [10] proposes a novel SDN architecture for distributed mobile sensor network which decouples data of user and control planes using separate radio frequencies. In [11], a hybrid SDN strategy is introduced that multiple mobile nodes send link status information (e.g. link quality, buffer size, queue length, packet arrival rate, etc) to the central SDN controller periodically. The central SDN controller pre-analyzes the information and send back to the distributed mobile nodes in order to make optimal routing decisions.

In [12], the authors propose E-Mesh, an energy-aware wireless routing algorithm for mobile sensor network which balances the need for energy saving with that of maintaining good quality of video content. E-Mesh is deployed at the network layer and works in conjunction with an innovative energy-aware MAC-layer duty cycle management scheme. In [13], the authors propose a novel energy-aware multipath (LTE and WiFi interfaces for mobile node) data transmission scheme which balances the support for increased throughput with energy consumption awareness. The proposed solution is located at upper transport layer in mobile devices and requires no additional modifications of the remote server.

V. Conclusions

The proposed SDN-based mobile sensor network architecture aims to overcome the limited computing and channel resources of traditional mobile networks. Complex routing algorithm are moved to centralized cloud based server and the computation burden of MAVs are largely reduced. MAVs are responsible for topology change monitoring and data forwarding only.

The proposed solution opens opportunities for both operators and UAV service providers in terms of networking management for large-scale air control of UAV swarm.

Acknowledgement

This project is supported by the National Natural Science Foundation of China (Grant No. 61501156) and Electronic Science and Technology Zhejiang Open Foundation of the Most Important Subjects (Grant No. GK130203207003/006).

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