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An Effective Review on Important Issues in Unmanned Aerial Vehicles (UAVs) Networks

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ABSTRACT: Unmanned Aerial Vehicles (UAVs) have tremendous power in the civil and public domains. These are specifically helpful in applications where human lives would otherwise be threatened. Multi-UAV systems can cooperatively complete missions more economically and effectively in comparison of single UAV systems. Since, there are several issues to be solved before efficient usage of UAVs can be built to offer reliable and stable context-specific networks. Much of the work conducted in the Mobile Ad Hoc Networks (MANETs) , and Vehicular Ad Hoc Networks (VANETs) fields does not approach the unique features of the UAV networks. UAV networks may change from slow dynamic to dynamic; have intermittent connections and fluid configuration. While it is thought that ad hoc mesh network would be most appropriate for UAV networks yet the multi-UAV networks architecture has been an understudied field. Software Defined Networking (SDN) could provide reliable deployment and management of new facilities and support to decrease cost, increase security and existence in networks. Routing needs of UAV networks go beyond the requirements of VANETS and MANETS. Protocols are needed that would adapt to dynamic topology, high mobility, power restraints intermittent connections and changing connection quality. UAVs may fail and the network may get divided building delay and interruption tolerance a significant design consideration. Limited node life and network dynamicity yields to the needs of continuous handovers where researchers are viewing at the work performed in the MANETs and VANETs fields, but the jury is still out. As energy supply on UAVs is restricted, protocols in several layers should contribute towards network greening. This article reviews the work performed towards all of these outstanding problems, related to this novel network class, so as to inspire further research in these fields.

KEYWORDS: UAV, Unmanned Aerial Vehicle, ad hoc networks, Multi-UAV Networks, wireless mesh networks, communication networks, routing, software defined network, energy efficiency, seamless handover.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are an evolving technique that can be harnessed for public, military and civil applications. Military usage of UAVs is more than 25 years old mainly consisting of border surveillance, strike and reconnaissance. Public usage is by the public agencies i.e. public safety, police and transportation management. UAVs can offer timely disaster warnings and guide in speeding up recovery and rescue operations when the public interaction network gets disabled. They can carry medical supplies to fields rendered inaccessible. In conditions i.e. wildfires, poisonous gas infiltration and wild animal tracking UAVs could be utilized to frequently envelope a huge region without safety risk of the personnel include. UAVs come in different sizes. Huge UAVs may be utilized singly in missions whereas small ones may be utilized in swarms or formations. The latter ones are proving to be quite helpful in civilian applications. As explained by Daniel and Wietfeld in [1] they are likely to become priceless inclusions in the operations of fire brigades, police departments and other homeland security organizations in the coming future. Besides, advancement in sensor and electronics technique have increased the UAV network applications [2] scope to involve applications as wind estimation, diverse as traffic monitoring and remote sensing [3]. In recent years, with the benefits of small size, light weight, low price, high flexibility, zero casualties, etc., unmanned aerial vehicles (UAVs) have been widely used in military fields, as well as in national economy. As shown by the U.S. Army Unmanned Aircraft Systems Roadmap 2010–2035, the US Air Force uses UAVs primarily for surveillance, reconnaissance, direct attack missions and battle damage assessment. Since, the short transmission range, limited energy and simple functions of single UAV limits its further applications, not enough to fulfil the several needs of the Army. Thus, there presents an immediate requirement for making UAV fleet networks to enhance the total operational efficiency through the cooperation of several UAVs. UAV fleet network obtains information sharing and data exchange through the real-time, reliable and high speed communication among UAVs. The building up of UAV fleet network would efficiently improve the work controllability, efficiency, survivability, and anti-jamming capacity of UAV fleet, hence enhance the tactical efficiency and explore the applications scope. UAVs often work in complicated and changing atmosphere with reliable operational ways and high mobility; thus, it is essential to apply the mobile Ad Hoc network (MANET) architecture in the UAV fleet network design.

II. CHARACTERIZING THE UAV NETWORK

In this section we see at the features that make the common thread in several works and the direction in which the research is going.

A. Multi-UAV network

Early utilization of UAV was featured by usage of a single huge UAV for a task. In these systems the UAV based communication network, thus, contains just one aerial node and one or more ground nodes. Today most civil and public applications can be conducted more effectively with multi UAV systems. In a multi-UAV system, the UAVs are smaller and less costly and work in a coordinated way. In mostly multi-UAV systems, the communication network, proving interaction between UAVs and between the UAVs and the ground nodes, becomes a significant component. These UAVs can be configured to offer facilities collaboratively and increase the network coverage by acting as relays. The mobility degree of UAVs is based on the application. For example, in offering communication over an earthquake struck field the UAVs would hover over the operation area and the connections would be dynamically slow.

B. Features of the UAV networks

There is a no. of aspects of the UAV networks that are not exactly explained and a clarification of these would help in characterizing the UAV networks:

1) Infrastructure-based or ad hoc?

Most of the existed literature considers UAV networks as ad hoc networks. Research on VANETs and MANETs are usually cited with reference to UAV networks but they do not fully approach the unique features of the UAV networks. Based on the application, the UAV network could have fixed, slow moving or highly mobile nodes. Some applications need UAV nodes to behave as BS in the sky to offer communication coverage to a region. Hence, unlike VANET and MANET ad hoc networks, the UAV networks could act more like infrastructure-based networks for these applications. These would have UAVs interacting with one another and also with the control center. This network would resemble the static wireless network with UAVs as BS except that they are aerial.

2) Server or client?

Another point of difference is whether the node behaves as a client or a server. In VANET they are often clients, in mobile ad hoc networks most of the time they would be clients and may also offer sending facilities to other clients' data. In UAV networks, the UAV nodes are often servers, either forwarding packets for clients or relaying sensor data to control centres.

3) Star or Mesh?

UAV networks architecture for communication applications is an understudied field. The easiest configuration is a single UAV linked to a control centre and ground based command. In a multi-UAV setting, the common configurations that can be observed are mesh, star, multi-star and hierarchical mesh. In star topology case, all UAVs would be linked directly to one or more ground nodes and all communication between UAVs would be forwarded through the ground nodes. This may lead to blockage of connections, higher latency and need of more costly high bandwidth downlinks. Additionally, as the nodes are mobile, steerable antennas may be needed to keep oriented towards ground node [15].

4) Delay and Disruptions prone networks

All wireless mobile networks are vulnerable to connection interruptions. The UAV networks are no exception. The extent of interruption is based on how mobile the UAVs are, the power transferred, inter-UAV distances and external noise. In the applications where UAVs offer communication coverage to a region, the UAVs are hovering and, thus, possibility of interruptions would be low. On the other side, in applications needing fast UAV mobility, there is a greater likelihood of interruptions. Delays in transferring data could be due to poor connection quality or because one or more UAV nodes recording the data due to end-to-end path not being existed.

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III. MOTIVATION AND CHALLENGES OF UAV NETWORKS

Promising though it may be, this field is comparatively new and less explored. There are several problems to resolve before efficient usage of UAVs can be built to offer reliable and stable context-specific networks. As we shall look later, while it provides the promise of enhanced capacity and ability, setting up and managing effective communications among the UAVs is challenging. All the components of the UAV communication networks introduce challenging problems that require resolution. Unlike several other wireless networks, the UAV networks configuration remains fluid with the no. of nodes and connections changing and also the nodes relative positions is changing. UAVs may move with different speeds based on the application, this would cause the connections to be set up in an intermittent manner. What challenges would such a nature pose? Firstly, some architectural design aspects would not be intuitive. The fluid configuration, the vanishing nodes and finicky connections would all challenge the designer to go beyond the general ad hoc mesh networks. Second, the routing protocol cannot be a simple implementation of a reactive or as proactive technique. The inter-UAV backbone has to iteratively reorganize itself when UAVs fail. In some situations, the network may get divided. The challenge would then be to forward the packet from a source node to a destination node while analysing the selected metric. The third challenge would be to manage subscriber's sessions by transmitting them continuously from an out of service UAV to an active UAV. Lastly, there is requirement to be ways of conserving energy of power starved UAVs for increasing the network lifetime. In the next section we explain all of these problems in more detail. The UAV networks area is challenging to researchers due to the outstanding issues that offers motivation for research. In vehicular and mobile networks the nodes join and leave from the network quickly and, thus, ad hoc networks have been detected to be appropriate in most conditions. Additionally, for frequent and flexible communication among nodes, mesh network configuration is quite suitable. Does this apply to the UAV networks as well? In UAV networks, the nodes could almost be fixed and hovering over the operation or scouting area around at a fast pace. Nodes could die out for several causes and may be substituted by novel ones. Some similarities motivate researchers to explore the applicability of the work performed for Vehicular Ad hoc Networks (VANETs) and Mobile Ad hoc Networks (MANETs), but works in these fields do not completely approach the unique features of the UAV networks.

IV. ROUTING

The UAV networks built for several applications may change from slow dynamic to the ones that fly at considerable speeds. The nodes may go out of service because of failure or power restraints and get substituted by new ones. In green networks, radios in the nodes may be automatically switched off for power conservations when the load is low. Connection interruption may quickly take place due to the UAVs and ground stations positions. In addition, the connections could have high bit error rates because of disruption or natural conditions. The reliability needs from the UAV networks are also different. For instance, while forwarding earthquake data may need a 100% flexible transport protocol, forwarding pictures and earthquake video may be performed with lower flexibility but limited delay and jitter needs. Bandwidth needs for data, voice and video are different. The UAV networks, thus, have all the needs of mobile wireless networks and more. Node mobility, intermittent connections, network partitioning, restricted resources and changing QoS needs build routing in UAV a challenging research issue.

A. Routing issues to be resolved

Additionally, the needs available in the generic wireless mesh networks, e.g., determining the most effective route, permitting the network to scale, assuring reliability, controlling latency, taking care of mobility and assuring needed QoS; routing in airborne networks needs energy-awareness, location-awareness and increased robustness to intermittent connections and changing configuration. Designing the network layer for UAV networks is still one of the most challenging issue [3]. There still available a requirement for a routing protocol tailored to the specific requirements of airborne networks that follows to high mobility, dynamic configuration and various routing abilities [30]. Routing protocols attempt to increase delivery ratio, decrease resource consumption and delays. In addition, one has to assume issues related to loop freedom, scalability, energy conservation, and effective usage of resources also requires to be resolved [31].

B. Applicability of existing routing protocols

A no. of routing protocols that have been introduced for MANETs attempt to adapt the table-based, proactive, protocols of the wired era to ad hoc wireless networks with mobile nodes. Some of these and also reactive or on-demand protocols endure from routing overhead issues and finally have bandwidth and scalability issues. Conditional update

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based protocols decrease overheads but location management remains a problem in dynamic networks i.e. UAV networks. Some protocols that propose the concept of cluster heads shows performance issues and single point of failure [32]. A review on WMN static or mobile nodes indicates that existed MAC and routing protocols do not have sufficient scalability and the throughput decreases importantly as the no. of nodes or hops increase. It goes on to add that protocol enhancement in a single layer will not resolve all the issues so all available protocols require to be improved or substituted by new ones for UAV Networks [33].
Because of apparent similarity of UAV networks with VANETs and MANETs researchers have studied protocols utilized in those atmospheres for possible application in aerial networks. Even in these atmospheres the search for more enhanced protocols is on. Since, multi-UAV networks may have a no. of different needs to take care of such as node localization and mobility patterns, frequent node elimination and addition, power restraints, intermittent connection management, application fields and their QoS needs. Because of several issues particular to UAV networks, whereas changes have been introduced to MANET protocols, there is a requirement to establish new routing algorithms to have flexible communication between UAVs [7] and from UAVs to the control center(s).

V. SEAMLESS HANDOVER

The UAV mesh nodes may be stationary over a disaster struck field to offer communication facilities across the destination area and build a network with slow dynamic connections. On the other side, in applications i.e. crop survey, which need a sweeping coverage of a region, UAVs may move around at needed speeds. At the time of a prolonged mission UAVs may periodically go out of service as they go out of power or create faults. Their interaction interfaces may also be shut down to conserve power, or one or more of the UAVs may be removed when less dense network is needed. In all these cases the network requires to reconfigure and the ongoing data, video and voice sessions are needed to be handed over to one of the working UAVs according to some pre-specified criteria. Handover permits for total continuity of network interaction with only a small increase of message latency at the time of the handover mechanism [65]. Subsection A explains the types of handoffs in UAV networks. Applicability of available handoff techniques and new developments that can be utilized in UAV networks are in Subsection B. Subsection C shows the IEEE standard media independent handover.

A. Handoffs in UAV networks

The real benefits of wireless mesh networks become apparent when self-organization is integrated with continuous handover to offer service continuity to the subscribers. Handover, or handoff as it is generally called, is general in cellular networks, where mobile stations quickly move out of the coverage region of one cell tower and into that of a neighbouring tower. Handovers can be soft or hard. In a standard or hard handover, the link from the old network is broken before it is built with the new network. This would disrupt all the subscriber sessions currently in progress at the mobile node (Fig 1a).
In case of seamless or soft handover, link is built with the new network before breaking the links from the old network. The original subscriber sessions at the MS are managed till the new connection is up and handover action moves the session to the new connection as illustrated in Fig 1b.

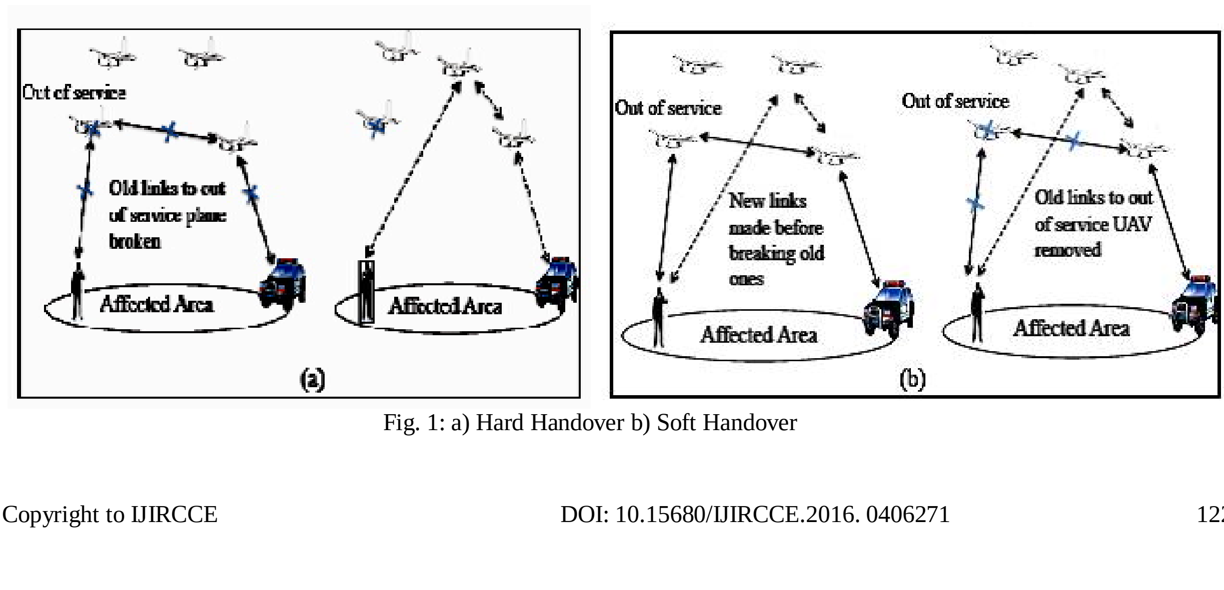

Fig. 1: a) Hard Handover b) Soft Handover

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Besides being soft or hard, handovers can also be categorized as *horizontal and vertical handovers.* Horizontal handovers are intra-system where the mobile access device moves from one access point to another in the same network. In situation of vertical handover, the transfer of link is between two networks of different techniques. Fig 2 shows these two kinds of handovers.

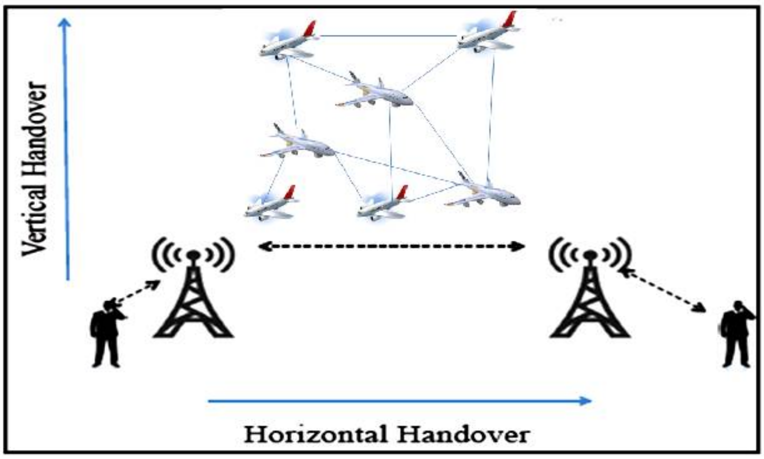

Fig. 6: Horizontal and Vertical Handovers

B. Applicability of Existing Handover Schemes

Lack of techniques for continuous handover in UAVs, form people look at the work performed in the MANETS and VANETs fields. Since, despite the requirement to offer continuous handover in VANETs, there are few studies related to mobility protocols and there are no practical studies on mobility protocols utilizing IEEE Wireless Access in Vehicular Environments (WAVE) communication [67]. WAVE contains IEEE 802.11p and IEEE 1609.x to offer connectivity under the hostile operation situations of VANET. Since, these standards do not approach the network mobility problems, either intra- or inter-technology. VANETs are featured by the high speed or mobility of nodes, resulting in short communication time, quick changes in network configuration and network partitioning. As VANETs are a particular kind of MANETs, routing Protocols and IEEE standards utilized in MANETs have also been taken for the VANET atmosphere. The literature review existed on vehicular communication is very restricted and adaptation of the work on mobile ad hoc networks [68].The random waypoint (RWP) model, in which mobile node movement is assumed random, is generally used in MANETs study. Because of the highly dynamic features of VANETs, network partition or combination can take place frequently, which leads to the un-existence of available path or existence of better paths. This causes the networks to reconfigure and may trigger handovers. The packet loss and handover latency during handover mechanism may cause critical reduction of QoS and system performance obtained by the subscribers. RWP model is, thus, taken to be a very poor approximation of vehicular mobility.

C. Media Independent Handover

IEEE 802 initially did not support handover among various kinds of networks. They also did not offer triggers to accelerate mobile IP based handovers. IEEE has now standardized Media independent handover (MIH) facilities through their standard IEEE 802.21 [73]. The primary function of MIH, called the Media Independent Handover Function (MIHF) is between the layer 2 wireless techniques and IP at layer 3 [75]. These facilities can be utilized for interoperability and handover between IEEE-802 and non-IEEE-802 networks, e.g., 3GPP, cellular, 4G. The networks could be of *the different or same* media type, wireless or wired. This standard offers link-layer intelligence and other related information of network to upper layers to analyze handovers among heterogeneous networks. It contains signaling and triggers and builds existed information from PHY/MAC to application and network layers. The standard is a hybrid implementation as it supports cooperative usage of information existed with the network and the mobile station.

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VI. ENERGY EFFICIENCY IN UAV NETWORKS

There could be two UAV networks scenario. First, energy for communication resources as well as for providing the UAV comes from the same source or, optionally, they could be from different sources. In either case, energy consumption by the communication resources is significant and can restrict the helpful flying time and, possibly, the network life. The significant point to observe here is that there is a huge consumption even when there is no reception or transmission, i.e., when the wireless interface is idles. Power rating of a general Wi-Fi 802.11n interface, in non-MIMO single antennal mode, is 1280mA/940mA/820mA/100mA under Transmission/Reception/idle/sleep modes, respectively [151]. A typical small drone may have battery capacity of 5200mAh, 11.1V. Such a drone draws about 12.5A and provides a flying time of about 25 min. Communication resources of the UAV in a mesh network generally obtains and transfers seamlessly. A quick computation would indicate that the flight time would be decreased by 16%, of the rated value, if communication resource utilizes the same battery as the UAV. Together with GPS and a couple of sensors, it can easily go beyond 20%. In practice, since, the net impact of this could be more serious as the battery voltage decreases down below l1.1V even before the power is completely drained, inhibiting basic UAV function.
Let us now assume the scenario where the communication resource has its own battery, separate from the UAV battery. In this situation, the battery weight requires to be taken into consideration in the restricted payload capacity of the UAV. In a series of experiments, the writers of this paper utilized separate AAA batteries to power up the airborne Open Mesh router. The router needed 8 AAA batteries to offer enough voltage to operate. Basic alkaline batteries weigh about 11.5g each and have capacity of 860mAh. [146]. If the flight is of 25 minute duration, with seamless reception and transmission, the consumption would be 740mAh. Eight cells would theoretically work for approx. 9 hours but, as the voltage decreases, the router would cease functioning and has to be brought down for recharge or change. In our experiments, completely charged alkaline cells offered good sufficient voltage for approx. 8 hours, enough for as many as 19 sorties. Taking the battery weight was another matter. Eight cells weigh 92g. The dead weight of the UAV utilized is approx. 1kg and it could carry approx 300 grams of payload. The batteries make about 30% of the payload that could be put on the UAV! Decreasing the energy consumption, thus, would result in increase in lifetime of network or increase in useful payload that can be carried.

VII. CONCLUSIONS

UAV networks are developing in significance and general interest for civil applications. Offering good inter-UAV connectivity and connections to the subscribers and any ground station is quite challenging. Research related to mobile ad hoc mesh networks is being used to the UAV networks, but even the former is an emerging field. In addition, a no. of characteristics i.e. nodes dynamicity, intermittent connections, fluid topology, bandwidth and power restraints set UAV networks apart from any other that have been researched before. Many researchers believe that there is requirement to re-build everything ground up. For efficiently process and show the existed information in correct point of view, it was considered essential to classify the UAV networks depending on a no. of features. It is significant to differentiate between ad-hoc and infrastructure UAV networks, applications fields in which UAVs behave as clients or as servers, mesh or star UAV networks and whether the deployment is hardened against disruptions and delays. Through this discussion we look how despite sharing some features with vehicular and mobile ad-hoc networks, UAV networks have their own unique characteristics. Having performed this categorization, we concentrate on the primary issues of routing, seamless handover and energy efficiency in UAV networks Routing has unique needs - determining the most effective route, permitting the network to scale, ensuring latency, controlling latency, taking care of mobility and assuring the needed QoS. Seamless handover permits for total continuity of network interaction with only a small increase of message latency during the handover mechanism. The packet loss and handover latency during handover procedure may cause severe reduction of system QoS and performance achieved by the subscribers. There has been strictly any study on continuous handover in the UAV atmosphere and more so utilizing IEEE Wireless Access in Vehicular Environments (WAVE) suite of protocols. Some mobility management protocols have been introduced but high mobility degree forces frequent handover and issues in communication. IEEE has standardized Media Independent Handover (MIH) facilities through their standard IEEE 802.21. These facilities can be utilized for interoperability and handovers between IEEE-802 and non-IEEE-802 networks, e.g., 3GPP, cellular, 4G. MIH, since, does not offer handover schemes, intra-technology handover, security and improvements to link layer technologies. Since, MIH is a nascent technology that has not been broadly deployed and measured. Energy efficiency is a very significant need in UAV networks. Decreasing the energy consumption supports in increase in lifetime of network and useful payload that

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can be carried Energy consumption can be decreased through load distribution, transmission power control or building nodes sleep. At the physical layer, transmission power can be decreased to the minimum needed for connectivity. Network layer can utilize the information about linked nodes to route packets. The data link layer schedules on/off times of data carrying and data carrying and signalling radios. Cross layer protocols will provide techniques operating at two or more layers.

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