

Collaborative UAVs Cloud

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Abstract—Most collaborative UAVs applications are built using traditional technologies that need the dedication of huge development efforts, time, and budget. In this paper, we introduce a new concept, Collaborative UAVs Cloud, to simplify the efforts and reduce the time and cost needed to develop collaborative UAVs applications. This concept utilizes the recent technology of mobile cloud computing for presenting a set of resources in multiple UAVs as a set of mobile cloud services. The cloud services in addition to ground cloud computing services can be used together to enable the development and operations of collaborative UAVs. In the proposed cloud, special collaboration methods are offered as services to reduce the time and cost of development hence they become plug and play components to be used when needed. This proposed cloud offers different opportunities in UAVs applications development and deployment; however, some technical challenges are present and need to be addressed before the actual benefits can be realized at a cost-effective price. Some of these challenges include the UAVs' energy levels, high mobility, and current locations. This paper proposes a framework for Collaborative UAVs Cloud and presents its opportunities and challenges.

Index Terms—UAVs, Collaborative UAVs, Cloud Computing, Service-Oriented Architecture (SOA), Mobile Cloud.

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), aircrafts without human pilots on board, developed rapidly. They are used not only in military missions but also in civil applications. UAVs can be very useful in agriculture, search and rescue, security and surveillances, environmental monitoring, large infrastructure monitoring, and terrain mapping. Such tasks require repetitive, hazardous and/or tedious tasks. Although, manned aerial vehicles can be used, such utilization require long hours of repetitive, high-level of focus, and costly flights that place a heavy burden and high risk on the pilots and very high operational costs. With recent advances in airframe, control, and communication technologies offered in UAVs allow them to efficiently replace manned operations for many applications. Using UAVs various important and repetitive tasks can be automated efficiently. This is mainly due to the high accuracy, mobility, and repeatability levels of UAVs [1].

Some UAV applications involve multiple UAVs working together to quickly achieve a specific task. However, building applications that will effectively and concurrently operate multiple UAVs and utilize them for a certain problem area requires a huge number of man hours [2] in design, development and testing. This is mainly due to the

lack of technologies that can be utilized to effectively coordinate the operations and cooperation of multiple UAVs.

This paper presents a framework for using mobile cloud computing models to enable the development and operations of collaborative UAVs applications. Mobile cloud computing is defined as moving data storage and data processing from mobile device into the cloud [3]. UAVs may use this technology for application development and collaboration. As a result, they do not need to be equipped with powerful capabilities and can be heterogeneous which could reduce the total cost. UAVs can use the cloud services and resources while the cloud applications can use UAVs as providers for services. UAVs connect to the cloud to collect and dispense data as well as to organize missions. Missions and tasks allocation to UAVs highly depend on their locations and capabilities. Thus, cloud computing could provide services to manage collaboration methods as well as offering specialized services for certain tasks such as sensing. This reduces the efforts needed to develop new applications using cloud services. In addition, it allows adding more UAVs as plug and play to the system. Collaboration services such as monitoring and saving UAVs locations and energy limits in addition to controlling UAV flight paths either direct from user commands or by collaborative tasks can be easily developed and offered.

The contributions of this paper can be summarized as:

- 1) Proposing a SOA model for collaborative UAVs that relies on the cloud and defining its layers and the components of each layer.
- 2) Highlighting the benefits gained from this model as well as discussing the challenges that need to be resolved to gain the most opportunities.

The rest of the paper starts with background information about UAVs and collaborative UAVs applications in Section II. Section III discusses earlier efforts towards collaborative UAVs Cloud and Section IV introduces the framework for mapping Cloud Computing to UAVs. More details of the proposed cloud services are presented in Section V, then section VI illustrates the collaborative UAVs cloud framework and its approaches, while Section VII discusses the opportunities and challenges. A discussion of the proposed framework is presented in Section VIII and Section IX concludes the paper.

II. BACKGROUND

The main technical requirement of collaborative UAVs is the availability of communication facilities among the

UAVs. A lot of research was done on traditional radio communication. In [4] an ad-hoc network model was designed for UAVs. This model differs from traditional to use new network model as Flying Ad Hoc Networks (FANET).

The main challenge issues in FANET is routing as the network topology changes dynamically and rapidly. UAV communications can be either UAV-to-UAV communication where UAVs communicate with each other or UAV-to-Infrastructure communication where UAVs communicate with fixed infrastructure locations such as ground stations. MANET uses mobile nodes in random network topology that changes rapidly; therefore, it can be used in UAVs FANET to make routing easier and to improve the performance of wireless communication systems. To increase FANET communication performance we need to decrease transmission power by communicating with the closer UAVs, as a result, MANET routing mechanisms are preferred in FANET but they are not directly applicable.

There are many applications for collaborative UAVs such as the example in [5], where UAVs are used for rescue operations. Here UAVs are used for environmental monitoring such as collecting data on air quality in different layers of the atmosphere as some information cannot be collected by ground systems due to fumes or smoke from fires. The main mission of the UAVs is to measure pollution and locate its sources in certain areas. The swarm intelligence based strategy can be used as it uses a completely distributed approach. In this strategy the airplanes have three phases of operation. First, the take-off stage where UAVs spread out in positions maximizing the minimum acceptable distance between them. Second, the monitoring stage, where UAVs sense the environment seeking pollution values above a fixed alarm threshold and broadcasts the sensed data through the communication channels. Third, the search stage, when pollution is detected, UAVs continue broadcasting and comparing sensed values with other UAVs periodically seeking the surrounding plane with the maximum pollution value and changing flight directions towards the UAV with the maximum value creating a team search in that specific area.

Using multiple UAVs collaborating together decreases the time to achieve specific tasks, however, developing such applications for UAVs with heterogeneous devices; different energy levels; and varying storage, communication, sensing and processing capabilities is a complex task without middleware [6]. Collaborative UAVs can be homogenous or heterogeneous in their communication, acting, sensing, storage, and processing capabilities as well as their energy levels. While applications that rely on homogenous UAVs are easier to develop, heterogeneous UAVs can offer great opportunities for providing cost-effective solutions for complex applications that require different capabilities for the various tasks involved.

There are six aspects of multiple UAVs collaboration; collaborative sensing using distributed sensors; collaborative acting to cover large areas faster; collaborative communication to allow UAVs to interact with each other; collaborative data processing which allows UAVs to process

networks, mobile ad-hoc networks (MANETs) and vehicular ad-hoc networks (VANETs) in terms of connectivity and routing capabilities. UAVs can be considered large data among the UAVs that have on-board high performance computers; collaborative storage that organizes data storage among multiple UAVs depending on their capabilities; and collaborative control of distributed components to achieve one goal [7] [8].

III. PREVIOUS EFFORTS TOWARD COLLABORATIVE UAVS CLOUD

In this section, a discussion about earlier efforts toward Collaborative UAVs Cloud is provided. This includes discussions of UAVs cloud applications, enabling technologies, and presenting UAV functions as services.

There are some efforts to utilize the Cloud for some UAV applications. For example, most UAVs missions are on terrain critical territories. Although geographic information systems (GIS) display proper terrain, they may not assure flight safety for UAVs. Using Google Earth for high quality 3D maps, a UAV uploads its flight data to the cloud and integrates it with the 3D terrain from the GIS to improve flight awareness. That was achieved in [9] using an Android smart phone installed on the UAV to share its flight information in the Cloud and be accessed through web page and displayed on Google Earth. The system was built using UAV Ce-71. The flight mission was provided in the cloud before the flight. An Android smart phone was used to collect flight information and send it to a ground station and to simulate the mission in a 3D terrain model through cloud web connection. The main problems were with information routing and technical difficulties to integrate flight information to Google Earth in real time over 3G mobile communications. Using a smart phone reduces the weight and size in the UAV and allows data communication using 3G mobile communication. Furthermore, an Arduino open-source platform was used to connect smart phone to the UAV hardware. In addition, flight information can be stored in MySQL which provides multi-user access and reliable data sharing. Web browsers can be used to access data in the cloud to view real time flight in Google Earth. A 2D plan is saved in the database before the UAV flight starts creating flight path by waypoints. When the mission is exacted, the UAV reads the flight commands from the database by mission serial number, then the smartphone measures actual data and saves it in the database and map the GPS data on the GIS 2D map. Google Earth is used to create the 3D view with more information to avoid collisions. Users can open the monitoring software that displays the current UAV locations on Google Earth or can replay historical data by mission serial numbers.

Distributed UAV applications development, deployment, operations, and management are generally very complex tasks. However, Service-oriented Architecture (SOA) can be used to reduce the complexity [10]. In [11] four prototypes were developed using SOA and smartphones. The concept started by implementing a service that transmits Motion JPEG images from wireless camera to smartphone via TCP/IP. Due to the TCP delay, reimplementation was done

using UDP. The first prototype was UAV that tracks a vehicle and sends images as SOAP-over UDP to smartphone. In the second prototype smartphones were connected to the vehicle that sends messages to fixed station as well as a UAV that transmits video feed back to the station. The third prototype, it sends messages to both local and remote service consumers. The fourth prototype focuses on the video performance that was effected by the message overload due to its high size by using a binary format instead of SOAP.

The Video Exploitation Tools in [12] is another example of SOA applications for UAVs. It allows the user to choose the region of interest (ROI) to view the UAV path as well as the video footprint on a map. The Visualization and Exploitation Workstation (VIEW) was developed for UAV video exploitation to integrate 2D and 3D visualization, processing, and analysis capabilities. It supports GUI interfaces through SOA. The VIEW SOA framework supports two functions. The Content Repository for storage capabilities by having a URL for each file and the Exploitation Application Server that integrates existing video exploitation as web services. The framework stores files that can be referenced using the exploitation services via SOAP documents. Two types of VIEW framework services were implemented: synchronous and asynchronous SOAP/HTTP services. The synchronous services return results in real time and support several services such as getting list of files and folders in storage, getting or deleting certain file by its URL, fetching results for asynchronous services that were requested previously, and pinging the VIEW to ensure that the framework is running. On the other hand, asynchronous services were implemented to avoid blocking the service by returning a request ID that is used to get the results later. This service includes Mosaicking and 3D reconstruction.

SOA allows viewing different UAV functions as services. For example, the sensing function that is considered as one of the most important functions of UAVs can be viewed as a service. The concept of *Sensing as a Service* (S^2aaS) was introduced in [13] to provide mobile sensing for cloud users. Collaborative sensing was provided using smartphones due to its unique hardware. Smart Phones include internal sensors such as camera, GPS, WiFi/3G/4G radios, accelerometer, digital compass, gyroscope and microphone. External sensors can also be connected via some interfaces. The user can request sensing services through the cloud. To implement an S^2aaS some issues should be addressed; Cloud system should be general to support scalability, new algorithms should be easily deployed, energy consumption management for both sensing and regular uses, and attractive mechanisms to make users participate in sensing activities. Energy-Efficiency should be improved using practical algorithms to minimize and balance energy consumption. Researchers have studied several issues in mobile sensing; balancing performance and resource demands, optimizing the information uploading process for continuous sensing on mobile phones; GPS-base location sensing is studied for single phones as well as collaborative sensing. The main issue is to minimize the energy consumption for sensing target points in the sensing schedule.

UAV payload is usually represented by sensors and can be integrated by the concept of SSI (Smart Sensor Interface) or a set of sensor arrays, MOSA (Mission Oriented Sensors Array) addressed in [14]. To choose the best services, knowledge is needed about the domain of applications as well as other selection criteria. This is done using Knowledge Based Framework (KBF) for Dynamically Changing Applications. KBF stores this information which can be either static defined manually or dynamic changes during operation. Adding more UAVs can be adapted easily during the mission as plug-and-play using SSI and Smart Sensor Protocol SSP which used to exchange information. Thus it chooses the needed services as the most suitable for the mission if a certain service is not available, KBF find an equivalent service.

Service-oriented middleware (SOM) [15] offers the opportunity to support collaboration and enhance efficiency and robustness, which can be used to design, build, deploy and operate application services among multiple UAVs to be self-configuring as proposed in [16]. SOM makes middleware more flexible to add advanced functions to UAVs and utilize capabilities as services offering a framework to develop advanced UAV applications. There are some requirements that SOM should support in UAVs such as; communication methods, service consumers, service transparency, abstraction, service configurability, security, QoS customization and ease of integration with other systems. UAVs consist of heterogeneous hardware items controlled by software services that can also be interfaced to other services to utilize certain functionalities. These services can be integrated using SOM which is distributed over UAVs to manage services sharing among UAVs and other systems. A service broker is needed to advertise, register and discover UAVs services and their description such as availability and location as UAVs are dynamic and many services may depend on locations. Communication is done either in synchronous mode, where a connection is established between consumer and provider to send a request and return response respectively; or in asynchronous mode when UAVs connections are unstable because such that the request is registered in the SOM and only short connections are established when messages are available.

IV. MAPPING CLOUD COMPUTING TO UAVS

Cloud computing, one of the major IT revolutions, is defined as a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction. This model can be used in UAVs to increase proficiencies and efficiency by collaborative UAVs. Figure 1 shows a Cloud Computing services model that consists of three service models: Software as a Service (SaaS) which is the online software applications, Platform as a Service (PaaS) to provide a set of APIs for functions for programmatic platform management and solution development, and Infrastructure as a Service (IaaS) including virtual machines, storage, networks, and firewalls. UAVs can

be mapped to Cloud Computing models to combine UAVs capabilities with Cloud features.

First, the Infrastructure model is divided to fixed components and mobile components. Fixed components include ground station components containing its transceivers and monitor devices, and the cloud computing components with its storage and high performance servers and processors. Mobile components include the UAV hardware containing its payload, sensors, internal memory and processor and other resources in UAVs. These are managed by PaaS.

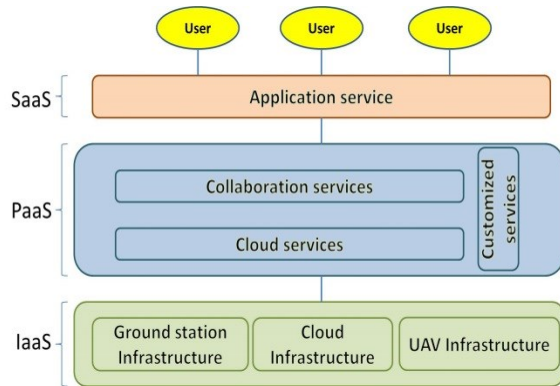


Figure 1 Mapping Cloud Computing to UAVs.

Second, the platform, which is modeled as middleware to isolate infrastructure from the applications, offers resources as services to be invoked by either UAVs or users. PaaS allows integrating services offered by the cloud and other available services for UAVs. The resources are either essential services or customized services. Essential services are services needed for the collaborative UAVs such as managing task allocation between UAVs to ensure that allocated UAVs contain the requirements needed to perform a certain task, organizing flight path and scheduling missions, as well as ensuring security issues to protect UAVs resources. Customized services offer advanced services that provide some specialized functions needed by some types of missions. For example, rendering images or creating 3D maps, and image or video capturing if a camera is available. Moreover, a service for any requested data is either obtained from its source in real time or from a historical database stored in the UAVs' the cloud storage. PaaS provides APIs to be used to create and operate SaaS.

Third, SaaS is the software applications/services available online and access PaaS services through standard APIs. The cloud implements some applications for users to request for certain missions to be done by UAVs. For example, software that manages collaborative UAVs for spraying crops in large farms. The user accesses the application to specify the location and size of the land then requests spraying crops by UAVs. It also offers monitoring interfaces for the user to monitor the progress and completion of the mission. The collaborative services manage the task allocation to suitable UAVs according to their statuses and capabilities such as cameras for monitoring, GPS for location, and fertilizer/pesticide tanks

for crop spraying. Furthermore, tasks planning and scheduling are managed. These services are available by PaaS and accessed through APIs. Another example is surveying forests to find the source of a fire. Collaboration services can manage the spread of UAVs over the forest and insure that UAVs are covering the whole area efficiently. Then UAVs use customized services to sense temperatures, capture photos, update status and invoke other services requiring the real-time information. Users monitor the mission through SaaS. The proposed framework of Collaborative UAVs Cloud is shown in Figure 2.

V. TYPES OF SERVICES: ESSENTIAL AND CUSTOMIZED SERVICES

Applications are developed for specific hardware or systems and this usually means implementing all the components needed. Alternatively, most of these components can be developed as services and integrated in the applications when needed. Services are divided into two types: essential services that are required for any type of collaborative UAVs and customized services that are offered and used based on the UAVs capabilities and the task that needs to be performed. Integrating these services reduces the time and cost of developing collaborative UAVs applications.

A. Essential services

Essential services offer the basic requirements for collaborative UAVs, using these services developers only focus on the main functionality of the mission rather than reinventing the wheel. Essential services include:

- **Mission organization service** is responsible for analyzing the mission then defining the resources needed to perform the mission according to the current and expected conditions. It defines the functional and non-functional requirements for the specified mission to be listed for the broker service. More subservices could be included for more efficient organization such as planning and scheduling services.
- **Broker service** where all other services are registered with their descriptions to be discovered and used later by clients. It is responsible of allocating tasks to the suitable UAVs. Hence, when a certain service is needed, the broker service obtains the requirements of the service then provides the information about the service provider, including its current location, communication method and any other information about the UAV. An algorithm is needed to distribute tasks among UAVs based on the resources available, locations, energy levels and other considerations. For example, to capture a specific location, rather than using a single UAV with GPS and camera that has low battery levels, two fully charged UAVs one with GPS and another with a camera can be used to perform the same mission. Tasks need to be distributed carefully to efficiently utilize the available UAVs resources. The mission organization service and the broker service are considered the backbone of collaboration.

- **Ground station command** when a user from the ground station sends commands to UAVs, a service is needed to handle them and respond efficiently. A command needs to be saved, decoded and executed. Some commands such as canceling a mission could be authenticated by certain users under specific conditions. These requirements can be provided by the command service.
- **Monitoring energy levels**, a service is needed to manage UAVs energy. Many decisions are taken according to the energy level. The UAV may return to a specific location when it reaches a certain level. In addition, before allocating a task to a UAV, it must ensure that it has enough energy to complete the task. If a UAV reaches low energy levels during a mission, it can be replaced with a similar UAV or with a set of UAVs according to the task organization service. The energy level of each UAV is saved in the broker service.
- **Location Monitoring Service** is needed due to the mobility of UAVs. UAVs' locations play an important role in allocating tasks. If a UAV is currently near the mission location, it is preferable to choose it than a similar UAV far from the mission location. Location monitoring service is responsible of locating the UAVs in an efficient method with minimum power consumption. For example, GPS consumes high power but gives accurate positions, while using Wi-Fi may give less accurate positions and consumes less power. Moreover, some UAVs may not have GPS, as a result, their location is known based on nearby UAVs. These methods are managed by the location monitoring service and the UAVs locations are saved in the broker service.
- **Security** is one of the most important requirements in UAVs as the data could be critical and/or confidential, particularly if it is a military or political mission. The data should be secured such that only users with right privileges can access it. Encryption and decryption processes can be used in data exchange. Other security mechanisms are required for data and resources protection. However, introducing these measures could affect other limited resources such as energy levels and speed of communication/execution.
- **Managing heterogeneous communication services**, UAVs can be equipped with different communication technologies for communication among multiple UAVs and with other systems such as the main control station and wireless sensor networks. In addition, not all UAVs can directly communicate with each other or with the main station. From an operational point of view, UAVs have a wide range of applications with varying communication and networking requirements [17]. In addition, different communication links such as cellular, satellite, line of sight, real-time mobile ad hoc networking, and delay-tolerate networking capabilities with data ferrying links may be available. This service is to manage the available heterogeneous communication methods.
- **Real time control**, UAV hardware should be controlled in real time to execute and manage flights. In addition, a service is required to avoid UAVs collisions.
- **Storage services**, UAVs store and retrieve data from storage resources, which can be in one UAV, multiple UAVs, or in the Cloud. When using storages in multiple UAVs, advanced mechanisms are needed to allow dealing with multiple distributed and maybe heterogeneous storages in the UAVs as a single storage resource.

B. Customized services

Customized services are used according to the available resources in UAVs and the tasks that are required for the mission. UAVs may or may not include these services while other customized services could be added for special missions:

- **Sensing Services**, as most types of payload can be considered sensors; such as temperature sensors, humidity sensors, radar, optical sensors and others. Sensing services collect data from these sensors and either store it in a data storage on board or sends it to be used by other services such as data analysis or image processing services.
- **Actuation Services**, as some UAVs may have to take actions according to the assigned tasks and their payload. UAVs may have output devices such as lights or valves for liquid or gas. A set of actuation services can be provided in each UAV for controlling usage of these devices.
- **Camera capturing and video recording**, these are considered as a separate service as more processes such as filtering and editing are used. Image and video capturing requires higher internal memory in the UAVs than other sensors. It also depends on the required resolution and environmental lighting conditions. Some enhancements can be added to this service due to UAVs mobility where cameras are not stable to capture clear images for example.
- **Image analysis**, it is provided as a separate service as the camera services could be requested by another UAV. For example, a UAV which has no camera requests an image from one nearby that has a camera. Analysis includes certain types of recognition such as face recognition or object movement detector. Furthermore, tracking an object or monitoring an area may need special image analysis.
- **Data analysis**, different types of data need to be analyzed to discover information for a certain decision. For example, in surveying a forest, the increased temperature during the flight may indicate the direction to the fire source. Data Analysis services consider the timing and location of data due to the mobility of UAVs and having different measurements in different times and locations.

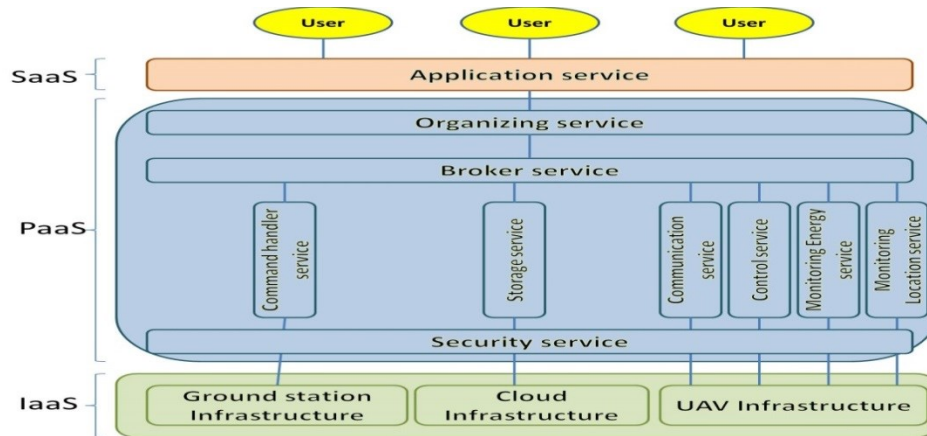


Figure 2 Collaborative UAV Cloud Framework

VI. COLLABORATIVE UAVS CLOUD

In a collaborative UAVs cloud, the user uses the online software application to determine the mission. The online application enables the user to access the service, regardless the time and place. Moreover, the user does not have to own the UAVs therefore, a third party provides the services. For example an agriculture service for spraying crops with insecticide or fertilizer. First, the user accesses the application to specify the location and service customization. Then, the task organization service analyses the mission and determines the resources needed to accomplish the functional and non-functional requirements according to the parameters that the user specified. For example, a special type of insecticide or image and video capturing with specific resolution. Next, a list of the resources needed is passed to the broker service- which all UAVs have registered their services in. The broker service allocates tasks to the appropriate UAVs and starts the mission.

Accordingly, the allocated UAVs work together to accomplish the mission. After that, UAVs interact together to collaborate and share resources and information needed to complete the mission. Results and reports are sent to the user to monitor and track the progress of the mission. However, multiple approaches of collaboration could be followed.

A. Decentralized Organizing

All UAVs have knowledge of others' services and interact directly to request the service or knowledge. Although this approach has many challenges for a huge number of UAVs because it consumes more communication and negotiation for finding and requesting a service as well as updating all UAVs with new parameters. This means that each UAV needs to interact with all other UAVs, also it results in high memory consumption for the UAVs to save the data of the services and information about other UAVs such as their energy levels and locations.

B. Centralized Organizing

In a centralized model a single site is responsible for registering and storing information about UAVs and their services as well as planning and scheduling tasks. This site could either be on the cloud or on one of the UAVs.

- Cloud Based Organizer

Information is stored and processed in the cloud as shown in Figure 3. Which allows for more storage and processing capabilities. However, it requires very reliable and fast connections to the cloud. Moreover, connection traffic and consumption are challenges in this approach. Furthermore, storing the data on the cloud represents a privacy and security threat as critical information could be harmed or accessed by unauthorized parties.

- UAV Based Organizer

One or a few UAVs are responsible for managing communications and organizing tasks, especially when no cloud connection is available. Therefore, multiple UAVs will perform as a cloud. Other UAVs may enquire about the required services from one of the UAVs in charge rather than sending the requests to all UAVs. However, this UAV may get damaged or overloaded with huge requests and information updates.

VII. OPPORTUNITIES AND CHALLENGES IN USING MOBILE CLOUD COMPUTING FOR COLLABORATIVE UAVS

There are many opportunities the cloud computing opens in collaborative UAVs. On the other hand, challenges are faced in implementing them. These challenges need some solutions.

A. Opportunities

- As the cloud has huge processing power, most of UAV data computations could be made on the cloud which makes UAVs applications more powerful.
- Cloud computing provides large and scalable storage rather than the limited UAVs storage.

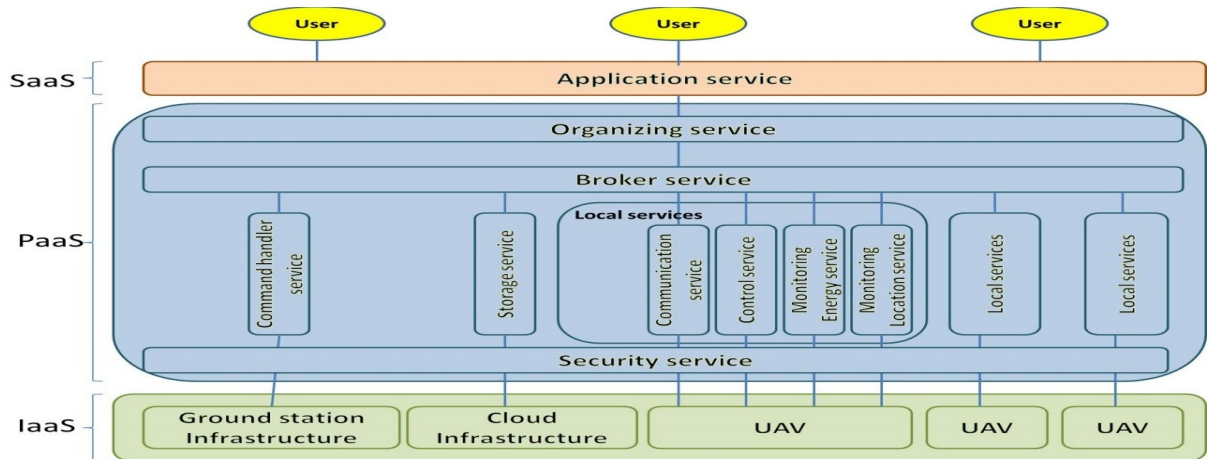


Figure 3 Collaborative UAVs cloud

- Storing data in the cloud increases reliability by ensuring data back-up thus offering access even when the UAV is damaged or lost during the mission.
- Cloud computing offers ubiquitous services which are needed for the UAVs storage and collaboration by sharing information and retrieving it at real time.
- Complex types of data such as video streaming need more processing, which consumes high energy and can be reduced offloading the processing to the Cloud.
- Collaboration between UAVs and ground stations can be performed using the Cloud.
- Using heterogeneous UAVs increases collaboration benefit and reduces costs by having specialized collaborative UAVs services work together as one super UAV.
- Using the Cloud, adding services to UAVs increases the ease of integration and eliminates the need for installing some of the processing, memory, and energy consuming services in each UAV.
- Integrating UAVs resources allows users to monitor them from anywhere at any time. In addition, this will allow viewing multiple UAVs as one super UAV.
- Using mobile devices for web services on UAVs allows sharing data with all the team in real time as well as historical reviews and gives the ability to use cloud resources such as Google Earth 3D maps. In addition, UAVs can be provided with the flight plans from the cloud database.
- Intelligent collaboration among multiple small, specialized UAVs allows for more efficient task achievement compared to using one big UAV.
- SOA introduces services through APIs, thus adding more UAVs or resources is easier. Using web services in UAVs allows developers to integrate the

services needed and increase the development efficiency by reusing well tested COTS services.

- Web services are based on standardized protocols, which make it possible to develop UAVs on different platforms and using varying programming languages. In addition, Web services have Web Service Description Language (WSDL) to describe these services, which allows choosing the most suitable services for the mission.
- The concept of sensing as a service and sharing data through the Cloud gives the opportunity to use the UAVs sensors by different cloud applications.

B. Challenges

Although collaborative UAVs Cloud can provide a number of opportunities for several collaborative applications, there are a number of challenges that must be addressed. These challenges include, but not limited to:

- Due to the energy limitations of UAVs, energy efficient algorithms are needed for the different aspects of collaborative UAVs Cloud. This includes the need for designing energy-aware and energy-efficient algorithms for collaborative communication, sensing, acting, processing, and data storage.
- Management mechanisms for efficient collaboration must be developed. This includes for example a capacity planning model that determines the number of UAVs needed to accomplish a mission. Generally, as the number of needed UAVs increases in relation to the size of area to be covered or the speed in which the mission should be completed.
- Using multiple UAVs and the cloud raises more security issues. UAVs are being widely deployed in domains that involve sensitive information and critical operations such as military, infrastructure

inspection, and rescue services. In such domains, it is necessary to secure communication, service execution and service availability. In addition, connecting UAVs to the cloud endangers it by the threats of malware. Furthermore, reliable communication is always needed to ensure timely execution of control commands to avoid accidents or collisions.

- As UAVs have limited capabilities, software mechanisms used for communication among UAVs and the Cloud such as web services must be efficient light-weight and do not heavily consume the available resources.
- An algorithm is needed to schedule and allocate resources efficiently and quickly for different tasks in a collaborative UAVs Cloud.
- It is inefficient to use traditional transport protocols such as TCP and UDP among UAVs and the Cloud. The reliability of the connections affects message delivery, as unreliable connections cause resending of messages in TCP, which leads to high traffic and resources consumption; on the other hand, using UDP generates less overhead and traffic, yet it does not ensure message delivery. There is a need to design a new efficient transport protocol that is suitable for a multiple UAVs environment.
- The availability of some services depend on some contexts such as the UAVs' locations, energy levels, or specific sensors readings. For efficient collaborative UAVs Cloud, contexts and other relevant issues must be considered.

VIII. DISCUSSION

Using several small UAVs is relatively inexpensive and preferable compared to one large UAV for most missions. According to [13], comparing the collaborative sensing based on real energy consumption to traditional sensing without collaboration it was found that the former achieved over 80% power savings. The cloud simplifies the development of collaborative UAVs services and allows for adding more services easily. When UAVs are connected to the cloud, data is available for users regardless of their locations.

Heterogeneous UAVs have different capabilities; therefore, it is better to offer their functions as services to other UAVs and to the cloud. The service consumers could be thin clients that do not have high capabilities, thus most of the processing and storage is done in the Cloud. Having well tested ready services simplifies developing collaborative UAVs applications with less efforts and costs. Essential services are used to manage basic functions that are needed for any collaborative UAVs application, while customized services are chosen depending on the capabilities of each UAV. Tasks allocation can be done efficiently based on the different aspects of UAVs energy, location and capabilities

also the environmental aspects such as distance and the estimated duration of the mission.

Another issue is energy consumption [13]. Some devices such as GPS are energy-hungry and can consume the battery power quickly, while Wi-Fi or cellular signals can also be used to obtain location information with less energy consumption, however with less accuracy. This leads to another challenge of relaying on less accurate location information. In multi-UAV systems each UAV can have multiple sensing tasks with different requirements at particular times and locations. As a result, an appropriate sensing tasks scheduling algorithm is needed to minimize energy-consumption while performing the sensing tasks. Dealing with each UAV as an independent system is not energy-efficient; however, it is more efficient to group multiple correlated tasks together. This is doable by exploiting the temporal-spatial correlations between them and scheduling sensing actions associated with them. In addition, there is a need to determine when to conduct common sensing actions based on user mobility status with the objective of minimizing energy consumption and satisfying the temporal and spatial requirements.

Furthermore, connections may not be reliable and some data could be lost or delayed. Therefore, choosing a suitable communication protocol depends on the required connection reliability versus timeliness. For example, in [11] TCP was found to be inefficient over unreliable connections, which led to using UDP instead. Hence, rather than implementing services using REST protocol which is supported in mobile devices such as smartphones, SOAP protocol was used with the UDP communication protocol.

One of the most important issues in collaborative UAVs applications is security where missions could be critical such as military missions. Also data is confidential and need to be highly secured and encrypted. In addition, only authorized clients can control UAVs. Therefore, it is important to make available several security services for UAVs applications to choose the suitable security levels.

IX. CONCLUSION

Using mobile cloud for collaborative UAVs applications offers many opportunities that are not available in traditional communication and collaboration methods. The cloud simplifies developing new collaborative applications. In a collaborative UAVs cloud, the UAVs use the cloud infrastructure; therefore, there is no need for high storage capacity on all UAVs since they can use the cloud storage which comes with services to manage reliable storage. Furthermore, the Cloud's powerful processors can be used rather than having high cost powerful processors in each UAV.

The Cloud can deal with the UAVs heterogeneity where communication protocols may differ in different UAVs. Moreover, UAVs with different resources need to be managed efficiently, which can be achieved using specialized cloud services. As UAVs are mobile, some special aspects should be considered in developing UAVs as a service in the cloud. The locations and energy levels of the UAVs play an important role in many decisions in the

collaborative applications. On the other hand, some challenges need to be faced in collaborative UAVs Cloud to gain the most benefits.

ACKNOWLEDGMENT

This work is supported in part by UAEU-NRF Research grant number 3IT045.

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