Path Planning for Internet of Drones

Aditya Goyal
Department of Computer Science and Information Systems
Birla Institute of Technology and Science, Pilani
Rajasthan, India
f2015848@pilani.bits-pilani.ac.in

Nikhil Kumar
Department of Computer Science and Information Systems
Birla Institute of Technology and Science, Pilani
Rajasthan, India
h20170119@pilani.bits-pilani.ac.in

Amit Dua
Department of Computer Science and Information Systems
Birla Institute of Technology and Science, Pilani
Rajasthan, India
amit.dua@pilani.bits-pilani.ac.in

***Abstract*— The Internet of Drones(IoD) is a multi layered, control architecture design intended to regulate and coordinate the navigation of Unmanned Aerial Vehicles(UAV) in a shared public airspace. UAVs have the potential to be employed in public space for purposes like surveillance, monitoring, package delivery, emergency services, etc. This paper provides a network architecture for scalability of UAVs in an urban environment addressing issues of path planning, safety, privacy, network connectivity, etc.**

I. INTRODUCTION

An Unmanned Aerial Vehicle(UAV), popularly known as a drone " is a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload" [1]. For the purpose of this paper, we shall restrict ourself to non-military drones.

With the onset of testing and trials on drones by a host of private companies, drones are bound to be deployed in near future. By 2022-2023 , commercial sales of drones will experience accelerated growth with total number of drones approaching 250,000 by 2035, of which 175,000 will be deployed in the commercial marketplace[2].

Drones can have various uses requiring varied functionalities such as surveillance, monitoring, package delivery, disaster relief, farming, cinematography, etc. Some of these such as farming or on site surveillance do not require the use of public airspace, hence shall not be discussed. Path planning for a large-scale deployment in public airspace poses various challenges related to safety, privacy, collision avoidance, congestion, signal availability, etc. Hence, a formal and standard protocol for regulated path planning of public airspace becomes imperative to serve the industry. NASA, in collaboration with the Federal Aviation Administration(FAA) and industry stakeholders, has already ushered a rigorous research on Unmanned Aircraft System (UAS) Traffic Management (UTM)[3-5].

In this paper, we shall propose one such architectural model. We believe that our model is practical and has the potential of large scale scalability unlike other models proposed so far.

Our proposed architecture for the Internet of Drones(IoD) is fairly similar to Air Traffic Management System(ATMS). Analogous to ATMS, we propose a layered model for path planning and maintenance of standard communication protocols. Such a model is intended to allow commercial operators to meet minimum operational requirements by having their own implementation for path planning. This allows them to leverage technology, operational efficiency and resource management the same as airline operators. It encourages commercial participation and healthy competition leading to overall research and development in the architecture. Unlike ATMS, we factor in issues like congestion and drones' technical capacity; and use designated pathways instead of a free flight for path planning.

Similar to a spectrum auction [6] where different frequency bands are auctioned off to interested telecom operators, various altitude bands can also be auctioned off to interested drone companies. However, owing to the availability of limited altitude bands, shared usage of bands in the same urban airspace might be necessary.

The paper uses some of the above mentioned already existent ideas and system models to devise an architecture for the Internet of Drones. The paper does not discuss methods or implementations for path planning. It proposes an architecture, framework and guidelines, and hence frames a concise problem statement for implementing path planning systems. Such path planning techniques have already been explored in great depth by allied domains like self driving vehicles or route planning for shared cab hailing services.

II. RELATED WORK

There has been ongoing research on the development of a suitable communication system for drones. In [7], Hall proposes a multi-tier inter-network that allows packets to flow across either long-range or short-range tier individually, or both concurrently, depending on availability of the tiers (for example, whether the drone is in cell coverage, or whether the drone has ad hoc WiFi capability). The above idea is useful for short-range inter drone communication especially in ad hoc cases related to collision avoidance. However, it has poor reliability and scalability for long-range communication especially because a network outage shall affect all drones in a region leading to no long-range information transfer from that region.

In [8], the authors argue that UAV's path should depend not only its destination but also on network availability to transmit periodic localisation messages with a satisfactory Quality of Service level. This Quality of Service level quantified as Package Loss Rate (P) ensures a threshold network that is essential for drone tracking and intercommunication. We have used the concept of threshold network availability while creating airmaps which shall be discussed in our proposed work.

There are two main approaches to path planning for the Internet of Drones. One is an online approach while another is offline. While an online approach requires a more robust communication system, it allows dynamic control over the drone, unlike an offline path. A systematic comparison between the two approaches has been done in [9]. Clearly, in an urban airspace that shall have high scalability, an offline approach is not viable.

A very comprehensive comparison of various path planning techniques for drones has been given by Goerzen et al in [10]. Such techniques can be used to implement our architecture and develop a system over the architecture.

The most significant work on the Internet of Drones has been done in [11]. The paper proposes a detailed architectural framework for implementing the Internet of Drones. However, some shortcomings in the paper need to be addressed.

1) The paper does not account for communication requirements for drones and assumes an ideal scenario where all drones will remain connected to ZSPs at all times.
2) The paper proposes a single altitude level airspace. This leads to poor resource utilization and might face issues in scalability due to congestion.
3) The paper proposes that all drones must broadcast information like its current location, Gate Data, 3D coordinates and future path to all Zone Service Providers(ZSPs) operating in that zone. However, the above idea is unviable because it will require a) excessive communication capabilities in terms of data packets sent, b) ideal maintenance of protocols among rivals ZSPs i.e, drones should transmit, timely high frequency data to all ZSPs, including rival operators. In a cost competitive or limited connectivity scenario, drones might be programmed to send poor quality data(low frequency, less precision) data to rival ZSPs leading to operational hazards.

III. PROPOSED SYSTEM MODEL

A. *Terminology*

In this section, we present different components of the architecture. The purpose is to model an architecture for the Internet of Drones over which a system can be designed and implemented. We use some terminologies during the course of the paper to refer to some physical and abstract entities that are a part of our architecture.

An airspace is a low altitude band in a physical region that is deemed suited for the Internet of Drones. It can be understood as an altitude band over an urban environment. An airspace is divided into multiple non overlapping altitude bands known as layers. Every layer of every airspace is divided into multiple sections. Each section has its own airmap.

An airmap is a network of airroads and nodes. A node is any region on the airmap that is not meant to be reachable by a drone during transit, and shall only be accessed with prior permission. An airroad is a path on airmap that can be used by drones for transit and has well defined boundaries. Every airroad will have features which consist of a list of minimum attribute requirements for a drone to use that airroad. These features might contain information about visibility, wind speed, drone speed, etc. Two adjacent sections of a layer will be connected to each other through points on airroads called junctions. Please note that two sections that are present in different layers(one above or one below) are not considered as connected and they do not form any junction.

Every layer of every airspace will have an allocated telecom operator. The telecom operator shall have a coordinating centre in every section of the layer. A coordinating centre is a physical entity for the purpose of collecting, aggregating and dissipating information from governmental agencies and all the drones in that section to the section centres operating in that section.

Every drone operating company that is functional in a layer shall have a section centre in the sections it serves. So, every section can have multiple section centres all of which represent different drone operating companies operating in that section.

These section centres may not be physical entities and can be realised as software machines. They will receive high frequency information from telecom operators through a standard protocol, process the information, and transmit updates to the drones they are linked with.

The governing body has been used as an umbrella term to refer to a single or a group of governmental agencies such as Federal Aviation Agency, Department of Homeland Security and local urban councils, which through a coordinated effort will be responsible to regulate the Internet of Drones.

B. *Description*

The governing body shall declare an airspace. Moreover, the governing body will decide the number of layers and individual band width of different layers in the airspace. This decision can be made based on the discretionary requirements. Ex. the lowermost band can be strictly reserved for emergency services, surveillance and monitoring. The layers above can then be open for commercial drone operators.

Every layer will be allocated a telecom operator. This shall be done based on maximum connectivity offered or conversely minimum Package Loss Rate. Bidding can be done to choose a telecom operator for every layer.

Once a telecom operator has been allocated, the governing body in consultation with the telecom operator divides the layer into different sections. The division of a layer into different sections should be done, mostly based on availability and location of coordination centres of the telecom operator. The division should be such that all regions of a section have the best possible network coverage with its coordinating centre. Once, sections have been created, the airmap of each section should be created by the local government in consultation with stakeholders. The choice of nodes and airroads is of prime importance. The airroads should not have any physical obstruction. Moreover, no airroad should be present in a private property or a no fly zone. Conversely, all private properties that are not a part of public airspace will be nodes. We will discuss this further in proposed work. This airmap should strictly be adhered to by all the section centres of a section.

Now, any drone operating company that wishes to operate in a layer will have to enter into an agreement with the telecom operator of that layer. This might be subject to prior permission from the governing body because the governing body might wish to reserve different layers for specific purposes. Once an agreement has been reached between a drone operating company and a telecom operator, the drone operating company will install section centres in the sections it wishes to operate in. Every section centre is physically connected(wired) to the coordination centre of that section to receive high frequency information about all the drones operating in that section. The section centres are expected to dynamically augment their airmaps based on information about drones received from the coordination centre and use the airmap for path planning purposes.

Drones will require prior approval before deployment. They need to be approved by the governing body. Drones need to possess minimum hardware and software requirements for an approval. They should have a short range collision avoidance mechanism along with some minimum manoeuvring requirement like minimum speed, network capabilities, etc. On approval, every drone will be assigned a unique Drone_id (similar to mobile numbers) and some static attributes describing its technical capabilities like payload offered, minimum visibility required, fuel capacity, etc. These static attributes can not be changed without a re-approval from the governing body. The Drone_id will also be used to identify the drone operating company of each drone.

Every drone operating in a layer will have to subscribe to one of the drone operating companies in that layer. It will be connected to the section centres of drone operating company it has subscribed to. Drones will have a set of static and dynamic attributes. It will contain information like available battery(dynamic), available fuel(dynamic) and maximum fuel(static), current payload(dynamic) and maximum payload(static), and drone technical capabilities like maximum speed(static), minimum visibility required(static) and maximum allowed wind speed(static). Every drone will receive all information regarding its path planning and implementation from the section centre of its drone operating company.

IV. PROPOSED WORKING MODEL

This section presents our proposed working model that shall be used to implement the Internet of Drones. The working model has been presented as an algorithm which is self explanatory in nature. Our model comprises of three main entities a) Drones, b) Coordination centres and c) Section centres. These entities regularly communicate with each other and are interdependent for their functioning.

Further, we have divided our system flow into three main layers. All three layers are mostly independent of each other and provide different functions. Layers allow organised division of function. have a greater scope of augmentation and allow concurrent processing and dissemination of information.

A. *Drone*

When a drone is called or evoked, it will be provided with a starting node and an ending node. Drones will maintain two sets of communications. One is short range and another long range. The short range communication shall be used for collisions avoidance. The short range communication depends on sensors and ad-hoc Wifi connectivity to detect the presence of any other drone or obstruction in close vicinity.

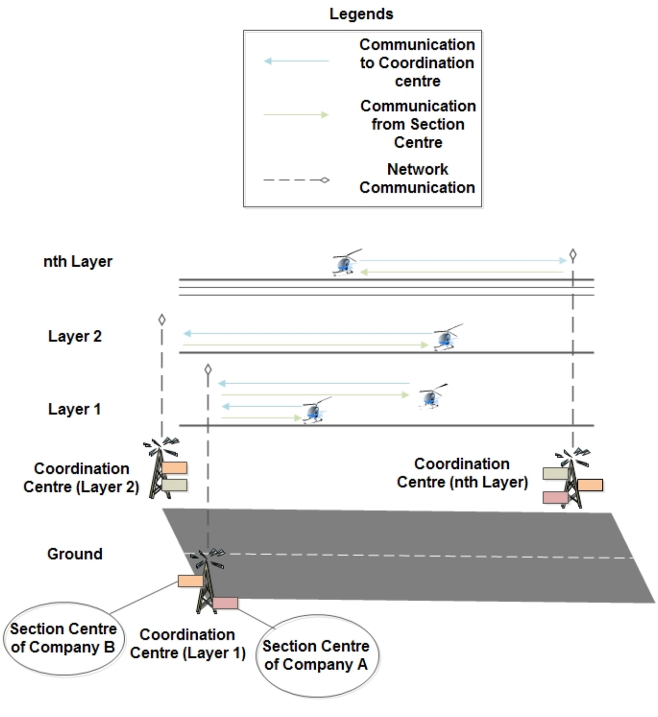

Fig. 1. **Communication of drones with Coordination centres and Section centres**

For long range communication, drones shall transmit information to the coordination centre and receive information from their section centre as depicted in the figure. Drones will receive all information about its path from different layers of section centres

Apart from this, in case of a hardware or software crash, an SOS signal will be sent to the coordination centre and a ground response team will be alerted.

Algorithm 1 Drone

```
x, x′, y, y′, start, end, exit, route
    ▷ x, y are present coordinates, x′, y′ are future coordinates, start is the starting node, end is the destination node and exit is the destination node/junction in the present section

Drone_id, {Attributes}
    ▷ Attributes contain fuel, battery, night vision, maximum speed, rotor diameter, etc.

procedure CALL(from, to)                ▷ First call to the drone
    start ⇐ from
    end ⇐ to
    START
end procedure

procedure START                         ▷ Drone in operation
    loop infinite
        SEND_NAVIGATION_SIGNAL(Drone_id, x, y,
          start, end, exit, route, {Attributes})
                ▷ Send information to Coordinating Centre
        exit ⇐ RECEIVE_N_SIGNAL
        route ⇐ RECEIVE_S_SIGNAL
        x′, y′ ⇐ RECEIVE_A_SIGNAL
                ▷ Receive information from Section Centre
        MOVE(x′, y′)
        if x, y == end then
            break
        end if

        if System_Crash then
            SEND_SOS_SIGNAL(Drone_id, x, y)
        end if

    end loop
end procedure

procedure MOVE(x′, y′)
    if !CHECK_COLLISION(x ← x′, y ← y′) then
            ▷ Use collision avoidance mechanisms to check if path is collision free

        x ⇐ x′
        y ⇐ y′
    else
        do_nothing
    end if
    {Attributes} ⇐
        UPDATE_ATTRIBUTES({Attributes})
            ▷ Attributes like fuel and battery might change with movement

end procedure
```

B. Coordination centre

The coordination centre will be responsible for aggregating information and sending it to all section centres. It shall maintain three sets of independent signals, namely a)Navigational signal, b)Features signal and c)SOS signal.

*1) **Navigational Signal**:* Signal received from drones presently operating with the section.

*2) **Features Signal**:* Features signal basically includes some dynamic changes that need to be done in the features of airroads. In particular, we have included weather update and governing body update. Weather update basically corresponds to changes like wind speed, visibility, rain which are dynamic in nature. Governing body update will deal with the declaration of temporary no fly zones due to security, construction activity or a temporary obstruction in an airroad. In case of an SOS signal, a temporary no fly zone might be declared on a particular airroad to avoid a cascading effect.

*3) **SOS Signal**:* Emergency signal received from drones presently operating with the section.

Algorithm 2 Coordinating Centre

```
Section_centres, Features
procedure MAIN      ▷ Live streaming of three different
                      types of signals independently
    NAVIGATION
    SOS
    FEATURES
end procedure

procedure NAVIGATION
    loop infinite
        if Navigation_Signal_Received then
            for all s ∈ Section_centres do
                SEND_NAVIGATION_SIGNAL(Signal, s)
            end for
        end if
    end loop
end procedure

procedure SOS
    loop infinite
        if SoS_Signal_Received then
            for all s ∈ Section_centres do
                SEND_SOS_SIGNAL(Signal, s)
            end for
        end if
    end loop
end procedure

procedure FEATURES
    loop infinite
        Features ⇐ Weather_Update
        Features ⇐ Governing_Body_Update
        if isUpdated(Features) then
            for all s ∈ Section_centres do
                SEND_FEATURES_SIGNAL(Signal, s)
            end for
        end if
    end loop
end procedure
```

C. *Section centre*

The section centre will be responsible for receiving information from the coordination centre and guiding the drones it is connected to based on that information. Every section centre will have the airmap of that section which has been declared by the governing body. The section centres are expected to dynamically update their copy of the airmap with incoming information about the location of drones in airroads and junctions, and hence update congestion and provide optimal routes. We have proposed a layered architecture for the section centre with three layers. Moreover, we have focused on building a protocol system for section centre rather than giving an implementable model. This is because the paper does not delve into path planning algorithms and; hence functions related to updating congestion and providing exits, routes and future coordinates have only been declared, not implemented. An abstract view of path planning by combined functions of all three layers has been depicted in the figure after the algorithm. Here is a brief overview of the three layers.

Node Layer
Section Layer
Airroad Layer

*1) **Node Layer(N):*** responsible for transit from start node to end node. This layer is responsible for choosing an appropriate end node or end junction for every drone that belongs to its drone operating company and has entered that section. It will also be responsible for establishing primary communication with the drone and delinking it with the section centre of its previous section.

*2) **Section Layer(S):*** responsible for providing a route from start node/junction to end node/junction within the section to every drone that is connected to the section centre. It is also responsible for handling features signal and SOS signal. In the case of an SOS signal, it should check whether the drone belongs to its drone operating company. In such a case, it will alert the on ground team to take appropriate measures. For a features signal, the airmap should be modified based on the updates in the features signal and all the drones should be checked. In case any drone does not meet the minimum features requirements of its route in the updated airmap, it should be rerouted accordingly.

*3) **Airroad Layer(A):*** responsible for providing future coordinates i.e immediate next movement to every drone. The responsibility of this layer is to successfully manoeuvre the drone through the entire route that has been provided in the Section Layer by providing the next step of coordinates for every movement.

Algorithm 3 Section Centre

```
list    ▷ Contains the list of drones presently connected with section centre

Airmap, features
```

```
procedure MAIN    ▷ All three layers work concurrently
    N
    S
    A
end procedure

procedure N
    loop infinite
        if Navigation_Signal_Received then
            Drone_id, start, end ⇐
                RECEIVE_NAVIGATION_SIGNAL

            if (new_Drone_id_found)&&(Drone_id ∈
              Drone_operating_company) then
                NEW_DRONE_ENTERED(Drone_id)
            end if

            Airmap ⇐ UPDATE_JUNCTION_CONGESTION(
                start, exit)
        end if
    end loop
end procedure

procedure NEW_DRONE_ENTERED(Drone_id)
    list.add(Drone_id)
    list'.remove(Drone_id)
    ▷ Remove drone from list of previous section centre
    if end ∈ section then
        exit ⇐ end
                    ▷ Endpoint of drone lies in the section
    else
        exit ⇐ CHOOSE_EXIT_JUNCTION(start, end)
    end if
    SEND_N_SIGNAL(Drone_id, exit)
end procedure

procedure S
    loop infinite
        route ⇐ RECEIVE_NAVIGATION_SIGNAL
        if is_Incremented(list) then
            NEW_DRONE_FOUND(Drone_id)
        end if
        if Features_signal_received then
            CHECK_FEATURES
        end if
        if SoS_signal_received then
            CHECK_SOS
        end if
        Airmap ⇐
            UPDATE_ROUTE_CONGESTION(route)
    end loop
end procedure

procedure NEW_DRONE_FOUND(Drone_id)
    start, exit, {Attributes} ⇐ list(Drone_id)
    route ⇐ FIND_ROUTE(start, exit, {Attributes})
    SEND_S_SIGNAL(Drone_id, route)
end procedure
```

```
procedure CHECK_FEATURES
    Features ⇐ RECEIVE_FEATURES_SIGNAL
            ▷ Checking whether drones meet updated features requirements such as temporary no fly zone, low visibility, increased wind speed, poor network manoeuvring capabilities

    for all d ∈ list do
        if !IS_SATISFIED(path, {Attributes}, features) then
            route ⇐ NEW_ROUTE(x, y, exit, {Attributes})
            SEND_S_SIGNAL(Drone_id, route)
        end if
    end for
end procedure

procedure CHECK_SOS
    Drone_id, x, y, route ⇐ RECEIVE_SOS_SIGNAL
    if Drone_id ∈ list then
        GROUND_FORCE(Drone_id, x, y)
            ▷ Inform Ground team about failure, a temporary no fly zone might be declared by the ground team. In such a case, the ground team sends a signal to the telecom operator to update features.
    end if
end procedure

procedure A
    loop infinite
        x, y, route ⇐ RECEIVE_NAVIGATION_SIGNAL
        for all d ∈ list do
            x′, y′ ⇐ FIND_COORDINATES(x, y, route)
            SEND_A_SIGNAL(Drone_id, x′, y′)
        end for
        Airmap ⇐
            UPDATE_AIRROAD_CONGESTION(route)
    end loop
end procedure
```

V. DISCUSSION

Few aspects and entities of our model are unique in nature and pivotal in ensuring the sustenance, stability and scalability of our architecture by providing cross cutting features. These have been discussed in further detail in this section.

A. *Telecom Operator and Airmaps*

we have proposed that the telecom operator should be chosen based on maximum coverage offered. Bidding can be done to generate revenue from this process by keeping a minimum eligibility in terms of required network coverage in that layer.

Furthermore, the airmap for each section should be prepared by the local governing body in consultation with the telecom operator. This is important to ensure that all the airroads in the airmap have a minimum threshold network coverage defined in terms of Package Loss Rate(P). If a region does not meet the threshold requirement, it can not be declared as an airroad in the airmap. This is important as it allows us to ensure that all drones remain connected at all times hence, reducing the risk of operational hazards.

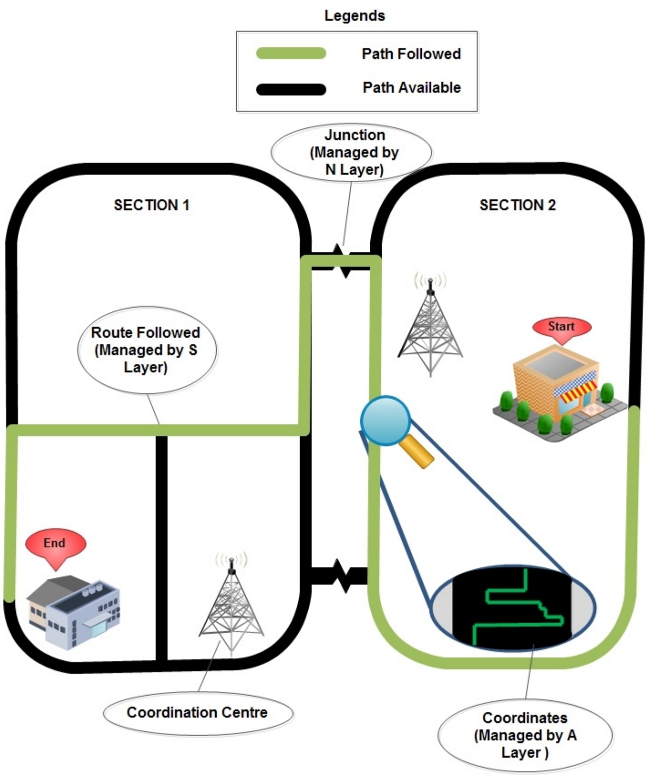

Fig. 2. **Sample Path of a drone by different layers of section centre**

B. *Airroads*

Every airroad has associated features which are regularly updated. This is of great importance in providing safety and yet having resource utilisation as features can be dynamically updated based on external conditions. Example. An airroad can be open to all drones during daytime and yet, require drones to have special night vision capabilities to navigate at night time.

C. *Node*

Nodes are regions in the airmap which are not a part of public airspace. They comprise the private airspace. This implies that drones can be operated with any mechanism and need not remain connected with coordination centre or section centre when inside a node. This allows private parties owning an airspace to use the drone as per their special requirements. Drones can be operated using remote controls and manoeuvre in free flight mode inside a node. Such a mechanism allows increased functionality as the operation to be performed within a node is independent of the transit of drone in public airspace. So, end drone users(package delivery, farming, surveillance, disaster relief, etc) can program the specific functionality required by the drone over the existing architecture provided. Example - a drone used for newspaper hawking can be programmed to reach each window after reaching an apartment through public airspace or drone can be navigated to each window through remote control after reaching an apartment (destination node for public transit).

*D. **Drones***

Our model encourages innovation and development in manufacturing drones. Firstly, through the concept of nodes, we allow drones to have additional functionalities over and above the requirement for using the public airspace to serve special and peculiar functions in private airspace. Example, functionalities such as the ability to sprinkle liquids, to create high stability 360° videos, to perform image recognition and tag any traffic violation or security threat, etc. can be layered over the basic navigational requirements. However, an approval system for drones ensures that they meet minimum requirements to operate in public airspace.

Secondly, our idea of matching attributes of drones with features of airroads rewards drones that have greater technical capabilities. Drones with better attributes like night vision, greater speed and wind speed tolerability will have access to more airroads and better routes and hence face less congestion. This encourages drone manufactures to invest in improving the performance of drones.

Beyond this, we believe that the concept that section operators, telecom operators and drones being independent components of the Internet of Drones gives space for an active participation of a variety of private parties of different scales and objectives.

VI. **FUTURE WORK**

Our model and architecture have been designed in a form that makes it implementable.In order to validate the proposed architecture at least one system should be based on it which is properly working. This will make the proposed architecture viable and practical to use. During the implementation of the system, if any discrepancy or inefficiency is faced, it can be used as feedback for designing further iterations of architecture.

We have not addressed two major issues. First is the issue of 'last mile' i.e, how drones are expected to move and interact after they have entered a node. Example, how will it reach the exact target(in a building) or how will it deliver a package. However, as mentioned earlier, we do not want this to be a part of any protocol and expect this functionality to be layered over the navigational requirement by drone manufactures/users according to their specific requirements.

Second, we have not given any specific algorithm for updating airmaps, incorporating congestion or devising routes. Again, as mentioned, we have provided this as an open problem statement open to the scientific community. We do not expect a single solution or algorithm to be used. In fact, we expect private parties(drone operating companies) to come up with their own solutions to implement these protocols. This will reward companies that can design more efficient solutions.

VII. **CONCLUSION**

We started with a problem statement to devise an architecture for the Internet of Drones. Any system can be implemented over the architecture laid by us. The proposed architecture is adaptable and highly scalable. It gives ample space for private parties to participate in the Internet of Drones ensuring that they can function harmoniously. It allows drones to transmit minimal information yet be maximally connected with the system. Foundation of the architecture has been laid by building a vocabulary of concepts for depicting the architecture, distinguishing the applicable segments of it and also choosing the limits of the architecture. Moreover, we planned a structure for the airspace and gave techniques to use that structure in the airspace. We depicted how various entities of the architecture are interdependent on each other how they shall communicate with each other. Furthermore, we investigated and examined a portion of the difficulties that need to be tended to, for a powerful IoD system. At long last, we talked about the future work and the benefits from the proposed system.

REFERENCES

[1] Dictionary of Military and Associated Terms, Unmanned Aerial Vehicle. US Department of Defense 18 Sep. 2018 https://www.thefreedictionary.com/unmanned+aerial+vehicle

[2] A. F. B. Hanscom and M. A. Bedford, Unmanned aircraft system (UAS) service demand 2015-2035, literature review projections of future usage, Res. Innov. Technol. Admin., U.S. Dept. Transp., Washington, DC, USA, Tech. Rep. DOT-VNTSC-DoD-13-01, Sep. 2013.

[3] NASA. (2015). NASA UTM 2015: The Next Era of Aviation. [Online]. Available: http://utm.arc.nasa.gov/utm2015.shtml.

[4] NASA. (2015). UTM Fact Sheet. [Online]. Available: http://utm.arc.nasa.gov/docs/UTM-Fact-Sheet.pdf.

[5] NASA. (2018). Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Concept of Operations. [Online]. Available: https://utm.arc.nasa.gov/docs/2018-UTM-ConOps-v1.0.pdf

[6] Cramton, Peter (February 2001). "Spectrum Auctions, Ch. 14" (PDF). Handbook of Telecommunications Economics: 605649.

[7] Hall, Robert J. "An internet of drones." IEEE Internet Computing 20.3 (2016): 68-73.

[8] Bekhti, Mustapha, et al. "Path planning of unmanned aerial vehicles with terrestrial wireless network tracking." Wireless Days (WD), 2016. IEEE, 2016.

[9] Yanmaz, Even, et al. "On path planning strategies for networked unmanned aerial vehicles." Computer Communications Workshops (INFOCOM WKSHPS), 2011 IEEE Conference on. IEEE, 2011.

[10] Goerzen, Chad, Zhaodan Kong, and Bernard Mettler. "A survey of motion planning algorithms from the perspective of autonomous UAV guidance." Journal of Intelligent and Robotic Systems 57.1-4 (2010): 65.

[11] Gharibi, Mirmojtaba, Raouf Boutaba, and Steven L. Waslander. "Internet of drones." IEEE Access 4 (2016): 1148-1162.