Delay/Disruption Tolerant Network Architecture for Aircrafts Datalink on Scheduled Routes

Mohammed Al-Siyabi, Haitham Cruickshank, and Zhili Sun

Centre for Communication Systems Research, University of Surrey, Guildford, UK
{m.alsiyabi,h.cruickshank,z.sun}@surrey.ac.uk

Abstract. DTN is a relatively new research field and many applications have been identified for it. It is an overlay network working over heterogeneous networks in challenged environments where the links are less reliable and the delays are expected to be very long. Due to the difficult working conditions of DTN, all types of available links are utilized to ensure better delivery of messages including the physical transportations methods such as buses and ferries. We propose using aircrafts in scheduled routes for data transportation for DTN application. We will show an analysis of aircrafts routes and possible scenario for DTN concept realization.

Keywords: Delay Tolerant Network (DTN), Aircraft, Air Traffic Control (ATC).

1 Introduction

DTN was first introduced as a new concept for interplanetary applications and expanded from there to cover more applications such as sensor networks, ad hoc, tactical military communications, acoustic marine and environmental monitoring. DTN links availability and duration are not guaranteed and they depend on opportunistic, scheduled, and predicted contact [1]. DTN works in challenged conditions such as scarce resources, limited bandwidth and connection durations. Disruption and long delays are common features and highly expected on this network.

However, DTN concept has advantages over traditional networks by providing more protection against data loss caused by network failures and disconnectivity. This is achieved by storing the data in DTN node's persistent memory until the next contact is available. DTN uses the store and forward mechanism to rise above the disconnectivity of intermittent links by overlaying a new protocol layer called bundle layers to transfer data messages which are also called bundles. It uses persistent memory to store the messages/bundles and forward them from node to node whenever the link is available. As shown in figure 1, which represents sending a message from source to destination, in case the intermediate node is not available, the node will store the message and forward it to the next node whenever the link is available again.These characteristics confine the potential applications of DTN to the delivery of un-urgent messages because of the expected long delays.

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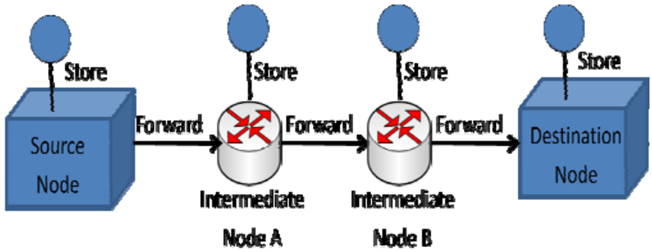

Fig. 1. Store and Forward DTN Architecture

Due to the challenged environment and scarce recourses in DTN, all types of available transmission means are used. Therefore, in addition to using the standard network backbone infrastructures, it has been proposed in DTN to utilize the existing transportations means such as buses, ships, ferries, bicycles, motorbikes and trains by physically transporting the saved data on a storage medium such as USP memory. There is a tendency in DTN to use physical transportation methods which is relatively a low speed movement compared with the high transmission speeds in network infrastructures. DTN is tolerant to delays and disruption; therefore, transportations are suitable to carry DTN messages at a standard transportation speed.

Using aircrafts in scheduled route as DTN bundle carrier is a novel trend for DTN applications. Throughout the DTN literature and to the best of our knowledge, there is no proposal to use commercial, private, military aircrafts for DTN applications the way we plan to introduce in this paper. There were some proposals to use motorbikes, ferries, buses, cars, bicycle and perhaps using Unmanned Aerial Vehicle (UAV) for some application [1],[2],[3],[4],[5]. Our contribution is to propose a valid application for new DTN technology by using airlines companies' aircrafts in scheduled routes to work as DTN bundles carriers during their flights along their routes.

Figure 2 shows the basic aircraft DTN architecture. The ground DTN node is located at a remote area with limited communication infrastructure under a scheduled flying route of a commercial airline company. The aircraft passes over the ground

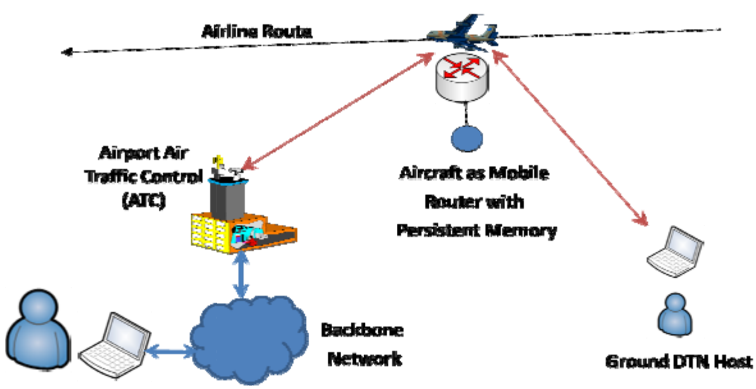

Fig. 2. Basic aircrafts DTN architecture

node at relatively systematic specific time intervals. The ground node has a ground to air DTN capable transceiver radio and transmits to the passing aircraft which is considered as a mobile router with persistent memory. In turn, the aircraft will store or deliver the message to the Air Traffic Control (ATC) then to its final destination through the backbone network.

This represents one way communication (up-link) from the ground node in remote areas to a user in urban areas. However, the two way communications from the user in the backbone network to the aircraft to the remote users will be more complex because it will require more coordination to enable the aircraft to decide when to download its traffic and where depending on the location of the ground remote node and the time expected for the aircraft to reach it.

2 Other DTN Transportation Mediums

There are many similar approaches in the literature to use transportation and scheduled transportation services to provide DTN service. However, to the best of our knowledge, this is the first time aircrafts in scheduled routes are proposed to be used for DTN services. All types of transportations are used in DTN including birds such as pigeons. In South Africa, they suffer from week broadband capacity at remote areas and an IT company wanted to prove this weakness to the media. They ran an amusing competition between ADSL speed and a humble pigeon. Winston, the pigeon, armed with a 4 GB memory stick travelled 60 miles and delivered the data while the ADSL had delivered 4 % of the data only[6].This indicates the usefulness of store and forward model for remote areas data transmission. The DTN concept works in a similar way to the pigeon transportation idea, where the data are stored in a storage medium and carried all the way to its destination. In South Africa also, they launched "Wizzy Digital Courier" [4] project in early 2003 to provide low cost internet access to schools using memory sticks carried physically to the users terminals.

In reference[2], at UMass Amherst, they deployed 40-node DTN operating on a public transit system called Diesel Net, a DTN consisting of Wi-Fi nodes attached to buses which travel on scheduled routes. Whenever they encounter other buses during their movements along their routes, they exchange data by establishing pair-wise connections between them. A similar approach can be applied to aircrafts where a number of scheduled aircrafts can exchange bundles among them along their routes. Reference [7] in Diesel Net describes how they evaluated DTN routing protocol called RAPID (Resource Allocation Protocol for Intentional DTN) using vehicular DTN test bed of 40 buses. They found out that the radio range is a parameter for optimum routing, and the same for the aircrafts radio range, which will decide the covered areas for DTN services based on the coverage range of both ground and airborne radios.

The performance of DTN depends on the number of participants, their communication capability, their storage capacity and their movements' pattern [8].This will apply to the aircrafts case where the quality will get better when there are more participating aircrafts and having high storage capacity, high data rate radio communications and their flying routes are within range of the ground terminals. The movement pattern of the aircrafts will be important to improve performance which is similar to [8] where they introduced autonomous agents or robotic agents, adopted and controlled their physical motion to the best optimum to meet the traffic demands in networks. The closest flying aircraft route to the DTN ground users is the best choice for transmitting bundles rather than one at farther distance which will degrade the radio performance.

Another approach, proposed by Li and Rus [9] algorithm, assumes peers broadcast the location of all other peers at frequent intervals using a communication channel. A similar idea can be used where one aircraft in a stable flying route is used to announce the locations and times of all other flights along their routes. This will help ground users to decide when and to whom to send. Zhao [3] proposed DTN ferries, which use ferries as DTN carriers. In his proposal, the peers schedule their movement to meet with the ferries movement in order to route their messages. This approach is more suitable to aircrafts because their flying route is fixed and therefore it is more appropriate for the ground terminals to schedule their movements and existence with the aircrafts movement.

3 Feasibility of Using Aircrafts for DTN Data Transport

Aircrafts transportation is the most popular, fastest, safest, widespread means of transportation on earth. Commercial air transport represents one of the major aspects of the world economy. It transports around 1.8 billion passengers annually over thousands of flights[10]. This business is growing and expected to increase the number of flights and passengers traffic to double the amount in the next 15-20 years [11].Worldwide aircrafts traffic flying routes represent a network of thousands of flights crossing the world every day. Based on Official Airline Guide (OAG) Facts, May 2009: Executive summary statistics, there are almost 81 thousand flights that take off daily worldwide and sometimes the number reaches 85 thousands in good seasons [10].

This gives indication of the potential application for this facility and might add a secondary service to airlines companies business to act as DTN bundles carriers. If aircrafts autonomously exchange and forward DTN bundles, this will be a great and big achievement for DTN technology. Aircrafts do not have any terrain obstacles and can fly over all types of topography. There are many remote areas (such as oceans and deserts) where it is very expensive to lay the terrestrial networks and there are many flights passing over some of these places on predictable times and locations. Therefore, they can be used as mobile routers to carry DTN bundles along their routes.

Aircrafts are flying at different altitudes with horizontal and vertical separation between them. Aircrafts can't just fly without orientation. They are flying in what is called air corridor where they follow fixed routes according to set plans and directives from ATC (Air Traffic Center) which is used to direct aircrafts during their flights. ATC have communication facilities of ground to air radios to communicate with the aircrafts [12].

Figure 3 [13] represent the worldwide air traffic daily routes of thousands of flights. These aircrafts can be used to receive, store and forward DTN bundles along their flying routes from sending DTN nodes on the ground. This is the basic idea behind the novel approach of using aircrafts in commercial flying routes to act as DTC carriers.

Fig. 3. Worldwide aircrafts traffic routes [13]

Another detailed example is shown in Figure 4 [14] which represents an example of the flying routes over Europe. It is obvious that the widespread of this service makes it an excellent choice to be a carrier for the DTN bundles. Ground to air radios on the ground and the airborne radios can be made DTN aware to enable them to act like DTN nodes.

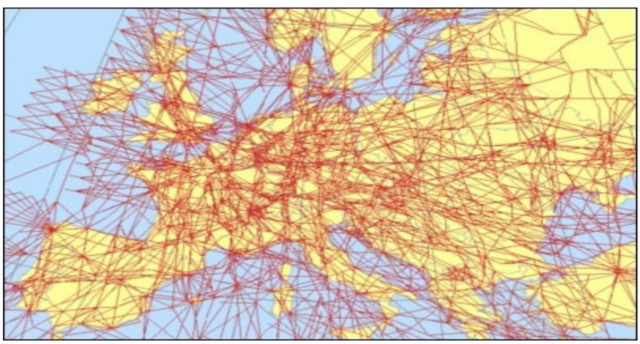

Fig. 4. An Example of main flying routes in Europe [14]

4 Aircrafts DTN Applications Concepts

DTN is an ongoing research field and aeronautical communications is also in continuous developments and is more focused on datalink applications than the traditional voice system. This research may provide the possible integration of new DTN concepts with the existing developments of aeronautical research.

4.1 Timing Concepts

Commercial airlines companies, cargo companies, military and governments run scheduled flights on timely fashions from airports to multi destinations. These flights are scheduled to depart daily or at any certain interval at fixed times of the day and arrive to their destination airports at the expected arrival time. Although there could be some unfortunate possible delays or flights cancellations, the aircrafts flying routes and duration time can be anticipated from ground users who can expect when they fly over their area and send their messages accordingly. Furthermore, the ground users do not need to know the destination of the passing aircraft. They can send their messages to any flying aircrafts which in turn will forward them to the nearest ATC, to the backbone network and finally to their destination.

4.2 Flying Aircrafts Repeaters

Flying aircrafts can be considered as repeaters/routers between terrestrial networks and satellite networks. If all flying aircrafts in the world are coordinating and cooperating together to forward and route messages, they will certainly act as flying air repeaters in addition to their genuine function to transfer people and goods. Similar applications are used in the military such as Airborne Early Warning and Control System (AWACS)) [15] where in addition to the detection tasks, the aircrafts might be used to extend radio coverage by acting as a repeater for ground units to transfer messages to further distances. After receiving DTN bundles, the aircrafts has two options to forward the bundles according to the applications priority and delivery options:

- At arrival: Store in persistent memory and forward only at arrival in ATC. This is applied to low priority traffic. The data might be stored in aircraft, downloaded physically into a flash memory and injected into the backbone network in the airport.
- During flight: Store in persistent memory and forward to ATC, other aircrafts or satellites while flying. This is applied for high priority traffic and might have higher cost to implement.

4.3 Fragmentation (Traffic Splitting)

Small size messages might fit into one flight while large size messages might be fragmented and sent to many aircrafts at different times. At destination, the fragments are reassembled to reestablish the messages. There might be proactive fragmentation where the messages are split in advance to be fit for the aircrafts capacity or reactive fragmentation in which case the arriving aircraft can’t take the whole messages. Therefore, the ground terminal will fragment the message, send a portion of it into the approaching aircraft and schedule to send the rest of the message bundles into the next one or two coming aircrafts depending on the message size and the aircraft capacity.

4.4 Aircraft to Aircraft

DTN transmission can be done via more than one aircraft. In some cases, when the arriving aircraft has limited capacity which might be filled from some previous DTN nodes along the flight route, that aircraft can free its capacity by sending its load to another aircraft that is out of range of the sending ground DTN radio, while it is in the range of the aircraft. This way the aircraft capacity is enough to receive the new traffic bundles from the DTN ground terminals.

5 Contact Duration and Capacity Calculations

It is important to estimate the contact duration of aircrafts with respect to a fixed user on the ground in order to calculate the expected capacity of the contact. The DTN application concept is based on using a basic type of ground to air VHF transceiver which can be deployed at remote areas. VHF Datalink (VDL) mode 2 is one of the common digital links used for sending data between aircrafts and ground stations. VDL2 will be the focus of this discussion and it is assumed that there exists a mechanism to transfer DTN bundles to aircrafts. VDL2 maximum data rate *(R)* is 31.5 Kbps [16]; therefore, it is required to calculate the total contact time *(t)* which the aircrafts needs to fly over the ground node using the basic equation below

$$\text{Time} = \frac{\text{Distance}}{\text{Speed}} \tag{1}$$

Aircrafts speed varies at different altitudes and for the purpose of this paper we will assume the scenario of a cruising speed flight at altitude *(h)* of 30,000 ft = 9.144 km at a ground speed *(S)* of 900 Km/h. We need first to calculate the distance *(d)* covered by an aircraft during which it is in line of sight (LOS) with respect to the ground DTN node. As shown in figure 5A, the radio coverage range is calculated using the communication radio horizon equation which is the straight line of sight distance *(d)* in kilometers to the earth horizon

$$d = 3.569\sqrt{h(m)} \quad km \tag{2}$$

Where *(h)* is the height above ground or sea level (in meters). As shown in figure 5B and 5C, the aircraft will become in horizon LOS with the ground node in two times:

1. From approaching the node horizon until it becomes above the node *(d1).*
2. After leaving the node until disappearing from node horizon *(d2).*

Therefore, the total distance *(d)* the aircraft is within the aircraft horizon is

$$d = d1 + d2 \tag{3}$$

Now, for our scenario, the aircraft height *(h)* is 30,000 ft (9144 m) and hence the radio horizon distance *(d1 and d2)* is 341 km and the total distance *(d)* will be 682 Km. Accordingly, the contact time *(t)* will be 45 minutes during which the aircraft will be in LOS with the ground node. However, this whole duration can't be used for data transmissions due to radios performance. The radio range is dependent on many factors such as the transmitted power, gain and atmosphere conditions. For better accuracy, we will consider the radio range is 180 NM or 333.36 km based on VDL2 physical layer validation report [17]. Therefore, the total distance *(d)* is 666.72 km and the contact duration *(t)* will be 44.5 minutes which is almost the same as the calculated results and therefore confirms our calculations.

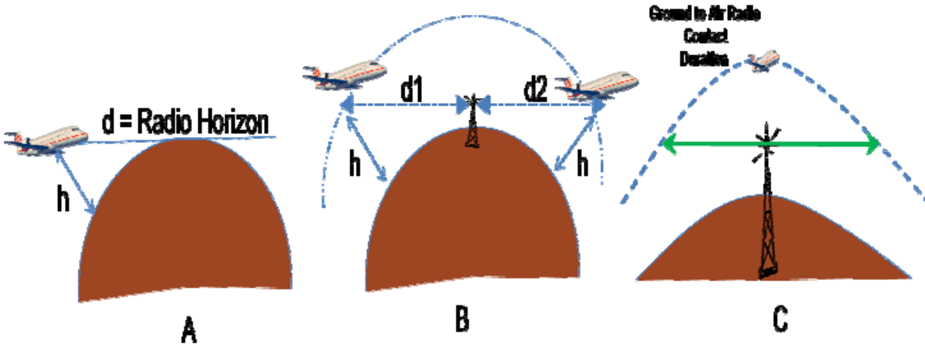

Fig. 5. Aircrafts contact duration calculations

For *(R)* 31.5 Kbps data rate of VDL2, the amount of data transmitted *(C)* during the contact duration will be 10 Mbytes. Therefore, for users who want to send data more than 10 Mbytes with the same aircraft speed and altitude used in our scenario, currently, this technology might not suitable due to the datalink limitations unless they fragment their load among more than one flight. However, the data rate might be improved in the future radio technology and accordingly the amount of transmitted data. Furthermore, this result is the best case scenario where the aircraft is assumed to be in direct LOS with the ground node while the real life situations will be affected by aircraft altitude, speed and angle with respect to the ground terminal plus height of the ground terminal, topography of the area, curvature of earth and radios performance.

Generally, we have derived equation (4) below to calculate the contact data capacity *(C)* (Mbytes) as a function of aircraft speed *(S)* (km/hr) and altitude *(h)* (ft) and the ground radio transceiver data rate *(R)* (kbps) for any scenario.

$$\mathrm{C\ (MB)} = 1.66 \times \frac{\mathrm{R\ (kbps)} \times \sqrt{h\ (ft)}}{\mathrm{s}\left(\frac{\mathrm{km}}{\mathrm{hr}}\right)} \qquad \mathrm{(MByte)} \tag{4}$$

In case HF radio transceiver is used, the HF Datalink (HFDL) provides long range communication and used by aircrafts to fly polar routes but with limited data rate *(R)* up to 19.2 Kbps [18]. Using equation (4) for the same scenario, the capacity *(C)* will be 6.15 Mbytes which is limited in today's technology but for some remote areas, would probably be of a great value.

6 DTN and Aeronautical Satellite

In addition to the navigation functions of satellites in aeronautical applications, they are used for voice and data communications between ground stations and aircrafts. There are non-air traffic management (ATM) uses for satellite communication which includes providing telephone services to passengers onboard the aircrafts. INMARSAT, IRIDIUM and other satellite systems are used for aircrafts satellite communication facilities [16]. Furthermore, aircrafts can provide additional services for ground

DTN nodes using their satellite facilities to provide remote ground users with data transportation services.

There are remote areas with no satellite terminal but having ground to air radios to contact aircrafts. On the other hand, there are some passing aircrafts which have access to satellite communication. In this case, the ground terminal will use their radios by connecting a laptop programmed with DTN technology. As shown in figures 6 and 7, the messages are sent from the laptop to the radio which will send it to the passing aircraft which in turn will forward it to the satellite and from there towards the final destination. In this case, the aircraft is used as a proxy hop to the satellite. This way the messages from remote areas will be sent to their destination faster and with less delay based on the best coordination between the DTN ground terminals and the passing aircraft.

Table 1. VHF VDL mode 2 and satellite data rates

Technology	**VHF**	**Satellite**				
System	VDL 2	Inmarsat SBB	Iridium	Global Star	Thuraya	IGSAGS
Data rate	31.5 Kbps	Up to 432 Kbps per channel	2.4 kbps Full duplex channels per user	Up to 9.6 kbps per user	9.6 kbps (per user)	30 kbps (per user)

Table 1 provides an overview of the VHF technology data rate and some satellite systems data links technologies[16]. First hop will be using VDL2 link from ground node to the passing aircraft at a maximum data rate of 31.5 kbps and second hop from the aircraft to the satellite at various data rate depending on the system of used satellite.

7 Aircrafts DTN Possible Application

There might be many applications for using aircrafts in flying routes as DTN bundles carriers because aircrafts are flying over many rural places and difficult terrain. The under-developed areas can use this service to send their messages to the backbone network. Ships in deep seas and offshore oil rigs depend on High Frequency (HF), Line Of Sight (LOS) for short distances and satellites for their communications. However, there are many flights passing over seas and oceans and big ships and oil rigs are normally fitted with ground to air radios. They can be used to send DTN bundles to the passing aircraft which might reduce cost and delay and provide alternative means of communication to them.

Military bases which are in remote areas can also use this facility along with border monitoring points which might send their monitoring reports to passing scheduled aircrafts to ensure better delivery speeds. Furthermore, environmental monitoring can take advantage of this service like the case with Zebra Net [5] where the monitoring reports can be sent to a passing aircrafts at certain set up times. Any sensor network can be adjusted to send its data to the scheduled aircrafts which might reduce the cost of setting a special purposes vehicle or flight to collect their data.

Another optimistic application might be implemented in high condensed flying areas such as Europe and USA. It might be possible to have a real time transmission during peak hours because there are many flying aircrafts which means more mobile routers and contact. As shown in figure 4 earlier, in Europe the routes are condensed and there are extra aircrafts which will secure better chances for more contacts in a real time manner of the traffic. When the ground DTN node connects to an approaching aircraft, it starts sending its bundles, which in turn forward it to other ATC backbone entities. However, as it moves away from the node, there will be more other approaching aircrafts which will mean the aircraft will hand over the receiving of bundles task to the new approaching aircraft and so on until the messages are fully transmitted. This can be applied to video streaming applications where a real time captured video can be sent via a passing aircraft to its destination. Of course in this case we assume the capacity and data rates of the transmitting radios in both ground and aircraft are enough to transmit the real time video stream.

In addition to the prime role of airlines companies to transfer goods and passengers, they might provide secondary services for DTN data transmission to ground subscribers. Every interested user might register with the airline company asking for the service and accordingly will be assigned an account with identified entitlements of the capacity, priority, traffic contract and expected Quality of Service (QoS). Therefore, the users now can transmit to any aircraft that belongs to the company fleet. Furthermore, Airlines companies can cooperate in same fashion like mobile companies to provide roaming services among their customers. If the passing aircraft doesn't belong to the registered company, the user can still send his bundles with a little agreed extra charge according to the roaming agreement between the two airlines companies. This is an optimistic application but with the rapid increase in the air transportation, we might live one day to see it happening.

8 Aircrafts DTN Bundles Scenarios

Bundles can be routed to destination via different possible routes. The general idea of flying DTN routing is shown in figure 6. Three example applications for this service are:

- Soldiers with handheld mobile DTN aware ground to air transceiver radio.
- Offshore oil rig in the ocean with static DTN aware ground to air base station transceiver radio.
- Remote areas with static DTN aware ground to air base station transceiver radio.

The three users are located under flying routes where tens of aircrafts pass over them every day. They want to send their messages to the backbone network i.e. Internet. They use DTN protocols applications to transfer their messages into bundles and send them to the nearest passing aircraft which can do any of the following tasks based on the traffic priorities:

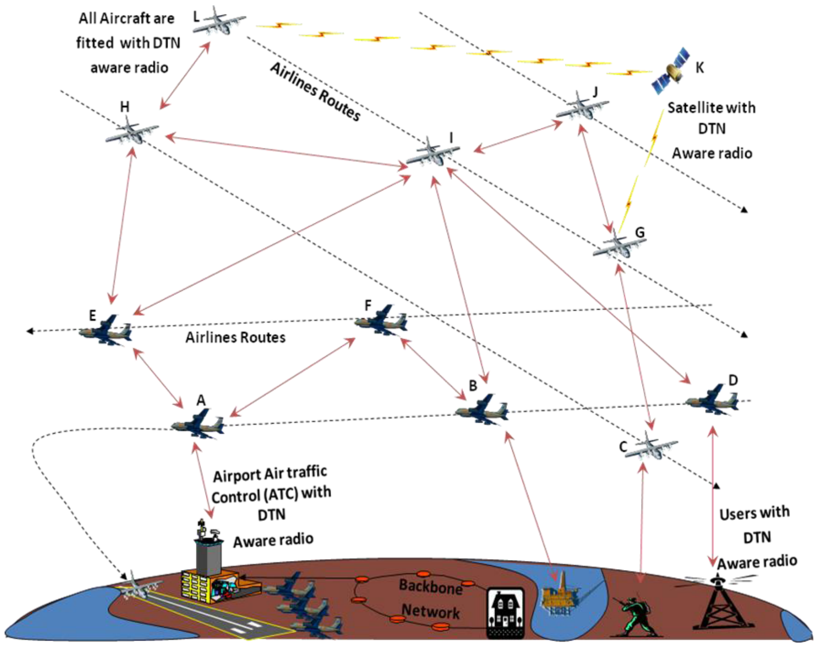

Fig. 6. Aircrafts DTN scenarios

- Store them all the way and download them physically using USP memory sticks in the ATC airport which will forward them to the backbone network and to their destination.
- Forward them to the ATC using the aircraft radio.
- Forward them to another aircraft in another flying route within line of sight of aircraft radio transmission. This can be repeated until the messages find their way to the ATC and then to their final destination.
- Forward them to a satellite.

There are different routes for the bundles to follow. For example, in case of the solider to deliver or receive his messages, this can be done via routes C-G-J-I-E-A, C-G-J-I-B-F-A and so on. Another example is for the offshore oil rig where bundles can take route B-F-A, B-I-E-A, B-I-H-E-A or B-I-J-G-K-L-H-E-A. Note that the final route includes using a satellite link. It is also possible to fragment the bundles and send some via route B-F-A and some via B-I-E-A.

As shown in figure 6, aircrafts are considered as flying mobile routers with persistent memory to store the messages until finding a node accepting them or until forwarding them to a destination. In this case, the aircraft will provide custody transfer to the ground DTN node and it will be upon the aircraft to deliver the messages. The optimum route for the message delivery depends on many factors such as number of aircrafts, sender location from the air routes and speed and altitude of aircrafts.

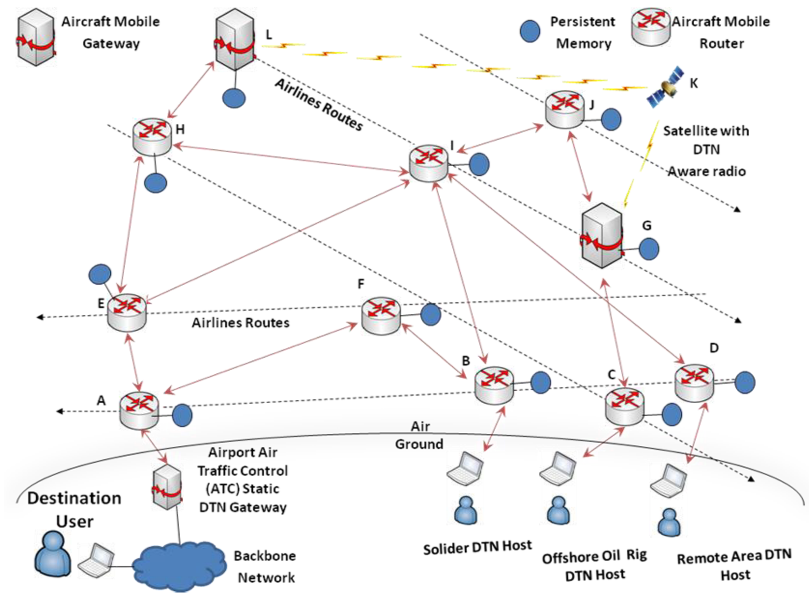

Fig. 7. Aircrafts as mobile routers for different scenarios

9 Research Opportunities

Delay Tolerant Network (DTN) itself is a new research network architecture and the DTN research group (DTNRG) in the Internet Research Task Force (IRTF) is working on its architecture and bundle protocol [19]. This novel trend for using aircrafts of airlines commercial companies in scheduled routes as DTN carriers will require a lot of research to validate its success. The research should be tied between the DTN architecture and the aeronautical communication applications of airborne radios and the ground terminal.

Routing is still under research in DTN and considered a difficult task due to the nature of lack of links connectivity. Adding the movement of aircrafts nodes to it will make it more complex. Routing might require an approach similar to the one used in MANET routing where some of the nodes are in constant movements [7].

Another research potential in this field is the DTN aircrafts addressing. Bundles source and destinations are identified by Endpoint Identifier EID and each endpoint is represented syntactically as a Uniform Resource Identifier (URI) which is used to represent the address in DTN. The aircrafts address is required to route the bundles to the correct aircraft from a group of flying aircrafts. An aircraft is identified by a system called Identifying Friendly or Foe (IFF). This system might be useful for address binding from URI address to the IFF code which belongs to a unique aircraft. More research in this is required to ensure the correct addressing of bundles to the correct aircraft in the correct route.

Radios on the ground and aircrafts need to be made DTN aware and fitted with persistent memory. Theses radios are designed mainly for voice applications between the pilot and the traffic control over VHF channels. Data link communications is already available in today's ATC tool set. Another research area is to explore the possibility of DTN application using the aircraft data link and the requirement for extra memory storage for DTN applications.

There are many research aspects in DTN security. Key management, authentication, access control, denial of service and others are among the active research in DTN bundling security architecture. Security is also implemented in aircrafts to some extent. The IFF code is used to authenticate aircrafts and likewise bundles must be authenticated before accepted in aircrafts which might be required to provide some means of bundle integrity within the custody transfer to the ground source node. The bundle protocol has identified some security blocks to enhance the security of DTN bundle transmission. These aspects might need further research to find the possible implementations within the aeronautical applications.

The notion of QoS in DTN is different from the traditional IP networks. This field has not been addressed a lot in the literature. DTN Bundle protocol has identified some bits for priority indications but the mechanism for providing quality of service for bundles flows are still not part of DTN architecture [20]. Aircrafts as DTN bundle carriers might require QoS criteria especially for its optimistic applications in condensed flying areas and peak flying times of real time transmission. Furthermore, in remote areas with limited resources and many users, contention to scarce resources might lead to traffic congestions and network degradation. These and other QoS issues are considered another research potential.

10 Conclusion and Future Work

DTN has good future applications and using aircrafts in scheduled routes is a promising application because flying routes are spread in vast areas and cover all types of terrain which are considered good carriers for DTN bundles. This paper presented some of the thoughts relating to this application which are considered as an introduction to a future implementation of DTN technology within aeronautical communications.

For future work, considering the three scenarios, we will expand into the contact durations estimations and capacity calculations to cover various aircrafts altitudes and speeds. Furthermore, we will look into the QoS issues within the DTN for this specific application and the impact of applying some congestion management techniques such as Admission Control to enhance the QoS of aircrafts datalink bundles delivery.

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