ENABLING CENTRALIZED UTM SERVICES THROUGH CELLULAR NETWORK FOR VLL UAVS

Ramazan Yeniçeri, Mehmet Hasanzade, Emre Koyuncu, Gökhan İnalhan
Istanbul Technical University, Istanbul, Turkey

Abstract

In this work, we present a low-cost small onboard Unmanned Aircraft System Traffic Management (UTM) concept allowing Very Low Level (VLL) Unmanned Aerial Vehicle (UAV) operators to access to a various type of centralized services such as e-identification, flight tracking, dynamic geo-fencing and automated flight restriction/permission with multi-level link redundancy that meets the requirements of future flight operations for small UAVs. The presented low-cost system provides ADS-B-like positional information broadcasting through the cellular network (i.e. 3G, 4G or LTE) out-link, which makes small UAVs visible for traffic controllers and other operators enabling continuous tracking and collaborative sense-and-avoid. The system further provides short-range information broadcasting, which uses standardized 63-byte data frame, through a wireless link for multi-level redundancy.

Introduction

The growing rate of "drone" market and applicability size of many types of drones is extensive, and it is clear that UAVs will eventually operate in all levels of airspace with a diverse degree of interaction with other airspace users, even people "sitting in their backyards." The UAV industry, through associated programs within NextGen and SESAR in U.S. and Europe, seeks new mechanisms for a UTM system enabling to share of airspace of manned and unmanned systems and allowing small UAVs safely operate in urban areas, without posing an unacceptable danger to other airspace users, or people and property on the ground. By focusing the use of small UAVs, which is operating in VLL airspace, in monitoring crops, wildlife, forest fires, and urban traffic, as well as package delivery, aerial photography, and movie production, it is necessary to seek for "fast-track" and low-cost approaches that rely on available technologies capable of achieving goals of safe and efficient UTM. The aim is to reduce the costs and lead-time to the market for new solutions to avoid that their unavailability could become a major barrier to further development of the industry.

ADS-B status sharing scheme supports better ATC traffic flow management, self-separation or station keeping, surface operations in lower visibility conditions which mainly aim air traffic safety. Currently defined form of ADS-B messages, whose candidate link technologies (VLD-M4, 1090 MHz ES, and UAT) have their origins in the late 1980s [1], do not include intent information [2]. However, intent awareness will contribute to better separation paths for self-sense and avoid operations. Therefore, status broadcast and intent broadcast for UAS needs to be unified in a simple and efficient way. The security requirements are not limited only to aircraft separation. FAA's Notice to Airmen (NOTAM) messages cover flight restrictions for space operations, air shows, sport activities, security issues, hazards, VIP requirements, and other special cases [3, 4]. Any UTM service requires to have such features.

It is estimated by FAA that number of hobbyist UAVs will be 4.3 million and commercial UAVs will be 2.7 million by 2020 [5]. The frequency of UAV flights is also increasing the probability of accidents. A UAV pilot in Seattle was sentenced to 30 days in jail on February 24th, 2017 after a prosecutor says he lost control of his UAV and crashed it into a crowd. This marks the first time in Seattle that a person has been charged in connection with the mishandling of a UAV, according to the city attorney [6]. According to the given statistics and the example event, the development of UAS flight regulations and surveillance schemes are mandatory and urgent. According to the FAA's roadmap, UAS must be integrated into the NAS without reducing existing capacity, decreasing safety, negatively impacting current operators, or increasing the risk to airspace users or persons and property on the ground any more than the integration of comparable new and novel technologies [7].

978-1-5090-5375-9/17/$31.00 ©2017 IEEE

In the European Drones Outlook Study prepared by SESAR [8], It is mentioned that appropriate communication systems have to be created for VLL UAVs, that these systems should also provide command and control (C2) functions and possible datalinks. It is necessary that these communication systems should communicate with air traffic controllers or future VLL UAV managements. Because of the level of safety in urban areas, mobile network systems (4G/5G, etc.) are also suggested to be used on VLL UAVs for redundancy. In addition to these, C2 link between VLL UAVs and control station should also meet with desired performance that always maintains a certain level of control of UAV [7]. Moreover, all the referrals mentioned here are meaningful for small unmanned aerial vehicles. While research and development have been done for large vehicles, there is still no adaptable concept for small vehicles. The reason for the large-scale research and development of large vehicles is that they are directly related to onboard human health and safety, and this is an indirect issue for UAVs. Therefore, the priority is given to manned air traffic. However, on the other hand, due to the high number of UAVs and the accidents that have taken place, it is now necessary to prepare a concept for tractability and applied certain rules for VLL UAVs.

Due to their limited payload capacity and limited energy source, it is not effective a small UAV to carry 1090 MHz ES or 978 MHz UAT transceiver. Moreover, in VLL airspaces, the Line-of-Sight (LoS) communication range drastically reduces. Usually, radars are not able to detect small VLL UAVs and manned aircraft do not tend to sense the UAS around. Accordingly, the small UAVs and its Unmanned Traffic Service (UTM) are responsible for monitoring the whole air traffic, and these small UAVs have to be away from the restricted manned traffic regions. Furthermore, the density of small UAV traffic in VLL airspaces can easily rise from ten to hundreds in small volumes (Figure 1), which is not possible to handle through case-one-case solutions without certain regulations. Therefore, the autonomy in UTM is a necessity.

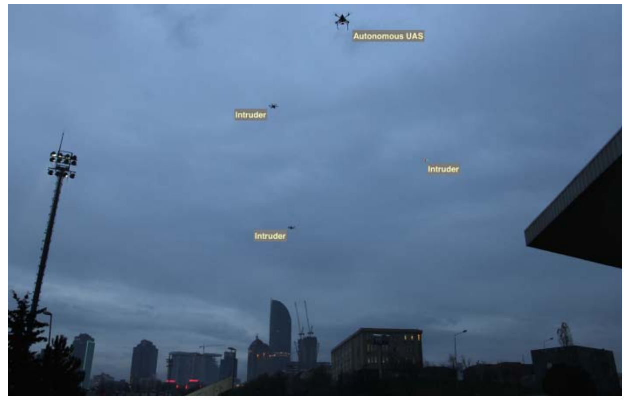

Figure 1. An Example Crowded VLL UAV Traffic Case [9]

In this work, we have proposed a conceptual UTM service infrastructure with the cellular network (i.e. 4G/5G) for the small size UAVs operating in VLL airspaces. The proposed service assumes that properly registered UAVs are equipped with onboard UTM device involving redundant communication channels and safety hardware. The proposed centralised UTM service provides; a) inter-UAV traffic, position and intent sharing, which enables sense-and-avoid mechanism; b) cooperative segregation from buildings, certain restricted regions, and manned air traffic sectors through dynamic geofencing information broadcast; c) automated clearance according to certificated safety level of the aircraft to ensure community safety; d) immunity to spatial and temporal loss of connection by redundancy. The presented low-cost onboard UTM device enables ADS-B-like positional information broadcast through the cellular network (i.e. 3G, 4G or LTE), which makes small UAVs visible for traffic controllers and other operators enabling continuous tracking and collaborative sense-and-avoid. Moreover, web-based e-identification and e-registration are done with automated procedures through the cellular network, and this connection allows UTM ground server to send text messages or cellular notifications to the operator if a further interaction is needed." The experimental onboard UTM is deployed in small quadrotor UAVs and proposed UTM infrastructure with GSM link be applied to perform proof-of-concept.

The rest of the paper is organized as follows. In Redundant UAS Communication section, the importance of communication redundancy and cellular network connection is expressed. In UAV Status and Intent Broadcast section, a new ADS-B-like status message including intent data is proposed. In following section Centralized VLL Airspace UTM Services, the concept of NAS integration is formulated using centralized service definitions that are utilizing communication redundancy and status and intent broadcast. Then, Experimental Testbed section presents some real flight data and primitive demonstration of centralized VLL Airspace UTM services.

Redundant UAS Communication

A radio communication protocol utilizes a frequency band and runs a frame modulation technique over the band. This modulation is simply called physical layer. For one solution of ADS-B, a band centered at 1090 MHz is utilized. The USA has adopted a second band at 978 MHz, because the former band has prior usage constraints (Mode S radar). As a physical layer of ADS-B communication, 978 MHz Universal Access Transceiver (UAT) defines the modulation method, bandwidth, and bit rate. The UAT modulates the data onto the carrier using a form of binary Continuous Phase Frequency Shift Keying (CPFSK) [10]. Timing structure and media access is also defined by UAT. The UAT has periodic 1 second time frame [2]. 800 ms of this frame is reserved for ADS-B sharing. There exist 3200 slots in 800 ms interval. A Message Start Opportunity (MSO), which is a pseudo random number, is associated for each slot. Each aircraft decodes the incoming UAT frame using this MSO sequence. When sending ADS-B, a MSO pseudo-random number is generated using aircraft's previously chosen MSO, its latitude and longitude. The Time Division Multiple Access (TDMA) created by this MSO-based method decreases the possibility of interference between aircraft and automatically establishes a media access mechanism [2]. There is no need to have neither a Media Access Controller (MAC) device utilized in UAT nor a master/concentrator/gateway unit that supervises the media access. The UAT modulation rate is 1.041667 Mbps [11]. The ADS-B Payload Type 0 is conveyed in the basic ADS-B message and in common use today [2]. Type 0 ADS-B message contains 36-bit synchronization sequence, 18-byte (144-bit) payload, and 96-bit Forward Error Correction (FEC) parity sequence, which counts 276 bits in total. TDMA based on MSO mechanism does not completely rescue from interference. According to the modulation rate of the UAT, transmission time of a basic ADS-B message occupies 264 us. Interval required for the basic ADS-B message notes that UAT receivers should be capable of handling message overlaps [12]. Even if solely ADS-B message transmission is guaranteed to end within 250 us, the UAT service may cover no more than 3200 aircraft and further statistical analysis is required to determine the maximum range for ADS-B messages.

Alternative link assessments for ADS-B has been worked around the beginning of 2000s. The VHF Digital Link (VDL) Mode 4 provides 19.2 kbps rate, which is very low compared to UAT [13]. For UAS realm, low-power short-range (compared to UAT or Mode S radar) physical layers without complicated MAC layers are also candidates for ADS-B-like message sharing (i.e. LoRa Transceivers). Wireless mesh (ad hoc) networks do not rely on a pre-existing infrastructure, such as access points in managed (infrastructure) wireless network like ZigBee. If ZigBee protocol will be used, broadcast messaging feature should be chosen. The primary goal, which is information broadcasting, inherently needs the same physical layer to be shared by all receivers at the same time, and to be shared by individual transmitters active in dedicated time divisions (like UAT). The performance of physical layer effects the bit rate, communication range, power requirements, error statistics, and finally the message format. Simply, there should be statistically less aircraft than the limit of media access method in a region. The region is determined by the communication range (in correlation with transmission power) in the line-of-sight (LoS). If the UTM services are able to control the number of UAVs parameter in any region (by restrictions), interference-free communication can be established by adjusting the region size, number UAVs, and message length. In this paper, it is assumed that using a well-designed sub GHz industrial/scientific/medical (ISM) modem, 3.2 Mbps data rate is achievable in 1,8 km LoS range at 1 W output power [14].

On the other hand, there exists a ready-to-use infrastructure for VLL UAS. This is cellular/mobile network. As the concerned altitude is below 150 m, cellular network successfully works. Higher altitudes are not targeted by cellular network coverage. Cellular network has many generation alternatives from 2G to 4G with varying data rates when it is evaluated for UTM communication. The 2.5G contains General Packet Radio Services (GPRS) which provides 35 kbps to 171 kbps data link [15]. The 2.75G contains Enhanced Data rates for GSM Evolution (EDGE) which provides 120 kbps to 384 kbps data link. The 3G Universal Mobile Telecommunications System (UMTS) provides 384 kbps to 2 Mbps data link. The bit rate rises upto 600 kbps - 10 Mbps range in 3.5G High Speed Packet Access (HSPA). The most recent generation 4G uses Long Term Evolution (LTE) theoretically promises 100 Mbps, although actual bit rates are in range 3 Mbps to 10 Mbps [15]. The slowest one, 2G network, is still enough for ADS-B-like messages in very small regions. Individuals connected to cellular network send messages to each other through a server connected to internet. Server may receive a message from a small UAV and may send back to all small UAVs around the transmitting one. Server may dynamically determine the UAV-specific region size according to the number of UAVs around a target UAV and the data speed between the server and the target UAV. This dynamical allocation of UAV vicinity is one of the efficiency features of proposed UTM.-Not only UAVs, but also their ground stations may have connection to internet via either cellular networks or wired/wireless LAN connections. Definitely, the latter way to access a centralized server replace the cellular network redundancy. As the exact data transmission path through internet cannot be controlled by the users, the latency between two UAVs through the server is not stationary. Thus, the measurement time related to ADS-B-like message should be added to the message in order to correctly run conflict detection, sense and avoid algorithms. In this paper, multi-level redundant communication channels are proposed based on 1) RF Broadcast Medium, and 2) Cellular (Mobile) Network. These channels are illustrated in Figure 2. A centralized UTM service resides in the center of the figure. The centralized UTM has double redundant communication channel access along with ADS-B/In capability. This makes centralized UTM be aware of manned air traffic around which enables the UAS to be guided by manned air traffic constraints. RF Broadcast Medium has UAT-like TDMA modulation. Eighty percent of the time frame is booked for ADS-B-like message sharing and twenty percent of the interval is planned for uplink messages. UAV-broadcasted messages and uplink messages from centralized UTM are simultaneously send through double redundant communication channels. However, UAV and UAV Operator should securely login to their accounts on centralized UTM service in order to broadcast ADS-B-like messages and receive uplink messages with others' ADS-B-like messages. Besides, centralized UTM is to have dense vicinity-based local RF transceivers in order to access RF Broadcast Medium, as the range of RF communication is not assumed to be more than 1.8 km in this paper. Uplink messages are easily targeted to a specific vicinity by multiplexing the active transceiver. High speed internet connection is required between these transceivers and the centralized UTM servers. Proposed communication redundancy is the key tool both to enlarge the centralized UTM service coverage and to decrease the UAV connection loss.

UAV Status and Intent Broadcast

A formal intent sharing mechanism is expected to be the key enabler for trajectory based operations. Independent from whether it is manned or unmanned, assuming that any kind of aircraft is sharing its intent or flight plan will enable collaborative efficiency and safety. Broadcasting ADS-B message is evolving to be a standard and standing as a phenomenon for UAS which lets developers for proposing new sufficient and efficient status and intent sharing mechanisms. The Flight Intent Description Language (FIDL) and Aircraft Intent Description Language (AIDL) proposed in [16] are utilized in our previous works [9, 17]. The fact that UAVs have high maneuvering capabilities and high sensitivity to disturbing effects results in relatively faster position and attitude changes than manned aircraft. Hence, briefly expressing the intent using FIDL, even just sharing the waypoints of planned UAV route provides sufficient information for UAS to utilize. The leverage of limited intent data should be compared with the zero-intent awareness case. It the route is planned in 4D, then the intent declaration also has time information, definitely.

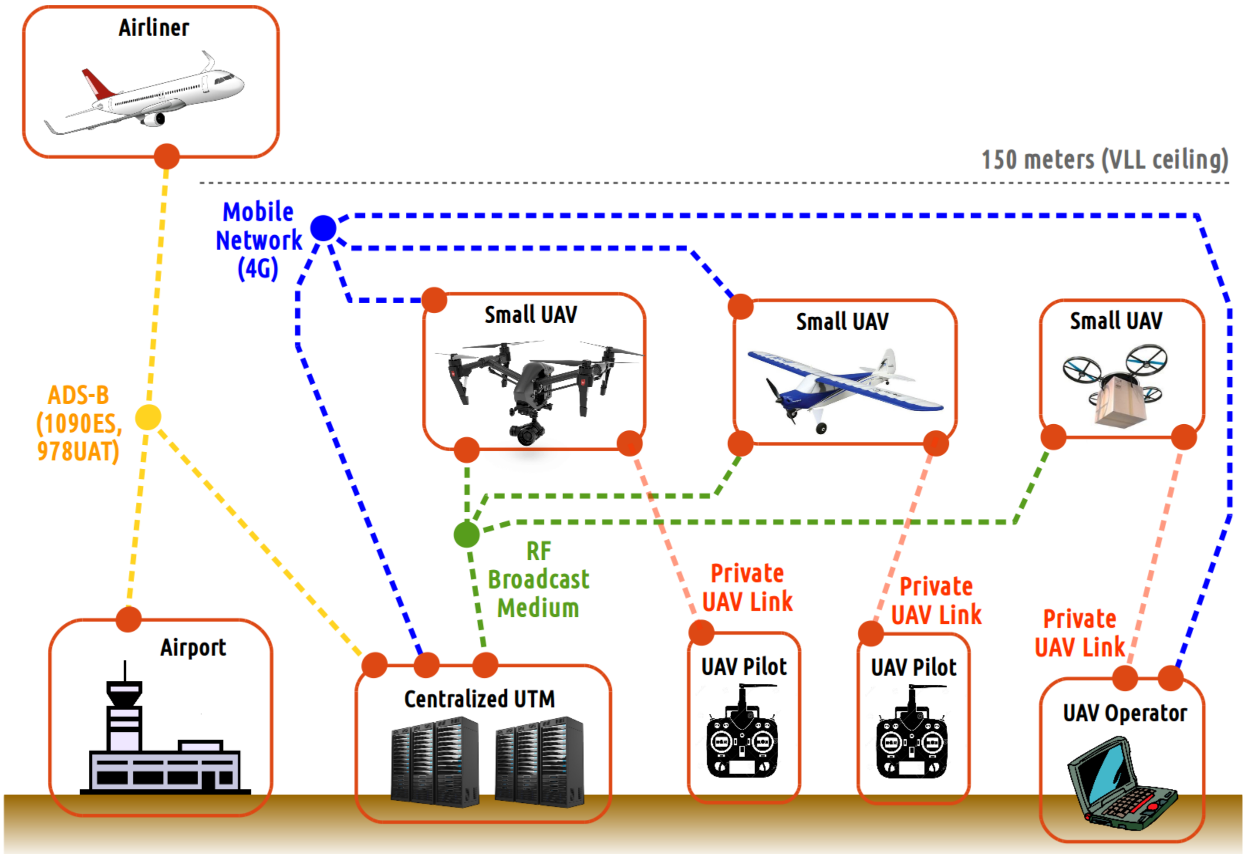

Figure 2. Redundant UAS - UTM Communication

This paper attempts to increase the utilization of the limited bandwidth redundant communication channels, which means decreasing the message size and frequency, and increasing the availability for more UAVs, as well. As a result, the status message and the intent message is unified with proposed Dependent Status and Intent - Broadcast (DSI-B) message. Message format is strongly adaptable for different utilization wills. Briefly, some fields in the message can be tagged as *not available* and they are extracted from the message. DSI-B message format and field names and sizes are depicted in Figure 3, and defined below.

Message Indicator (MI): DSI-B message is a byte sequence which starts with 8-bit Message Indicator which actually has $(10101010)_2$ value. This byte is also used as synchronization byte for RF broadcast.

Message Type and Version (MTV): It is a 8-bit sequence whose first (leftmost) 5 bits represent the message type as 5-bit unsigned integer, and following 3 bits represent the message version as 3-bit unsigned integer. Message type is 1 for DSI-B messages, and this paper proposes the first version. Thus, the expected value for this field is $(00001001)_2$ for message proposed in this section. Other possible values for message type are reserved for future messages which will use the same communication infrastructure.

Message Field Availability (MFA): This field is 16-bit length Boolean sequence which indicates the availability of following message fields from Sampling Time to Altitude of 3rd Upcoming Waypoint. Identification number never becomes unavailable. If a field is tagged as *not available* by setting 0 to associated bit, then the field is skipped while constructing the message. As a result, decrease in message length occurs. The length of each field should be known by any parser of DSI-B message in order to calculate the correct length.

UAV Identification Number (ID): This is the field that takes unique values for each UAV. The ID number of a UAV is assigned during registration. It is a 32-bit sequence whose first 8 bits represent the class and following 24 bits represent the item number. Classification of UAVs is out of scope for this paper although its requirement is mentioned.

Sampling Time (ST): Clock type (2-bit), year from 2017 to 2032 (4-bit), month (4-bit), day (5-bit), hour (5-bit), minute (6-bit), second (6-bit) bit sequences are consecutively composed and 32-bit sampling time field is obtained. There are four onboard clock type definitions: $(00)_2$ stands for GNSS synchronized, $(01)_2$ stands for mobile network synchronized, $(10)_2$ stands for synchronized by other source via ground station, $(11)_2$ stands for no-synchronization. Following date and time values are unsigned integer type bit sequences.

Transmission Media Record (TMR): This 8-bit field records the information of transmission. As the redundancy of communication is desired, the acceptor of the message needs to have ability to merge messages from different channels. And also, the acceptor needs to know which channels are used for message delivery. Leftmost 6 bits of 8-bit field is utilized. From left to right bits mean that message is 1) sent by source UAV's RF broadcast modem, 2) sent by source UAV's mobile network modem, 3) sent by source UAV's ground station data link modem, 4) transferred through ground station's internet connection, 5) transferred through centralized services to target UAV's mobile network modem, 6) transferred through centralized services to target UAV's RF broadcast modem. Decoding this record explicits the redundant paths that the DSI-B message travels along as depicted in Figure 3. The first three bits are determined before DSI-B message transmission from the source UAV. Bit 4 is modified by ground station if it can be able to transfer. Bit 5 is set to 1 if centralized service successfully receives the DSI-B through internet and decides to re-send to mobile network modem of the target. For redundancy, this resend process occurs normally. The centralized service also senses whether the source UAV is able to send DSI-B using its RF broadcast channel looking into bit 1. If the source UAV is not able to do that and centralized service is equipped with the required RF transmitter in that region, it can decide to resend DSI-B through RF broadcast channel by setting bit 6 to 1. When TMR field is modified, the checksum needs to be recalculated.

Approximate Range (AR): 8-bit unsigned integer field stores the estimated actual range of UAV in kilometers. This is calculated and declared on UAV's own. Of course, centralized services is capable of calculating an alternative range using the recorded flight data and referring to registration database. This quantity should be broadcasted in order to correct decision of separation maneuvers on centralized services. Field saturates at 255 km and ranges greater than this value is ignored and 255 km range is declared.

Latitude (LAT): It is 24-bit field constituted by successively organized unused 2-bit zero, 1-bit sign bit, 8-bit unsigned integer degree value (between 0 and 180), 6-bit minute of arc (between 0 and 60), 6-bit second of arc (between 0 and 60) from left to right. It stores latitude of UAV.

Longitude (LNG): It is 24-bit field similar to LAT and stores the longitude of UAV.

Altitude (ALT): It is 16-bit unsigned integer quantity in meters and stores the altitude of UAV.

Ground Velocity North-component (GVN): The velocity measured by UAV is decomposed into orthogonal components: towards North, towards East, and towards up. Each component is represented by 16-bit signed fixed point quantity in Q15.3 format. Speed unit is meter/second for this field. The value range is [-4096 m/s, +4096 m/s), and the resolution is 0,125 m/s. The velocity measured by UAV is decomposed into orthogonal components.

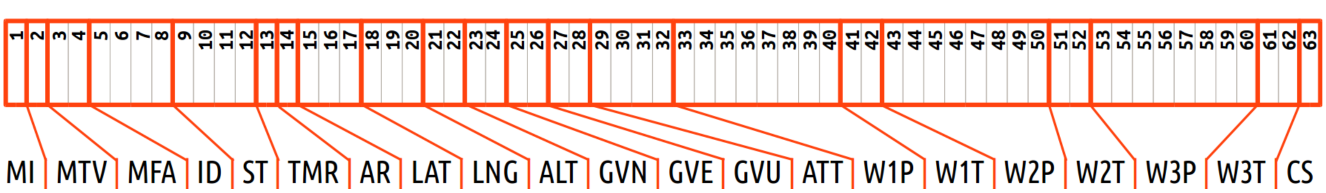

Figure 3. DSI-B Message Format

Ground Velocity East-component (GVE): The velocity vector component towards east direction. Field format is the same as GSN.

Ground Velocity Up-component (GVU): The velocity vector component towards up direction (normal vector of earth surface at LNG, LAT). Field format is the same as GSN.

Attitude (ATT): The yaw, pitch, and, roll angle of UAV are 9-bit signed integers and organized successively in order to form 32-bit attitude field. The first 5 bits of the field is ignored. The unit for quantities is degree.

Waypoint #1 Position (W1P): 24-bit lattitude (same format as LAT), 24-bit longtitude (same format as LNG), 16-bit altitude (same format as ALT) belonging to first upcoming waypoint are written to 8-byte W1P field successively.

Waypoint #1 Time (W1T): The remaining time estimation for the arrival to the first upcoming waypoint is given in 16-bit unsigned integer field. The unit for this field is second. This field implicitly carries the information about the speed intent of the UAV.

Waypoint #2 Position (W2P): Same as W1P, but for the second upcoming waypoint.

Waypoint #2 Time (W2T): Same as W1T, but for the second upcoming waypoint.

Waypoint #3 Position (W3P): Same as W1P, but for the third upcoming waypoint.

Waypoint #3 Time (W3T): Same as W1T, but for the third upcoming waypoint.

Checksum (CS): The available fields from MI to W3T is used in order to calculate 1-byte CS value. Checksum promises the target UAV the data integrity in DSI-B message.

DSI-B message is adaptable to availability of flight data on UAV. For an example scenario, a UAV which is not able to estimate its approximate range and not able to share its waypoints still creates DSI-B messages. Then, the MFA field stores $(1101111111000000)_2$ which means the length of message including MI and CS is 32 bytes. The DSI-B message is 63 bytes long when all fields are available. The minimum content requirements needs to be defined by UAS regulations. At first glance, the period of sharing the waypoint information can be distinguished from the period of sharing the position and velocity information. DSI-B utilization policy is to be discussed separately in future works

Assuming that the DSI-B messages of surrounding UAVs arrive to a UAV through redundant channels, and none of the UAVs has lack of onboard UTM device. The subject UAV knows current status of all UAVs and also senses their intent according to their incoming three waypoints. Even in the absence of centralized separation messages, subject UAV is still able to avoid from collision with others. There is no obligation to run DSI-B sense and avoid mechanism on ground station instead of UAV. This brings simplicity of implementation as the software flexibility on ground stations is usually better than UAV's onboard equipments. Certainly, fast implementation opportunities are promoted by the proposed concept.

Centralized VLL Airspace UTM Services

The authority, who is providing Centralized VLL Airspace UTM (CVUTM) services, is of critical responsibilities to maintain the safety of NAS. As the VLL UAS flights are used to occur below 150 meter altitude, safety needs awareness of geographical formations and buildings. Air traffic, weather condition, flight restrictions or their brief results should be known by the individuals in NAS. Collection, storage, evaluation, and delivery of such data and delivery of related warnings and directives are the fundamental responsibilities of such Centralized VLL airspace UTM service provider. In order to save the feasibility of any NAS integration system and keep the complexity level low, the CVUTM services are simple observation and information distribution services. Proposing any device that temporarily takes the control of a UAV in behalf of safety has definitely creates more safety risk. This type of equipments are kept of this proposed concept.

In other respects, abstaining from a flight experience with an equipment other than an airworthy one is the principal responsibility of NAS user (i.e. small UAV pilot or operator). Succeeding expectation from a UAV operator is the loyalty to the safety regulations of authority. First of all, one have to prove his/her merit with a small UAV flight license. In order to achieve the loyalty, a small UAV have to be flown liberally but within the given boundaries. These boundaries cover static elements like geographical formations and buildings, and dynamic elements like atmospheric conditions, air traffic, capabilities of the owned UAV. The realization of this loyalty occurs by obeying the messages fed by the CVUTM services.

It is obvious that the authority and the operator should share the responsibilities for a safe NAS. Thus, the small UAV is not only the object of flying action. There are two more roles for UAV. It should be an instrument for data collection for both parts: authority and operator. The status of a UAV sensed and the intent of flight should be recorded if exists by own. This data is essential for CVUTM services and should be delivered to it. Besides, UAV is the collector of data from CVUTM service and from other aircraft in the name of operator. As a result, redundancy in connections between UAV and around is crucial to keep a UAV in touch. Furthermore, a UAV needs to have some safety equipments in order to perform urgent safety critical operator commands when something unexpected happens.

It is possible to assign the rule set in very detail using the infrastructure constituted by internet, CVUTM, UAV with safety equipments and redundant communication, but not focused by this paper. The aim is to draw the big picture of a possible low-cost, easy-to-implement infrastructure. However, it is clear CVUTM to carry out the rules for cases like conflict of any type of aircraft, separation necessities, threatening the people on ground, security policies. Violation of the warnings and prohibitions sent by the CVUTM service with aforementioned responsibilities deserves to be charged or punished. Again, the type of sanction is determined by the rules which are out of scope of this paper. Here, infrastructure only specifies the means of notification.

It is assumed that being pilot or operator of a small UAV is subject to licence. After receiving the training and passing the qualification exams, one receives the rights for flying or operating a small UAV. Proposed CVUTM services provide a simple browser based interface for an operator to register his/her own with the licence number, licence class, and personal information which includes addresses, phone numbers, email addresses, and optional social media accounts. This is the necessary condition for making a notification to a UAV operator via internet.

According to current technology, some safety accessories like parachute, air cushion, enclosing cage and flasher/siren can be integrated to UAV. The regulations may involve using only certified safety equipments or may need proving the safety equipments by live or recorded demonstration. Although the accessories like parachute have the possibility to save both the UAV and the objects around, an air cushion or enclosing cage has the possibility to only decrease the amount of damage on UAV. Despite a siren or a horn with proper flasher seems to have a weak contribution to create safety, it gives the time for around people to show their reflex and gives the chance to protect their own from serious injuries. Hence, the safety accessories can be divided into three groups according to their effects. Therefore, UAVs should also be classified from zero safety equipment class to having something like a parachute when being registered to the CVUTM services.

Definitely, a registered small UAV is given an ID number by the CVUTM service. This ID number is broadcasted by the UAV within the DSI-B message as given in previous section. Redundancy in communication means will increase the probability of DSI-B message to arrive CVUTM servers. After arrival and message parsing, ID number is searched in the UAV databases and its technical and safety information is retrieved. Here, it appears that one owner or responsible pilot or operator information is also required when registering a UAV. Responsible person's license number should be a field in the record of UAV. The second step should be retrieving owner's personal information from a second database. The retrieval of both UAV and owner record from databases is called e-identification and performed in CVUTM.

The core service of CVUTM is obviously the surveillance of VLL UAS. All useful actions performed by CVUTM are based on the success of surveillance. The service part including these actions are called shell services. Most important part of core services is running a brief flight record database and its detailed recent event buffer.

Redundant DSI-B messages from one UAV for an instant are received by CVUTM services and merged to a single event record. This enables using the storage capacity efficiently. In the meantime, weather forecasts and reports are obtained from meteorological services. The geographical formations and recent building information are also acquired from third parties such as state departments, municipalities, satellite operators and map data providers. Related departments of the state provide FAA's NOTAM-like information about space operations, air shows, sport activities, security issues, hazards, VIP requirements, and other special cases. The CVUTM services also need to collect ADS-B data of manned aircraft in the NAS. All information should be systematically collected and assorted in order to run centralized conflict sense algorithms and also generate the shell services.

Shell services are categorised into four groups: 1) Public uplink messages, 2) Addressed uplink messages, 3) Web-based open broadcasts, 4) Access to contact person.

Public uplink messages are the ones which the CVUTM service sends to all small UAVs in VLL airspace. These messages have no receiver address and they should be concerned by all UAVs in the vicinity. The first public uplink message service is the weather report. Therefore, all UAVs are informed about current weather situation and upcoming weather events. Second subservice ise Common Flight Restriction (CFR) service. The CVUTM uses this service messages to carry out necessary NOTAM required situations, to avoid building collision, and create separations between manned air traffic and VLL UAS. The CVUTM has no service for manned air traffic that informs about the UAV traffic. Thus, proposed services forms a unidirectional interface for NAS integration of small UAS in VLL airspace. Weather reports and CFR messages are periodically broadcasted by CVUTM in a vicinity based distribution manner using communication channel redundancy. CFR services are illustrated in Figure 4.

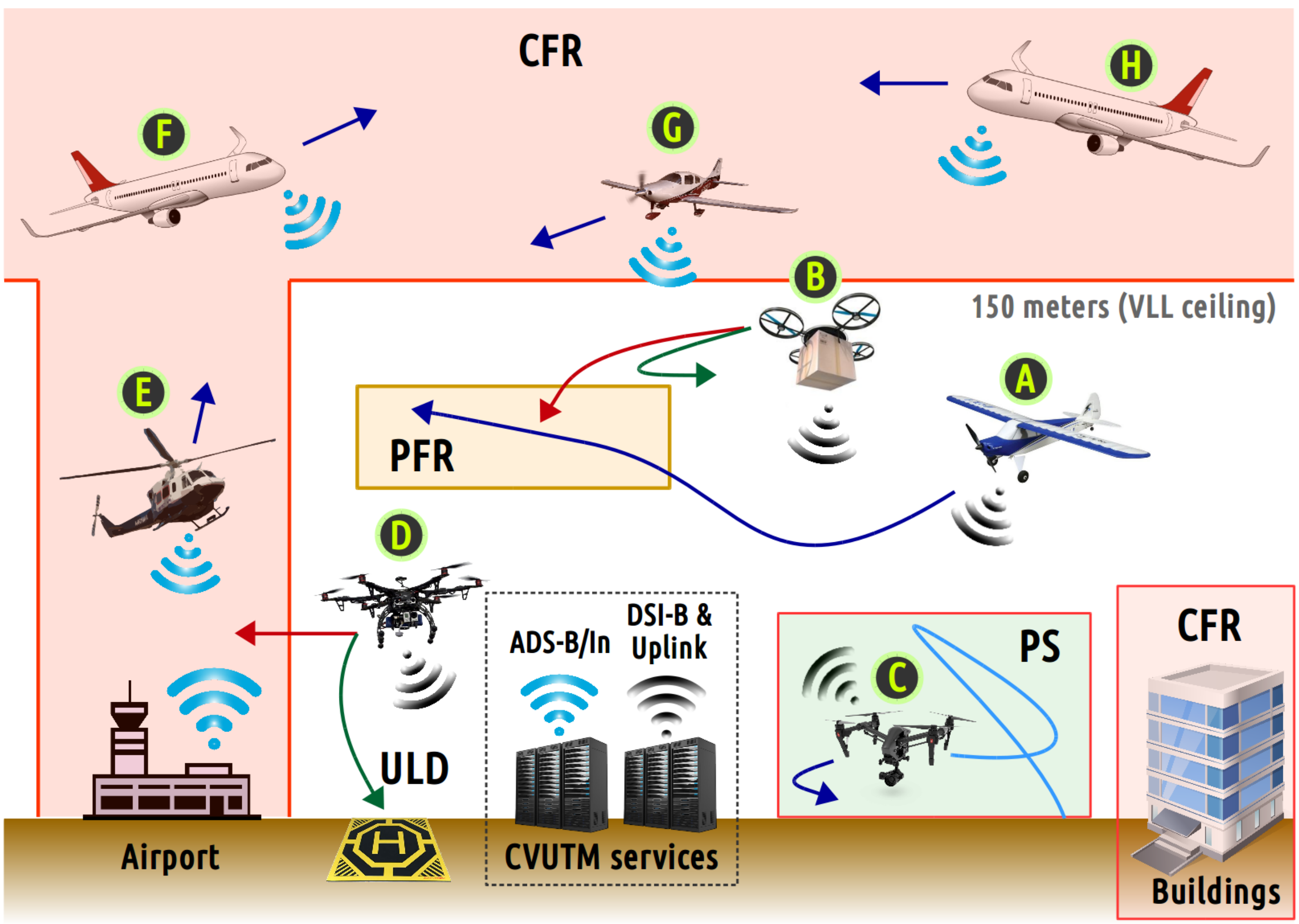

Figure 4. Centralized CVUTM Services

Addressed uplink messages are simply the instruments for manipulating UAVs individually. Messages are broadcasted to each vicinity through redundant communication channels, but solely the UAV whose ID is included concerns the message. The subservices are put in order according to the expected frequency of occurrence as follows, 1) Private Flight Restriction (PFR), 2) Private Segregation (PS), and 3) Urgent Landing Directive (ULD). PFR sets a flight restricted volume for a bounded or unbounded time interval. PS sets a free-to-fly volume again for a time interval. Both are employed for safe separation of UAVs from unmanned aircraft. The safety gaps should be considered while creating these messages. Not only the real situations that need separation may trigger the PFR and PS messages. If the safety regulations involve any aperiodic loyalty inspection then these messages created by virtual scenarios may be sent. If a more detailed enquiry including physical survey is needed, then any loyal small UAV may be landed using ULD message. This message is a tool for engaging extreme cases. It is possible to designate this message as the last step before a physical interception against a violation or an invasion case. In Figure 4, PFR, PS and ULD services are illustrated.

Web based open broadcast of some brief data reflects the respect of CVUTM services to the community. Brief UAV traffic data and related weather reports should be accessible by the community, as UAS is acting in VLL airspace which is just above the people living there. The desire of people to know that they are safe from danger is probably ensured by the transparency of UAS integrated to NAS. Moreover, open reports available through web services based on collected UAS traffic data increase the reliability of CVUTM.

Web based services of CVUTM comprise easy and quick access to the contact person (owner, operator or pilot) of any registered small UAV. When a UAV violates a rule, CVUTM is capable of sensing this and the contact person is immediately and automatically noticed. The notification may include a fine. This notification method gains its legality depending upon the contact person's signature on registration agreements. The CVUTM's applicable means of notice delivery are sending short message through mobile service provider, sending e-mail, sending a message to owners web account, and sending a phone message.

Experimental Testbed

An unmanned aerial vehicle has been prepared so that the proposed concept can be implemented and tested. In Figure 5, there exists Istanbul Technical University Aerospace Research Center (ITU ARC) autopilot system and ITU ARC INS system on the UAV. They are under development for years in ITU ARC. The autopilot board holds a microcontroller from STM32 Cortex M4 family. This unit performs low level tasks such as autopilot control, processing of INS data, and safety protocols. In addition, the autopilot uses Raspberry pi V3 in an integrated manner. This Linux-based computer performs high level tasks such as trajectory planning, live camera view broadcasting, logging system data and redundant communication. Remote control receiver is used to communicate with the remote control to provide the necessary inputs on the vehicle. This receiver is directly connected to autopilot, because of any critical situations, desired inputs should be transmitted to autopilot controller without any latency. The 4G/3G Modem and the XTend RF modem in Figure 6, which are recommended in this article, are also installed to test for redundancy communication. The most suitable Propeller - Motor - ESC - Battery configuration is prepared for the vehicle.

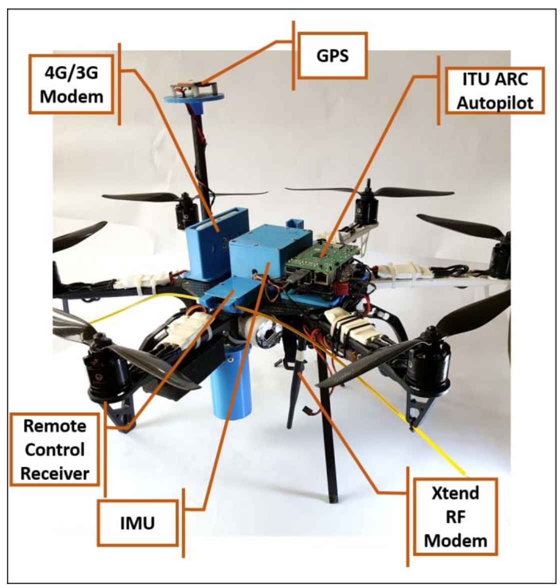

Figure 5. Experimental UAV

XTend devices are used to emulate RF links within the system which is shown in Figure 6. This device works in the ISM 900 MHz band and uses the ZigBee protocol. It is preferred because of its long range, low power consumption and ease of use. Also variable power (100mW-1W) feature provides convenience for multi-UAV emulation. The system has been configured in broadcast mode so that anyone within range can receive the specified message. Within the system, two Xtend RF modules are used for UAV and ground station.

Figure 6. 4G/3G and Xtend RF Modem

4G/3G wifi modems shown in Figure 6 are used to provide internet access on the vehicle and ground station. The interlayer communication was provided via a web server. Unique IP addresses on this line do not change when switched on or off. Therefore, this provides convenience for system testing and flight. Depending on the base stations of the modems, it can switch between 4G/3G in itself. Since the size of the messages sent to the cloud is very small, these transitions do not cause a disruption in the communication system. The 4G/3G modem in the autopilot system communicates with the onboard WiFi modem on the Raspberry Pi computer. Likewise, another 4G/3G modem communicates with WiFi in the ground station. Static IP addresses are assigned via an intermediary web server, where IP addresses do not change when each task is repeated, or when the UAV and the ground station are turned off and on, and the task can be performed quickly. In addition, XTend modem on the vehicle communicates with the autopilot via UART. The data structures that are planned to be sent on the autopilot are transmitted via another XTend modem connected to the ground station. Similarly, since XTend modems are set in broadcast mode, all unmanned aerial vehicles within range send the specified data to each other. UAVs that are connected/not connected to the internet due to damage are also notified by vehicles via Xtend modems.

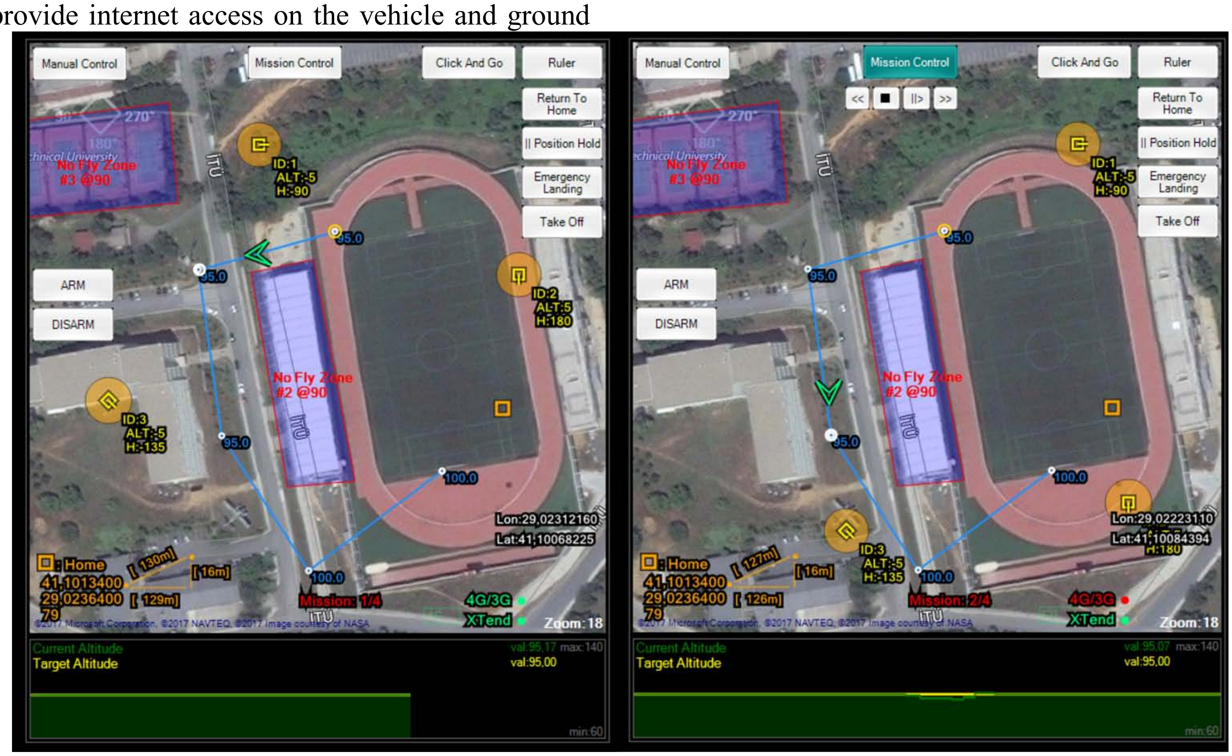

Figure 7. Redundant Communication Test Scenario on Ground Station Software

In Figure 7, an image from the screen of the ground station which has been designed and developed by ITU ARC is given. All desired information about the vehicle can be reached by ground station such as waypoints, missions, current mission, attitude, positions, speeds, etc. as well as all the required controls and inputs. The important part is that other vehicles can be seen by the ground station in the environment when the DSI-B data is received. Also no-fly-zones (defined by PFR messages) can be seen by their coordinates, as well. In this way, route planning can be done accordingly. In order to control the communication systems, there is also the indicator text in the bottom right of the ground station screen. This indicator, written as "4G/3G" and "XTend", is green when it is alive, and red when it is not connected. There are also other features such as "Emergency Landing", "Return Home" and "Arm/Disarm" for critical situations or like "Position Hold", "Take off" and "Click and Go" function for flexibility.

In Figure 7, two situation is shown by two pictures. In both scenarios, no-fly-zones are visualized, the DSI-B messages are received and visualized in the surrounding space and waypoint tracking is made according to these conditions. In the first scenario on the left side, both 4G/3G and XTend modems work together without any problem where it can be monitored by the green indicator texts: "4G/3G" and "XTend". On the right side of Figure 7, the picture has been taken afterwards, and the "4G/3G" indicator has gone red, which has been showing that the internet connection is not available at that moment. However, it can be seen that communication can still continues via XTend channel which is still green and the necessary information can still be received. In this way, it is proven that the system provides redundancy in the communication.

Conclusion

The number of unmanned aerial vehicles that have increased rapidly over the past decades has also increased the safety problems. In this work, it is aimed that the authority will monitor the UAVs in VLL airspace, warnings can be created against the vehicle operators/pilots in order to protect both other aerial vehicles and the people from possible accidents. With the DSI-B protocol specified, the desired data is sent and the concept for NAS integration in VLL airspace is established according to the rules by the CVUTM services. Based on this concept, the DSI-B message format and double redundant communication system are proposed. The possible issues and situations that unmanned aerial vehicle users should pay attention to are mentioned. The proposed conceptual system satisfies the needs for an onboard sense and avoid mechanism.

In future, the classification of unmanned aerial vehicles is going to be investigated. The aim of this research is also develop additional system-adaptable concepts to increase the awareness of unmanned aerial vehicle users. Moreover, GSM based localization based on triangulation provides additional geolocation information for the small UAV and this tool is also can be utilised by the CVUTM services.

References

[1] Scardina, John, 2002, Overview of The FAA ADS-B Link Decision, U.S. Department of Transportation Federal Aviation Administration.

[2] Manual for the Universal Access Transceiver (UAT), 2003, International Civil Aviation Organization.

[3] Aeronautical Information Manual - Official Guide to Basic Flight Information and ATC Procedures, 2015, U.S. Department of Transportation Federal Aviation Administration.

[4] Advisory Circular - Temporary Flight Restrictions, 2004, U.S. Department of Transportation Federal Aviation Administration.

[5] FAA Aerospace Forecast Fiscal Years 2016-2036, 2016, U.S. Department of Transportation Federal Aviation Administration.

[6]http://lawnewz.com/crazy/drone-pilot-gets-slapped-with-30-days-in-jail-after-losing-control-of-craft-knocking-woman-old-cold/

[7] Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap, 2013, U.S. Department of Transportation Federal Aviation Administration.

[8] European Drones Outlook Study - Unlocking the value for Europe, 2016, SESAR.

[9] Pasaoglu, Cengiz, Nursel Akcam, Emre Koyuncu, Ahmet Farabi Tarhan, Gokhan Inalhan, 2016, Collaborative Intent Exchange Based Flight

Management System with Airborne Collision Avoidance for UAS, Journal of Intelligent & Robotic Systems, vol. 84, pp. 665-690.

[10] Moody, Chris, Warren J. Wilson, Brian Dunbar, Tom Hopkinson, Jim Howland, Rob Strain, 1997, A Prototype Transceiver for Evaluating a Multipurpose Broadcast Data Link Architecture, MITRE Technical Report, MTR 96W0000028R1.

[11] Radio Navigation Aids, 2007, Aeronautical Telecommunications Annex 10 to the Convention on International Civil Aviation Volume I, International Civil Aviation Organization.

[12] Nguyen, Minh A., Amir I. Zaghloul, 2004, Extension on Characterizing Packet Interference in a High-Density Traffic Environment, The 23rd IEEE Digital Avionics Systems Conference, pp. 11.B.6-11.1-6 Vol.2.

[13] Bachman, Lawrence, Nikolas Fistas, 2001, ADS-B Link Alternatives Assessment, Aeronautical Mobile Communications Panel (AMCP).

[14] DIGI XLR Pro Long-range 900 MHz RF Module Datasheet, 2017, Digi International, Inc.

[15]http://www.speedguide.net/faq/what-are-the-actual-speeds-of-gprs-edge-umts-hspa-366

[16] Lopez-Leones, Javier, Miguel A. Vilaplana, Eduardo Gallo, Francisco A. Navarro and Carlos Querejeta, 2007, The Aircraft Intent Description Language: A Key Enabler for Air-Ground Synchronization in Trajectory-Based Operations, IEEE/AIAA 26th Digital Avionics Systems Conference, Dallas, TX, 2007, pp. 1.D.4-1-1.D.4-12.

[17] Tarhan, Ahmet Farabi, Emre Koyuncu, Mehmet Hasanzade, Gokhan Inalhan, 2014, Formal Intent Based Flight Management System Design for Unmanned Aerial Vehicles, 2014 International Conference on Unmanned Aircraft Systems (ICUAS), Orlando, FL, pp. 984-992.

Email Addresses

yenicerir@itu.edu.tr

abdullahmeh@itu.edu.tr

emre.koyuncu@itu.edu.tr

inalhan@itu.edu.tr

2017 Integrated Communications Navigation and Surveillance (ICNS) Conference

April 18-20, 2017