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TECHNICAL COMMISSION

Agenda Item 36: Air Navigation — Emerging Issues

INTEGRATION OF REMOTELY PILOTED AIRCRAFT SYSTEMS IN CIVIL CONTROLLED AIRSPACE AND SELF-ORGANIZING AIRBORNE NETWORKS

(Presented by the Russian Federation)

EXECUTIVE SUMMARY

The ICAO Twelfth Air Navigation Conference in its Recommendation 1/10 Automatic Dependent Surveillance – Self-Organizing Wireless Data Link Networks offers ICAO "…to study the issue of self-organizing wireless data link networks use…".

Given report contains information of the rationale of the development and application of self-organizing airborne networks, first of all in the integration of remotely piloted aircraft systems (RPAS) into civil controlled airspace. It presents requirements for data links implementing airborne networks operation as well as their operational benefits.

Action: The Assembly is invited to:

a) take into consideration benefits of the self-organizing airborne networks conception, first of all in order to provide for the safety of flights in the integration of remotely piloted aircraft in civil controlled airspace;
b) take into consideration the potential of self-organizing airborne networks technology concerning the extension of its use to manned aviation both for surveillance and organization of digital voice channels;
c) request ICAO Council to study this proposal in the course of modernization of The Global Air Navigation Plan on 2013-2028 with the aim to include the self-organizing airborne networks conception in B1-RPAS module.

Strategic Objectives:	This working paper relates to the Safety and the Environmental Protection and Sustainable Development of Air Transport Strategic Objectives.
Financial implications:	Financing to the extent of ICAO regular programme budget.

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[1] English and Russian versions provided by the Russian Federation.

References:	Doc 9750-AN/963, Global Air Navigation Plan Doc 9896, Manual on Aeronautical Telecommunications Networks (ATN) using standards and protocols of Internet Protocol Suite (IPS) Project, Version 1.1 Manual of Remotely Piloted Aircraft Systems

1. INTRODUCTION

1.1 The ICAO Twelfth Air Navigation Conference in its Recommendation 1/10 Automatic Dependent Surveillance – Self-Organizing Wireless Data Links Networks offers ICAO "…to study the issue of self-organizing wireless data link networks use…".

1.2 Traditionally management of communications in the integration of remotely piloted aircraft systems (RPAS) in civil controlled airspace considers following data links in ICAO RPAS Manual Draft:

- Command data link to transmit control commands from the remote pilot station (RPS) to remotely piloted aircraft (RPA);

- Information (status) data link to transmit RPA status information from RPA to RPS (position and other navigation parameters as well as status information about systems managing RPA behavior); both above mentioned data links for RPS and RPS interaction stand as C2 (Command/Control) data link;

- VHF two-way voice radio communications between an air controller and a remote pilot (RP) as well as two-way data transfer between ATC and RPS (also via RPA).

1.3 Requirements to RPS and RPA communications shall meet required communications performance (RCP) corresponding with the employment of manned aircraft in given airspace class.

1.4 RPS may interact with RPA and ATC both in RLOS (Radio Line of Sight) and beyond it (BRLOS - Beyond Radio Line of Sight); in the latter case they use satellite or airborne links. In case of satellite communications there is no information about the network between the RPS and the satellite, nor the number of earth-to-satellite signal hops, nor the consequential signal delay. Satellite communications introduce the key operational challenge of increased and potentially unpredictable signal transmission delay, as well as the regulatory challenge of certification or regulatory oversight of the Satellite Communication Service Provider. In case of airborne communications certain demands to C2 data link (refer below) lead to complete information about available airborne network (A-network) between RPS and RPA (network map); number of air-air hops and signal delays are minimized and known.

1.5 Among fundamental problems of studied integration should be selected:

- provision of continuous reliable communications between RPS and RPA as well as between RPS and ATC especially in BRLOS conditions; it should be stated that up to now this problem has no solution since satellite communications user has got above mentioned deficiencies;
- unsolved problem with the selection of "Detect and Avoid" (D&A) working principles; ACAS use is unacceptable because of multiple regulatory, design and economical causes; task of a compact and effective D&A system development is pending to be solved;

- the link of RPS and RPA interaction (C2 data link) inherently is digital; manned aviation interaction with ATC is based on voice communications and data links adopted by ICAO; the question, how to implement C2 data link interface with ATC communication channels (voice + data), remains open.

2. SELF-ORGANIZING AIRBORNE NETWORK CONCEPTION

2.1 RPS, PRA AND ATC INTERACTION

2.1.1 Up to now we have been studying the case when RPA receives information from corresponding RPS and ATC. In its turn RPA sends information to corresponding RPS and ATC. Other ways of RPA and RPS interaction with each other and with airspace users are also possible. For example, RPA1 is controlled by RPS1, and RPA2 is controlled by RPS2. Data of RPA1 position may be received by RPS2, while data of RPA2 position may be received by RPS1. As a result both RPS1 and RPS2 may receive information of both RPAs positions. This condition may extend to many RPAs and other aircraft with the same equipment, thus increasing common situational awareness. In given example the transfer of RPA status information should be managed as follows:

- RPA position data is broadcasted;
- status data of devices defining RPA behavior from RPA to its RPS, information on built-in control of systems, etc., may be transmitted (to relevant RPS) in broadcast or in point-to-point mode.

2.1.2 One of the key points providing for PRAS integration in civil airspace is the requirement of RPS and RPA communications reliability. When any RPA may be connected with its RPS both directly and via some other routes with given reliability parameters, the robustness of RPAS operation in civil airspace increases significantly. When any RPA is able to receive data aside its own RPS and transmit data aside its own RPA, it actually provides for the relay function in retransmission mode via RPA. In this case RPS may send a command signal for its RPA behavior modification both directly and with the help of one or more RPAs functioning as an airborne relay station/stations. Instead of RPA it is possible to use other aircraft if only they are equipped with appropriate C2 data link transponders. Receiving information from near-by aircraft, using it for own situational awareness and self-separation (actually serving as a basis for consequent “detect and avoid” systems), transmitting own position data and re-transmitting data received to all equipped aircraft, RPS and ATC, RPA will function as an airborne communications node. One of critical parameters of this network is its robustness (increased stability to interference and various failures). RPA may receive control signals/send status information both directly from/to its RPS and via near-by RPA or other equipped aircraft (functioning as relay stations) by several additional routes, if necessary. A-network should meet some requirements given below, the same concerns C2 data link as well. Given requirements (Appendix A) have been offered to the RPAS Manual Draft being developed by ICAO UASSG.

2.2 RESULTS ACHIEVED THROUGH SELF-ORGANIZING AIRBORNE NETWORK USE WITH RESPECT TO RPAS

2.2.1 Use of self-organizing A-networks allows to implement robust functioning of RPAS in civil controlled airspace under BRLOS conditions. RPS is able to interact with its RPA (to send command signals and to receive status information) almost without delays both directly and via manned and unmanned aircraft which are in direct radio line of sight and are equipped with “a networked transponder”. The same concerns RPS – RPA – ATC interaction; RPA position information may enter

ATC both directly and via other aircraft, if necessary; an air controller interacts with RPAS pilot by a method accepted for given airspace class through negotiations and data transfer. Absence of a direct radio line of sight stops to be a limiting factor; multiplicity of possible automatic data links provides for the robust functioning of the system. If there is no network, there is no danger of collisions with other equipped aircraft. As concerns non-equipped aircraft, then since we are studying only controlled airspace under an air controller responsibility, it is an air controller who undertakes to separate all aircraft in the air including unmanned ones, since he is aware of positions of all aircraft either directly or via A-network.

2.2.2 Use of the combination of an unmanned ground RPAS-gateway and RPA access via self-organizing A-network allows to manage RPA flights in any part of controlled airspace without any effect on ATC and manned aircraft interaction.

2.2.3 Flights of all aircraft are performed under an air controller's supervision; manned aircraft are controlled by means and methods applied in given airspace, for RPAS the described RPAS module is used.

2.3 EXPANSION OF SELF-ORGANIZING A-NETWORK USE

Expansion of self-organizing A-network use may be performed in following directions:

2.3.1 Combination of manned and unmanned aircraft.

If manned aircraft are equipped with C2 data link transponders with above mentioned requirements all such manned and unmanned aircraft in direct radio access form a common "cloud" with internetwork exchange rules. If just one aircraft of the cloud has got an access to ATC system, information of each aircraft from the cloud becomes available to ATC system with minimum delays. In its turn each aircraft from the cloud may timely receive necessary instructions or other information from ATC system. Two-way exchange of information (from aircraft to ATC and from ATC to aircraft) via A-network allows to implement both applications based on surveillance like ADS-B Out/ADS-B In/TIS-B/A-SMGCS/search and rescue according to the latest ADS-B message and whole range of services based on two-way FIS-B (operative weather, D-AIM, SWIM, wake turbulence safety, CPDLC, AOC, etc), DGNSS navigation, etc.

2.3.2 Use of low-orbit satellites like Iridium or Gonets.

Even with a C2 data link transponder on board an aircraft will have no access to the cloud or to ATC if it has no radio access to any aircraft or directly to ATC. For such a "lonely" aircraft when within about 400 km radius there are no other aircraft we study the following. Aircraft signals of ADS-B Out type, either 1090 MHz extended squitter signals or VDL-4 signals in airborne VHF range, enter low-orbit satellites like Iridium or Gonets (Russia), then these signals are relayed to ground receiving hub and further via ground links are delivered to interested users, first of all to ATC. Signals delays with the use of low-orbit satellites are minimized. The chain "lonely aircraft – satellite – ground station – ATC" become kind of a node of an air-space network with one-way direction of information. No additional on-board equipment is necessary here, except above mentioned C2 data link transponder. While achieving radio access to aircraft from a cloud that has been "lonely" earlier, the aircraft enters A-network and servicing via satellite terminates thus minimizing the satellite link loading. If there is no direct radio access because of absence of equipped aircraft in the vicinity of studied aircraft the hazards of their collision are eliminated. Cases with non-equipped aircraft have been studied earlier.

Russian Federation has organized works on the creation of a satellite system for maritime surveillance using Automatic Identification System (AIS) with VHF radio channel and for aircraft surveillance using ADS-B systems based both on 1090 ES and VDL-4. AIS and VDL-4 transponders are based on common technology of self-organizing time division multiple access (STDMA). In 2013 Russian Federation will launch its first satellite with AIS receiver on board, in the nearest years there will be executed launches aimed on VDL-4 ADS-B implementation.

3. OPERATIONAL BENEFITS

3.1 Use of self-organizing A-networks allows:

a) With regard to RPAS to provide for robust surveillance and RPAS control in civil controlled airspace;

b) To ATM to extend rendered surveillance services

c) To improve ATM surveillance while increasing flight safety level due to the improvement of the whole surveillance system, to use shortened intervals of aircraft separation, to increase aircraft throughput and efficiency of airspace use while decreasing demands to the ground coverage with surveillance systems;

d) To airlines to increase safety level and flights efficiency due to better situational awareness and presentation of necessary information.

3.2 Supposed benefits support ICAO effective strategic aims of A - Safety of Flights and C – Environment Protection and Stable Development of Air Transport.

4. CONCLUSION

4.1 Aviation industry has got to solve the problem of RPAS integration into civil controlled airspace under BRLOS conditions. Self-organizing airborne networks sending control signals from RPS to RPA and receiving information about RPA status as well as interacting with ATC both directly and via a network of duly equipped aircraft with minimum signal delays allow to solve this problem.

4.2 Aviation industry is constantly looking for ways to increase flight safety level, to acquire operating and financial benefits especially on routes without surveillance; in this regard the possibility to use self-organizing A-networks including manned aviation is significantly increasing mutual situational awareness of pilots and air controllers thus promoting more efficient management of airspace and aircraft.

4.3 Hence the Assembly is invited to consider the benefits of the self-organizing A-network conception, first of all to provide to the safety of flights in the integration of remotely piloted aircraft in civil airspace, as well as to request ICAO Council to study given proposal in the course of updating Global Air Navigation Plan on 2013-2028 with the aim to include the self-organizing A-networks conception in B1-RPAS module.

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APPENDIX

REQUIREMENTS TO SELF-ORGANIZING AIRBORNE NETWORK AND C2 DATA LINK

1. MAIN PRINCIPLES OF SELF-ORGANIZING AIRBORNE NETWORK FUNCTIONING

1.1. Main A-network function is to provide for the data exchange between objects within ordinary radio access area. Such objects include any manned and unmanned aircraft, moving and fixed ground and sea vehicles with transmitters/receivers equipped with hardware/software to perform functions of switched network nodes.

1.2. All A-network objects are referenced with geographical coordinates and with time e.g., by GNSS. Ordinary radio access area is an area where every object has got a radio access to one neighbouring object at least.

1.3. Data is being exchanged in a batch mode. All information circulating in the network is available to all users (nodes). If necessary, every user may send data to another one in point-to-point mode. If there is no direct radio access between objects, the information is transmitted (relayed) via other objects.

1.4. To estimate the authenticity of signals, reveal natural interferences and artificial false simulated signals and their discard, subsequent use in “detect and avoid” system, the time of every batch sending is referenced with the time scale, this time is input in the batch message. The time of the signal arrival with the user is determined at its reception. The difference between the signal sending and reception allows to calculate the distance between the sender and the receiver.

1.5. Routing and batch switching functions are delegated to the network hardware/software which supplies protocols of interaction coordination, search for assigned objects, provision and integrity monitoring of batches.

1.6. For the case when all network nodes apply one and the same radio frequency to send and receive messages, the node should store all received messages till sending them. Management of the network operation should provide for the minimization of the data store period in all nodes participating in the relay chain to deliver data to necessary user.

1.7. A-network is built on a self-organizing principle; it stores and regularly updates the network map including:

- current architecture of the network – space graph whose nodes are defined by geographical coordinates and are available for the connection of objects and their interaction;
- table of distances between objects calculated on their geographical coordinates;
- table of distances between objects calculated on measured time value of the signal propagation between objects;
- table of obvious discrepancies in distances determined from coordinates and propagation time;
- table of communication channel throughput between objects; and

– database of the locality and obstacles to forecast boundaries of the direct radio access area.

1.8. Network addresses (numbers) of objects with geographical, time and network references are known to all network objects.

a) A-network provides for following additional telecommunications functions:

b) certain object, it is possible to apply a “storm” principle, that is to broadcast a demand protected from re-broadcast in the same channel between nodes;

c) Message priorities are defined/assigned according to the contents. Messages may be routed both manually and automatically depending on their rating. Urgent (or critical to delivery time) messages are forwarded according to the minimum number of relay stations. Messages demanding for increased authenticity are forwarded along the shortest possible routes with the highest stability to interferences. Routing of messages not demanding for special attention is performed with the aim to decrease the throughput losses in channels between nodes;

d) Management of voice data exchange in addition to data exchange; voice networks and data networks apply different frequencies in conformance with the frequency plan; if necessary, A-network manages the node switching for the voice communications;

e) Ability to broadcast voice messages (implementation of a party line function using A-network parameters for the voice communications management);

f) Ability to store information received beforehand from other objects when RPA is beyond A-network, and deliver it to the network within the access area (mail service); and

g) Protection of transmitted information from unauthorized access, replacement, interception, insertion of false information with the aim to check the authenticity of messages.

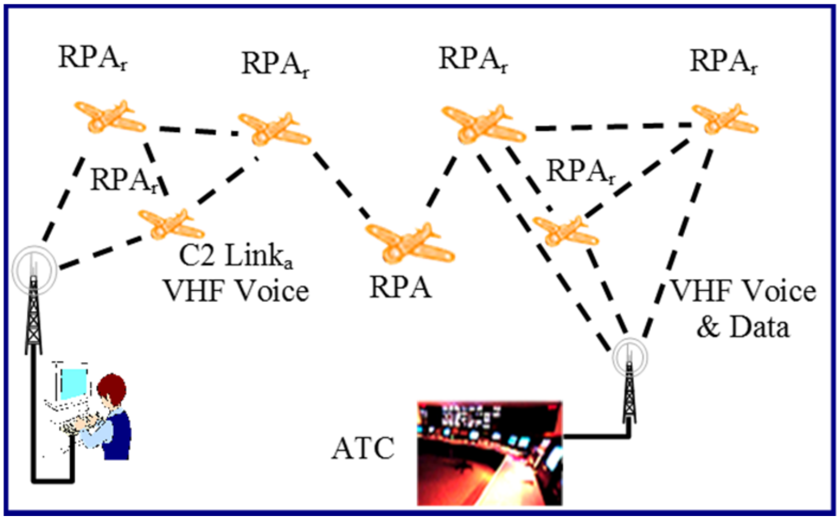

Fig. 1. General scheme of RPA interaction with RPS and ATC

1.9. General scheme of RPS and RPA interaction as well as ATC and RPS via RPA is given in Fig. 1. Locking two A-networks providing for RPS and RPA interaction from one side and RPA and ATC from the other side via RPA results in a unique A-network with interacting RPS and ATC as nodes. Each network between RPS and RPA as well as between RPS and STC may form a linear chain.

2. INTERFACE GATEWAY OF C2 DATA LINK AND VOICE COMMUNICATIONS/ATC DATA LINK

2.1. ICAO RPAS draft manual foresees following interface of ATC communication channels and C2 data link. It is supposed that RPA has got at least one VHF radio and C2 data link has VHF frequency resource necessary to provide for voice communications and data communications, if needed. Here VHF voice messages from ATC to RP come to RPA, are digitized and then are relayed to RPS via C2 data link. Voice messages from RP to ATC are digitized in the RPS, sent to the RPA via the C2 link, converted to analogue voice messages and transmitted via the VHF radio.

2.2. Asymmetrical approach (ATC personnel sends and receives voice messages in an analogue form while RP does the same in a digital form) is supported by the wish not to change ATC equipment and procedures in the global scale. However this significantly complicates the equipment of all RPA, both large and small, and should be executed considering limitations on mass, size, placement in RPA, power supply, control, maintenance, etc. Another possible approach may be the one when voice from ATC to RPS is digitized not on board RPA but near ATC ground facility. Surely it will demand to install some new certified ground equipment using two frequencies for voice – VHF one for analogue voice communications to serve manned aircraft with Party line management, the other for digital voice communication on C2 link for RP with relay via RPA. Digital voice communications is much easier and more efficient in use; it is a common way in sound industry as well as in wireless telephone communications. New equipment located on the ground should not affect the operation of manned aircraft and would concern only RPAS activities. Besides VHF voice communications there will be also data relay from ATC to RPS via C2 link. Thus it is necessary to have a gateway between ATC communications (both voice and data) and C2 data link, and here we may study two approaches. The first is to change nothing in the ground equipment and to assign the all task to RPAS with due attention to all above mentioned limitations. The second is to simplify the on-board part of RPAS and delegate some tasks to the ground though not to ATC but to certain ground modules of RPAS, to establish a ground gateway for RPAS. Here it looks proper to give a following analogy. While establishing aircraft surveillance it is possible to make significant investments in the upgrade of primary surveillance radars (PSR) not touching aircraft. However organization of cooperative surveillance with the use of secondary surveillance radars (SSR) splitting the surveillance upgrade work between ground and on-board means will be much more efficient. Organization of an unmanned ground RPAS-gateway will have no effect on the management of manned aircraft flights, but will deliver information in both directions – from RPAS to ATC to build up a complete ATC picture and from ATC to RPS to perform flights under full ATC control. Instead of many gateways on board RPAS we apply one common ground gateway.

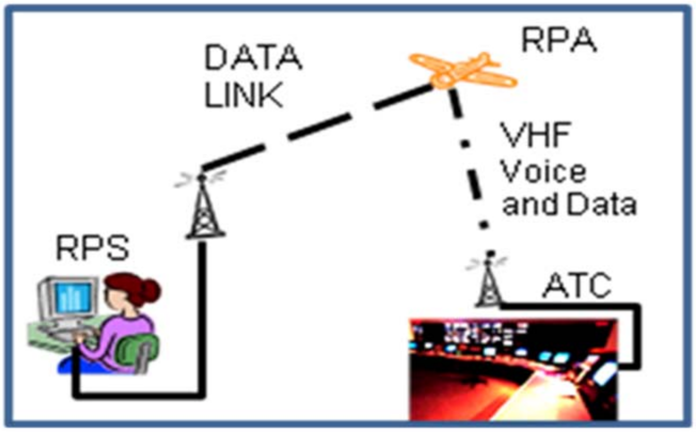

Fig. 2. RPAS and ATC interaction under RLOS

2.3. Module of RPAS includes:

- RPAS systems which control RPA from RPS with the help of C2 data link;
- unmanned ground RPAS-gateway providing for RPAS and ATC interaction.

2.4. Within RPAS module every RPS controls its RPA operation with the help of C2 link. To know own position RPA may use surveillance means developed by the manufacturer that must be certified. Information about position may also come from each RPA to an appropriate RPS with the help of surveillance means standardized by ICAO – SSR, ADS-B or multilateral transponder. RPA surveillance data arrive at ATC via ATC surveillance channels (not shown on the scheme). To avoid certification of RPAS surveillance means for ATC RPAS developers may apply above-mentioned ATC surveillance means.

2.5. Besides communications interface ground RPAS gateway solves also the task of surveillance interface. Let's consider the case when in some airspace manned aircraft are surveyed with the help of SSR. RPAs might be surveyed in this airspace with SSR transponder but by many reasons such transponder on-board RPA might be not acceptable, in addition it demands to have the ground radar in RPS. To find the solution is to use for RPA surveillance ADS-B methods and tools, how it is doing in ground RPAS gateway. This gateway gets ADS-B data from RPA and sends it to ATC; in addition ATC performs TIS-B function sending information on all aircraft, manned and unmanned, to all RPSs with ADS-B In function providing. So RPASs and ATC are interfaced not only for communications but surveillance as well.

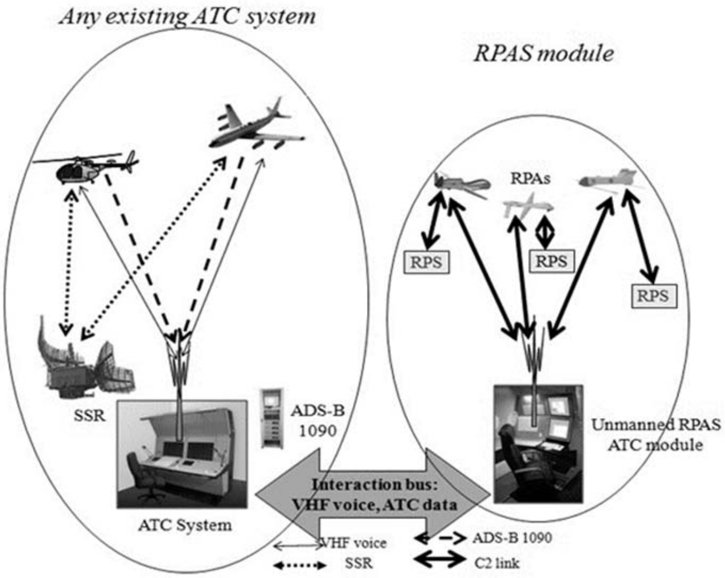

Fig. 3. Ground RPAS-gateway to interface ATC voice and data with C2 data link in RLOS

ADS-B In function providing. So RPASs and ATC are interfaced not only for communications but surveillance as well.

3. INTERFACE OF VOICE/DATA COMMUNICAITONS FROM/TO ATC AND C2 DATA LINK IN SELF-ORGANIZING A-NETWORKS APPLICATION

3.1. In the absence of direct line of sight between ATC and RPA besides satellite communications with inherent unlimited delays, it is possible to use A-networks as follows (Fig. 4).

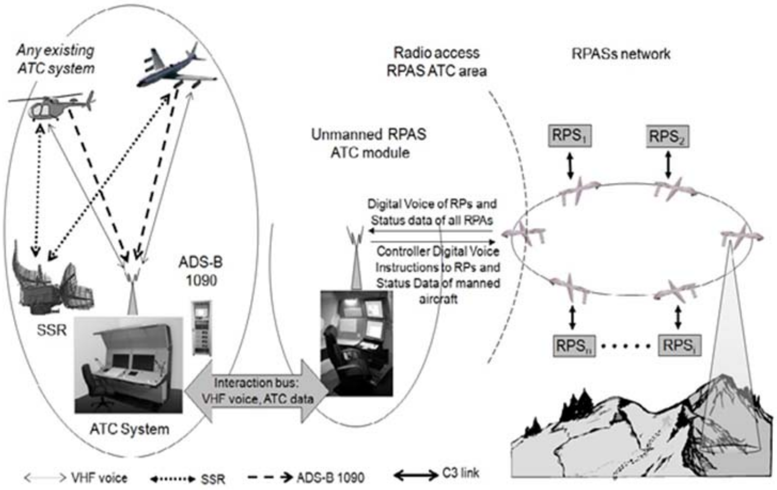

Fig. 4. Combination of ground RPAS-gateway with RPA access via A-network

3.2. Combination of unmanned ground RPAS-gateway and RPA access via A-network allows to manage RPA flights in any part of controlled airspace with no effects on ATC and manned aircraft interaction.

3.3. Flights of all aircraft are executed under air controller supervision; manned aircraft are supervised by means and methods applied in given airspace, for RPAS they use above mentioned module of RPAS. This case has got a following peculiarity: cloud of RPA flies along some route in the form of an elongated ellipse. For example, on one side of this elongated route each RPA performs some functional task; on the other side of the route each RPA contacts with an unmanned RPAS gateway.

3.4. RPS positioning on the ground may be random. There is only one restriction, i.e. that every RPSj should interact with any RPAk when this RPAk is in RPSj access area. Here every RPSj will maintain permanent control of its RPAi without actual delays of signals if certain requirements to A-network are observed. Air controller has in possession all circulating in the network information about positions of all RPAs; all RPs know positions of all manned and unmanned aircraft.

3.5. If necessary, A-network establishes voice communications in voice network (on another frequency) switching appropriate nodes of voice network. The size of A-network and number of necessary RPAs in the network actually depend only on the duration of flight and velocity of RPA.

3.6. Note that in voice communications for all RPs schemes in Fig. 3 and 4 provide:

– reception of air controller’s voice instructions;

– listening to all negotiations between air controller and pilots of manned aircraft as «Party line», that may be delivered to all RPs via ground RPAS-gateway;

– listening to all negotiations between air controllers and all RPs that are delivered to ATC and may be relayed to all pilots of manned aircraft with the help of VHF ATC antenna.

3.7. If above mentioned participation in “Party line” “via ground” is not enough and it is necessary to have direct interaction between pilots of manned and unmanned aircraft though it is not foreseen in Annex 10 Volume 3 for manned aircraft, it would be necessary to install a two-way relay station; ATC voice component of C3 (Command/Control/Communications) data link would present common VF radiotelephony communications; due to some reasons the solution with such a relay station on board a RPA will not look elegant. However if this is the case, the voice relay station in ground RPAS gateway may serve as a stand-by solution, for example, for large distances between aircraft, for unstable air-air connections, various communication lineouts, etc.

3.8. Note that the gateway issue concerning ATC and C2 data link interface only for data transfer (location of gateways/gateway and their number) should be considered regardless of voice communications.

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