Abstract:

A flight management system for unmanned aerial vehicles (UAVs), in which the UAV is equipped for cellular fourth generation (4G) flight control. The UAV carries on-board a 4G modem, an antenna connected to the modem for providing downlink wireless RF. A computer is connected to the modem. A 4G infrastructure to support sending via uplink and receiving via downlink from and to the UAV. The infrastructure further includes 4G base stations capable of communicating with the UAV along its flight path. An antenna in the base station is capable of supporting a downlink to the UAV. A control center accepts navigation related data from the uplink. In addition, the control center further includes a connection to the 4G infrastructure for obtaining downlinked data. A computer for calculating location of the UAV using navigation data from the downlink.
FLIGHT MANAGEMENT SYSTEM FOR UAVS

CROSS-REFERENCE TO RELATED APPLICATIONS
[001] The present application claims the benefit of priority to US Provisional Patent Application Serial Number 62111764, filed 04-FEB-2015, entitled "Control And Flight Management For UAV And Multiple UAVs Flight Management And Control By 4G And Further Generations Of Cellular Infrastructures And Networks." The aforementioned application is hereby incorporated herein by reference.

TECHNICAL FIELD
[002] The present invention is in the field of aviation control. More specifically the control of unmanned aviation vehicle flight and cellular networks.

BACKGROUND ART
[003] The usage of UAVs is growing steadily. Mission spectrum is wide and keeps widening, a typical list of missions includes: reconnaissance, military targeting and attack, fire control, and parcel delivery. Currently commercial UAVs require special wireless links to control their flight, each such link may not be geographically sufficient to cover the entire flight path, rather, it provides for a limited section of the path. Typically only a few miles are supported by the link, usually requiring line of sight to the UAV.

[004] While the UAV typically communicates with a wireless ground stations, the human controller is connected to ground stations via a ground network. If the ground station is part of a nationwide system of
control stations that coordinate with each other, there is a possibility of a smooth handover of UAV from one ground station to next. An alternative scenario is that of a controller directly communicating with the UAV via a wireless link.

[005] An issue associated with UAV flight control, is the lack or lesser interaction of these aerial vehicles with the general flight control. The weight of UAVs is often less than 25 kgs, and for this and various other reasons their tracking by many radar system is not facilitated. This not only indicates a lack of possibility to control flight using common tracking systems but the hazard that such vehicles pose to civilian, military air traffic, other UAVs and objects on the ground through actual collision or otherwise intervention in flight courses.
BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of a general flight path with ground station support.

Fig. 2 is a schematic diagram of a UAV with data link.

Fig. 3 is a schematic description of the major components with which a UAV for implementing the present invention is equipped.

Fig. 4 is a schematic diagram showing the interconnection of a flight data collection and distribution server.

DISCLOSURE OF THE INVENTION

[006] As the bottleneck in UAV communications (uplink and downlink) is the struggle for bandwidth, it is maintained that the deployment and use of generation 4.0 (known as 4G) and above is to provide a viable data link for UAV flight path control and optionally additional tasks. 4G infrastructure is now being implemented worldwide.

[007] In accordance with the present invention, a UAV flies along a flight path while using the cellular 4G infrastructure to implement the mission control. As can be seen in Fig. 1, flight path 22 which also represents a time line is the path along which UAV 24 flies or is intended to fly at time T1, T2 and T3. At T1 base station (BS) 26A intercommunicates with UAV 24, at time T2 BS 26B replaces 26B and at time T3 BS 26C replaces 26B. In comparison with control system of the prior art, the BSs attending to the flight control of the UVA in accordance with the present invention, come in lieu of the customary ground stations.
The complete data path is shown schematically in Fig. 2. UAV 24 uses data link 32 to connect with flight control centre 34. The data link in accordance with the present invention is embodied in 4G infrastructure employing compatible modems on the UAV.

Minimal network properties required

In order to fulfill the task in accordance with the present invention, cellular infrastructure of the 4th generation (known also as 4G) and above is used to provide the data link to the UAV. Properties of the 4G system are defined by ITU's International Mobile Telecommunications Advanced program (IMT-Advanced program). The ITU stands for International Telecommunication Union, which is an agency of the UN.

On-board H/W components of a UAV accommodated for mission

Schematically shown in Fig. 3, UAV 40 carries on board computer 42 connected to one or more cellular modems 46, these modems are operational with 4G cellular network. An example of 4G modem is Netgear AT&T Aircard 340U 4G USM which is an LTE (long term evolution) modem. To these one or more modems, one or more cellular antennae 52 are connected, to provide RF to the downlink and/or as uplink receiving antennae for each of the modems. Box 54 represents hardware payload elements, typically sensors that provide navigational information to be downlinked to the flight control centre. LTE advanced and Mobile Wimax communication standards are considered as complying with the 4G requirements. Navigational information derived from on-board inertial sensors (gyrosopes and accelerometers) can be used to navigate the UAV in case of a total failure of the supporting cellular network, or a failure in receiving data from the GPS satellites. Navigational information can be derived from the signal of the supporting cellular network, which may be very important if signal from the GPS satellites is insufficient. The cellular network can identify
the location of the UAV as by at least two base stations and as "triangulation" algorithm in order to provide the location of the UAV.

Providing for UAV related Uplink and downlink data

In order to control the UAV in its flight path, downlink is required to send commands and flight parameters to the UAV. In the other direction, uplink data is transmitted to the control centre to provide navigation related data collected in the UAV, and which is relevant for the analysis of the compliance of the UAV with the path. Such data is for example, telemetry, GPS data collected by on-board GPS receiver and on-board inertial data, these are represented by box 54. The collected data all or part of the collected data from the sensors can be uploaded to the internet cloud as IoT (Internet of Things) data. The uplink and downlink data from or to the UAV can be sent to more than one end point. Such data as payload data as video stream that is sent from the UAV camera or data as the UAV flight parameters data can be sent to more than one end point via the 4G infrastructures to different working stations or even to personal devices as Smart phones, tablets (with 4G modems) directly or indirectly and simultaneously. In the other direction, it is possible that the driving control and flight management of the UAV can be done in parallel from different End Points of the 4G infrastructures but coordinated between the UAV remote pilots so in definite moment only one is the main UAV remote pilot that actually drives the UAV. For example more than one person can drive and control the UAV at specific time but at any moment the UAV driving control can be switched to a different person connected to different end point, receiving the same flight parameters and other payload data of the UAV simultaneously.

UAV payload data and uplink for transmitting same
In addition to the control and flight management, another aspect of the present invention is to do with a payload uplink, specifically not associated with the data related to the flight management. The uplinked data of this category relates to another aspect of the present invention, implemented through the 4G infrastructure discussed above. Box 64 represents hardware payload elements, typically sensors that provide information to control centre 34 or to another data collecting facility. An inconclusive list of such sensors include optionally video camera/s, thermal IR camera/s (known also as FLIR), and RADAR. Other sensors which may be of use are thermometers, pressure gages, humidity gages and other meteorological and other environmental sensors. Payload data from such sensors can be loaded to the internet cloud for various data analysis agencies while the UAV is on mission or after.

BS and on-board antennae

BS antennae are typically Omni-directional. However for the sake of the purpose described in the present disclosure, directional antenna can be used to point at some angle upwards.

The adaptation of the UAV to the implementation of cellular networks connectivity includes the on-board antennae as well. In order to extend the effective distance of a UAV from the cellular BS, two types of antennae can be used in a complementary manner which will be described below. The two types of antennae in this case are omni-directional antenna and unidirectional antenna.

In this aspect of the invention, the omni-directional antenna can be used to search for the strongest emitting antenna of a BS. After detection of the strongest antenna, the unidirectional antenna can be directed to the same antenna in order to acquire the signal from same antenna.
The unidirectional antenna then locks on the direction of the cellular BS antenna so the higher gain of the unidirectional antenna enables the detection of weaker signals and by that extend the UAV range from the BS.

This aspect of the invention can contribute to the quality of service (QoS) with respect to the UAV. This aspect of the invention is expected to increase the QoS in problematic locations for example where a BS is at a suboptimal distance, and in places in which BS is of poor coverage and in general where the received signal is weak.

The omni-directional antenna can continuously search for alternative BSs signals. Thus, if a signal has become weak or lost altogether, rendering the unidirectional antenna ineffective, the omni-directional antenna is switched back to keep the connection with the wireless link albeit a different BS, providing a better signal.

A plurality of SIM (subscriber identity module) cards

In another aspect of the present invention, the one or more modems on-board the UAV may contain each one or more SIM cards. This enables the UAV to shift from one to another cellular network in order to increase the robustness of the communications system. Moreover, it becomes possible for the UAV to use a plurality of networks at once thereby increasing effective bandwidth.

Quality of Service for the UAV

Flight control traffic for UAVs over 4G, must have ensured bandwidth and network access. There are several supporting measures that can be taken in order to keep the QoS above a defined threshold. One such measure is discussed above with respect to the use of two antenna types. One other measure is discussed below in the context of an auxiliary UAV. Another
measure is the implementation of a virtual mobile network, similar to the MVNO (mobile virtual network operator) also known as Molo (mobile other licensed operator), in which the infrastructure, typically BS are licensed to an operator other than the proprietor of the infrastructure. Such technological/legal operative, it would be practical to allocate a portion of the infrastructure use to a UAV operator under agreement, in which case the QoS would be more under control of the UAV operator. By definition such a virtual network operator may dedicate the network solely for the use in accordance with the present invention. Another aspect of supporting measures for the flight/mission is discussed below under the header of flight plan below.

[026] In order to use the frequencies bandwidth optimally in the cellular infrastructures including the base stations, the system is to dynamically allocate the bandwidth of the cellular network and its base station. For example if there is a demand for additional bandwidth for confirmed UAVs flight plans, more of the frequencies bandwidth will be dedicated for the UAVs network with a lesser frequencies bandwidth being allocated for the primarily mobile phone wireless network. Such a dynamic allocation of the frequencies bandwidth can be managed as by the cellular infrastructures management system.

[027] Participation of more than one UAV in a mission

[028] In addition to the UAV carrying out a certain mission, other UAV/s may be involved in the same mission. An auxiliary UAV (AUAV) may be employed to extend the cellular network participating in the mission. For example, a AUAV can carry on-board the amount of UAV required for creating a microcell, the AUAV may assist in the UAV providing the mission, to extend geographical limitations of the cellular system interacting with the UAV, or in keeping a QoS definitions in control, essentially as the microcell created by the AUAV is to serve the UAV exclusively. The notion of picocel in this context is theoretically possible but then the two UAVs will have to keep very close in order for the connections to take place.
Flight plan

Since this term has formal connotations, as a formal plan presented to the flight control authorities by the flier of a plane, the term is used hereinafter in a more loose sense than is usually used in the context of flight formalities. Thus, the intended course of a mission, from a geographical point of view of a UAV in accordance with the present invention, draws a geographically based scheme of flight in all three dimensional aspects of the space. The flight plan in accordance with the present invention takes into consideration not only the course of the planned mission in geographical coordinates and flight altitude along the route, but also the availability of BSs along the routes, service providers deployed along the proposed plan, and alternatives. In such a plan, the possibility of employing an AUAV for specific sections of the plan is state in order to increase extent of service, overcome blockage or reduction in reception quality of the cellular network, etc. The consequences of the flight plan on the QoS are such that on sections of the flight plan there may be more BSs available, then in other sections. The availability of more than one cellular infrastructure along the path, may be used to prefer a specific service provider along the way, thereby switching between SIM cards available on - board the UAV, either applying a preplanned move or by an on flight decision. Further, different bandwidth requirements along the flight path may be planned ahead and be integrated in the flight plan. For example if the flight plan includes a video acquisition term from one point to another point, the bandwidth for the downlink at the specific limits is to cover the bandwidth allocation requirements at the stage.

The system may confirm the requested flight course after confirming and consider the local flight authorities regulations requested by the submitted the flight program according to the regulations and other UAVs expected and confirmed flights and after checking and verifying that the flight requested program is in allowed airspaces.
The confirmed flight plan and path in the 3D space and time can be downloaded by the 4G downlink to the UAV to be accepted by the on-board computer for further processing to control the UAV flight. This can be managed by the FDCDS (discussed below) as well. The flight control according to the downloaded flight plan can be then achieved for example by an on-board autopilot or by the remote pilot which may be a person who drives remotely the UAV.

Implementation of the current invention can increase safety of flight for large number of simultaneously flying UAVs, as well as for human life and safety of property on the ground since the availability of the UAVs flight parameters via the same payload wireless link implemented by the 4G cellular modem and link and the relatively easy addition capability of supervising and control of the UAVs that is proposed by the current concept and invention. There is no known current wireless network that is especially advantageous and able to support all the benefits as can be provided by the implementation of the current invention.

A flight data collection and distribution server (FDCDS) constitutes another aspect of the invention. The data sources and distribution targets of the server, are described schematically with reference to Fig. 4. FDCDS interacts with subscribing UAVs 84, with subscribing airplanes 86, with participation 4G cellular providers 88 and with aerial traffic control authorities (ATC) 90. The interaction with the UAVs 84, aero planes 86 and cellular network providers has a strong on-line aspect as they may be involved with on-going missions. The involvement with control centre 34 and ATC 90 has more off-line aspects. The purpose of having an active FDCDS is to monitor struggle over bandwidth, facilitate better planning of flight missions and prevent collisions. The FDCDS can be used as a major tool in the implementation of aerial flight control.
The data about flight missions of UAVs, stored and constantly updated in database 94 can be used as a planning tool to select best flight plans. In case the FDCDS detects that a UAV is out of its confirmed flight path, in the 3 dimensional space, the FDCDS can assume control thereby setting the UAV in the original flight path. The FDCDS can also confirm or reject request for flight plan. In case the flight plan is confirmed by the FDCDS, the FDCDS can download to the UAV the confirmed flight plan and flight path including the 3D path, and reference to time. The flight plan may be downloaded by the 4G structure downlink to the on-board computer. Alternatively the UAV may receive just a confirmation number if the flight plan is already downloaded.

[035] In a similar attitude to various levels of autopilot controlling flight parameters, the FDCDS can in cooperation with on-board computer 42 can assume control of rudder, ailerons, elevators, and the engine. Another practical option is the use of a standard purchased autopilot unit so the driving control data for the flight driving control channels as for the rudder, ailerons, elevators, and the engine. The connection of the cellular modem to such autopilot unit can enable stable and accurate flight track in various weather conditions. The flight driving control channel between the cellular modem mounted in the UAV can interface and/or use standard protocols for remote control for platforms as standard S.BUS serial data protocol or any other standard serial data wireless link protocol for remote control of platforms.

[036] Other autonomous vehicles.

[037] Although the disclosure referred to hereabove to UAVs, it should be understood that the system of the invention can be applied to other autonomous vehicles, more specifically to autonomous land vehicles and autonomous boats. With the exception that there is usually no need to implement altitude references in earth-bound missions, or at least much less in term of altitude is to take place.
[038] **Use of the system of the invention in the managing of UAV fleets.**

[039] The idea of using fleets of UAVs in regular haulage and dispatch missions is gaining momentum and is expected to become prevalent. The FDCDS of the present invention lends itself easily to managing such fleets together with keeping track of the consignments. The use of data relating to the flight missions obtained from a plurality of UAVs and using data from other sources such as weather models, facilitates the dynamic assignment of flight plans that can provide minimal dispatching time of parcels by UAVs of the fleets. Moreover, such plans can be dynamically calculated in-flight for optimization.

[040] **Integrative computer on board the UAV**

[041] As mentioned already above, computer 42 is connected to the modems and does its share in the communications of the UAV and cellular infrastructure. In addition, the same computer can be employed in the task of maneuvering the UAV by controlling the motors of the devices that direct the flight (aileron etc.) and also it can control the power output of the propulsion engine to change the thrust, for example by controlling the fuel supply. The same computer can be implemented in the control of the various sensors including cameras on-board the UAV.

[042] **Flight supervision**

[043] The supervision, control and management of flight in accordance with the present invention, preferably uses the FDCDS 82, may track each flight since location speed and other navigation data can become available if it is connected via the same cellular infrastructure then in case of out of course. The system can prevent deviation from an authorized course by sending limitation commands to the UAV specifically in case of risks of entrance to forbidden airspaces. To perform such supervision, automatic or non-automatic, use is made of UAV telemetry and flight parameters such air and ground speed,
altitude, measured on board the UAV, location by GPS and other flight parameters. The UAV uplink data sent via the 4G infrastructures may include also relevant information as left fuel or left electrical energy in the battery of the UAV in order to enable efficient and safe UAV flights.

[044] In case of risk of physical danger to a supervised UAV that may caused by another UAV, the system can alert about the risk by sending flight driving commands in order to prevent the contention, automatically or by the human operator of the UAV or by the UAVs flight supervision and control system.

[045] A new flight plan can be requested and confirmed during other flight plan as when there is a need to change the flight course during flight. Such supervision and control may enable in real time priority for UAVs that are in a mission of emergency services by sending alerts and other flight instructions in real time to other UAVs. Such supervision and control system may increase safety in the air and on the ground and can enable automatic by computerized and/or by human supervision as well while supplying and recording of each UAV flight details including location, speed, height, direction and other vital flight data.
CLAIMS

1. A flight management system for unmanned aerial vehicle (UAV), comprising:
   • a UAV equipped for cellular fourth generation (4G) based flight control, said UAV carrying on board:
     ■ at least one 4G modem;
     ■ at least one antenna connected to said at least one modem for providing uplink wireless RF to the 4G network;
     ■ a computer (42) connected to said modem;
   • a 4G infrastructure to support sending via uplink and receiving via downlink from and to said UAV, said infrastructure further including at least:
     ■ a base station capable of communicating with said UAV along its flight path;
     ■ an antenna in said at least one base station capable of supporting a downlink to said UAV;
   • a control centre to accept navigation related data from said downlink, said centre further including at least:
     ■ a connection to said 4G infrastructure for obtaining downlinked data;
     ■ a computer for calculating location of said UAV using at least data from said downlink, and
     ■ a connection to said 4G infrastructure for providing uplink.

2. The flight management system as in claim 1, wherein said UAV further comprises at least one sensor and wherein output data of said sensor is transmitted via said downlink and said 4G infrastructure to said control centre, and wherein said output data of said sensor is not associated with flight management.
3. A flight data collection and distribution server (FDCDS) for collecting data from at least subscribing UAVs and from at least one supporting 4G cellular network and from air traffic control authorities, wherein said server also distributes data for users who are involved in at least planning of flight missions.

4. The flight management system as in claim 1, wherein data collected from a plurality of UAVs and other sources, facilitates the dynamic assignment of flight plan.

5. The flight management system as in claim 1, wherein said computer is an integrative computer that is an integral part of the communications system and further performs the following functions:
   • directs the maneuvers of said UAV by controlling the actuators of the flight control and thrust of the propulsion engine, and
   • controls the sensors.
Fig. 1
PRIOR ART

Fig. 2
PRIOR ART
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC (2016.01) G05D 1/10, G06G 5/00

According to International Patent Classification (IPC) or both national classification and IPC.

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC (2016.01) G05D 1/10, G06G 5/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched.

Electronic database consulted during the international search (name of database and, where practicable, search terms used).

Databases consulted: Google Scholar, PatBase

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
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Date of mailing of the international search report: 16 May 2016

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Telephone No. 972-2-5651701

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<td>Invention/s 1</td>
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