Integrated System Conception of Low-altitude Air Defense and Air Traffic Control Based on Cellular Mobile Communication Network

Zhao Guhao\textsuperscript{1,2}, Wu Yarong\textsuperscript{2}, Yang Yuan\textsuperscript{2}, Zhu Jie\textsuperscript{2}, Yao Dengkai\textsuperscript{2}, Yang Nan\textsuperscript{2} and Hao Chenlu\textsuperscript{2}

\textsuperscript{1} State Key Laboratory of Air Traffic Management System and Technology
\textsuperscript{2} Air Force Engineering University, College of Air Traffic Control & Navigation

Email:zghlupin@163.com

Abstract: Low-altitude airspace as a national valuable strategic resource, because of the lack of effective monitoring method, and can not be fully utilized. Integration of air defense and air traffic control is an important problem in air traffic control establishment and this paper has discussed a kind of integrated system of low-altitude air defense and air traffic control based on cellular mobile communication network, which can effectively meet demand of early warning detection in low altitude air defense and at the same time can meet demand of air traffic control to air surveillance, communication and navigation. The proposed method can effectively solve the low-altitude airspace detection, monitoring and communication problems, and give full play to the economic value of low-altitude airspace.

1. Introduction

Low-altitude airspace is airspace scope [1] with vertical true height lower than 1000m and is main area of general aviation activities. In recent years, general aviation develops rapidly in China, annual increase of freight gross reaches more than 10%, industry scope increases increasingly, application fields expand increasingly and flight kinds increase increasingly, and flight demand is vigorous increasingly. With continuous and quick development of economy and continuous improvement of people’s living level, it is expected that annual increase of general aviation in China will reach more than 15% in future 10 years [1]. Low altitude airspace management reform and utilization of low-altitude airspace to the maximum is important system support to promote quick development of relevant industry fields, such as general aviation industry, aviation manufacture industry and traffic transportation industry, etc., to complete emergent rescue ability to accident and disaster and to promote emergency reaction for explosion protection and counterterrorism.

Although general aviation in China develops rapidly, there is still relatively large distance compared with America. As of the end of 2016, according to statistics, there were 230 thousand planes in American general aviation fleet and annual flight hours were 28 million hours, which are respectively 200 times and 40 times of China [2]. It is caused by seriously insufficient general airports and seriously shortage of aviators, but the most important reason is low airspace utilization rate caused by air-defense pressure. It is related to difference of national defense environment between China and America and America is bordered by ocean to the east and west and by ally Canada in the north and by “backyard” Mexico in the south. America nearly does not have air-defense pressure of the homeland...
and can set almost all airspace lower than 1200 feet as uncontrolled airspace. However, safety environment near our country is complex and it is difficult for ground-based radar early-warning detection system to find out target on ground object surface and background because of earth curvature function and uneven ground surface, etc. Low-altitude airspace cannot be “opened” thoroughly for national defense pressure and only part of low-altitude airspace can be opened conditionally on the premise of complete supervision and management and control to low-altitude airspace aircrafts. First and foremost, we shall solve supervision and management and control problems to low-altitude airspace aircrafts to give full play to economic value of low-altitude airspace.

2. Difficulty and problem of low-altitude airspace defense and air traffic control

2.1 Difficulty of Ground supervision

Low-altitude airspace aircrafts are characterized by small model, slow speed and low height, etc. and is hard to be found out by ground-based radar for limit of earth curvature and terrain. Therefore, for “invisibility, not hearing and loss of communication” phenomenon in these airspaces, it is difficult for aviation management and control departments to master movement status of aircrafts. To ensure homeland air-defense safety and flight safety of aircrafts, management method of prohibition use and strict review and approval shall be adopted for these airspaces[3].

2.2 Difficulty of low-altitude communication guarantee

Firstly, limit of coverage, at present, very high frequency and superhigh frequency are mainly adopted for military-civil-aviation ground-air communication and there are a lot of dead zones of communication in low altitude scope of ground-air communication base station for the influence of earth curvature and ground barrier. Secondly, complex electromagnetic environment, compared with mid-high altitude, there are a lot of military and civilian wireless communication systems in low-altitude area, so that ground-air communication will be influenced easily, which will seriously influence communication ability in addition to serious multipath effect. Thirdly, relatively low data chain ability, at present, general aircraft does not have data chain communication ability and there is very large difference of military and civil aviation on data chain system, which is a difficult problem for integrated system of air defense and air traffic control in low altitude airspace.

3. Problems of new air traffic control technology in low-altitude airspace air defense and air traffic control

With development of navigation, communication and network technology, various new technologies are continuously applied to air defense and air traffic control field and relatively favorable effect has been reached. However, there are still some problems of these new technologies in low-altitude airspace air traffic control and air defense application.

3.1 Application difficulty of automatic dependent surveillance-broadcast (ADS-B) in low-altitude airspace

Compared with traditional radar supervision, ADS-B technology is characterized by low cost and high precision and is thought as development direction of future air traffic control field. However, there are still certain application difficulties and defects of ADS-B in integrated system of low-altitude air traffic control.

Firstly, transitive dependency of supervision and communication information depends on density of low-altitude in-air aircrafts. ADS-B mainly transmits supervision and communication information by air-to-air data chain and completes summary and download of data by space data chain in part of area and supervision and communication covering to large area can be completed by several limited ground stations when in-air aircraft density reaches certain degree. However, general aviation scope of China cannot reach networking density required by ADS-B in short term and integrated system of air-defense and air traffic control cannot obtain ADS-B supervision information when civil aviation
suspends flying comprehensively in war zone under special condition, such as war. Secondly, characteristics of ADS-B technology do not have supervision ability to non-cooperative target and contribution to low-altitude airspace air defense is limited. Thirdly, dependence on satellite navigation technology is serious and it is easily to be influenced by deception jamming and present research shows that there is a kind of deception jamming bug in satellite navigation system, which reach the purpose of deception and interference by making receiver work out false position information by emitting false navigation code sequence. Low-altitude airspace aircraft adopting ADS-B is easier to be influenced by malignity deception jamming than plane in air route; in this sense, low-altitude air defense and air traffic control system that depends too much on ADS-B is a great threat to no matter flight safety or air-defense of the homeland.

3.2 Application difficulty of photoelectric detection technology in low-altitude airspace

Photoelectric detection technology is system to realize detection and identification to target by utilizing optical signal difference reflected or radiated by target and background. Advantages of the system are no active radiation, well concealing performance and high tracking measurement precision. However, when it is applied to integrated system for low-altitude air defense and air traffic control, there is certain limit: firstly, low information update frequency, when low-altitude target is scanned and detected by completely utilizing photoelectric detection system, image is required to be disposed by complex algorithm, which seriously influences detection rate. Secondly, influenced by self characteristics of target and environment background, when target coating is consistent with background or self infrared radiation of target is relatively weak, it is difficult for photoelectric detection system to find out target. Thirdly, constrained by meteorological condition, visible light wave band detection system is greatly influenced by meteorological condition, exploration distance and detection precision under weather of rain, snow, fog and haze, etc. will decrease urgently.

3.3 Application difficulty of floating platform detection technology in low-altitude airspace

Floating platform detection technology rises detection equipment to air by means of captive balloon, so that detection scope of system to low altitude target will be larger, which has improved early-warning ability. However, in practical application, floating platform detection performance is limited by several factors: firstly, it is seriously influenced by weather clutter, which is mainly cloud and rain clutter and to ensure detection scope, floating platform shall be generally risen to 2000~3000m air \[4\], which is higher than general cumulonimbus and it is easy to generate clutter signal that is hard to be distinguished from target echo for movement of clouds and self movement of platform. Secondly, influence of platform noumenon and detection equipment by weather is relatively large; for example, balloon-board radar is easily influenced by wind; in ground air inflation, ground mooring, air berthing and releasing recycle phases, it has different degree requirements to wind speed, that is to say that it will lead to un stability of in-air posture and violent swing of sphere, so that it will influence detection precision and even lead to tearing and crashing of platform when wind speed is larger than certain value. Thirdly, existence ability of battlefield is poor and floating platform is characterized by relatively large general volume, poor concealing performance, insufficient maneuvering ability and weak anti-strike ability, so that it is easy to be destroyed by antipersonnel weapons.

4 Low-altitude airspace management and control network based on cellular mobile communication

Development of cellular mobile communication in China started from 1987 and the first simulated cellular mobile communication system was opened in Guangzhou in November of 1987. Later, mobile communication network has been established in Shenzhen, Zhuhai, Shanghai, Beijing and Shenyang, etc. After development of 27 years, China has established the largest cellular mobile communication network in the world. According to data issued by Main Index Completion Condition of Communication Industry in April 2014 (II), until April 2014, the total number of mobile cellphone
users in China is 1.251867 billion, of which total number of 3G users is 454.195 million. In the end of 2013, total number of cellular mobile communication network base stations exceed 1.4 million and the number of 4G network base stations that increase in this year will exceed 500 thousand. Therefore, in the end of 2014, total number of cellular mobile communication base stations of China in operation will reach more than 1.9 million, of which the number of 4G network base stations reaches 1 million. At present, more than 98% area with people in China has been covered by cellular mobile communication network.

4.1 Low-altitude covering characteristics of cellular mobile communication network
At present, cellular mobile communication network mainly aims at ground users; therefore, mobile communication terminal on ground and in building shall be taken into prior consideration for design and position placing of its communication base station antenna, etc. To utilize electromagnetism resources reasonably and avoid interference of service area, declination setting is usually adopted for communication base station antenna and common declination modes include mechanical declination and electric declination, as shown in Fig. 1.

![Figure 1. Declination Modes of Cellular Mobile Communication Base Station Antenna (a) Mechanical Declination; (b) Electric Declination](image1)

In addition to improving covering of base station to ground by adopting declination setting of antenna, antenna radiation of mobile base station is wide in horizontal direction and narrow in vertical direction and antenna direction figures of typical communication base station is shown as Fig. 2 and Fig. 3.

![Figure 2. Section of Electromagnetic Wave Beam in Horizontal Direction](image2)

![Figure 3. Section of Electromagnetic Wave Beam in Vertical Direction](image3)
It is not hard to see that directional pattern of mobile communication base station antenna in horizontal direction presents peach shape and covers relatively wide area to make antenna cover more areas. However, in vertical direction, main lobe of directional pattern of antenna presents spindle shape and there are several minor lobes with relatively strong power on the top and bottom. In the perspective of directionality, covering of mobile communication base station to air area that is lower than 1000m is insufficient. However, seen from a lot of practical cases, mobile communication signal in low-altitude airspace is still relatively strong. It may be caused by reasons in two aspects; firstly, several minor lobes of electromagnetic wave beam in vertical direction can provide signal with certain strength; secondly, dipping electromagnetic wave beam covers low-altitude airspace after reflection of ground and building. In addition, there is no barrier in air, so it has provided favorable condition for spreading of mobile signal. It is obvious that antenna still can provide certain degree signal covering to low-altitude airspace even if no any supplementary establishment is made to cellular mobile communication network. However, signal covering performance of the whole cellular mobile communication network in low-altitude airspace refers to problems of wireless multipath effect and multi-network fusion, etc. and at present, there is no targeted research and verification report.

4.2 Location ability of cellular mobile communication network

Research on wireless positioning technology starts from automatic vehicle location system in 1960s and later the technology is widely applied in public transportation, taxi dispatching and public security tracking, etc. Wireless location can be divided into wireless location of satellite and wireless location of ground and wireless location based on cellular mobile communication base station belongs to wireless location of ground. This paper only discusses application of cellular mobile communication network to aircrafts location. Location technologies of cellular mobile communication network mainly include:

(1) Location technology based on cell identification code (Cell-ID)

Cell-ID location technology is the first-generation network location technology and has been largely applied to most mobile operators. The technology is the easiest technology with lowest cost in network location technology and location to mobile terminal can be realized in area as long as it is covered by base station. Location precision in the mode is low and when base stations are relatively dense, its location precision is nearly 250m~400m and it can only be provided to application occasion with relatively low location precision when base stations are few and location precision reaches more than 500m.

(2) Location technology of time advance

Time Advance (TA) is a parameter in GSM network and can be used to ensure time slot synchronization of information frame between Mobile Station (MS) and Base Transceiver Station (BTS) and distance between mobile terminal and base station can be obtained according to TA value. TA location technology can be used together with Cell-ID and it can be confirmed that terminal is located in an arc in base station center. TA location precision is not high and is related to dimension of cell.

(3) Location technology to angel of arrival

Angel of Arrival (AOA) is to measure direction of electromagnetic wave by utilizing antenna array and to calculate position of mobile terminal of target by utilizing relative angel of several base stations that is provided by two or more than two antenna arrays.

(4) Location technology for time of arrival

Time of Arrival (TOA) is to measure time of arrival of signal transmitted by mobile terminal by several base stations and spreading distance of signal is calculated by accurate transmission moment included in signal. The technology requires strict time synchronization between terminal and base station and precise location and at least three base stations are required for measurement and calculation. Advantage of location technology of time of arrival is relatively high measurement precision, but difficulty and cost are relatively high if strict time synchronization between terminal and base station is required.
(5) Location technology of time difference of arrival

Location Technology of Time Difference of Arrival (TDOA) calculates time difference that signal transmitted by mobile terminal reaches different mobile base stations by calculating difference value based on TOA and works out position of mobile terminal by mathematical method and advantage of the technology is not to require strict time synchronization between terminal and base station and time difference of two base stations confirms a hyperbola and at least two rubber hyperbolas are required to confirm a point of intersection; therefore, at least three base stations are required for location to confirm position of mobile terminal.

In foresaid 4 kinds of mobile communication base station location technology, location precision of TA location technology is unfavorable; TIA location technology requires strict time synchronization and realization difficulty and cost are relatively high; AOA location technology requires two or more than two precise intelligent antenna arrays in communication terminal. Realization difficulty of TDOA location technology is relatively low and relatively high location precision can be realized. It is not difficult to found out according to its location principle that location precision is the highest when location signal of mobile terminal is received directly by base station rather than by reflection. Position of low-altitude aircraft is relatively high and at the same time it can observe several ground base stations directly; therefore, location precision is relatively high and TDOA location technology is more suitable to location to low-altitude airspace aircraft comprehensively. Low-altitude airspace aircraft transmits TDOA location information externally during air flight and after base station receives location information and ground air traffic control network can work out position information of target aircraft at location information transmission moment by time difference that location information reaches base station and can transmit position information and relevant aviation information to target aircraft by data transmission function of cellular mobile communication network.

4.3 Communication capability of cellular mobile communication network

Our current cellular mobile communication network is in coexistence of 2G, 3G and 4G. Te concept and performance of every mobile network are as follows:

(1) 2G network

At present, our main mobile access way still is 2G network. 2G network normally refers to GSM network (CDMA network for China Telecom), works at 900MHz frequency band and supports the voice communication and short message communication, with its data transmission rate at 9.6kB/s.

(2) 3G network

Refer to the cellular mobile communication network using and supporting high speed data transmission. Apart from supporting the voice communication short message communication, in the data transmission, it can support a transmission speed at least 2Mbps, 384kbps and 144kbps respectively in indoor, outdoor and driving environment. What’s more, it also supports the simultaneous transmission of sound and data information.

(3) 4G network

Integrated with 3G and WLAN, 4G technology can transmit the data, high-quality audio frequency, video and image, and support the downstream and upstream network bandwidth respectively at 100Mbps~150Mbps and 50Mbps.

The comparison of data communication rates of every generation of communication network under different systems is as shown in Table 1.
Table 1. Comparison of 2G, 3G and 4G Data Communication Rates

| Communication standard | 2G | 3G | 4G | 5G |
|------------------------|----|----|----|----|
| Cellular system        |    |    |    |    |
| GSM                    |    |    |    |    |
| CDMA2000 (EVDO RA)     |    |    |    |    |
| TD-SCDMA (HSPA)        |    |    |    |    |
| WCDMA (HSPA)           |    |    |    |    |
| TD-LTE                 |    |    |    |    |
| FDD-LTE               |    |    |    |    |
| CCFD                   |    |    |    |    |
| Downstream rate        | 9.6| 3.1| 2.8| 14.4| 100| 150| 20Gbit/s |
| Upstream rate          | 2.7| 1.8| 384| 5.76| 50 | 40 | 10Gbit/s |

Viewing from the data communication rate, 2G network can achieve the mobile terminal location, but cannot satisfy the need of high-speed aeronautical data transmission; Although 3G has a data chain rate (about 1Mbps) slightly higher than that of ADS-B system, considered about the movement features of aircraft flying at low-altitude airspace, these two basically hold the line; At present, the data rate of 4G network is far higher than all existing aeronautical data chain system; However, the existing 5G communication experiment system shows that, the communication rate of 5G communication network even reaches 10Gbit/s, far higher than any one of existing mobile wireless communication systems, which completely can support the real-time transmission of high-definition video data. Therefore, the cellular mobile communication network completely can meet the data transmission demand of aviation activities at low-altitude airspace.

5. Advantages and disadvantages of air traffic control system based on cellular mobile communication network

According to above data, analysis and description, the advantages and disadvantages of air traffic control system based on cellular mobile communication network are listed as follows:

Advantages:

(1) Matured network: Three commercial networks have been built and cover most territory and all populated areas of our country, which can backup for each other, in a high reliability.

(2) High communication rate: At present, the commercial cellular mobile communication network has entered into 4G era, at a theoretical downstream data communication rate up to 100Mb/s. Following the input to use of new cellular mobile communication network technology, the data rate will further improve.

(3) Support air-air/air-ground communication mode: By utilizing the communication capacity of cellular mobile communication network, it can support the ground-air, air-air voice and digital communication business.

(4) High compatibility: Three data chains of 1090ES, UAT and VDL-4 are mutually incompatible. While, the air traffic control network based on mobile communication base station does not rely on the communication chains among machines, and the airborne terminal of different system can achieve the interconnection through the ground network. Meanwhile, different network data can be uniformly controlled.

(5) Strong extendibility: Support all extensive applications based on cellular mobile communication network and mobile communication terminal.

(6) Easy to be popularized and generalized: Airborne equipment is equivalent to one cell phone, so that the airborne location and communication equipment is relatively cheap, which is easy to be widely popularized and generalized.

(7) Independent of GPS: Both of the aircraft location and communication in the air traffic control system based on cellular mobile communication network are only rely on the ground network system, and the aircraft is at moving state in the air, requiring switching the accessed base station constantly. If a malicious attacker wants to control one aircraft by cheating, he/she must control the whole communication network at first.

Disadvantages:
(1) Unknown air coverage performance: Although the original intention to build the cellular communication network is to meet the ground mobile communication demand, but a large number of aviation flight practices show that, the air lower than 1000m still is covered by the signal. However, at present, there is no specific research and laboratory report on the coverage performance of low-altitude mobile communication signal.

(2) Limited network coverage at no man’s area: In the cellular mobile communication network, the network coverage is often subject to the coverage rate of the population. However, the general flight activities are not limited to the populated area, and the flights at no man’s area also require the control and information service. Researching the cellular mobile communication base station network topology at no man’s area, with low input and high coverage rate, is an important link to achieve complete control coverage of low-altitude airspace within our territory range.

6. Opinion and suggestion to the construction of low-altitude airspace network based on cellular mobile communication network

(1) Renew the existing mobile communication base state and increase the air antenna

The current mobile communication users mainly are from the ground, so the base station antennas all have a downward inclination. Although, some time, the wireless communication signals can be received in the air at a true height about 1000m, these signals mostly come from the reflection of surface feature or the side lobe of antenna, which are at low stability. If the professional air antenna can be set on the cellular mobile communication base station, the signals sent by the antenna will not be reflected by the buildings or other tall objects, and may have no unnecessary multipath effect at the same time, so as to obtain good communication effect. The single mobile base station antennas are less than RMB 200, at a low cost to the upgrading and reconstruction of existing mobile communication system.

(2) Improve the coverage rate of mobile communication base station at no man’s area

Comprehensively consider the demand of mobile communication at no man’s area and low-altitude airspace aviation control, research the cellular mobile communication network topology at no man’s area with reasonable structure, high coverage rate and acceptable preliminary input, coordinate with mobile communication operator to build the mobile communication base station, and achieve the air traffic control network coverage of low-altitude airspace at no man’s area, which are the key to finally achieve the low-altitude airspace control network coverage all over the country on the basis of cellular mobile communication network.

(3) Develop the new generation of air traffic control technology closely based on new generation of mobile communication network

Our country has already become the international standard dominant power of 5G mobile communication technology. In the short-term foreseeable future, it is inevitable that 5G communication will be the backbone network of our mobile communication. The air traffic control information network built relying on 5G mobile communication networks will certainly be far superior to the existing air traffic control information network in the communication rate, networking performance, maximum containing capacity and other aspects. Besides, some key technologies in 5G, like space division multiplex technology, can provide the brand-new mature technical support for the cooperative target location of low-altitude airspace.

7. Conclusions

After 30-year construction, our cellular mobile communication network has relatively completely cover the most part of our territory and population, which has 3 great basic operators, with 2G, 3G and 4G networks in simultaneous operation, mobile communication network rich in resources and 5G technology predominant in the world. If the control and information service can be provided to the general aircrafts by taking full advantage of the location function of cellular mobile communication network, it can efficiently make up the insufficiency of existing air traffic control radar and
communication system, and perfect the control on low-altitude airspace, to provide the important basic network facility support for the low-altitude airspace opening.

The conception of building the aircraft control network in low-altitude airspace based on cellular mobile communication network is of great realistic meaning to the development of both homeland air defense and general aviation. However, for the moment, this conception is at a distance from the realization and remains many specific problems to be researched, verified and solved. For example, the low-altitude airspace coverage effect problem of mobile communication signal, fusion and utilization problem of network signals of different systems, and high-speed accurate location in flight, etc.

Acknowledgment
Supported by the National Natural Science Foundation of China (Grant No. 61601497)

References
[1] Central Military Commission of State Council. Opinion about Deepening Our low-altitude Airspace Management Reform
[2] China Air Transportation Association. China General Aviation Development Report in 2012 [R]. 2013(3): 29–31.
[3] Li Xingchao, Application and Analysis of New Air Traffic Control Technology in Low Altitude Airspace Management [J]. Electronic Test, 2015(12), 126–127
[4] Zhan Lixiao, Tang Ziyue, Zhu Zhenbo and Fu Ying. Modeling and Simulation of Rain Clutter for Tethered Aerostat Borne Radar [J]. Radar Science and Technology, 8(1), 2010, 15–19.
[5] http://news.sina.cn/?sa=t124d6753233v71&from=mbaidu&stun=20007&vt=4
[6] Gu Jing and Li Mingyuan. Technology of Cellular Phone Position [J]. Modern Electronics Technique, 168, 2004, 68–70
[7] Li Jing. Research and Implementation of Marine Rescue System Based on Mobile Location [G]. Dalian. Dalian Maritime University. 2011