Aircraft tracking using mobile devices

Michał Andrzejewski
Electronics and Information Technology Department
Warsaw University of Technology
M.Andrzejewski@stud.elka.pw.edu.pl

Radosław Schoeneich
Electronics and Information Technology Department
Warsaw University of Technology
R.Schoeneich@tele.pw.edu.pl

Abstract — The following article presents an overview of airship tracking system using mobile devices equipped with GPS receiver, running under Android operating system. It describes general approach, usage of store, carry and forward paradigm in delay and disruption tolerant networking and elements of architecture and implementation of presented applications. Shown results represent tests run in real environment.

Keywords - tracking, monitoring, general aviation, aircraft, disruption tolerant network, DTN.

I. INTRODUCTION

The dynamic development of mobile devices and navigation systems in recent years has introduced many new everyday services. Among the most commonly used are location and remote monitoring. Their potential was quickly spotted by industries related to the transport and logistics, where knowledge about the current position and status of objects such as vehicles and packages is often a key factor in the success of the operation.

The main task of the monitoring system is to provide reliable information about the position of the tracked objects. This information can be interpreted and used in different ways, depending on current needs. In general, however, it serves two basic purposes: to increase safety and to improve efficiency. Location data are widely used in planning and decision support systems, fleet management and emergency assistance.

Unfortunately, despite the continuous development of systems of various complexity, there is still no good solution that could be used to monitor general aviation aircraft. For commercial and military aviation, there are several extensive technical capabilities, such as primary or secondary surveillance radars or satellite systems capable to track objects in real time with very high accuracy. However, the cost of such solutions disqualifies them from usage in general aviation flying clubs, flight schools and by private users.

Key idea of this article is to consider popular mobile devices (such as smartphones, tablets, Personal Digital Assistants) as a reliable source of location data and their usage in real application.

II. ENVIRONMENT

General aviation aircraft are moving in the sky at various altitudes and with different speeds, depending on the type of an airship, airspace category or purpose of the flight. However, assumption can be made that the vast majority of flights take place at an altitude up to 1000m above the ground level at speeds not exceeding 250 km/h. Flight paths at such altitude can be set freely, but near the airports some constraints exist and an obligation to accurately proceed between specified points.

General aviation flights may run across areas with different levels of urbanization, and at potentially large scale of height above ground level. This means that the use of GSM mobile network to monitor the aircraft may be inefficient or even impossible. This is due the fact of cellular antennas settings. Additionally, the level of noise and interference caused by signals from nearby stations raises with the altitude. In practice, however, very often even at the height of up to 1500 meters mobile network is available, and quality of connection allows data transmission. Making a voice call is however not possible at this altitude. This makes an opportunity of creating simple tracking system based on GSM-capable devices and data transmission provided by mobile telephony operators. Results obtained in this field are presented later in this article.

The environment in which flights are made, is a challenge for active position monitoring systems. Continuity and quality of data transmission becomes a major issue. Direct use of GSM network as a way to transmit information related to the location may not give expected results in terms of reliability and availability. This is an area where algorithms developed for use in incoherent networks may be applied. Their essence is to enable operation in the harsh environment of unknown characteristics.

III. SUBJECT OF RESEARCH

The main task and also the source of the biggest problems of active monitoring systems is to develop a suitable method for data transmission. A suitable method, consisting of software and technology, should provide high availability and reliability. In the ideal case, monitored object should always have the possibility of an effective data transmission.

The research, which became the basis for this article was focused on:

• exploring the possibilities of using mobile devices and GSM networks to keep track of general aviation aircraft,
• testing and evaluating prototype of aircraft tracking system in a real environment,
• identification of advantages and disadvantages of the proposed solution,
• proposing possible directions of development and improvement of the system.

During the development of an aircraft monitoring system, the natural choice was to provide transmission using wireless communications. The concept of the satellite communication solutions was rejected because of their high cost. Emphasis has been placed on technologies directly offered by mobile devices with data transmission over GSM network in particular. Fig. 1 presents the basic scenario, where proposed system in addition to direct communication between the aircraft and data collection server, uses also the paradigm of data storage and forwarding. This approach, commonly referred to as a store-carry-forward paradigm, is specific to delay and disruption tolerant networks. The aircraft marked as SP1 is out of GSM coverage, so it can not send data on the position in a direct way. Using a wireless network, it communicates and exchanges all necessary information with the aircraft marked as SP2. The aircraft SP2 can then forward information regarding both objects to the server collecting data. The system has information about the positions of both vessels despite the fact that SP1 is not in a GSM range to establish a direct connection.

![Wireless data transmission scenario](image1)

Wireless communication channel between objects must meet the following conditions for its use in the proposed system to be possible:

• time required to establish two-way communication channel and its effective range should allow data exchange between aircraft flying in opposite directions at speeds of around 150 km/h,
• each pair of nodes using appropriate software should be able to connect automatically in the same way,
• establishing the connection shouldn't require any additional operations from the user.

Lack of any of these features reduces the area of application of wireless communication between the aircraft and makes it difficult to achieve given functionality.

A. Architecture of aircraft tracking system

The system this research has been based on is divided into two parts, performing distinct functions and embedded in different environments, as shown in the Fig. 2. It separates two basic areas of functionality - one related to the collection and transmission of data carried by the mobile application, and the other responsible for their analysis and visualization using an application server. It was a natural approach, given the purpose and the use of both items supplied in two applications.

![Aircraft tracking system architecture](image2)

Mobile devices transmit files to an FTP server using the best currently available mean of communication. This can be a 2G/3G mobile network, Wi-Fi or another, depending on the particular device. If establishment of a direct connection to a remote server hosting the data is impossible due to lack of network coverage, high levels of noise, latency, or other actual problems, the application uses the store-carry-forward paradigm and gathers data locally. At a time when it is again possible to transfer data to another node, the device acts as discussed before.

An attempt to transfer data to the server is controlled by an event timer - the expiration of the specified period of time since the last attempt to send or other parameters associated with the flight.

Before a file is put on the FTP server, its validity is checked, and the transmission is performed only when attempting to send a file containing more data than the former. This allows nodes that are willing to send data less accurate than those already stored on the server not to overwrite and lose them.

In order to simplify whole process and increase the reliability of data exchange between system elements, it was decided to use one common data model. This allows the system...
architecture as a whole to remain open, since all it requires is that the source data have a specific format.

Usage of database management systems was rejected and flat text files in a specified comma separated values format were used instead. This reduces the requirements for the server, simplifies the implementation and development of the solution and allows further analysis using common tools. Text files can still be imported and stored in a database when necessary.

B. Technical limitations

Available methods for wireless connectivity between mobile devices are limited to two common standards: IEEE 802.15.1 (Bluetooth) and Wi-Fi.

The first one has too short range in order to be used for communication between aircraft in flight. For this purpose it is necessary to establish an effective connection between the devices in a distance of at least 300 meters, while Bluetooth allows efficient transmission at a distance several times smaller. In addition, the process of finding neighboring nodes using this method can take tens of seconds. The use of Bluetooth in incoherent networks is possible, but requires distances between nodes to be small, as well as their relative speeds [1].

Use of Wi-Fi networking was a natural choice. Despite the low power of transmitters mounted in mobile devices, it was possible to connect two nodes within a distance of about 200 meters apart in the open area. One of the devices, the Samsung Galaxy tablet, worked as an access point, while the second - LG-GT540 mobile phone - as a client. This combination allowed a stable exchange of data at speeds of about 100 kbps. Unfortunately, the long time needed to set up an access point and then to connect the other device (in this particular case - a total of more than 45 seconds) and the need for manual adjustment of connection parameters prevented this method from the application in the system.

In the course of the work it was discovered that the mobile device platform capabilities are insufficient to meet all the required functionality. The main limitation was the lack of ability to automatically establish a wireless connection in ad-hoc mode between devices without user intervention. This feature is essential for establishing a connection in an incoherent network and the exchange of data between nodes. Application Programming Interface of Android operating system used in experiments does not support such mechanism, nor is it possible to emulate. There is also no documentation on this issue available.

Further studies show that the mechanism for supporting automatic wireless connections between mobile devices is not available on any other of the popular platforms.

Therefore, it was impossible to verify and evaluate inconsistent network performance in practice. The actual implementation required from the operating system and the mobile device functionality, which it was not able to provide. Perhaps in the future, with the development in this field of technology, this will become possible. After examining the possibility to connect the devices during the flight (discussed further in the next section) it was decided to abandon the functionality associated with the use of incoherent network in the proposed system.

IV. TESTS AND RESULTS

An important element of the work was to conduct several series of tests, not only to check the correctness of the implemented system, but also its usefulness in proposed applications. Results were used to verify presented concepts and theoretical considerations in actual, real environment.

Tests in the target environment were divided into three stages. In the first, a prototype of mobile application was used. It was able to collect environmental data, such as the GSM signal strength, network mode, the height and position of the airship, etc. In addition, the aircraft was equipped with a second instrument - Garreht Volkslogger - which is a logger device certified by the International Air Sports Federation used to record position in gliding competitions. At this stage, the ability to perform data transmission using the GSM network at different heights was verified. Another income was the examination of GPS receiver accuracy by reference to the indications presented by the certified device. This part of the test was conducted in May and June 2011.

The second step was to test the basic, working implementation of aircraft monitoring system between July and October 2011. The system was used to monitor the position of student pilots and pilots during training in the area of Warsaw-Babice airfield.

The last stage completed in November 2011 was to test the operation of the system in the mountainous region. Differences in system's behavior were identified and investigated basing on analysis of data collected during the flights in the vicinity of Bezmiechowa. Some additional opportunities for air-to-ground communications were diagnosed.

A. Collecting data about environment

Fig. 3 shows the altitude above mean sea level and GSM signal strength during one of the flights. The value of the signal strength equal to -113 dBm is identified as the inability to connect to the network. Data were sampled with a period of 30 seconds.

![Figure 3. Altitude and GSM signal strength correlation](image)

Obtained results differed significantly from what was expected. It was anticipated that the range of the GSM network will be unavailable for much of the flight because of the altitude and its characteristics. Data collected during the first
test flights, however, revealed that GSM network was available up to a height of about 1400 meters above terrain at urban areas throughout the duration of the flight. This is the result of reflection and reinforcement of radio waves from the ground, buildings, etc.

Position samples collected by the mobile device does not differ significantly from those provided by a professional logger. The maximum absolute error was 8 meters for static measurement and 25 meters for the measurement of motion on average. Errors associated with determining the height were greater, however they did not exceed 75 meters.

During one of the flights, an attempt to establish a wireless connection using Wi-Fi network between two parallel flying aircraft was made. They were flying at an altitude of 500 meters at speeds of 120km/h. The distance between objects was 150 meters. On board one of the aircrafts was a device which acted as an access point, while the second tried to connect to that network. An access point was seen by the other device, but the connection could not be established. Performed test showed that in given conditions it is not possible to create and use Wi-Fi networking.

Results confirmed however, that the use of mobile devices for determining the position is sufficiently accurate for use in most of the monitoring applications. The quality of connections over the GSM network was sufficient for efficient transmission of data text files within a given height of 0 - 1000 meters.

B. Tests in lowland area

Most of the testing was made in the lowlands, because it is an environment in which the highest number of general aviation flights are performed. The mobile device was installed on board several aircrafts operating various types of flights in the northern area of Mazovia region. Position of the aircraft was observed in visualisation system and verified with reports collected via VHF radio. Between July and November 2011, 28 such flights were made. Below analysis in Tab. I shows 12 flights selected of them.

<table>
<thead>
<tr>
<th>Flight #</th>
<th>Flight duration [s]</th>
<th>Time in seconds [s]</th>
<th>ATBT&quot;</th>
<th>MTBT&quot;</th>
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<tr>
<td>11</td>
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<td>180</td>
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The most important parameter of such system is the location data refresh rate, understood as time between air-to-ground communication. Information about the successful upload to the server are recorded in the logs, so it is possible to calculate the time between successive transmissions. During the test, the interval of 180 seconds was set up to make updates of the data as frequent as possible, but not to excessively exhaust the battery. Tab. I shows a summary of flight time, the value of the maximum interval between transmissions of data and the average. Both of these times directly translate to the refresh rate of position data, therefore it is desired to minimize both of them.

Each of the flights presented in a table has taken place in different weather conditions, using a different route and at different heights. For this reason it is impossible to directly compare obtained results. Obtained average values for each flight lead to the conclusion that despite initial concerns related to the use of GSM network for data transmission, the frequency of updating information about the position of the aircraft is sufficient for the intended application.

C. Tests in mountainous area

The usefulness of the system to monitor flights taking place in a mountainous environment, due to potential differences in performance, was also tested. The research was focused on the influence of the location of GSM network base stations on the system effectiveness, compared to the results collected before. In the mountainous terrain antennas are placed on the tops of hills to embrace the largest area lying below. It was expected that due to the smaller than in the lowlands height difference between GSM transmitter and the aircraft, the average interval between transmissions would be smaller. Because of the weather conditions, only 3 flights were made, as shown below.

<table>
<thead>
<tr>
<th>Flight #</th>
<th>Flight duration [s]</th>
<th>Time in seconds [s]</th>
<th>ATBT&quot;</th>
<th>MTBT&quot;</th>
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<td>3</td>
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</table>

During the first flight, it turned out that in close proximity to one of the mountain ranges it is possible to connect to public Wi-Fi network. Its access point was located near one of the hotels and its range included a substantial portion of the ridge. The results of the flights are shown in Tab. II taking both transmission methods into account.
The achieved results confirmed that the air-to-ground communication using the Wi-Fi standard during the flight is possible, though available only in specific conditions. Shortening the average interval between transmissions is the result of virtually uninterrupted stay of the aircraft in a GSM network and usage of available Wi-Fi for data transmission.

V. CONCLUSIONS

The results of the analyzed system, based on data collected during test flights, were better than expected. It was possible to obtain better average refresh interval of location data than initially planned. Value of 300 seconds was thought as satisfactory, while the average value for 12 flights in a lowland area was 209 seconds. Increasing the frequency of data transmissions could further improve this value, however, this would be associated with an increased resource consumption.

Area of testing had a significant impact on the results. Analyzed flights were made up of several dozen kilometers from Warsaw agglomeration and mostly ran above the urban areas. Execution of test flights over areas characterized by poor coverage of GSM network is likely to lead to a deterioration of results.

Analysis of the system in mountainous terrain allowed the discovery of additional options - usage of Wi-Fi networks for data transmission. Thanks to this observation, capabilities of mobile applications were increased and results could be improved.

The biggest obstacle in the development of the system is lack of possibility to create automatic connections between devices on an ad-hoc basis. This prevents direct application of the store-carry-forward paradigm, which could improve performance.