Space-Time-Scheduling in a Surveillance Network

Prof. Dr. Erwin Mayer
Fakultät Elektrotechnik und Informationstechnik (E+I)

Badstraße 24
77652 Offenburg
Tel.: 0781 205-256
E-Mail: erwin.mayer@fh-offenburg.de

1960: Geboren in Haslach i.K.
Studium der Informatik an der Universität Karlsruhe und University of Texas (UT), Austin
1987: Diplom
1987–1990: Softwareentwicklung bei der Nixdorf Computer AG, Berlin, im Bereich Verteilte Relationale Datenbanken
1990–1993: Promotion am IBM European Networking Center, Heidelberg, Themenbereiche Multicast-Synchronisationsprotokolle, Computer-Supported Cooperative Work (CSCW)
1994–2006: Projektleiter und Abteilungsleiter bei der COMSOFT GmbH, Karlsruhe. Entwicklung von System- und Anwendungssoftware für die internationale Flugsicherung
Seit 2006: Professor an der Hochschule Offenburg für die Fachgebiete Betriebssysteme und Telematik

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1.6 Space-Time-Scheduling in a Surveillance Network

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Introduction

Under a grant of the German ProInno program („Erhöhung der Innovationskompetenz mittelständischer Unternehmen") the Hochschule Offenburg participated during the past 2 years in an industry project prototyping a new type of service for modern Air Traffic Control (ATC) applications.

Objective of the project has been the joint development of hardware and software components for a so-called TIS-B (Traffic Information System - Broadcast) support infrastructure to enable new cockpit applications increasing the air situation awareness for pilots of commercial airliners [1]. At the core of the project is a space-time-scheduler, controlling a battery of TIS-B groundstations over a Wide Area Surveillance Network [4].

The project has been successfully concluded and is currently in its evaluation phase. Industry partner was the Karlsruhe-located company COMSOFT, international market leader in ATC sensor networks.

Application scenario

Modern aircraft will be growingly equipped with so-called ADS (Automatic Dependent Surveillance) equipment [2]. ADS derives the aircraft's position from a GNSS (Global Navigation Satellite System) and broadcasts positional and other cockpit information over the 1090 MHz channel air-to-air and air-to-ground. The plane-to-plane transmission enables new applications like CDTI (Cockpit Displays of Traffic Information) [3], which provide to pilots of ADS Aircraft a graphical view of the current traffic in the airspace around the plane (see figure 1.6-1).

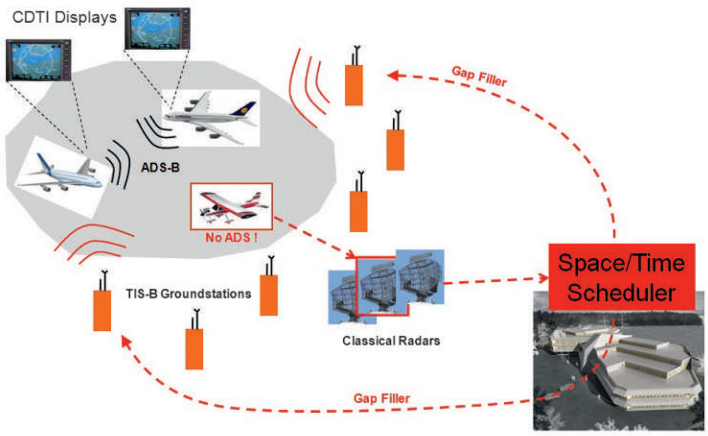

Abb. 1.6-1: *Gap Filler Application Scenario*

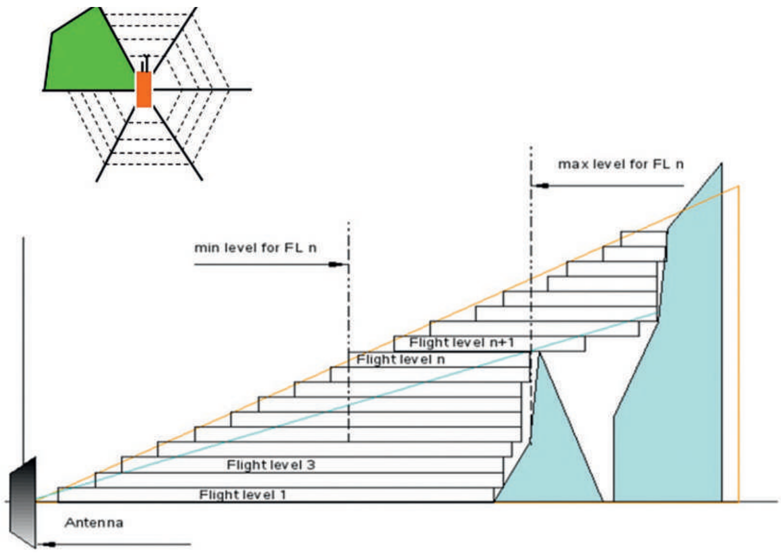

Abb. 1.6-2: *TIS-B Groundstation Model (XML representation)*

However, as a major drawback, not all aircraft are equipped with ADS, hence there may be planes invisible on a pilot's CDTI. The proposed solution to this is to complement the CDTI-contents with information from the ground. Classical PSR/SSR (Primary/Secondary Surveillance Radar) sensors determine the position of non-ADS-aircraft and this position is fed back ground-to-air tothe ADS-aircraft by a coordinated battery of TIS-B groundstations, implementing a so-called „gap filler" application (figure 1.6-1). Ground-to-air reports have to fulfill the same specification as normal ADS-B reports, as specified in [5].

Problem description

Aircraft do not stand still but rapidly change their position over time. Therefore also the proximity relation between aircraft is highly time-variant. For a given airplane A, the function prox (t, A) shall represent the set of airplanes that are at a given time in the proximity of A, namely within a pre-configured airspace cylinder with the aircraft in the cyclinder's center.

The TIS-B groundstations GS1, GS2, GSn, which are geographically distributed over a country or region, are modeled by their position, expressed in WGS (World Geodetic System) coordinates, their maximum transmission range and a location-specific line-of-sight, specified as a stacked set of visibility sectors (see figure 1.6-2; 6 sectors, 60 deg).

It is the task of the TIS-B server to create a sequence of Send Requests.

The task of the scheduler is to select the right ground station for the right airplane at the right time. Note that a single SR may be optimized to serve more than one ADS-B aircraft, if the ADS-B aircraft are in the same direction from an antenna. Also note, that, because the SRs are sent over a real network to the groundstations, the scheduler needs to reserve enough time such that each SR reaches its respective transmitter before its scheduled send time.

There exist further constraints to the specification of send requests and optimization criteria, which are described in [8].

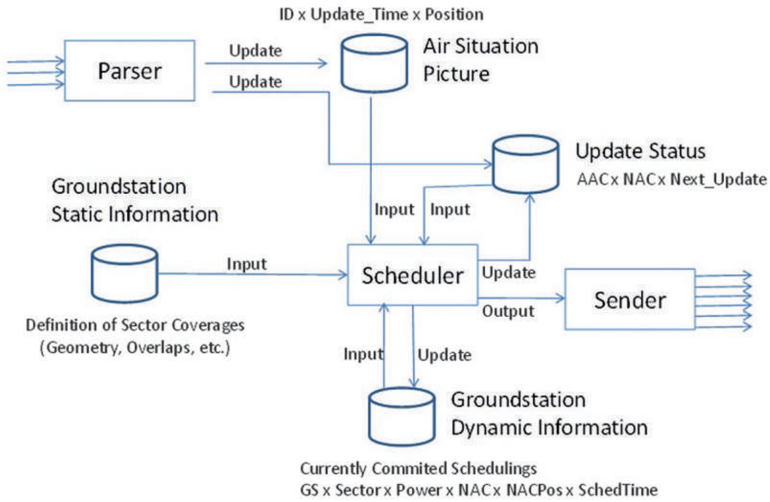

Abb. 1.6-3: *Top-Level Architectural Overview of TIS-B Server*

The Space-Time Scheduler

Two design alternatives for the scheduler were evaluated: An input-driven approach, triggered by sensor position updates, and a master timer approach, performing state transitions in cyclic intervals. An analysis of the expected load, the realtime requirements and the scaling of the system with respect to the number of flights and groundstations showed that the second variant (master timer) is preferable.

The scheduler draws back on various static information (in particular with respect to the positioning, type and reach of the groundstations) and maintains three major dynamic data structures: a representation of the current air situation, the proximity relation between ADS and non-ADS aircraft and a per groundstation list of already committed but not yet executed schedulings (note that Send Requests may still be on the way over the network to the groundstations while further schedulings have to take place). Figure 1.6-3 gives an overview.

With each tick of the master timer, the proximity relation is updated and over an adapted Earliest Deadline First (EDF) strategy ([6]) the required new schedulings are derived. Several integrated optimization steps ensure that the number and reach of Send Requests are minimized. Finally, because of scheduling and network delays, the position of the aircraft needs to be correctly extrapolated in 3D space, starting from a measured position reported by ground sensors, before messages are dispatched.

Using both real (live) and a set of created artificial test scenarios the scheduler was configured, evaluated and tuned. A focus of the tuning was in particular to ensure a good scaling of the scheduler for a large number of aircraft and groundstations, as this will likely be the case for future air traffic.

ATC Workbench

The TIS-B server implementation is finished, has during the past year undergone extensive testing and evaluation. In order to support this process a test and evaluation environment has been created, that represents a starter framework for further work in this domain. Table 1 describes this ATC Workbench.

While the workbench has been primarily used during system evaluation, today, many of the tools are also used separately, e.g. the Recording/Replay tool and the 2D/3D visualization engine for traffic analysis (see figure 1.6-4). The developed RF load analyzer represents an independent support tool for groundstation placement. Namely, for an ATSP (air traffic service provider) that considers the use of TIS-B technology, the tool helps to identify a best-possible geographical positioning of the groundstations taking into account the countries geography (e.g. elevations) and air traffic patterns. Using as input a real stream of aircraft position reports, it computes for each tentative placement of the groundstations, the resulting coverage and distribution of radio frequency load, allowing to minimize the load in critical regions.

Recording/Replay Toolkit	System for recording arbitrary sensor data streams and replaying them at a later point in time with the same relative timing behavior between the plots. ASTERIX[1] data is automatically updated to match replay time. Encoding/decoding is defined over a flexible XML schema-bas ed approach. [1]ASTERIX=All-Purpose Structured Eurocontrol Surveillance Information Exchange
2D-Surveillance Display	Tool displaying in an overlay mode the aircraft plots, as well as the TIS-B server-generated Send Requests. The tool employs the Google Maps API, alternatively OpenStreetMap.
3D-Surveillance Display	Google Earth-based visualization engine for (live) aircraft visualization. Various camera modes and dig-down possibilities for analyses of the underlying data are available.
Air Situation Scenario Generator	Test tool capable of generating ASTERIX-compliant sensor data streams with user-specified characteristics; includes a 3D trajectory editor and an automatic load profile generator.
RF Load Analyzer	Generates for a given (artificial or real) scenario, together with a given set of groundstations and a set of parameters for the space/time scheduler, the resulting RF (Radio Frequency)-load per airspace cell.

Table 1: *ATC workbench delivered by the TIS-B server project*

Outlook

While the final evaluation and exploitation of the TIS-B server is still ongoing, there already exist a number of perspectives for continuation of the work. An ongoing research topic at the HSO, currently complemented by a Bachelor thesis, is the use of Peer-to-Peer (P2P) networking concepts [7] for the distribution of surveillance data. P2P streaming as used, e.g., for multimedia dissemination, has properties that lend themselves also for dynamic N:M geo-data exchange as used for ATC surveillance in a secured network. The ATC workbench developed as part of the TIS-B server project can be readily used for the ongoing work in this domain.

Finally, as intended from the beginning, the TIS-B server project has established a system environment in the Lab that today represents a ready-to-use study field for students of the Applied Computer Science (Angewandte Informatik) program at the HSO. Several Bachelor theses and projects in this interesting application domain are ongoing and motivate students to work with and learn newest technologies.

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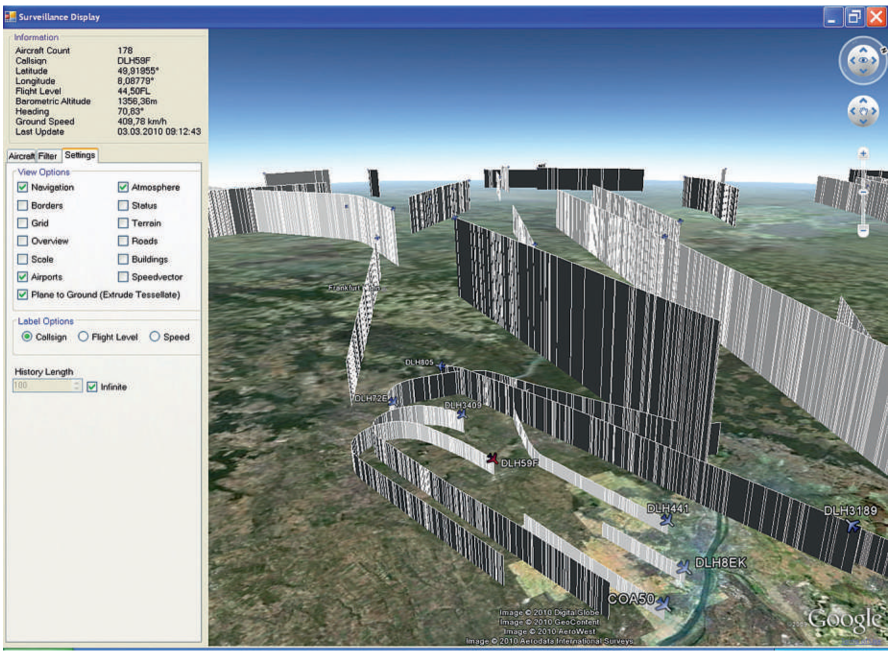

Abb. 1.6-4: *Google-Earth-based 3D Analysis Tool*