FACTS2: Framework for Aeronautical Communications and Traffic Simulations 2

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ABSTRACT

Civil air traffic is currently growing by about 2.7% per year and, thus, is expected to double in the next 26 years. To cope with this growth the current communication, navigation and surveillance infrastructure for civil aviation is undergoing the transformation from analogue to digital systems. To fulfill the requirements of digital ATM communication we need large-scale simulations to simulate future aeronautical communication systems scaled to the increased amount of participants. This paper presents FACTS2 – the Framework for Aeronautical Communications and Traffic Simulations 2 – enabling the German Aerospace Center (DLR) to use simple software building blocks called "simulation services" to create complex simulations for this purpose. Via FACTS2 we can simulate and evaluate arbitrary air-to-ground or air-to-air wireless point-to-point or broadcast data links between arbitrary entities such as ground-stations, aircraft, or drones in a mobile environment.

CCS CONCEPTS

• **Computing methodologies → Modeling and simulation**; Modeling and simulation; • **Software and its engineering →** *Software creation and management*.

KEYWORDS

Framework for Aeronautical Communications and Traffic Simulations 2 (FACTS2), large scale systems, Air Traffic Management (ATM), aeronautical traffic data simulations

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1 INTRODUCTION

At the heart of the modern air transportation system lies the air-ground communication infrastructure enabling air traffic controllers to ascertain efficient aircraft guidance and safe aircraft separation in all phases of flight [3]. As it is suffering from increasing saturation in high density areas, air navigation service providers strive for the sustainable modernization of the aeronautical communication infrastructure. Air traffic management (ATM) communication shall transition from analog voice communication to more efficient digital data communication supported by automated decisions of computer systems. This digitization of the air-ground communications infrastructure has to be evaluated carefully to ascertain its safety, security, sustainability and efficiency. Since avionics development and flight trials are expensive, aeronautical communication systems are evaluated in large-scale computer simulations first.

Various tools have been used to evaluate improved aeronautical communications systems. Khanna et al. [7] created the FASTE-CNS traffic analysis and capacity planning tool for communications. The L-band Digital Aeronautical Communication System (LDACS) was evaluated by Ayaz et al. [1] using OMNeT++ as described by Hoffmann et al. [5] in the first version of FACTS. It is a common feature of these simulators that they are, barring basic model-view-controller separation, monolithic tools. Monolithic tools are inherently complex and difficult to maintain. In addition, monolithic simulators make it hard to generate and store intermediate results for later re-use and analysis.

In order to support agile development of new aeronautical communications systems the German Aerospace Center (DLR) strived to overcome the limitations of monolithic simulation tools and created the *Framework for Aeronautical Communications and Traffic Simulations 2 (FACTS2)*. FACTS2 is a simulation framework based on modern, service-oriented software architecture: Simulation services organized in a parallelized toolchain of loosely coupled software services split by the separation of concerns.

This paper describes the software architecture and underlying design principles of FACTS2 in Section 2. The envisioned content of the demonstration is briefly described in Section 3 before concluding the paper in Section 4.

2 ARCHITECTURE AND DESIGN

The architecture of FACTS2 is based on the application of the UNIX design philosophy of separation of concerns and the combination of simple services to solve complex tasks. Particular simulations are implemented as toolchains of simulation services implementing partial simulations of the overall problem. In this paper we follow

Hürsch and Lopes in the definition of separation of concerns [6]: *"Separation of concerns separates the basic algorithm from special purpose concerns, allowing the locality of different kinds of information in the programs, making them easier to write, understand, reuse, and modify."*

We apply this approach by implementation and combination of simple software building blocks called "simulation services". Each service implements one partial simulation in the overall simulation toolchain such as:

- Simulation of infrastructure consisting of static entities such as ground-stations, airports, runways, sectors and movable entities such as aircraft or drones.
- Simulation and generation of aeronautical data traffic (e.g., COCR, CBR, FCI data traffic).
- Simulation of flight patterns or parsing of real-world flight patterns.
- Simulation of arbitrary aeronautical data links and protocols via those links (e.g. ALOHA or GBAS via LDACS).
- Simulation of cell planning depending on the used data links and simulated ground infrastructure (e.g., cell range depending on environment).
- Report functionality on data link properties, cell planning, flight movements, security and more.
- View plane to depict all flight movements, infrastructure, cells and handled data packets.

The simulation toolchain is formed by calling individual simulation services from the command line and linking them via the UNIX pipe interface. Alternatively services can be invoked using the Portable Batch System (PBS) [4].

The benefit of our approach is that specialized partial simulation services are easier to create and maintain, and can be reused in different simulation toolchains. Since each service has to deal with one particular aspect of the simulation only, the workload can be distributed at service level making the overall solution less constrained by computational limitations improving scalability.

The information flow between services is realized through XML. Our interface format encodes changes of the simulation state, formally the derivative of the simulation state. If $S(t)$ denotes the simulation state at time t, FACTS2 services encode its derivative E as XML(E) with $E = \left\{ \frac{d}{dt}S(t) \neq 0 \right\}$.

Simulation state can thus be inferred by each simulation service by decoding XML(E) and integrating over the non-zero simulation events E under the assumption $\frac{d}{dt}S(t) = 0$ if no simulation event has been encoded. Interpreting event-driven simulations as derivatives of time-stepped simulations allows us to combine time-stepped simulations (e.g., mobility models integrating motion equations) and event driven simulations (e.g., data link simulations) within the same toolchain.

Our approach lends itself naturally to a network-transparent extension that we call "service-oriented simulation". The approach presented here includes technology-neutral and loosely coupled services, which are not location transparent. For a fully service-oriented variant of our simulation approach it is referred to [2].

3 DEMONSTRATION OF FACTS2

The FACTS2 services called in Listing 3 simulate the L-band Digital Aeronautical Communication System (LDACS) [8] in an evaluation scenario of one hour (13:00 to 14:00) of air traffic and data traffic over Germany. The air traffic is extrapolated to the year 2030 according to EUROCONTROL growth scenario C ("ScC"; random seed 1234). The simulated flight trajectories are merged into one stream, augmented with data traffic, and cropped geographically. After the data link simulation ("ldacs"), a graphical view ("viewgl") is generated and further output to standard out is suppressed ("–nooutput"). Black squarres in Figure 3 denote the position of simulated aircraft and in Figure 1 we can see the report on the LDACS data link. Note that this command can easily be submitted to PBS if scripted appropriately.

The first part of the demonstration will walk the participants through Listing 3. We will build the simulation toolchain step-by-step on a laptop. In each step we will inspect the simulation input/output and discuss the simulation events added by each service and the interface format akin to Listing 2. In the second part of our demonstration we will build a simulation toolchain interactively with the audience. Here, FACTS2's output can always be connected to a graphical view as illustrated in Figures 3 and 4. We will start with the simulation of a single data-link enabled flight similar to Listing 1 and Figure 2. Then we will place a ground-station into the simulation and evaluate the comparative performance of two example aeronautical communication systems. Finally, we will give an outlook how FACTS2 simulations can be scripted to benefit from parallelization. If questions to coding details occur during presentation, we are delighted to explain them.

4 CONCLUSION

FACTS2 – the *Framework for Aeronautical Communications and Traffic Simulations 2* – is the next generation simulation tool used by the German Aerospace Center to support the agile development of new aeronautical communication systems.

In our demonstration attendees will be able to see how FACTS2 enables us to evaluate wireless aeronautical data links in a heterogeneous simulation environment that takes contributions from various domain-specific simulations into account.

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A FIGURES, PHOTOS, AND SCREENSHOTS

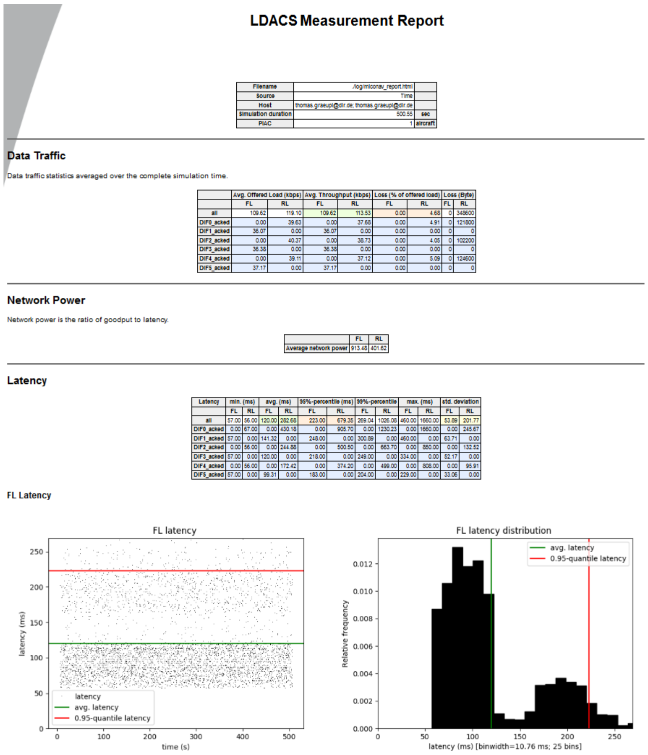

Figure 1: FACTS2 report function, listing properties of LDACS air-ground data link.

Figure 2: FACTS2 simulated flight running listing 1 from EDMO airport near Munich to Prague. KML report viewed with Google Earth.

```
$ ./flight EDMO LKPR |
  ./kml --outfile Flight_EDMO_LKPR.kml
```

Listing 1: FACTS 2 simulated flight from EDMO to LKPR airport.

```
<!-- create an airport -->
<create_airport icao_code="CYYZ" id="25247"
    name="Lester B Pearson International"
    pos_alt="165.50640" pos_lat="43.67610"
    pos_lon="-79.62767" />

<!-- create a flight -->
<create_flight time="0.000" id="9947"
    flt_number="WN535" pos_lat="39.26728"
    pos_lon="-99.90824" pos_alt
    ="11887.20020" pos_heading="88.096"
    apt_dept_id="26440" apt_dept_name="
    Denver Intl" apt_dest_id="26365"
    apt_dest_name="Nashville Intl" ac_type="
    B737" />

<!-- update flight to simulate movement -->
<set_flight time="60.000" id="9947" pos_lat
    ="39.27125" pos_lon="-99.74830"
    pos_heading="88.219" />
...
<set_flight time="4260.000" id="9947"
    pos_lat="38.29044" pos_lon="-88.78475"
    pos_heading="113.859" />

<!-- delete flight after arrival -->
<delete_flight time="6300.000" id="9947" />
```

Listing 2: XML output of simulation of infrastructure creation and flight movement.

```
$ ./airtraffic ./ 13 14 2030 ScC 1234 |
  ./merge |
  ./datatraffic |
  ./country --country de
            --shapefile ./shapefiles/de.shp |
  ./ldacs |
  ./viewgl --nooutput
```

Listing 3: LDACS data link simulation for Germany.

```
$ zcat wwatm_24h_3s_updates.xml.gz |
  ./viewgl --nooutput
```

Listing 4: Worldwide air traffic movement for 24 hours with 27,302 IFR flights with a peak instantaneous aircraft count of 3,579 aircraft viewed from a stored simulation result.

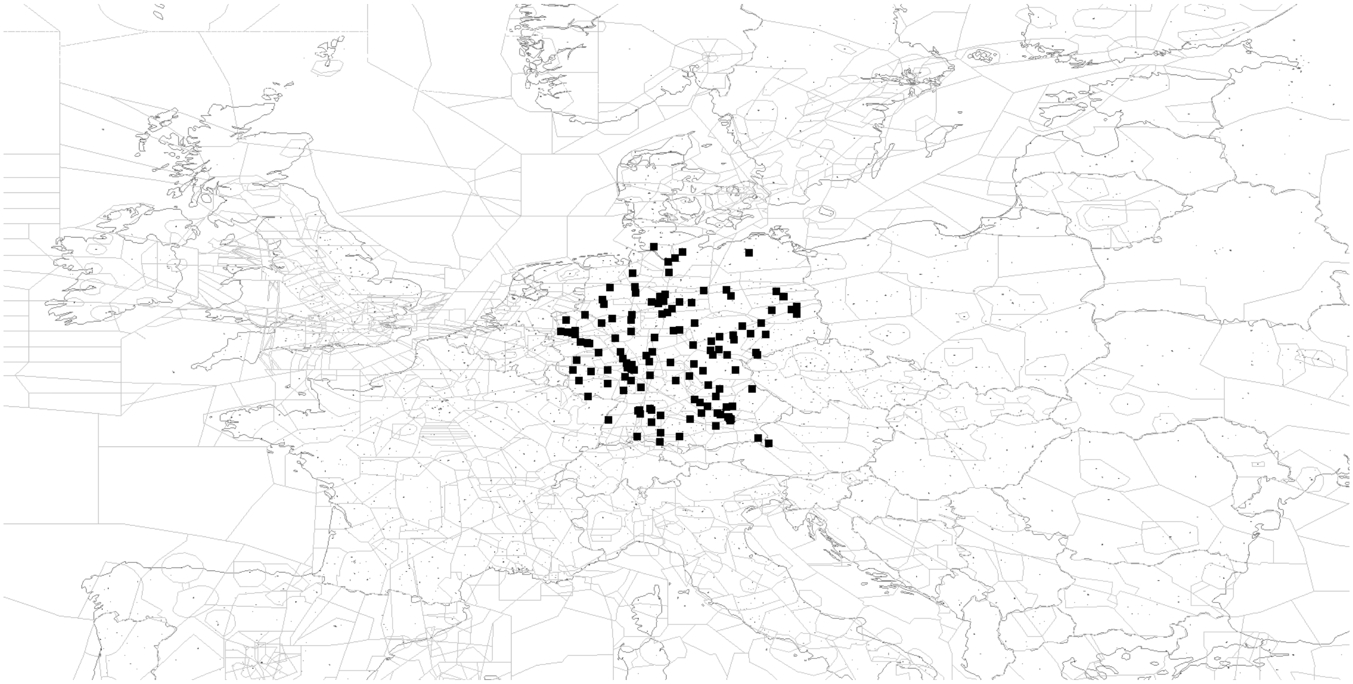

Figure 3: FACTS2 running Listing 3 in light mode.

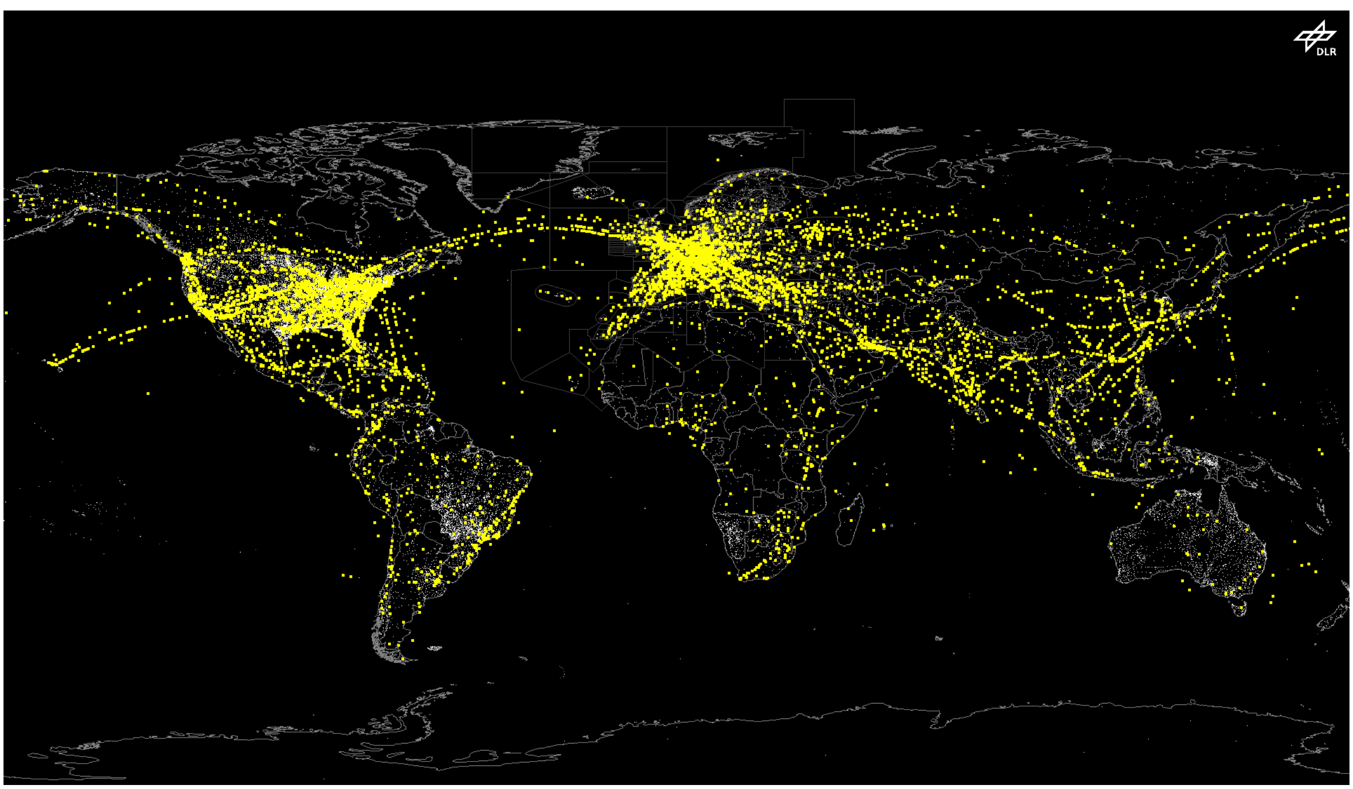

Figure 4: FACTS2 simulating worldwide air traffic movements as in Listing 4 in dark mode.