COMMUNICATIONS PANEL (CP)

FIRST MEETING

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Agenda Item 7: Communications Panel Work Programme and Timelines

Current Status of LDACS Development

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SUMMARY
In this information paper, we describe the current status of the LDACS development. Main focus is given to the achievements and the current status of the LDACS1 development. In addition, an extension of LDACS1 towards navigation is described and discussed. This extension addresses the need to introduce an alternative, positioning, navigation, and timing system for the case when global satellite navigation systems are temporarily unavailable. Conclusions and an outlook on open issues are given at the end of the paper.

ACTION
The CP is invited to note the contents of this information paper.

1. INTRODUCTION

1.1 Within the Aeronautical Communications Panel (ACP) of ICAO, a common understanding has been reached that a Future Communications Infrastructure (FCI) is required to support applications and services as foreseen within a modernized Air-Traffic Management (ATM) environment. ATM modernization is currently performed in several large projects: SESAR (Single European Sky ATM Research) in Europe, NextGen (Next Generation Air Transportation System) in the US, and CARATS (Collaborative Action for Renovation of Air Transport Systems) in Japan.

1.2 As shown in Figure 1, the FCI comprises a set of data link technologies integrated into a single communications network: LDACS (L-band Digital Aeronautical Communications System) for
air/ground communications, a dedicated data link to be used at large airports (AeroMACS, Aeronautical Mobile Airport Communications System), a satellite component, and a direct air/air data link. LDACS is one of the most important data links within the FCI, since it covers the main part of air/ground communications.

1.3 The VHF Data Link (VDL) Mode 2 technology is currently introduced in Europe. This data link delivers connectivity with limited capacity. Most probably, VDL Mode 2 will not be capable to fully support modern ATM applications and services as required within SESAR, NextGen, and CARATS. Thus, air/ground communications needs to be enhanced on a mid-term scope. A promising approach is to supplement VDL Mode 2 with the more performant LDACS data link.

1.4 There are two LDACS candidates, LDACS1 and LDACS2. LDACS1 employs a broadband transmission using Orthogonal Frequency-Division Multiplexing (OFDM). A bandwidth of 500 kHz is used for both forward and reverse link by applying Frequency-Division Duplex (FDD). In addition, adaptive coding and modulation is applied. With that, LDACS1 follows modern and highly efficient transmission concepts as also used in, for example, the fourth generation of mobile radio systems. In contrast, LDACS2 follows a more conservative approach. It is based on Global System for Mobile Communications (GSM) technology, that is, second generation mobile radio technology. It is a narrowband single-carrier system with 200 kHz transmission bandwidth and time-division duplex (TDD).

1.5 In the following, we present the current status and the achievements of the LDACS development. After a brief comparison between LDACS1 and LDACS2, we concentrate on LDACS1. There are two reasons for that. Firstly, the more advanced technology used in LDACS1 leads to considerably better performance. Secondly, work on LDACS2 has been very limited within the last years without any industry interest to further pursue this technology.
2. ACHIEVEMENTS AND CURRENT STATUS OF LDACS

2.1 Brief Comparison Between LDACS1 and LDACS2

2.1.1 LDACS1 is an FDD system using 500 kHz bandwidth for both forward and reverse link. Compared to the LDACS2 TDD approach with 200 kHz bandwidth, the available bandwidth for LDACS1 is five times that of LDACS2. With that, an LDACS1 channel makes available considerably more capacity. To compare achievable data rates between LDACS1 and LDACS2 in a fair manner, the overall net data rate is considered. Here, overall data rate refers to the combined data rate in forward and reverse channel. Using the strongest coding and the most robust modulation scheme available in LDACS1, an overall net data rate of approx. 561 kbit/s is achieved. Using light coding and higher-order modulation, LDACS1 shows a max. overall data rate of approx. 2.6 Mbit/s. The overall net data rate of LDACS2 is around 70-115 kbit/s.

2.1.2 In contrast to LDACS2, LDACS1 applies modern communications concepts which are state-of-the-art in mobile communications, like OFDM and adaptive coding and modulation. In addition, the use of OFDM makes LDACS1 highly flexible and scalable. This enables long-term evolution of LDACS1 towards higher data rates. If required, LDACS1 can be scaled to make available higher bandwidth channels with higher capacity. No new data link developments are required.

2.1.3 Continuous research and development since 2007 makes LDACS1 considerably more mature than LDACS2. Detailed evaluations of the physical and medium-access layer have been performed. A receiver concept with strong interference robustness has been developed and evaluated. Numerous publications, well above 30, describe the advances in LDACS1 system design.

2.1.4 For LDACS1 several demonstrators have been developed. In Europe, DLR, the Austrian company Frequentis AG, and the German company Rohde & Schwarz have developed LDACS1 demonstrators. In JAPAN, ENRI has implemented LDACS1 on a GNU radio hardware platform for testing and simulation. In China, the Beihang University has implemented an LDACS1 demonstrator and performed preliminary flight tests.

2.1.5 The LDACS deployment is foreseen for the L-band (960-1164 MHz). LDACS2 deployment is restricted to the lower part of the L-band (960-978 MHz), whereas LDACS1 makes available additional deployment options due to its interference robustness. The choice for an appropriate deployment option has also to consider interference from LDACS towards the existing L-band systems, e.g. the Distance Measuring Equipment (DME).

2.2 LDACS1 Work in Europe and Germany

2.2.1 LDACS1 work in Europe is performed under the framework of SESAR. The SESAR Joint Undertaking (SJU) project P15.2.4 “Future Mobile Data Link System Definition” deals besides other topics also with the LDACS1 development. During the last years, LDACS1 technology has been matured and an updated LDACS1 specification has been produced. The Frequentis AG developed an LDACS1 demonstrator for compatibility testing. Currently, this demonstrator consists of a complete LDACS1 transmitter including a base-band implementation according to the updated LDACS1 specification and a front-end implementation which fulfils the strict spectral mask requirements. This demonstrator has been used for assessing the LDACS1 transmitter impact upon DME/TACAN receiver in laboratory measurements performed at the labs of DFS. These lab tests have been finalized recently.

2.2.2 Besides the LDACS1 work in SESAR, LDACS1 is also further developed in several projects in Germany. In DLR internal projects, an LDACS1 demonstrator has been implemented. This
demonstrator comprises the LDACS1 transmitter according to the current specification and a software LDACS1 receiver. The DLR demonstrator has also been used for the laboratory measurements performed at the labs of DFS. In addition, using the LDACS1 software receiver this demonstrator has been used to assess the impact of DME/TACAN towards LDACS1.

2.2.3 Within another DLR project, different interference mitigation techniques for LDACS1 have been developed and evaluated. Large amounts of the performance loss due to L-band interference can be mitigated by applying these techniques. In addition, an iterative receiver structure has been developed which is capable of further improving LDACS1 performance.

2.2.4 The German national project ICONAV (Integrated Communication and Navigation functionality for LDACS) has been initiated by DLR and the German company Rohde & Schwarz. The project is led by Rohde & Schwarz. The goals of the project are twofold. Firstly, an industry-like LDACS1 demonstrator is developed comprising transmitter and receiver implementation. Secondly, an interface is designed to allow the inclusion of navigation functionality into LDACS1. In parallel, a DLR internal project has been performed. In this project, the LDACS1 ranging and navigation capability of LDACS1 has been evaluated. This evaluation has been performed in theory, simulations, and flight tests. More about the results from this project is given under Section 3.

2.3 LDACS1 Work Outside Europe

2.3.1 In Japan, ENRI (Electronic Navigation Research Institute) performs evaluations of LDACS1. For that, ENRI has developed a GNU radio hardware implementation of LDACS1.

2.3.2 In China, the Beihang University (aka Beijing University of Aeronautics and Astronautics, BUAA) together with the National Key Laboratory of CNS/ATM performs theoretical studies and simulations on LDACS1. In addition, an LDACS1 demonstrator has been developed and preliminary flight tests have been performed.

3. LDACS1 EXTENSION TOWARDS NAVIGATION

3.1 The need for an APNT (Alternative, Positioning, Navigation, and Timing) system in aviation has become obvious after so-called “personal privacy devices” or “GPS jammers” had been identified as severe source of interference for GPS signals. Relying more and more on GPS navigation in aviation demands for appropriate back-up operations in case of temporary GPS failures.

3.2 Aircraft positioning can be performed using the signals available from the LDACS1 communications system. In the LDACS1 system, the ground stations are synchronized among each other and transmit continuously. With that, the LDACS1 ground stations establish a “pseudolite” system, a kind of “GPS on the ground”. Measuring the pseudo-ranges to four ground stations allows to determine a three-dimensional position and the time offset between the synchronized ground stations and the aircraft clock. The number of range measurements might be reduced if other sensors are taken into account, e.g. barometric height sensor, inertial sensor, DME ranging, etc.

3.3 Within a DLR internal project, the range performance achievable with LDACS1 signals has been evaluated. According to the Cramer-Rao lower bound, a ranging accuracy of a few meters can be achieved theoretically. Simulations show that this bound can be reached tightly for realistic carrier-to-noise power ratios.
To evaluate the ranging performance in a real world environment, DLR performed a flight measurement campaign. Four LDACS1 ground stations have been set up south-west of Munich, Germany. The ground stations have been exactly synchronized to each other to avoid masking effects on the range accuracy by synchronization errors. An airborne receiver has been installed in a DLR research aircraft, a Dassault Falcon 20E. The receiver mainly consisted of a data grabber which was able to record the signals from the four LDACS1 ground stations simultaneously. The research aircraft flew a kind of butterfly pattern at three different flight levels: FL100, FL280, and FL280. The received signals were evaluated offline after the measurement campaign. Figure 2 shows the ground station distribution and the “butterfly” patterns flown.

The results of the flight measurement campaign are summarized in Figure 3. No post-processing other than averaging the range measurements over one second intervals has been performed. As a result, a bias of 6.7 m and a RMSE (Root Mean-Squared Error) as low as 15.2 m has been observed. The bias is mainly caused by the troposphere and can be significantly reduced by applying state-of-the-art tropospheric error models. The RMSE is mainly due to multipath propagation and can also be reduced further by applying appropriate mitigation algorithms, e.g. Doppler smoothing or particle filtering.

4. CONCLUSIONS

We have presented the current status of the LDACS development. Main focus was given to the achievements and the current status of LDACS1. Current and recent work in Germany, Europe, and outside Europe has been reported. In addition, an extension of LDACS1 towards navigation has been described and discussed. This extension addresses the need to introduce an APNT system for the case when global satellite navigation systems are temporarily unavailable.
4.2 We consider the LDACS1 technology well-suited to serve modern ATM applications. It realizes a high-capacity data link. In addition, LDACS1 is highly flexible and scalable due to the physical layer technology applied.

4.3 LDACS1 has been considerably matured within the last years and first compatibility investigations (LDACS1 vs. DME) have been performed within SESAR. Several LDACS1 demonstrators have been developed and are currently further matured.

4.4 In addition to its original and main purpose, LDACS1 offers an excellent opportunity for extension towards navigation. This navigation functionality of LDACS1 can be used to set-up an APNT service on top of the communications infrastructure. The theoretical ranging performance achievable with LDACS1 signals is in the order of meters. A measurement campaign has shown that the ranging performance in a real world environment is in the order of a few tens of meters and, thus, is sufficient for establishing an APNT service.

5. OPEN ISSUES

5.1 Further L-band compatibility evaluations are needed involving not only additional simulations and measurements with DME/TACAN, but also with UAT (Universal Access Transceiver), SSR (Secondary Surveillance Radar) Mode S, and the military L-band communications system JTIDS (Joint Tactical Information Distribution System).

5.2 A deployment concept has to be developed which ensures L-band compatibility with all other L-band systems. In addition, a strategy has to be developed to migrate from current data link
technologies, especially VDL Mode 2, to the more performant LDACS1 data link in a smooth and cost-effective manner. Supplementing VDL Mode 2 with LDACS1 might be a promising approach.

5.3 A final LDACS1 specification has to be developed including technology amendments as required and standardization has to be initiated.

5.4 The available LDACS1 demonstrators have to be further matured with the goal to make available fully functional prototypes. These prototypes shall be used for subsequent flight testing.

6. ADDITIONAL INFORMATION

6.1 At the LDACS homepage, additional information about LDACS1 is available. The homepage can be found under: www.ldacs.com

7. ACTION BY THE MEETING

7.1 The CP is invited to note the contents of this information paper.