BANDWIDTH SIMULATIONS OF THE TRAFFIC INFORMATION SERVICE IN CONTRACT MODE (TIS-C) OVER VDL MODE 2 WITH THE ACTS SIMULATOR

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Abstract

The concept of Traffic Information Services in Contract Mode (TIS-C) is new, in that it proposes client-server protocols between the air and the ground similar to those known from the World-Wide Web by extending these with contractual behaviour for mobile safety applications. The advantages of TIS-C in comparison to Traffic Information Services in Broadcast Mode (TIS-B), especially when combined with a mandate for Automatic Dependent Surveillance – Broadcast (ADS-B) based on cheap and available MODE-S technology have been discussed in previous work. In addition it has been argued that TIS-C even when operated over the available Digital Link Mode 2 (VDL 2) can fulfil basic requirements of applications for Airborne Separation Assurance System (ASAS), and do much more. The technical concepts and protocols of TIS-C have been elaborated and are available now.

This paper presents the results of the validation of the TIS-C concept over VDL2. The validation tool that is used is the Aeronautical Communications Technologies Simulator (ACTS), which has been developed in EUROCONTROL and is one of the most performing VDL2 simulators at the moment. Different TIS-C applications for ASAS are analysed in their use of bandwidth, and several scenarios run with changing traffic loads, equipage rates, and VDL2 parameters. The technical and operational assumptions for parameters of the simulations are discussed. The work proves that the TIS-C concept over VDL 2 is possible for many applications, but also shows its limitations. The validation results emanating from the simulations are presented for the first time in this paper.

Introduction

The mission of Air Traffic Management (ATM) is the safe, orderly and expeditious management of air traffic. Over the last few years there has been a constant increase in the amount of air traffic and this is predicted to continue for the next decade [1]. The current ATM system seems to reach its performance limits, and therefore new operational concepts are needed [2]. Some significant research is being undertaken for the integration of the air and the ground systems under the umbrella concept of Cooperative Air Traffic Services [3, 4], which includes applications for Controller-Pilot Data Link Communications (CPDLC), ADS-B and ASAS.

CPDLC has started to be implemented, in U.S.A. with the Free Flight Build 1 programme by the Federal Aviation Administration and in Europe with the LINK 2000+ programme1 by EUROCONTROL. The creation of a master plan [5, 6] for the implementation of the first package of ground-surveillance and airborne surveillance applications will further promote ADS-B and ASAS applications. Research continues on both sides of the Atlantic2 with a special focus on ASAS applications.

The concept of cooperative air traffic services foresees a higher share of tasks between the air traffic controller and the flight deck. ASAS applications treat new types of air traffic management procedures where controllers delegate work to the flight deck. Four categories of applications have been defined by the different degrees of the delegation of tasks: situational awareness, spacing, separation and self-separation [7]. Situational awareness applications will help the

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1 http://www.eurocontrol.int/link2000/overview.htm
flight deck to get a better picture of the context, mainly with the help of an airborne air situation picture based on ADS-B. For the second category of applications, spacing, the controller delegates some tasks where the flight deck may catch up with leading aircraft or merge into streams [8]. The fourth category, self-separation, handles the fully autonomous aircraft, and the third category, separation, is something in-between, where the flight deck is responsible for the resolution of conflicts, but is still instructed on the procedure to follow.

**TIS-C**

TIS-C has been developed as an enabler to support cooperative air traffic services. It proposes client-server protocols between the air and the ground similar to those known from the World-Wide Web by extending these with contractual behaviour for mobile safety applications. The advantages of TIS-C in comparison to TIS-B, especially when combined with a mandate for ADS-B based on cheap and available MODE-S technology have been discussed in previous work [9]. The technical concepts and protocols of TIS-C have been elaborated and are available now [10].

With TIS-C the flight deck requests information from ground service providers and then receives services from the providers upon successful contract handling. The initial services are traffic-related and mainly focussed on pilot situational awareness, i.e. information about adjacent aircraft, their flights and eventually conflicts are uplinked.

**TIS-C Application Data**

The data content vary depending on the operational application that TIS-C supports, as described in the operational scenarios below. Therefore the size of the data that is sent from the ground to the air must be defined. This paper does a simple octet (or byte) count. Further optimization could be achieved by the use of compression e.g. the Packed Encoding Rules (PER) applied in the ATN³. However, object IDs are not counted, e.g. Java counts 4 bytes for one object ID.

The data types have been defined in previous TIS-C concept definitions [11, 12], which collected it from the AVENUE⁴ data directory [13], the ASTERIX radar data definitions [14], the ICAO ADS-C SARPs⁵ [15], and the technical evaluation of data links for TIS-B [16].

Table 1 gives some sizes of formats for different uses. The simple 3D position corresponds to a blip, the 4D position is a time-stamped blip, the smallest track will allow correlation with ADS-B data in the flight deck and adds air speed and heading, the next is a real track correlated with a flight plan containing ground speed and track angle, next is a track containing two 3D positions as simple trajectory-change points, and last is a full track with a projected profile of 20 4D positions.

The flight deck may request a flight plan of adjacent aircraft. This contains the flight ID, aircraft information (model, company, ICAO flight type), departure (airport name, ATD) and arrival information (airport name, ETA), requested FL, cruise speed. The route is not added, because TIS-C allows for a request of the projected profile. The total size of a flight plan is 56 octet.

The flight deck may also receive medium-term conflict information. In the simple mode only the conflict geometry is sent to the aircraft consisting of: MTCD ID, time of closest point of approach (CPA), flight ID, own start of conflict 3D position, own CPA, own end of conflict 3D position, other flight wake-turbulence category, other start of conflict 3D position, other closest point of approach, and other end of conflict 3D position. The total is 150 octet for one conflict, there may be several conflicts per aircraft.

In the extended MTCD-mode additional trajectory information is sent for n aircraft in proximity at the conflict. The trajectories can be optimised as 3D trajectories with one position per minute look-ahead plus one 4D position at the time of closest point of approach, i.e. $20 \times 22 + 1 \times 30 = 470$ (octet) per trajectory.

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³ Aeronautical Telecommunications Network
⁴ AVENUE project
⁵ Standards And Recommended Practices
ACTS Simulator

The Aeronautical Communication Technologies Simulator\(^6\) (ACTS) in its version 1.5 Beta has been used for the validation, which is running faster than real-time on a simple 750 MHz PC. Figure 1 shows the main page of the simulator. ACTS is a generic telecommunications simulator with a very powerful model for VDL 2. It allows the variable setting of many generic and specific system parameters: The propagation model, which is specific to each frequency band; physical layer parameters like power, feeder loss, antenna gain, noise figure etc.; medium-access-control layer parameters and data-link layer parameters. ACTS can simulate many ground-stations and the effects that occur on the telecommunications channel under these circumstances.

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Figure 1. ACTS V1.5 AVLC Window

Validation. ACTS is continuously refined and improved, and has gone through a rigorous
validation campaign. The validation is on different
levels:

- The application of certification-oriented tests,
typically those of system MOPS\(^7\) to individual
ground-station models in order to confirm its
correct behaviour,
- Theoretical mathematical models are used for
validating the main trends in the results,
- Cross-check with independent simulation when
available,
- Field trials with defined simplest scenarios,
- Initial operation feedback.

The powerful features and its validation status
make ACTS one of the most performing VDL 2
simulators at the moment.

Simulation Parameters

The settings of the simulator can largely
influence the results of the simulation. The
following parameters and capabilities were set
during the simulations and impact the output:

- Only one ground-station, i.e. no handover and
  hidden stations effects decrease channel
capacity.
- No TMA is simulated, i.e. only flight levels 200
  – 400 are used. The effect of an airport is not
  simulated.
- Random air traffic distribution, i.e. in a scenario
  with 100 aircraft these are evenly distributed
  over the range and the flight levels.
- 10 m antenna height, 190 NM range.
- No other applications like CPDLC services
  were simulated.
- The propagation model used 2 way vertical
  polarisation, over both dry and wet land.
- Parameters on the physical layer were set to
  136.975 MHz channel frequency, 600000 K
  noise temperature, 12 KHz reception filter
  depth, 44 dBm ground station and 42 dBm
  aircraft emission power, 3dBm ground antenna
  gain and 1 dBm aircraft antenna gain.
- The P-factor in the CSMA\(^8\) layer was set to
  13/256.

- ATN was not taken into consideration. It is
  assumed that ATN protocols and ATN data
  compression result in a zero-overhead balance.
  However, as some of the scenarios lose
  packages, the ATN in connection-oriented
  mode would try to recover, and this cost has not
  been included.

Operational Scenarios and Simulation
Results

Situational Awareness Applications

TIS-B broadcasts traffic information to all
aircraft in a specific “logical volume”. It is
interesting to which extend TIS-C is able to emulate
TIS-B. TIS-C will not broadcast, but can be used to
uplink selective, adjacent flights. Five scenarios
have been simulated:

* Five Aircraft Positions at Five Seconds.
  (Figure 2, legend: 5ac 5sec) Each uplink target
  receives the simple 3D position (26 octet) of five
  adjacent aircraft at an interval of 5 seconds.

* Ten Aircraft Positions at Five Seconds.
  (Figure 2, legend: 10ac 5sec) Each uplink target
  receives the simple 3D position (26 octet) of ten adjacent
  aircraft at an interval of 5 seconds.

* Three Aircraft 4D-Positions at Three Seconds.
  (Figure 2, legend: 3ac p4D 3sec) Each uplink target
  receives the 4D position (34 octet) of three adjacent
  aircraft at an interval of 3 seconds.

* Three Aircraft Track 1 at Three Seconds.
  (Figure 2, legend: 3ac track1 3sec) Each uplink
  target receives the Track 1 (42 octet) of three
  adjacent aircraft at an interval of 3 seconds.

* Three Aircraft Track 2 at Three Seconds.
  (Figure 2, legend: 3ac track2 3sec) Each uplink
  target receives the Track 1 (63 octet) of three
  adjacent aircraft at an interval of 3 seconds.

The long update rates of 5 seconds intent to
simulate an en-route environment for ASAS
procedures and intensive situational awareness. The
short update rates of 3 seconds intent to simulate a
TMA requirement with varying information about
flight vectors.

\(^7\) Minimal Operational Performances Standards

\(^8\) The Medium Control Access sub-layer in VDL 2
Spacing Applications

Spacing applications hook one aircraft behind another in the case of station-keeping; and merge one aircraft, eventually into an existing sequence in the case of traffic-merging.

Station-Keeping at 15 seconds. (Figure 3, legend: SK 15sec) Each uplink target receives a full track (63 octet) of one adjacent aircraft at an interval of 15 seconds.

Station-Keeping at 5 seconds. (Figure 3, legend: SK 5sec) Each uplink target receives a full track (63 octet) of one adjacent aircraft at an interval of 5 seconds.

Station-Keeping at 3 seconds. (Figure 3, legend: SK 3sec) Each uplink target receives a full track (63 octet) of one adjacent aircraft at an interval of 3 seconds.

Traffic-Merging at 15 seconds. (Figure 3, legend: TM 15sec) Each uplink target receives a full track (63 octet) of one adjacent aircraft at an interval of 15 seconds and an additional full track (63 octet) for a second adjacent aircraft at half the update rate, i.e. 30 seconds.

Traffic-Merging at 5 seconds. (Figure 3, legend: TM 5sec) Each uplink target receives a full track (63 octet) of one adjacent aircraft at an interval of 5 seconds and an additional full track (63 octet) for a second adjacent aircraft at half the update rate, i.e. 10 seconds.
Traffic-Merging at 3 seconds. (Figure 3, legend: TM 3sec) Each uplink target receives a full track (63 octet) of one adjacent aircraft at an interval of 3 seconds and an additional full track (63 octet) for a second adjacent aircraft at half the update rate, i.e. 6 seconds.

The long update rates would support situational awareness, the short update rates cooperative manoeuvres, the very short also for reduced horizontal separation e.g. TMA or approach. Station-keeping would in general send the leading aircraft track. Traffic-Merging would in general add the trailing aircraft track at half the update rate.

![Real channel load (%)](image1)

![Net throughput (%)](image2)

![Success rate (%)](image3)

![Max. turnaround delay (ms)](image4)

Figure 3. Real Channel Load, Net Throughput, Success Rate and Maximal Turnaround Delay for Station-Keeping and Traffic Merging

**Separation Applications**

Simple MTCD. (Figure 4, legend: MTCD) Medium-term conflict information would support ASAS applications form the separation- and self-separation- categories. It helps the controller and both flight decks to have a common view on the conflict situation. TIS-C has been defined as to uplink the complete conflict geometry, together with the predicted trajectories for aircraft in proximity to the conflict. The frequency that conflicts occur has been set to one per ground station per minute [17]. Each uplink target receives a MTCD (150 octet), the number of uplink targets correspond to the number of uplinks per minute in the range of the ground station.

Extended MTCD. (Figure 4, legend: MTCD and 3 FPs) It could be useful for the flight deck to receive the MTCD as defined above, and in
addition receive predicted trajectories of the three most adjacent aircraft at the time of the closest point of approach. Each uplink target receives a MTCD plus three trajectories \((150 + 3 \times 470 = 1560)\), the number of uplink targets correspond to the number of uplinks per minute. The information is split into two packages per minute, each 780 octet.

**Trajectory Negotiation.** (Figure 4, legend: TN)
For this applications which is close to the COTRAC\(^9\) service [4] it is assumed that an aircraft downlinks its flight plan containing a 4D projected profile once per centre entry, and gets one correction per sector, i.e. one trajectory uplink. No real negotiation is assumed, all uplinked trajectories become clearances and are acknowledged. For convenience the trajectory is chosen to be a Full Track (663 octet), the uplink-rate is one per minute per VDL 2 ground station and the downlink-rate is 0.1 per minute per aircraft.

**Air-to-Air CD&R\(^\text{10}\).** (Figure 4, legend: A2A CD&R) Upon a MTCD two aircraft receive the MTCD and three flight plans of adjacent aircraft and exchange each its trajectory twice where the TIS-C ground server acts as a relay, i.e. 4 trajectory uplinks and 4 trajectory downlinks. Conflicts occur once per minute in the range of the ground-station. The information is \(2 \times 780 + 4 \times 470 = 3440\) octet, approximated with 870 downlink and three times 870 uplink per minute per target due to limitations.

**Discussion**
1. All applications can be supported for 20 aircraft in the range of the ground station with near to 100% success rate and very good delays. 50 aircraft can be supported for five aircraft positions at five second, for three aircraft 4D-positions at three seconds, for three aircraft Track 1 at three seconds, for all spacing applications, and also for MTCD, MTCD with three flight plans, and trajectory negotiation. 100 aircraft can be supported by no situational-awareness application, but by station-keeping at 15 seconds, MTCD and trajectory negotiation.

2. With the exception of situational awareness, the results are more than sufficient for operational use, i.e. it is most unlikely that 100 aircraft would make one conflict with an exchange of trajectories per minute in the volume – here the simulation shows simply the limits of the system without operational significance.

3. The maximum turnaround delay increases with increasing number of uplink targets. That means that information is received with a delay, which is dangerous for time-critical information. Therefore the aircraft architecture should include a tracker, which would use even obsolete information for a better prediction of the current positions of the adjacent aircraft.

**Conclusions**
The results of the simulations show that TIS-C over VDL 2 seems to be feasible. All applications could be used with operational satisfaction. A limitation would be the full situational-awareness applications. The correct mode of operation should therefore be to deliver situational awareness only upon event to a limited number of aircraft in that volume. Situational awareness of adjacent aircraft would be better given by the uplink of predicted trajectories rather than the frequent “broadcast” of air situation pictures. Another feasible use for situational-awareness with TIS-C would be to operate in gap-filler mode, i.e. when only a few aircraft receive adjacent position information.

Next steps should be to evaluate a mix of applications, something which is not feasible with this version of the simulator, which would put higher loads on the channel. Furthermore, the foreseen frequency utilisation could be extended to several bands as planned for the real VDL deployment scheme, which would increase available channel capacity. Furthermore, the VDL 2 simulation should be refined to emulate a hypothetical ground infrastructure of VDL 2 stations, which should decrease channel capacity.

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\(^9\) Flight Plan Consistency
\(^\text{10}\) Conflict Detection and Resolution
This evaluation is a major step for the TIS-C concept. So far the results are very encouraging! The major assumptions that TIS-C can replace TIS-B and do much more even when operated over VDL 2 seem to be correct. Some of the simulated scenarios, especially for conflict detection and resolution would not be possible with TIS-B. The ASAS community should be glad to find that they could build their applications only by using Mode-S Extended Squitter and VDL 2, i.e. available and ready-to-deploy technology, which would make the overall concept much cheaper and help for an early operational use of ASAS.

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