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Progress Report and Initial Results of IDRP Large Scale Simulations

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SUMMARY

This working paper is produced in the frame of the ATN validation activity using simulations. It presents the initial results of the IDRP Convergence Modelling study, which aims at evaluating the ATN routing concepts related to the handling of mobiles.

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1. Objectives of the Study

The high-level objectives of the IDRP Convergence Modelling Study are to study the convergence of IDRP, and to assess the validity of ATN routing concepts. The project thus contributes to the ATN SARPs validation programme.

More precisely, the project involves the study of the propagation in the ground part of the ATN of routes to mobiles by means of computer simulations in order to:

-- demonstrate the existence of stable states of the ground network as far as routing is concerned (i.e. demonstrate the **convergence of IDRP**),

-- check that the routing information is correct (i.e. that routes become available to all the systems that should have them, and that there are no false routes),

-- provide indications on the performances of the propagation of the routes by IDRP, namely:

- the amount of traffic generated by the operation of IDRP,
- the measurement of "Convergence Delay",
- the measurement of "Route Unavailability Period",
- the measurement of "Route Update Rate".

To reach the above objectives, a computer model (the **IDRP Convergence Model**) has been developed using the OPNET tool. The core of this model is the model of IDRP over a simplified connection-less network service. Aircraft are simulated globally by an Event Generator that simulates aircraft handovers by generating JOIN and LEAVE events. The detailed operation of IDRP on air-ground links is not simulated.

The definitions of the measurements of the performances of IDRP are specific to the study. The Convergence Delay, Route Unavailability Period, and Route Update Rate are defined and commented in Section 3. They aim at assessing specific ATN routing concepts : the routing hierarchy that comprises ATN Islands, ATN Backbone, and "Home" Routing Domains (RDs) for mobiles, and ATN transit routing policies.

It must be noted that no route aggregation or merging can be performed by the model. Hence, only routes with the empty RIB-Att are handled.

2. General Information on the Project

The project presented here takes place within the frame of the ATN validation activity using simulations, in relation with the ATN/OPNET Simulation User Group. It is a joint project of Eurocontrol and CENA.

The project started in October 1994. The IDRP Convergence Model was designed independently from ATN routing protocol models that existed at this date. The whole model was entirely developed on the basis of the information found in the IDRP standard (Ref. 2) and the Draft ATN SARPs (Ref. 1), without re-using any existing model component.

The exploitation of the IDRP Convergence Model is on-going. The initial exploitation results are presented in this paper. Final results, and a more detailed analysis, will be provided in the Final Report due in mid-February of 1996.

3. Definition of Measurements

This section presents measurements that were defined to provide indicators on whether ATN Routing Concepts are valid or not, focusing on the validation objectives listed in Section 1.

A specific software tool was designed and developed to retrieve the measures of interest from the simulation traces. The IDRP convergence model itself is independent from the definition of the measurements. Simulation traces only record events affecting the Loc-RIBs which are maintained as indicated in the IDRP standard.

3.1 Convergence Delay

One of the indicators of convergence is the **Convergence Delay**. It is the delay after which a stable state is reached for the routing information, after the operation of IDRP has been triggered by a routing event generated by the mobility of aircraft. The state is considered as stable when the modifications to the Loc-RIBs triggered by a given routing event ceases.

For a given simulation run, there are as many convergence delays as routing events generated by the aircraft mobility (i.e., sequence of JOIN and LEAVE events simulating aircraft handovers). It must be noted that successive routing event sequences may influence each other as concerns convergence delays.

The representative value for the simulation run is the average value (arithmetic average of samples).

3.2 Route Unavailability Period

As specified in Section 2.1.3. of Ref. 3, the convergence requirement is that when:

1. an aircraft ceases to be in contact with the air-ground RD through which the preferred route to that aircraft passed, and,

2. an alternative route exists,

the time taken between the lost of communication and the establishment of a replacement communication path neither results in the loss of a transport connection between the ground system and the aircraft, nor does transit delay increase beyond the minimum acceptable QoS.

At this stage of the IDRP Convergence modelling, no data communication traffic is simulated. Hence, it is not possible to directly observe whether the transport connection is lost or not, neither to observe whether the transit delays are kept in reasonable bounds or not. Then, to assess the convergence requirement, one of the main indicators which can be provided by simulation runs is to evaluate the time a route to a given aircraft remains unavailable, when there is a change in the route to that aircraft, and when an alternative route to that aircraft exists.

The **route unavailability period** corresponds to the time interval between the instant the aircraft ceases to be in contact with the air-ground RD through which the preferred route to that aircraft passed, and the instant a certain RD selects the alternative route. This RD is the point on the route between the Backbone RDC and the aircraft where the route is altered to pass through a different air-ground router.

The representative value for the simulation run is the average value (arithmetic average of samples).

3.3 Route Update Rate

Another major indicator of convergence is **the rate of route updates for each router of the Backbone RDC**. Indeed, since the Backbone RDC centralises the knowledge of all the actual routes to each aircraft, it is important to determine the frequency at which each preferred route to an aircraft is replaced by an alternative route to that aircraft within each router of the Backbone RDC. It reflects the stability of the route to that aircraft.

The representative value for the simulation run is the average value (arithmetic average of samples).

4. Specifications for the Exploitation

4.1 Topologies

The ATN Manual (Ref. 1) specifies a specific network topology (i.e. ATN Islands, ATN Backbones and "Homes") in support to the mobile routing. The modelling of routing policies that characterise ATN Islands and ATN Backbones is included in the model.

The simulation exercises focus on the study of the air traffic within the ECAC (European Civil Aviation Conference) area. It is assumed that there is only one Routing Domain (RD) per ECAC country. Within an RD there is only one router acting as a BIS. This is a model constraint. Each BIS of the topology is an air-ground BIS, including BISs within the Backbone Routing Domain Confederation (RDC). Only one Backbone RDC is considered, as it is assumed that the ECAC will constitute a single ATN Island (i.e. an RDC). As a whole, the modelled networks are constituted by 27 BISs.

The connections between the modelled BISs have been determined in order to balance the number of hops between any BIS and the Backbone RDC. The maximum number of hops from any BIS to the Backbone RDC is limited to four. On the other hand, the number of air-ground BISs adjacent to the Backbone RDC has been limited.

Relying on the above assumptions, two topologies were retained for simulation exercises to allow the evaluation of two different types of ATN specific topologies. They are:

- a centralised ATN topology in which the Backbone RDC is constituted of only one BIS,
- a distributed ATN topology in which several BISs compose the Backbone RDC.

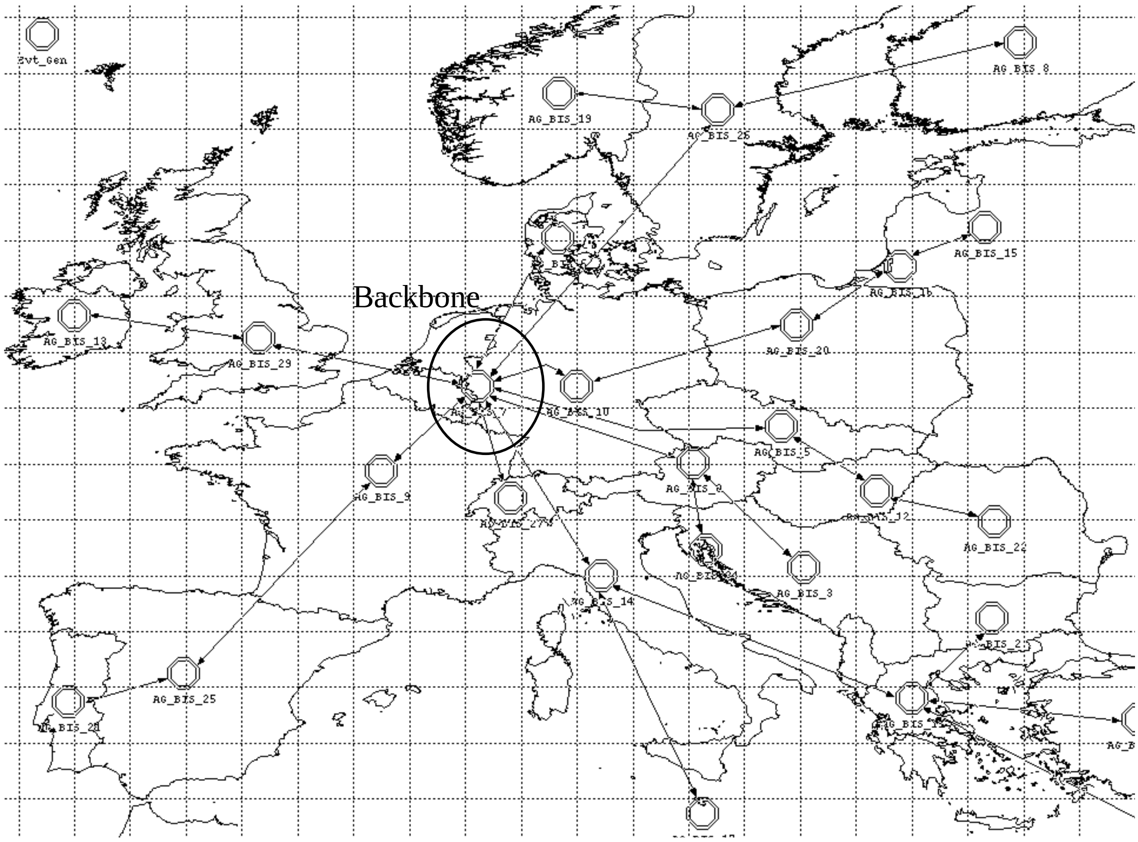

Figure 1: ECAC Centralised Topology

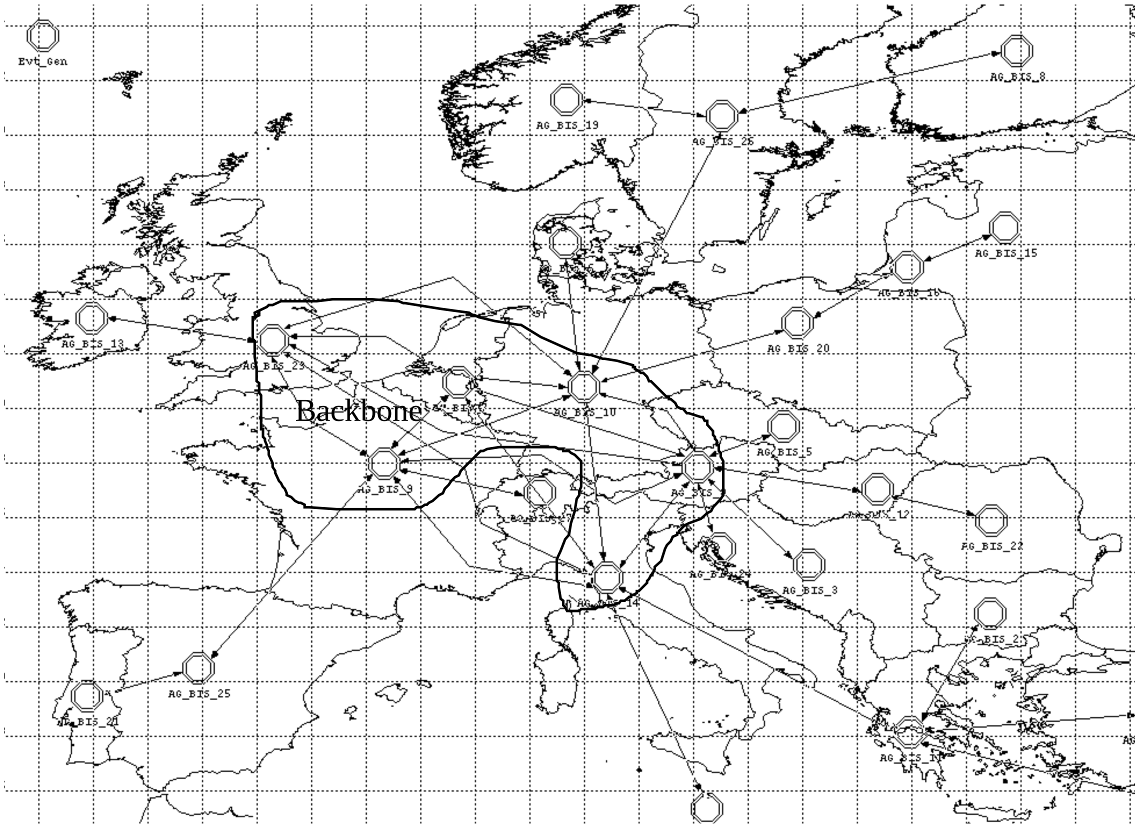

Figure 2: ECAC Distributed Topology

The topologies are logical topologies: the nodes and the sub-networks connecting them may be redundant in an actual network to avoid a general failure when a component fails. In any case, the study does not include network reliability issues.

The model of the links include the simulation of delays up to the internet level as the connection-less network service is not simulated in detail. The parameters were set to reflect basic performances of connections between BISs via wide-area packet switching networks (WANs): the throughput was set to 19200 bps (this represents the access to the WANs), and a fixed delay of 200 ms is added. The fixed delay is the dominant component of the delay for end-to-end transmission of UPDATE PDUs.

The topologies are associated to transit routing policies. Four types of transit policies are modelled, the different types characterise end routing domains (ERDs), off-backbone transit routing domains (TRDs), and backbone transit routing domains. End routing domains do not re-advertise routes to mobiles. Off-backbone TRDs re-advertise routes to only one RD: to an backbone RD if there is one which is adjacent, or to the off-backbone TRD which is the next hop towards the Backbone RDC. Members of the Backbone RDC re-advertise to each others all the routes to mobiles, but do not re-advertise them to adjacent off-backbone TRDs. Each RD in the Backbone RDC may act as the "Home" for a group of mobiles, but this is not exercised in the simulations as only one ATN Island is modelled.

4.2 Aircraft Mobility Scenarios

The scenarios applied to study the operation of IDRP are not communications scenarios (i.e. exchanges of messages) but events generated by the aircraft mobility and triggering IDRP operation. In the context of this modelling studies "scenarios" or "connection scenarios" only refer to aircraft movements. They consist of the generation, for each aircraft, of events that will trigger the diffusion of UPDATE PDUs over the ground part of the modelled ATN. These events are JOIN and LEAVE events sent by airborne BISs to air-ground BISs.

For this study, the simulation runs do not rely on scenarios based on actual data. The main objective is to provide a rough estimate of the indicators of convergence. For such a purpose, it is sufficient to consider pseudo-random connection scenarios. This means that values of the connection durations, of the overlapping periods between connections, and the simulated flight durations are randomly generated according to probability distributions. The choice of the successive air-ground BISs to which a mobile connects is also determined by the outcome of a pseudo-random distribution. If necessary, the same sequences of distribution outcomes may be reproduced from one simulation run to the other by the setting of a "seed" that determines the random number generation.

A connection scenario consisting for each aircraft of **renewed connections with a certain overlap** is considered. This means that, at the entrance of the aircraft in the ECAC coverage, a first IDRP connection is established with an air-ground BIS. Before this first connection ends, a second connection with another air-ground BIS is established. Then, the first connection is closed, after a certain overlapping period with the second connection. This connection establishment mechanism applies all along the aircraft flight, opening and closing as many connections as necessary for the whole **flight duration, averaging 80 minutes** in simulation exercises. It is not necessary to consider that an airborne BIS will support more than two IDRP connections at the same time.

Except for the very first connection for a given aircraft, **this connection scenario triggers only minor changes** for the route to that aircraft (See Ref. 3., for the definition of "minor route changes"). Such a connection scenario ensures that the required conditions are often met to measure the route unavailability periods defined in Section 3.2.

4.3 Configurations of IDRP

In addition to the network topology described in Section 4.1, the complete definition of a network model encompasses the individual configuration of each BIS model. The configuration information corresponds to the content of the "idrpConfig" managed object specified in Ref. 2. It particularly includes, for each modelled BIS:

-- its NET

-- the RDI (Routing Domain Identifier) of the local RD

-- the RDIs of the RDCs it belongs to

-- parameters related to the Local Selection Policy

-- parameters related to the Transit Policy

-- the nominal value of the "minRouteAdvertisementInterval" timer

The NETs and RDIs are address identifiers internal to the model, but they respect the ATN addressing scheme.

The RDCs which are modelled are the Fixed ATN RDC, a single ATN Island RDC, and a single Backbone RDC.

Routing policies used by the routing decision process are selected among implemented routing policies. The transit routing policy is selected among the three different ones presented in Section 4.1. There is no fully configurable policy information base in the model. The Local Selection Policy used in all the simulations is the hop-count policy, i.e., the one which selects as preferred route the one with the lower hop-count.

In the IDRP Convergence Model, the minRouteAdvertisementInterval is submitted to jitter as specified in the Ref. 2.

4.4 Synopsis of the Exploitation

The exploitation of the IDRP Convergence Model is focused on providing the indicators defined in Section 3. The scheme which was retained for the exploitation was chosen in order to yield a range of values if possible.

4.4.1 Identification of Varied Input Parameters

There are numerous possible input parameters to the simulations. The current study particularly examines the influence of the following parameters on the convergence indicators:

-- the topology of the Fixed ATN,

-- the value of the "minRouteAdvertisementInterval" timer,

-- the average duration of IDRP connections between the airborne- and the air-ground BISs,

-- the average duration of overlap between successive IDRP connections established by each airborne BIS,

-- the number of airborne BISs.

The reason why each of these parameters is expected to have an impact on the convergence of IDRP in the ATN is summarised in the following sub-sections.

4.4.1.1 Topology

It is expected that, for the same aircraft mobility scenario, more traffic will be generated by the use of IDRP in the distributed topology than in the centralised topology because of the transit routing policy of Backbone RDs.

The convergence delay, which is a measure of route instability, is also expected to be higher in the distributed topology.

4.4.1.2 Average Connection Overlap Period

The expected impact of **Connection Overlap Period** on the IDRP Convergence is that the risk of having a large route unavailability period should increase when the time two successive connections overlap decreases.

A short Connection Overlap Period means that a JOIN event on a second air-ground router is rapidly followed by a LEAVE event on a first air-ground router. In this case, it is possible that the withdrawal UPDATE PDU triggered by the LEAVE event may be received at the point on the route between the Backbone RDC and the aircraft where the route will be altered to pass through the air-ground router on which the next connection is established, before the UPDATE PDU advertising the alternative route. This means that the measured route unavailability period will not be null.

Another consequence of that, is that the route instability measured by the convergence delay will increase. It is possible not to reach a stable state between the JOIN (alternative route) and the LEAVE (former route) events.

4.4.1.3 minRouteAdvertisementInterval Timer

The effect of the minRouteAdvertisementInterval timer is to slow down the propagation of minor route changes.

For this reason, a higher value of minRouteAdvertisementInterval should lower the route update rate measured for the BISs that constitute the Backbone RDC.

There should be a influence of the ratio between the duration of overlap between connections and the value of the minRouteAdvertisementInterval timers. For high values of the connection overlap period, the minRouteAdvertisementInterval can have a maximum impact in constraining the propagation of alternative routes because the former route and the alternative route co-exist in the network for a longer time.

Note that, for this study, the minRouteAdvertisementInterval timers are fixed for all the modelled BISs to the same values for each simulation run.

4.4.1.4 Duration of IDRP Connections

The IDRP connection duration reflects the rate of route changes associated with the aircraft mobility scenario. Indeed, an IDRP connection corresponds to a couple of JOIN and LEAVE events separated by a time interval corresponding to the duration of the connection. The lower the connection duration is, the higher the injected rate of route changes is.

A short duration of IDRP connections should increase the measured route update rate. It must be noted however that other input parameters influence the measure.

4.4.1.5 Number of aircraft

The number of aircraft can be increased to assess the volume of traffic generated by the operation of IDRP in the modelled ATN. This information is useful in dimensioning systems.

There should be no influence on the route update rate as it is defined. Indeed, it was chosen to measure the average rate at which routes to individual airborne system are updated.

Note that at this point, there is no limitation to the capacity of the modelled BISs in terms of numbers of BISPDUs they can handle per unit of time, nor to the length of queues within the subnetworks or the connection-less network protocol.

The observation of simulation runs with only one aircraft at a time is interesting for the detailed examination of all the possible types of sequences in the update of the Loc-RIBs.

The choice of 2400 aircraft over the ECAC is based on estimations of the maximum for 2015.

4.4.2 Simulation Exercises

The simulation exercises described in this section are defined to verify the expected impact of input parameters as described above, and to measure performances of IDRP as concerns route dissemination for a set of input parameters.

Simulations are grouped in exercises The table in each section lists the simulations which are examined in each exercise. Note that the same simulations can be found in several tables. For each exercise, the varied input parameters are highlighted in the table.

The first columns of the tables lists the names of the input parameters which are varied for the exploitation of the IDRP Convergence Model. This is the list presented in Section 4.4.1. Each subsequent column identifies one simulation by a fixed set of the input parameters, the values of which are averages.

Final results will result from a number of simulation runs carried out for each set of input parameters. This is to check that results of simulation runs are independent from the simulated durations and from the "seed" used for pseudo-random number generation.

4.4.2.1 Reference Simulation Runs

The results of the reference simulation runs will provide a basis of comparison to analyse the impact of the relevant input parameters on the indicators of convergence.

Number of Aircraft	1	1	2400
Connection Duration	Nominal 25 min.	Nominal 25 min.	Nominal 25 min.
Overlapping Period	High 10 min.	High 10 min.	High 10 min.
minRoute Advertisement Interval	Nominal 1 min.	Nominal 1 min.	Nominal 1 min.
Topology	Centralised	Distributed	Distributed

4.4.2.2 Influence of minRouteAdvertisementInterval on the Route Update Rate

The simulation runs defined in this section, aim at observing the effect of minRouteAdvertisementInterval on the route update rates. Such an effect should be emphasised when the route change rate increases, i.e., when the connection duration is low.

Number of Aircraft	1	1	1	1	1	1
Connection Duration	Nominal 25 min.	Nominal 25 min.	Nominal 25 min.	**Low 12 min.**	**Low 12 min.**	**Low 12 min.**
Overlapping Period	High 10 min.	High 10 min.	High 10 min.	High 5 min.	High 5 min.	High 5 min.
minRoute Advertisement Interval	**Low 30 sec.**	**Nominal 1 min.**	**High 6 min.**	**Low 30 sec.**	**Nominal 1 min.**	**High 6 min.**
Topology	Distributed	Distributed	Distributed	Distributed	Distributed	Distributed

4.4.2.3 Impact of Overlapping Period on the Route Unavailability Period

As explained in Section 4.4.1.2, a short overlap between successive IDRP connections should raise the risk of having large route unavailability periods. It is thus interesting to determine whether the network still converges to a stable state in such a case, an to evaluate the period of route unavailability.

Number of Aircraft	1	1	2400
Connection Duration	Nominal 25 min.	Nominal 25 min.	Nominal 25 min.
Overlapping Period	**Low 2.5 min.**	**Low 2.5 min.**	**Low 2.5 min.**
minRoute Advertisement Interval	Nominal 1 min.	Nominal 1 min.	Nominal 1 min.
Topology	Centralised	Distributed	Distributed

5. Initial Results

For these initial results, each of the presented values comes from a single simulation run.

Tables of results contains average values of measurements defined in Section 3.

Results are presented only for simulations with one aircraft.

5.1 Influence of the Topology

5.1.1 On Convergence Delay

Convergence Delay (s)	***Centralized Topology***	***Distributed Tology***
Reference simulations	2.	18.
Low Overlap Period Simulations	1.	20.

5.1.2 On Route Unavaibility Period

Route Unavaibility Period (s)	***Centralized Topology***	***Distributed Tology***
Reference simulations	0.1	14.
Low Overlap Period Simulations	0.1	16.

Average values in seconds.

5.1.3 On Route Update Rate

Route Update Rate (updates/s)	***Centralized Topology***	***Distributed Tology***
Reference simulations	0.002	0.004
Low Overlap Period Simulations	0.002	0.006

Average values in number of updates per second.

5.2 Influence of minRouteAvertissement Interval

5.2.1 On Route Update Rate

Route Update Rate (updates/s)	***Nominal RouteAdvertissement***	***Low RouteAdvertissement***	***High RouteAdvertissement***
Reference Connection Duration Simulations	0.004	0.007	0.005
Low Connection Duration Simulations	0.007	0.006	0.006

Average values in number of updates per second.

5.2.2 On Other Convergence Indicators

Convergence Delay (s)	***Nominal RouteAdvertissement***	***Low RouteAdvertissement***	***High RouteAdvertissement***
Reference Connection Duration Simulations	18.	9.	99.
Low Connection Duration Simulations	21.	11.	80.

Average values in seconds.

Route Unavaibility Period (s)	***Nominal RouteAdvertissement***	***Low RouteAdvertissement***	***High RouteAdvertissement***
Reference Connection Duration Simulations	14.	7.	107.
Low Connection Duration Simulations	37.	39.	49.

Average values in seconds.

5.3 Influence of Overlap Period

5.3.1 On Route Unavaibility Period

Route Unavaibility Period (s)	***Reference Overlap Period***	***Low Overlap Period***
Centralized Topology Simulations	0.1	0.1
Distributed Tology Simulations	14.	16.

Average values in seconds.

5.3.2 On Other Convergence Indicators

Convergence Delay (s)	***Reference Overlap Period***	***Low Overlap Period***
Centralized Topology Simulations	2.7	1.3
Distributed Tology Simulations	18.	20.

Route Update Rate (s)	***Reference Overlap Period***	***Low Overlap Period***
Centralized Topology Simulations	0.002	0.002
Distributed Tology Simulations	0.004	0.006

Average values in seconds.

5.4 Influence of Connection Duration

5.4.1 On Convergence Delay

Convergence Delay (s)	***Reference Connection Duration***	***Low Connection Duration***
Low minAdvertissement Interval Simulations	9.	11.
Nominal minAdvertissement Interval Simulations	18.	21.
High *minAdvertissement Interval Simulations*	99.	80.

5.4.2 On Route Unavaibility Period

Route Unavaibility Period (s)	***Reference Connection Duration***	***Low Connection Duration***
Low minAdvertissement Interval Simulations	7.	39.
Nominal minAdvertissement Interval Simulations	14.	37.
High *minAdvertissement Interval Simulations*	107.	49.

Average values in seconds.

5.4.3 On Route Update Rate

Route Update Rate (updates/s)	***Reference Connection Duration***	***Low Connection Duration***
Low minAdvertissement Interval Simulations	0.007	0.006

Nominal minAdvertissement Interval Simulations	0.004	0.007
High *minAdvertissement Interval Simulations*	0.005	0.006

Average values in number of route updated per second.

6. Other Outcome of the Study: Prevention of Routing Loops

In addition to the numeric results, the preliminary exploitation of the IDRP Convergence Model was instrumental in discovering a defect in the specification of IDRP.

It proved necessary to avoid systematic persistence of routes after mobiles had lost contact with the ground network.

The problem and its resolution is detailed in Ref. 4.

7. References

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Tony Whyman,
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8. Glossary

ATN Aeronautical Telecommunication Network

BIS Boundary Intermediate System

ECAC European Civil Aviation Conference

IDRP Inter-Domain Routing Protocol

ISO	International Standards Organisation
PDU	Protocol Data Unit
RIB	Routing Information Base
RIB-Att	Routing Information Base Attribute
RD	Routing Domain
RDC	Routing Domain Confederation