CEC TEN-T ATM Task UK/96/94

ACCESS

ATN Compliant Communications

European Strategy Study

Define Network Topology - Routing Architecture

Definition of the European ATN Routing Architecture Option 2

Document Reference	: ACCESS/NATS/203A/WPR/045
Author	: Eurocontrol & NATS
Revision Number	: 1.0
Date	: 09 June 1998
Filename	: N045I1-0.DOC

DOCUMENT CONTROL LOG

Revision Number	Date	Description of Change
0.1	15 December 97	Document creation from ‘ATNI- TF 'Proposed European Routing Architecture’ - Issue 1.0 - 31/10/97
1.0	09 June 98	Formal release at issue 1.0

Executive Summary

This document details routing option 2 and provides an alternative routing framework for the initial European ATN network to the deliverable produced for WP203. This document is the Eurocontrol input to ACCESS entitled ‘ATN Implementation Task Force - Proposed European Routing Architecture’ Issue 1.0 and has been reformatted as an ACCESS document.

TABLE OF CONTENTS

1 Introduction

This paper is an initial draft of an ATN routing architecture which is proposed as a potential candidate architecture for the European Region. In its current version it focuses on routing to aircraft which is considered to be the key challenge of any ATN routing architecture definition. It is planned to be progressed in order to include other facets of ATN routing.

1.1 Scope

The objective of this paper is to provide input to the final definition of the European routing architecture and to the comparison and assessment of different alternatives as part of this definition process.

1.2 References

Reference	Title
[EUR6]	ATNI- TF 'Proposed European Routing Architecture' - Issue 1.0 - 31/10/97 Ref DED6/ATN/ATNI-TF/Doc/17

2 Key Assumptions

The routing architecture proposed in this paper is based on the following key assumptions:

2.1 Assumption 1: Design Criteria

The most important design criteria for the European routing architecture are (in the order of decreasing relative importance):

- stability of the architecture;
- low volume of routing information traffic;
- reasonable routing and forwarding load per ATN router;
- swiftness of convergence;
- low number of Boundary Intermediate Systems (BISs).

2.2 Assumption 2: Quasi-Static Nature of Ground ATN

The topology and the structure of the ground ATN is largely stable, i.e. it varies at a low rate and only a limited number of end systems and intermediate systems change their status per time unit.

A consequence of the above assumption is that the routing information exchange of the ground systems, when compared to aircraft can be neglected in a first approximation. Therefore, the routing architecture will be defined to satisfy the above design criteria, namely the routing information exchange related to aircraft.

2.3 Assumption 3: Availability of Direct Routes to Aircraft Within Area of Interest/ Responsibility

It is assumed that each Air Traffic Service (ATS) organisation will operate (itself or via a third party provider) a ground communications infrastructure (including air/ground subnetworks, ATN routers and end systems) which, in general, allows direct data communications with aircraft via this infrastructure at any location within its area of responsibility or interest. In other words, the need for communications with aircraft outside its area of responsibility or interest is very low. Equally, communications with aircraft via the infrastructure of another organisation is assumed to be limited to very rare events (e.g. total failure of own or third party provider’s infrastructure).

To conclude, ATS organisations will primarily be interested in routes to aircraft within its own (or contracted third party provider’s) infrastructure. Furthermore, they will be interested in alternative routes, which use outside resources, for backup or failure situations only. Due to the low probability of such situations, it is assumed that the use of non-optimal paths is acceptable in these cases.

2.4 Assumption 4: ATN Routing Policies

The set of routing policies mandated for the ATN by the ATN Internet Communication Services (ICS) Standards and Recommended Practices (SARPs) is considered to cause the prevailing amount of aircraft related routing traffic when compared to the set of routing policies which may be additionally defined by the individual Routing Domain (RD) operators.

3 General Design Issues

3.1 Stability of ATN Routing Architecture

From simulation studies performed by CENA/Eurocontrol it has been concluded that complex topologies for an ATN Island Backbone should be avoided as they significantly increase the convergence time. For example, a routing architecture which comprises more than 3 BISs in the Backbone of the European Region ATN Island tends to be unstable under operating conditions which assume air traffic levels forecast for the beginning of the next century in Europe. This result tends to favour an architecture with Backbone (BB) RDs which are limited to a very small number of BB BISs. Without consideration of additional aspects, a BB RD comprising a single BB BIS only, seems to meet this objective and supports several of the above stated design criteria at the same time.

Consequently, the following recommendation can be derived:

Recommendation 1: The number of BISs in an ATN Island Backbone should be limited as far as possible.

3.2 Volume of Routing Information Traffic

Given a fixed number of end systems in the network, the total amount of exchanged routing information is governed by eight main factors:

1. The dynamic of the network, i.e. the number of changes requiring routing updates (and consequently the exchange of routing information);
2. The type of routing domains (RDs);
3. The overall number of RDs and the number per RD type;
4. The arrangement of RDs, i.e. the level of interconnection between RDs, i.e. the number of RDs connected to a given RD and the number of (BIS-BIS) connections per RD pair;
5. The type of ATN routers;
6. The overall number of ATN routers per RD and the number per type and per RD;
7. The level of interconnection between ATN routers, i.e. the number of ATN routers connected to a given router;
8. The ATN routing policies.

3.3 ATN Routing Policies

The routing information exchange related to aircraft, which is mandated by the set of ATN Routing Policies specified in the ATN ICS SARPs, is illustrated in the following table:

Class	Exchanged Routing Information	From	To	Type of Routing Info
1	Route to every known aircraft	BB RD	Attached BB RDs of local Island	Highly dynamic
2	Route to every known aircraft for which receiving RD has advertised a route to the aircraft's home	BB RD	Attached BB RDs of other Island	Highly dynamic
3	Default route to all aircraft	BB RD	Attached RDs of local Island	Static
4	Default route to all aircraft	Non-BB Transit Routing Domain (TRD) on the path to the local Island's BB	Attached non-BB RD	Static
5	Route to every known aircraft for which receiving RD has advertised a route to the aircraft's home	Non-BB TRD	Attached non-BB RD	Highly dynamic
6	Selected route to every known aircraft	Non-BB RD	Attached BB RD of local Island	Highly dynamic
7	Selected route to every known aircraft	Non-BB RD	Attached non-BB RD on the path to the local Island's BB	Highly dynamic
8	Route to local NETs/NSAPs	Mobile RD	Attached Ground RD	Quasi-static

Table 1: ATN ICS SARPs Mandated Routing Information Exchange Related to Aircraft

As illustrated in Table 1, a total of 8 classes of mandatory routing information related to aircraft exist which have to be exchanged between attached RDs in a given routing architecture. These 8 classes can be categorised as follows:

1. **Static or quasi-static routing information**

This category comprises routing information which is (almost) static and consequently has a very low update rate. Into this category fall classes 3, 4 and 8 above. The routing information related to those classes is excluded from further consideration as it contributes only marginally to the overall routing traffic volume and load.

2. **Routing information propagated to the home**

This category comprises routing information which is necessary to support the reaching of aircraft operating outside the local Island. It comprises classes 2 and 5 in the above table. With respect to **Assumption 3**, Air Traffic Service Operators (ATSOs) are not likely to be interested in communications to aircraft which are currently operating outside the ATSO's local Island. Consequently, a routing architecture should be selected which alleviates ATSOs from routing traffic classes 2 and 5 as much as possible. Therefore, it is proposed that the European aircraft form an independent separate European Homes Routing Domain Confederation (RDC) located outside the European (ATSO) Island. This European Homes RDC will consist of the set of Home RDs of the individual European aircraft operators and may be set up and operated by the services of an International Aeronautical Communications Service Provider (IACSP). It will be connected to the European (ATSO) Island BB. As a result of such an architecture, routing traffic of class 5 will be eliminated in the European (ATSO) Island and consequently no longer considered in the analysis of this paper. *(Note: A corresponding design proposal has been made in ACCESS WP 203).*

Consequently, the following recommendation concerning the definition of the European ATN routing architecture can be made:

Recommendation 2: The homes associated with European commercial aircraft should be comprised in a "European Homes RDC" which is located outside the European ATN Island.

From the above considerations, routing information classes 1, 2, 6 and 7 remain as major routing information streams to be accommodated in the proposed routing architecture. These include highly dynamic routing information subject to short update cycles and consequently cause high processing load and transfer volumes. The following proposal for a European routing architecture aims at minimising these information streams and consequently supports the design objectives stated above. *(Note: we will see that this also holds for the stability of the architecture).*

4 Design Recommendations

4.1 Number of BB RDs per Island

As can be easily seen from Table 1, Class 1 routing information may be completely eliminated if a routing architecture is selected which contains a single BB RD per Island. There is nothing to be gained from having several BB RDs within an Island. A multi-RD BB would neither increase the availability of the BB, nor the reachability of aircraft. On the contrary, a single-RD BB would:

- distinctly reduce the routing information traffic to be exchanged in the Island's BB, as each BB RD has to distribute all learnt routes to all other BB RDs within the same Island;
- increase the stability of the Island's BB, as no routing loops may occur between the RDs which are members of the BB.

From the above considerations, the following recommendation can be derived:

Recommendation 3: It is recommended that the BB of an ATN Island is limited to a single BB RD.

4.2 Number of BISs per BB RD

According to ISO/IEC 10747, all BISs within a RD have to share the same level of routing information. This requires the exchange of learnt routes between the BISs of a given RD and the processing of received routing information into appropriate Routing Information Bases(RIBs). This holds for all types of RDs including BB RDs. It is quite obvious that a BB RD that contains only a single BIS will not be subject to this BB RD-internal routing information exchange and RIB update. However, is it acceptable to have only a single BB BIS ?

To answer this question it is worth reflecting upon the rationale and role of the BB in the ATN routing architecture: The ATN BB is a default route provider to all aircraft without explicitly advertising all known routes throughout the Island. It collects all (selected) routes to aircraft connected to the local Island, keeps this information in a repository, updates this repository along with the reported changes in the connectivity of aircraft with respect to the local Island, but it does not re-distribute this information. Rather, it advertises a single static route to all aircraft, i.e. RDs opting to use this route for communications with a given aircraft, "access" this repository which will finally route the packets to the aircraft. Therefore, the BB can be seen as a central database on all known routes to aircraft within the Island and belonging to the Island. In this context it is most important to note that this route database is a backup facility to cater for such situations in which no direct route to the aircraft is available to the sending ATN ground system. However, according to **Assumption 3** this will be a failure situation and consequently **use of the Island's BB will be restricted to rare, failure situations for backup purposes**. Therefore, the BB can be seen as a (non-perfect) safety net. This safety net should be designed in order to provide the required backup functionality but it should not be forgotten that it is only for backup purposes and may not need a highly sophisticated bullet-proof architecture.

From the above discussion it is concluded that a simple BB architecture which contains only a single BB BIS is appropriate and should be acceptable given that a single-point-of-failure can be avoided and the availability of the BB ensured according to the required performance margins. *(Note: It is believed that this may be achieved using conventional mechanisms, such as fault-tolerant platforms, duplicated or redundant systems which are available in industry as state-of-the-art technology).*

Furthermore, such an architecture would be in line with the postulated design criteria, and:

- guarantees stability, as no routing loops can occur;
- it minimises the number of BB BISs;
- minimises the routing information traffic volume by completely eliminating inter-BB RD traffic;
- supports high convergence rates within the BB as routing information will be processed at a single, central point.

(Note: The aspect of reasonable processing load per BIS is discussed in the following section).

What is the price to be paid for a single BB BIS per Island ?

By definition, a single BB BIS per Island can be located at a single geographical position only. This means that, depending on the actual location of this BIS and the size of the Island, long access links from the individual RDs of the Island to the BB BIS may result. There are two aspects to be considered in this context: Firstly, routing information concerning aircraft which is advertised by the individual RDs to the BB has to travel long distances causing potential delays in the availability of the information at the BB. *(Note: This situation is the same as the route server proposal detailed in ACCESS WP 203).* Secondly, if the default route to all aircraft advertised by the BB BIS is selected by a given Island BIS, the packets forwarded to a given aircraft along this route may cross large parts of the Island (in order to arrive at the BB BIS) and then travel back a long way to an A/G BIS of an RD which may be a geographical neighbour of the sending RD. This may result in extended round-trip times for the exchanged information. *(Note: These introduced delays have still to be investigated and checked with the required performance figures. However, it should be noted that such a route will only be selected in failure situations, as explained before).*

From the above discussions, the following recommendation is derived:

Recommendation 4: It is recommended that the European ATN Island BB RD is limited to a single BB BIS. This BB BIS should be architectured in a fault-tolerant or redundant manner.

4.3 Number of Islands in the European Region

From an operational perspective, the question to be answered is whether all Island RDs can be connected to the Island's BB in a way that ensures the delays experienced when using the "default route to all aircraft" is within operationally acceptable limits. This aspect has been discussed in the previous section to some extent and will not be detailed here for the time being.

From a technical point of view the basic question to be answered is whether the BB BISs are capable of performing the required processing on the routing information related to aircraft within their performance limits ? This comprises two main aspects:

- number of BIS-BIS connections to be maintained simultaneously;
- number of routes to be processed per time unit.

In an attempt to provide an initial answer to the second question, the following rough estimation is made:

Relevant Factor	Estimated Value
Peak Instantaneous Aircraft Count (PIAC) in the European Region	3000 aircraft
Average flight time between change in network connectivity requiring update of the selected route to the aircraft	20 minutes:
Maximum number of routes received by BB BIS for the whole European Region	3000/(20*60) = 3 per second

Table 2: Estimated Route Update Load of Single European BB BIS

The maximum number of routes to aircraft that can be handled by a single BB BIS in an Island that covers the whole European Region is about 3 route updates per second. This is believed to be within the order of performance provided by existing state-of-the-art industry routers.

The number of BIS-BIS connections to be maintained by a single BB BIS is largely dependant upon the internal routing architecture of the Island. This aspect will be discussed in more detail in the following section. However, for a first approximation, the European BB BIS would be required to maintain 20 (?) BIS-BIS connections in the case of a single European Island and each European State having direct attachment to this BB.

From the above discussions, the following recommendation is derived:

Recommendation 5: It is recommended that a single European ATN Island for the whole European Region is established. If mandated by operational or institutional constraints, a separation of the European Region into a few (2 or 3) ATN Islands would be acceptable without compromising the postulated design goals for the routing architecture.

4.4 Connecting RDs to the European ATN Island Backbone

If the above proposal is accepted, namely the formation of a single European ATN Island with a single BB BIS, there are 2 alternatives for the connection of Island RDs to the BB BIS:

- Direct attachment of RDs to the BB BIS (Alternative A);
- Attachment via TRDs to the BB BIS (Alternative B).

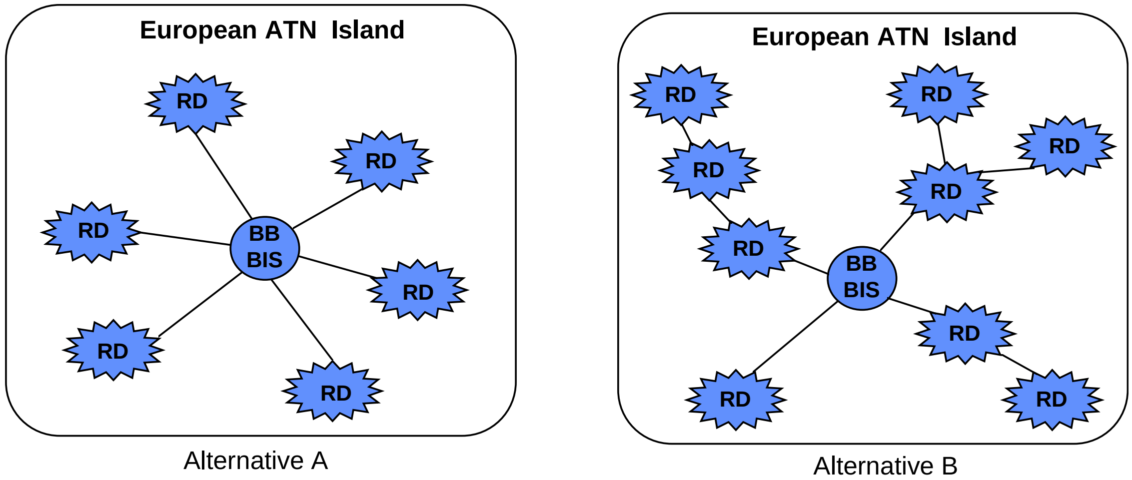

Figure 1: Basic Alternatives for Connecting RDs to the Island's Backbone

Both alternatives are illustrated in Figure 1. There is not a lot of difference between the two alternatives; alternative B can be seen as an extension to alternative A. In both alternatives the BB BIS will act as the hub in a star-type routing topology. This star-type topology will prevent routing loops and ensure the stability of the overall routing architecture.

In Alternative A all RDs of the Island are directly attached to the BB, i.e. there is a single hop from any Island RD to the BB which is supported by a direct BIB-BIS connection between the RD and the BB BIS. Although this configuration may look very compact with close adjacency of RDs to the Island's BB, there may in practice be long access links to the BB for those RDs which are geographically remote from the location of the BB BIS. However, the main design criteria for this architecture will be the number of BIS-BIS connections which can be supported simultaneously by the BB BIS. As the BB BIS is assumed to be capable of supporting only a limited number of BIS-BIS connections, there will be an upper limit for the number of RDs to be accommodated in such a routing architecture. It is assumed that this limit will be exceeded by the anticipated number of RDs in the European Island and consequently alternative B will have to be considered.

In alternative B, those RDs which are not directly connected to the Island's BB will have the same aircraft related routing information available to them as those RDs directly connected to the BB, and consequently will not suffer from being "remote" to the BB. Beside the direct routes to aircraft connected to their RD (assuming an A/G RD), they will also know the default route to all aircraft. This default route to all aircraft, however, will always be via the RD(s) between the given RD and the BB BIS and will comprise at least three BIS-BIS hops depending on the level of chaining.

It should be noted that in alternative B there is much more impact on those RDs which are connecting "remote" RDs to the BB than on the "remote" RDs themselves. These Transit Routing Domains (TRDs) on the path to the BB have to carry the additional routing traffic, namely those routes to aircraft which are connected to the "remote" RD and which have to be advertised to the BB according to the ATN routing policies. Furthermore, by doing so, they implicitly offer to carry any user data which the "remote" RD may send to/via the BB BIS or receive from/via the BB BIS. This may impact upon the load of the TRD's BISs, but, as explained before, is assumed to be a rare event. To compensate, the TRD learns about the direct routes to aircraft which are connected to the "remote" RD and consequently will be in a position to use these more direct routes as compared to the default route to all aircraft via the BB, if required.

From the above discussions, the following recommendation is derived:

Recommendation 6: It is recommended that the RDs within the European ATN Island are grouped around the European Island's BB according to a star-type topology. In order to limit the number of direct attachments to the BB, **this routing star should be organised in a hierarchical fashion whenever operationally and institutionally acceptable**.

Alternative B is considered most appropriate for those states which opt to subdivide their Administrative Domain (AD) into several RDs. In this case, it is recommended to connect only one of these RDs directly to the Island's BB whereas the remaining RDs are connected to this TRD according to the structure illustrated in Figure 2. As can be seen from this figure, a star-type structure within the AD is proposed. The RD which is directly connected to the BB acts as the default route service provider to all aircraft for the RDs of this AD. This RD can be considered as the BB within the AD. As a result of the mandatory ATN routing policies, it knows about all the aircraft currently connected to the whole AD (i.e. all RDs of the local AD) and can provide to any RD within the local AD a 2-BIS-BIS-hop route to any of these aircraft. To aircraft which are currently not connected to the AD but connected to the European Island, it provides a default route via the Island's BB.

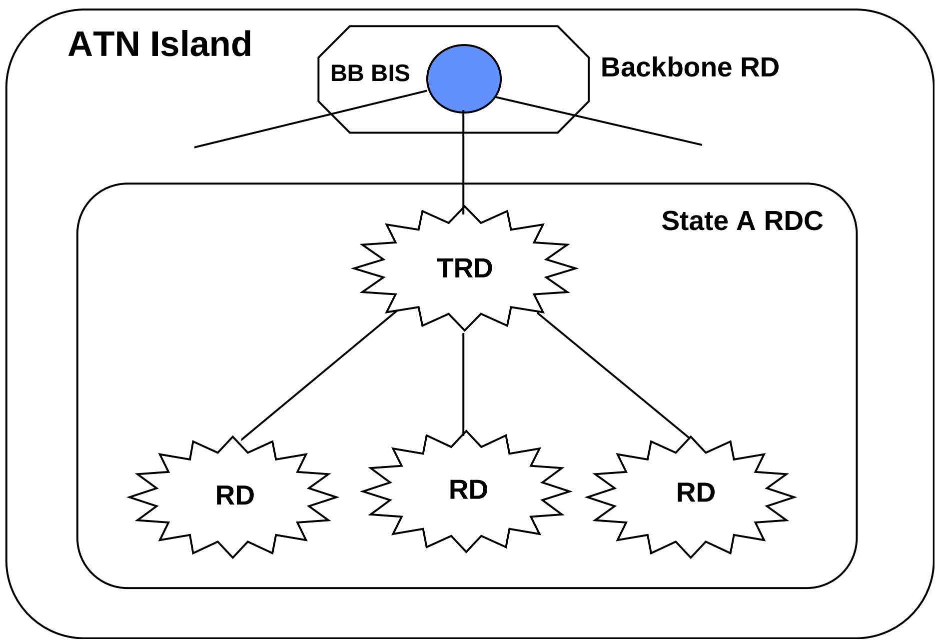

Figure 2: Generic Example of Proposed Arrangement of RDs within RDC

Assuming that the RDs in Figure 2 are each associated with an Area Control Centre (ACC) and are connected to mobile subnetworks covering the area of responsibility of the ACC, each ATN system within this RD will have a direct route to those aircraft operating in the area of responsibility of the associated ACC (assuming that the aircraft has logged on to the RD). Furthermore, each ATN system of the AD (e.g. European state) will have via the AD's BB a default route to all aircraft operating in the area of responsibility of the state and will have via the AD's BB and the Island's BB a default route to all aircraft operating in the local Island. Such a routing architecture is believed:

- to fully meet the connectivity and routing requirements of the ATS providers;
- to minimise the routing information exchange in both the individual ADs and the whole Island;

- to provide a high level of stability and scalability, and;
- to ensure rapid convergence of advertised routes.

From the above discussions, the following recommendation is derived:

Recommendation 7: It is recommended that administrative domains (ADs) which are separated into several RDs, are arranged according to a star-type topology with the hub of the star connected to the Island's BB.

If required/mandated by operational or institutional constraints, a separation of the European Region into a few (2 or 3) ATN Islands would be acceptable without compromising the postulated design goals for the routing architecture.

4.5 Number of BISs per RD

Each route that enters a RD and that is selected as the preferred route according to the receiving BIS's policy has to be distributed to all other BISs within the same RD. Consequently, the number of routes that have to be exchanged within a RD increases linearly by the number of BISs within the RD.

From this considerations, the following recommendation can be derived:

Recommendation 8: The number of BISs within a RD should be minimal and is recommended to be one.

5 Proposed European Routing Architecture

Along with the eight recommendations derived in the above sections, the following example routing architecture is proposed for the European Region.

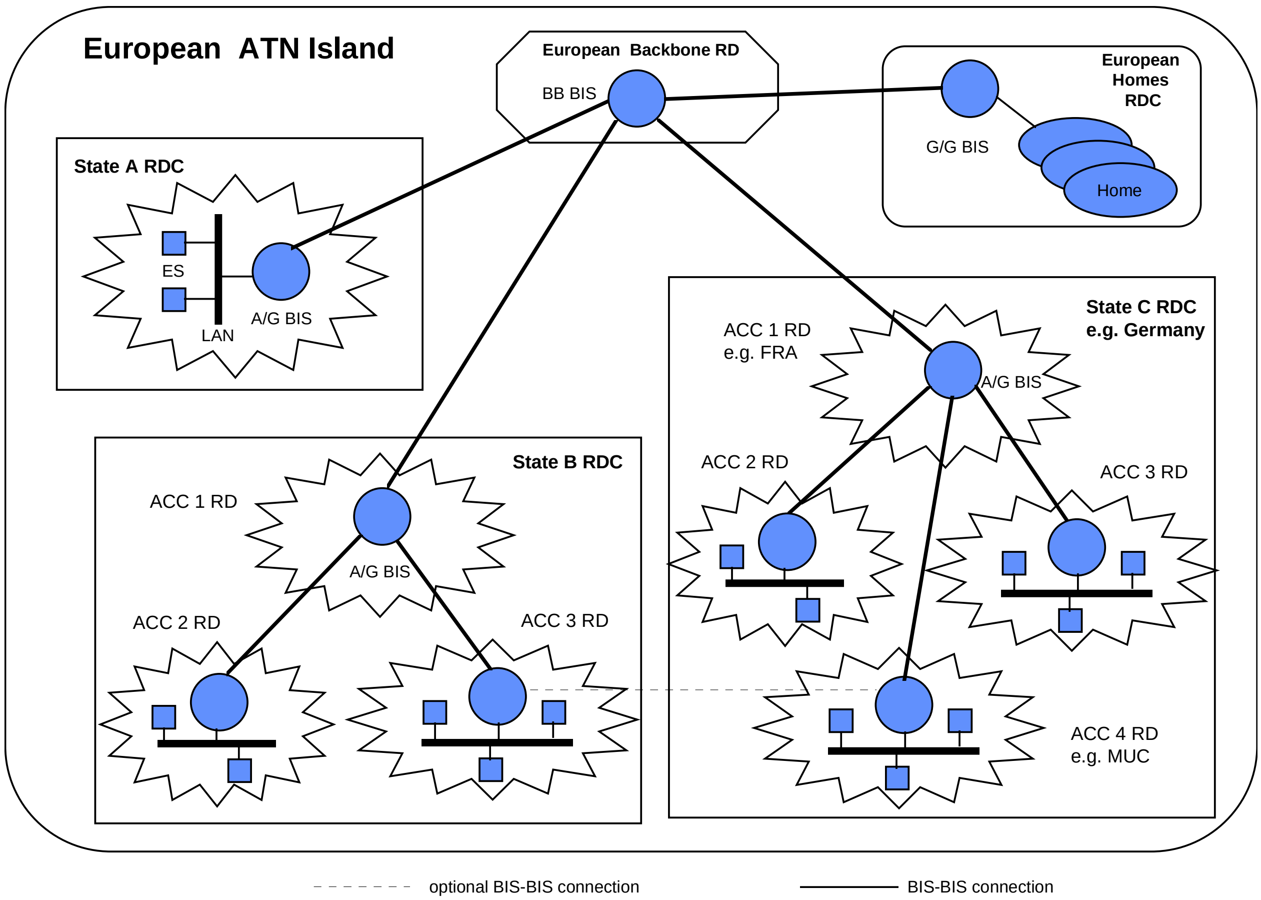

Figure 3: Generic Example of Proposed Routing Architecture for European Region

The design of this routing architecture has been mainly driven by considering the routing to aircraft and focusing on inter-domain routing aspects. It has to be refined in a second step taking into account the requirements and design drivers for the ground-ground routing in the European Region. Furthermore, it may be detailed with respect to Level 2 and 1 intra-domain routing and with respect to other ATN user groups.

Initial ideas in this context include the integration of centralised pan-European ground facilities, such as the Central Flow Management Unit (CFMU) or the European Aeronautical Information Service (AIS) Database, into the BB RD of the European ATN Island, and the full accommodation of ATSO ground systems in A/G RDs.

Appendix A

A1 - Acronyms

ACC	Area Control Centre
AD	Administrative Domain
AIS	Aeronautical Information Service
ATS	Air Traffic Services
ATSO	Air Traffic Service Operators
BIS	Boundary Intermediate System
CFMU	Central Flow Management Unit
IACSP	International Aeronautical Communications Service Provider
ICS	Internet Communication Services
NET	Network Entity Title
NSAP	Network Service Access Point
RD	Routing Domain
RDC	Routing Domain Confederation
RIB	Routing Information Base
SARPs	Standards and Recommended Practices
TRD	Transit Routing Domain