

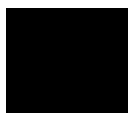
PROGRAMME FOR  
HARMONISED AIR TRAFFIC  
MANAGEMENT RESEARCH  
IN EUROCONTROL



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EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION, EUROCONTROL



## **PD/3 Demonstration Facility Intersite Simulation Requirements Specification**

PHARE/EEC/PD3-1.2.2/WD;1.5

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1.0	21-04-95	Revised to take into account comments arising on Version 0.2	All
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1.4	30-08-95	Further minor amendments arising from ISTF review	All.
1.5	07-05-96	Update to PHARE deliverable.	sec 1.

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## 1. Scope, Introduction and PD/3 Objectives

### 1.1 Scope of the Document

This report is the Multisite Simulation Requirements Specification prepared by the PD/3 Intersite Simulation Task Force on behalf of PD/3. It describes the status of intersite simulation requirements in 1995 before the PMB decision to abandon the multi-site aspect of PD/3.

This document:

- Reports on the work carried out by the Intersite Simulation Task Force (ISTF) of PD/3 as a follow up to its initial activities.
- Identifies requirements for intersite simulation in PD/3
- Makes initial sizing estimates, based on the task force's understanding of the likely system configuration

In addition to further use by PD/3, this document should be of use to other groups interested in carrying out multisite simulations.

Through the document, references are identified by brackets, thus: [].

### 1.2 Introduction

Today's ATC system is at times unable to handle the demands made upon it. Restrictions imposed to safeguard the system from overload often lead to delays during peak periods. In less busy areas the required capacity goals can be achieved by the well-proven technology and procedures that represent "best current practice". However, in the busier areas the scope for increasing capacity through existing ATC methods and technology is limited. Although improvements in the existing methods and technologies must be pursued, changes in the technology and processes of ATC must also be envisaged if capacity and productivity gains are to be secured. The main limiting factor in the present ATC system is the capacity of the controller and hence a means must be found by which the controller can be enabled to handle a larger number of aircraft in a given airspace without significant increase in workload. This will have to be achieved whilst maintaining or improving system safety.

To evaluate the performance of new concepts taking advantage of enhanced technologies, a series of real time simulations entitled "PHARE Demonstrations" will be executed in which the proposed options will be compared and as a result of which recommendations will be made for the future European ATM system.

The term Demonstration is used in the context of PHARE to describe a large scale validation activity, comprising integrated ground system, air system and air-ground datalink facilities. A Demonstration is the last step in a validation process consisting of functional testing, basic evaluation of individual tools and partial validation of subsystems of increasing complexity.

The two first Demonstrations PD/1 and PD/2 will concentrate on the air and ground systems available in the 2000 timescale and will address en-route and TMA research issues more or less separately, using current controller working methods.

PD/1 and PD/2 will investigate the provision of automated assistance to both the Planning and Tactical Controllers and the application of datalink for air to ground communication. The provision of automated assistance to the controller will support him in the resolution of conflicts and in planning the efficient use of the airspace. The introduction of datalink to communicate between the airborne systems and ground environment is expected to remove some of the communication load from the controller, to enable the use of onboard data to improve the precision of the ground system's aircraft model for trajectory and conflict prediction, and in addition a limited exchange of trajectory data.

PD/1 and PD/2 will provide a first step in the process of introducing automated tools and datalink facility within an advanced ATC and airborne environment and of obtaining the controllers' reactions. The results of PD/1 and PD/2 will provide inputs to following PHARE Demonstration as well as help to refine the techniques used in measurement and analysis of the results.

PD/3 will concentrate on the air and ground systems available in the 2005-2015 timescale and will address the influence of different controller working methods. It will bring together the en-route and Extended TMA results, extending the work to encompass a series of full multisector/multicentre demonstrations. PD/3 will try to propose a set of operating procedures based on the results obtained through the program.

### **1.3 PD/3 objectives**

#### **1.3.1 General**

- Validation of the EATCHIP concepts
- Partial definition of the description of the future Air Traffic System concepts

#### **1.3.2 Specific**

The three specific objectives of the large scale PHARE demonstration 3 project are to:

- Provide evaluation of a future ATM concept for the time period 2005 - 2015, which supports the transition of the introduction of 4D and Data-Link equipped aircraft, by combining the following functional elements:
  - - Multi-Sector Planning
  - - Air-Ground integration
  - - Traffic Organization
- while keeping the man in the loop.

- Keep the man in the loop by following a Human Centred Approach with the introduction of new tools to support the controllers in the environment characterised by the above mentioned functional elements.
- Evaluate the feasibility to progressively introduce this new ATM concept.

PD/3 will constitute a further step towards the validation of a long-term air-ground integration concept, but will more specifically concentrate on the validation of the medium term system where the controller remains a key control element. It can also be stated that PD/3 mainly aims at providing results to support the specification of the European ATM System, which will be the first operational system with advanced functionalities and is conceived to progressively replace the system operational at the end of EATCHIP Phase III.

PD/3 will be the first full multi-sector, multi-centre demonstration that will involve a number of research centres' ground and airborne facilities with the expected functionality associated with application timescale 2005-2015. It will be hosted by CENA at Athis-Mons and Toulouse, by EEC at Bretigny and by NLR at Amsterdam.

PD/3 is expected to meet two different sets of objectives: first a set composed of operational objectives, and secondly a set of "collaboration" objectives.

The defined **operational objectives** concern the demonstration of the feasibility of the PD/3 operational philosophy in accordance with the way the foreseen enhanced CNS technologies or automation capabilities can be used and integrated to support it. They must cover:

- the en-route environment
- the extended TMA (ETMA<sup>1</sup>) environment
- the integration of the en-route and ETMA concepts
- the integration of the various air and ground systems by interconnecting them through PATN<sup>2</sup>

For the en-route environment PD/3 is intended to demonstrate the quantitative capacity and productivity benefits of the core<sup>3</sup> PD/3 operational philosophy, ie the traffic organisation planning philosophy, including the following and progressive ATC enhancements:

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<sup>1</sup>The ETMA environment covers the APP sectors and also the ACC terminal sectors dealing with the descending and climbing traffics to and from the concerned airport. On the other hand "En-route" concerns only the ACC sectors outside the extended TMA and dealing mainly with in-cruise traffic

<sup>2</sup>The use of PATN in PD/3 will provide an additional integration test for the ATN concept in a (simulated) ATC environment

- introduction of advanced assistance tools
- introduction of multi-sector planning optimising the way the traffic is organised at a scale larger than the traditional sector
- introduction of 4D trajectory negotiation and 4D planning in a multi-sector environment (some issues concerning for example the mode of co-operation between air and ground, the role of the aircraft and the pilot in the future ATM concept, or the controller or pilot HMI could then be investigated)

In a similar way for the ETMA environment PD/3 is intended to cover the experimental domains related to the traffic organisation planning philosophy with the following ATC enhancements:

- introduction of advanced assistance
- introduction of a general planning function including the Arrival and Departure Managers
- introduction of 4D trajectory negotiation and planning

One important aspect of PD/3 concerns the integration of the en-route and ETMA concepts with the demonstration of a planning function supporting the transition between the en-route and TMA flight phases.

The defined **collaboration objectives**, ie in connection with the capability of the PHARE partners to cooperate in large distributed demonstrations, are to:

- demonstrate the capability for a group of ATC research establishments in Europe to join their skills and efforts to specify, design and implement a common demonstration environment based upon a standardised architecture and integrating the components developed under the other PHARE projects
- demonstrate the feasibility to elaborate and run large distributed demonstrations taking advantage of the facilities available in the various establishments.

The results expected from PD/3 can be summarised as follows:

- demonstrating the feasibility of introducing the multi-sector planning and then the 4D trajectory negotiation in association with the multi-sector planning, and hence the feasibility of the traffic organisation planning philosophy in en-route and ETMA environments

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<sup>3</sup>The core operational philosophy mainly refers to the research domains retained in PD/3 for the en-route and ETMA environments. It is only a part of what should be a complete ATM operational philosophy

- validation of the compatibility of the retained controller - automated system integration options with the traffic organisation planning philosophy
- validation of the compatibility of the pilot - automated system integration options
- validating the interface between the various en-route and ETMA modes of operations and planning tools
- assessing and comparing the quality and performance (e.g. capacity gain or controller workload), the potentialities and drawbacks of the different concepts and associated tools
- proposing directions and improvements for further experiments and demonstrations

## 2. Distributed Architecture

This section describes the requirements for the distributed architecture for the PD/3 demonstration facility.

It consists of the following:

- Review of assumptions, requirements derived from the PD/3 experimental objectives and criteria used to determine architecture requirements
- Description of proposed architecture(s)
- Sizing assumptions
- Outline of required testing approach

### 2.1 Approach to PD/3 Architecture Selection

This section comprises a summary of the assumptions and requirements derived from experiment objectives, and the criteria which have been considered when making proposals for the architecture requirements for the PD/3 demonstration facility.

#### 2.1.1 Experiment Assumptions and Requirements

The PD/3 philosophy for air traffic management will retain the concept of organisation of airspace by geographical volumes, namely sectors and centres, within which each sector is under the responsibility of a controller team. Air traffic will continue to be routed along predefined a route network. Improvements in capacity will be achieved through exploitation of technological advances such as datalinks and tools and an enhanced planning function.

This philosophy is basically consistent with the assumptions concerning airspace structure and traffic flow in existing simulators of current day and near-future ATC systems. Hence these existing simulators shall act as a basis for construction of the PD/3 demonstration facility.

However, there will need to be enhancements to bring these simulators to the level of functionality of the ATM systems anticipated for the PD/3 timescale.

#### 2.1.2 Criteria for Selection of Architecture

A number of candidate architectures have been considered for PD/3 [2]. In assessing them, particular weight was given to the operational and collaboration objectives specified for PD/3 [3]. In particular, the collaboration objectives included “..demonstrate the feasibility to elaborate and run large distributed demonstrations taking advantage of the facilities available in the various establishments..”. This objective was felt to argue strongly for the combination of existing simulators, running locally at their own existing sites, to create a distributed simulator.

Other factors, principally focusing on technical and organisational issues, which were considered to be important were:

- Organisational simplicity. Large scale movements of staff between establishments, whether operational or technical, would be a particularly difficult and expensive problem to overcome. This argued, for example, against an attempt to co-locate the simulators at a single site and using LANs to provide a “distributed” simulator.
- Use of Existing Components. The PD/3 objectives [3] include reuse of facilities and simulators already existing at the different sites. This factor argued for enhancement of existing systems and against trying to build a new simulator to install at all sites.
- Engineering and development simplicity. A loosely coupled system, such as that proposed, minimising inter-site dependencies was felt to be simplest and hence lowest risk.
- Communications feasibility. High levels of inter-site voice or data communications would place a high load on the communications networks and raise the likelihood of bottlenecks and delays. Hence it was felt that inter-site communications between simulator components should be minimised.
- Testing feasibility. The architecture shall allow testing to be carried out efficiently. For example it shall be possible to run the individual simulators standalone as well as collectively.

Application of these criteria [2] has led to the identification of an outline configuration for the demonstration facility architecture, which is described in section 2.2.

## **2.2 PD/3 Demonstration Facility Architecture**

The proposed configuration for the PD/3 demonstration facility is shown in Figure 1 below. There are anticipated to be three separate simulators, one located at each of CENA, NLR and the EEC (although CENA may choose to include two simulators in the configuration). Each simulator would represent one ATC centre. It is currently anticipated that these simulators will be based respectively on DAARWIN, NARSIM and SIM5+. Each of them would require the integration of a number of tools (PATs) and datalink capability. Adaptation to CMS principles and APIs, and use of PARADISE components, should be made in the different sites as appropriate.

An air server component will be required at each of the three sites, with simulation of air traffic being distributed across the sites. It has been assumed that pseudo-pilots will be colocated with the respective air server.

There will be a number of independent flight simulators, including the NLR RFS, the EEC MCS, and perhaps also ISTRES. There may also be a number of research aircraft participating in the simulations, provided by NLR, CAA and DLR.

Communications shall be divided into the following main subdivisions:

- operational communications, for air-ground and ground-ground data communications
- simulation-specific data communications
- voice communications

Alternative multi-site architectures are not considered to provide sufficient reduction in risk or complexity to constitute acceptable fallback options. Hence the only fallback option which is retained as a serious option is to reduce the architecture to a single site

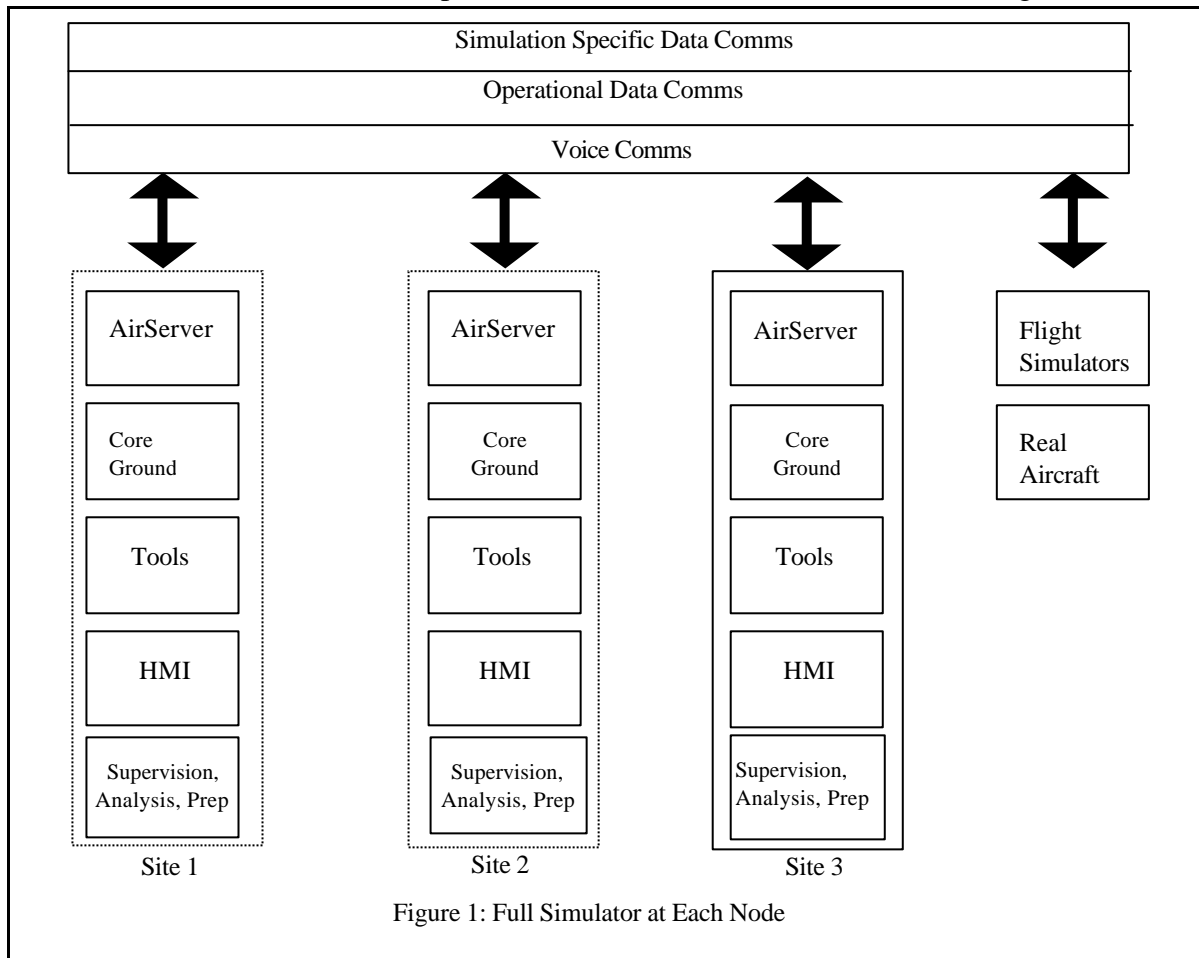


Figure 1: Full Simulator at Each Node

configuration, but use of this option would not meet the PD3 objective of a distributed simulation.

### 2.3 Sizing Assumptions

This section summarises the sizing assumptions which have been made when preparing the proposals made in this document. It shall be noted that the assumptions made here are proposals for a first order of magnitude sizing estimate and are based on the best information available. These may differ from what is eventually adopted, and hence this may result in differences between the conclusions drawn here and what is ultimately required.

The operational ATC organisations to be studied in PD/3 are being defined by other teams [1]. For the purposes of the analysis presented here, it has been assumed that:

- A configuration of simulators such as that shown in Figure 1 is adopted. Note that CENA may require to add a fourth simulator.

- The airspace to be simulated will comprise parts of Amsterdam TMA, Maastricht upper airspace, Reims ACC, Paris ACC and Roissy Charles de Gaulle TMA, together with TMA and En-route adjacent sectors including emulation of adjacent multisector planning areas. Given the distance from Schiphol to Roissy-Charles de Gaulle, it is assumed that a flight duration of somewhat less than one hour is to be expected. The minimum simulation time is one and half hours, and typically simulations are expected to last for up to three hours.
- The number of controller positions required for the simulation configuration is in the process of definition. For sizing purposes it will be assumed that five positions will be required at each centre. In particular, there may be a requirement to have more positions at CENA. The three organisations simulated will require different combinations of controller staff, each of whom will require different support tool combinations. Depending on the choice of operational concept these will be split between roles such as Multi-Sector Planning Controller, Planning Controller and Tactical Controller. The high level requirements for each role are defined in [1].
- The model assumed for estimating the simulated traffic flows is shown in Annex C. The approach taken to preparing the model is to examine the estimated flows into and out of each sector, taking into account the number of aircraft which can be controlled at a time and the time spent in each sector. It is assumed that the En-Route Tactical Controllers will control 30 aircraft each and that the Arrival and Departure Tactical Controllers will control 10 aircraft each. It is further assumed that each aircraft will spend about 10 minutes in a given sector, and that multisector planning will require flights up to an hour ahead to be considered. It should be noted that the multisector planning is assumed to be concerned essentially with flights running along the Paris-Amsterdam axis; the large amount of traffic within an hour's time window (eg from Manchester in the north to Toulouse in the south) is not considered as a part of the experiment. Assuming two En-Route sectors at the EEC and one En-Route and one TMA sector at NLR and CENA, this gives the requirement that the following number of flights will need to be initialised in the simulation systems during a three hour run:

CENA	450 flights
NLR	450 flights
EEC	460 flights

Precise numbers of controllers and pseudo pilots will depend on the final assumptions concerning productivity and working procedures. They will also depend on experiment configuration. For example, the inclusion of datalink capability may significantly affect the number of aircraft which a pseudo-pilot can manage concurrently.

## 2.4 Multisite Testing Strategy

In addition to the normal testing objectives such as verifying that the specification has been met, the testing strategy will have to ensure that the distributed simulation facility is able to function robustly given the complex communications arrangements.

It shall be possible to test each simulator separately in a standalone mode, perhaps using dummy programs to provide external interfaces at lower levels of realism. In parallel with standalone testing and validation the dummy external links shall be replaceable by real external interfaces to the other simulators to enable the coordinated testing of functions. It will be important that multisite testing is not delayed until each individual simulator enhancement is completed: multisite testing shall be started as early as possible. To this end, the teams working on PD/3 need to develop comprehensive external interface documents.

In addition to the software aspects of testing, the data defining each of the scenarios will also need to be checked carefully for correctness and consistency between the sites.

Given this degree of complexity of testing, it will be necessary to establish a coordinated testing plan amongst the PD/3 partners.

### **3. Software Environment**

This section summarises principal conclusions regarding the simulator software environments. There are several main sections. These are as follows:

- Requirements on the software components of the PD/3 Demonstration Facility
- Mapping of partner's simulation facilities to the proposed architecture
- Integration of external components
- Implications of different exploratory scenarios for demonstration facility

#### **3.1 Intersite Aspects of Software Components of PD/3 Demonstration Facility**

This section summarises the intersite aspects of each of the components of the PD/3 demonstration facility. The components are:

- GHMI
- Tools
- Core Ground System
- Air System
- Communications Facilities
- Supervision Facilities
- Data Preparation and Analysis
- Simulation Environment

##### **3.1.1 GHMI**

The GHMIs will require the following general characteristics:

- provide controller support in accordance with the different roles specified by the PD/3 Operational Task Force in the PD/3 Operational Specification [1]. There will probably be a need to provide a number of functionally different types of working position each using different tools and display facilities.
- the working positions will have to support the proposed tools (ie PATs) and integration of datalinks.
- the working positions may well be different for different experimental scenarios, so there will be a need for the controller working positions to be flexible in configuration and capability.

Design of working positions shall take into account the experiences and plans for other activities, such as PD/1, PD/2, ODID and SWIFT.

The operational concept demands intersite interactions in a number of aspects, and there will need to be proper integration of intersite communications aspects when the simulator

designers are preparing the GHMI concept. They will need to take into account the constraints of intersite communication issues, particularly message transmission delays. There will be significant differences between LAN and WAN performance and reliability. Good examples of where this must be considered are those of datalink integration and multi-site planning.

The ISTF will not specify the GHMI since this is not an intersite simulation task.

### **3.1.2 Tools**

Integration of the following externally-supplied tools within each of the simulators will be required for the PD/3 scenarios [1]:

- trajectory predictor (TP)
- flight path monitor (FPM)
- conflict probe (CP)
- (highly interactive) problem solver (HIPS)
- arrival manager (AM)
- departure manager (DM)
- cooperative tools (CT) services comprising presentation of conflict situations and agenda/reminder facility
- multi-sector planning tools comprising on-line traffic complexity analysis, workload estimation and “lookahead” analysis of future situation in response to strategic decisions. (TLS)
- negotiation manager (NM)

Different PD/3 organisations (ORGA and ORGB) will require different configurations and levels of advancement of the tools, so the integration of the tools will need to be flexible. The approach to integration will depend on the local circumstances of the individual simulators employed, within the context of common agreed PATs interface specifications.

Datalink communication procedures will be an integrated part of several tools and many of the tools will require integration with the GHMI.

Particular tools, such as for multi-sector planning and conflict detection, imply the need for inter-centre data exchanges. New ground-ground messages will be required in support of this requirement.

The speed and robustness of WAN connections may place constraints on the usage of the tools.

### **3.1.3 Core Ground System**

It is currently anticipated that a considerable amount of additional functionality will be required in the simulator ground systems to achieve intersite simulation in PD/3. In general terms this will include:

- Exchange of flight plan information and updates with other centres.
- The surveillance simulations of each simulator will need to accept and display remotely generated data from the other centres when there is overlap on radar displays. Simulated surveillance systems will need to represent handling of multiple track sources in these areas of overlap.
- Inter-centre communication between air traffic controllers in adjacent centres.
- Software to support all the required tools and especially the multi-sector planning function. This may include, for example, selective issue, on demand of flight plan information to remote centres for assessment of traffic load.

Note that this will not address the extensive internal changes which will undoubtedly be necessary to the simulators since this is outside the scope of ISTF tasks.

At present the different simulators do not use the same data formats and specific data items. A likely approach will be for the three partners to define a common superset or data abstraction including and defining all the data required. This would act as a common baseline. The common superset should be based on existing standards such as ASTERIX, SYSCO/OLDI and ADEXP. However the existing protocols and data formats may need extension to accommodate future system functionality. Such extensions may be based on existing work on future systems, such as PATs/CMS data formats.

All messages exchanged between simulators shall be constructed using this agreed format, and the differences between the agreed message format and the data acceptable to each simulator resolved by appropriate, site-specific interfacing software. Inevitably this data conversion will create an additional load on the simulators, introducing delays in information availability and slowing response times.

The up-to-date data will be distributed across the simulators and their individual components. The concept of a reference database (c.f. PD/1) modelling the data contained in the simulators will be useful in establishing a consistent and coherent data model across the system.

### **3.1.4 Air Server**

The air server shall be required to simulate many aircraft in a simplified model. More realistic representations of aircraft will be provided by simulators and research aircraft.

The configuration shown in Figure 1 is based on the concept of using three separate air servers, one each in the simulators at EEC, NLR and CENA. This has the advantages of significantly simplifying and minimising the telephone line costs of controller-to-pseudo-pilot voice links, and reducing the volume of state vector data sent over the network. Conversely it makes the software implementation more complex and risky when compared with a single air server.

Software development will be required to enable the simulation of aircraft flying between the three areas simulated by the servers. When an aircraft is about to move from one centre to another, a set of management messages will be exchanged between the air servers, and the

aircraft state vector and trajectory will be used to initialise navigation of a new aircraft in the receiving air server.

Pseudo-pilots would be associated with sectors rather than aircraft, and would hand over their aircraft when they move from one sector (or centre) to the next. The information transferred would also need to include items such as current clearances, control instructions and the possible results of trajectory negotiation.

A number of enhancements will be required to the current air systems used in the simulators. In summary, these are:

- The air server will have to simulate aircraft equipped with FMS. This will have to deal with trajectories generated taking into account 3D and/or 4D constraints, or a mix of constraints.
- A 4D trajectory calculation algorithm will have to be implemented. This may be based on the existing EFMS or a simpler, general purpose trajectory predictor.
- The air server will need to achieve adequate runtime performance. This may be a problem if many 4D trajectory recalculations are required as a result of the chosen PD/3 operational concept.
- Datalink message exchange needs to be implemented in the air server.
- The pseudo-pilot HMIs will need to be able to be usable for the full aircraft sample envisaged in the scenario. For example, they will have to deal with aircraft controlled purely by voice and by aircraft equipped with datalink. The pseudo-pilot HMIs will have to be developed to allow simulation of datalink communications interaction.
- Pseudo-pilots will have to be trained fully to use the facilities of the new air servers.

Most of these tasks relate to general upgrade of the simulator facilities. The ISTF will principally address the datalink message exchange and distributed air server problems.

A related intersite issue is that a separate activity should be launched to ensure that the air servers used by the different centres will provide broadly comparable results. If the air servers produced significantly different results, this could affect the validity of the overall result.

A PD/3 requirement is for aircraft simulators and research aircraft to participate in the experiments. Aircraft simulators and research aircraft could be used for all or only part of a given flight. In the latter case the air servers will need to support transfer of simulation of flights to and from aircraft simulators.

### **3.1.5 Communications Facilities**

A balance must be established between the provision of a highly “realistic” communications environment and the practicability of implementation. In particular, the level of realism of the implemented communications facilities must not be such that it frustrates or risks compromising the success of the operational simulation. There are a number of reasons for this, not least the difficulty in predicting future communications network performance.

Software will be required for the following aspects of communications:

- Operational data communications, including both air-ground and ground-ground links
- Real time distributed simulation-related communications links to pass information which is required purely because of the use of a simulation environment
- Distributed simulation management software, required to coordinate the simulation components.
- Voice communications systems

### **3.1.6 Supervision Facilities**

Enhanced supervision facilities will be required to support the distributed simulation. Particular new features will be as follows:

- Enhanced monitoring software, able to present the status of other simulation nodes
- Enhanced supervision software, enabling users to establish and co-ordinate the distributed simulation
- Communications software enabling the supervisory staff to co-ordinate the simulation

Possible implementation solutions range from development of a standalone package which will be interfaced to each of the simulators, to the enhancement of each of the existing simulator supervisory components.

### **3.1.7 Data Preparation and Analysis**

Suitable data preparation and analysis tools will be needed to ensure consistency of input data between the sites and to support common analysis of results.

### **3.1.8 Simulation of the Environment**

Provision of a realistic environment will be important in achieving convincing results from the PD/3 simulations. The following will need to be included in the simulation:

- Adjacent sectors, feeding the simulated centres with, for example, overflying traffic on crossing routes.
- The aircraft sample contained in the simulation configuration files loaded at the start of runs shall be realistic in that they shall include a provision for the effects of external systems, such as the CFMU having allocated slots to flights.
- Meteorological data.

This will be a responsibility for analysis in the overall facility specifications.

## **3.2 Mapping of Partner's Facilities to the PD/3 Demonstration Facility**

This section summarises the proposed use of each partner's facilities for construction of the multisite simulation.

### 3.2.1 DAARWIN

The MASS/DAARWIN/HEGIAS platform is currently proposed as a basis of the CENA distributed simulation facility. The main areas of the platform in which enhancements are anticipated are :

- interface to data communications with other elements of the distributed facility
- interface to remote voice communication
- enhancements of the air server subsystem for new functionality (e.g. D/L) and distributed operation
- integration of advanced tools (PATs or other tools like multi-sector planning tool) within ground system
- appropriate GHMI functionality
- provision of distributed supervision support
- enhanced preparation/data collection facilities
- access to meteo server

### 3.2.2 NARSIM

The NLR ATC simulator (NARSIM) will act as the NLR ATC simulator in the multisite PD/3 distributed simulation facility. The principal areas in which enhancements are anticipated are:

- the general architecture will be upgraded to a client/server architecture
- flexibility will be enhanced with respect to simulation control and monitoring:
  - adding and removing servers during a simulation run
  - support of optional multisite supervision control
- the air server will be extended with new functionality as follows:
  - support of datalink with and without pilots intervention
  - distributed simulation operations of air servers
  - with flight handover support attached to the change of frequency
  - support of 4D FMS
- an interface to data communications will be implemented
- an interface to remote voice communications will be implemented
- the integration of the ground system with advanced tools (PATs)
- a harmonised and renewed GHMI
- implementation of new and enhanced validation facilities
- access to meteo server

### 3.2.3 SIM5+

The SIM5+ system is currently proposed as the basis for the EEC component of the PD/3 distributed simulation facility. The principal areas of the simulator in which enhancements are anticipated are:

- interface to data communications
- interface to remote voice communications
- enhancement of air server subsystem for new functionality (eg datalink) and distributed operation (ie distributed air server).
- incorporation of advanced tools within ground system
- more advanced functionality for GHMI
- provision of distributed supervision support
- enhanced data collection/preparation facilities
- access to meteo server

### 3.2.4 Aircraft Simulators

It is currently proposed that the following aircraft simulators will be integrated within the PD/3 distributed simulation facility:

- EEC MCS.
- NLR RFS.
- ISTRES

## 3.3 Integration of External Components

A number of externally-produced facilities will need to be integrated within the various simulators.

The approach to the integration of tools within simulators will depend on the characteristics of each simulator concerned. The PATs integration should make use of PATs/CMS APIs and the experiences of the PD/1 and PD/2 demonstration facilities.

The following externally-produced tools will need to be integrated [1]:

- trajectory predictor (TP)
- flight path monitor (FPM)
- conflict probe (CP)
- problem solver (HIPS)
- arrival manager (AM)
- departure manager (DM)

- cooperative tools (CT)
- multi-sector planning tools (TLS)
- negotiation manager (NM)

Other external components which may supply components for integration include PATN, GHMI, CMS and Meteo.

### **3.4. Implications of Experiment Organisations**

#### **3.4.1 PD/3 Organisations**

The PD/3 programme envisages the implementation of a number of different organisations. These organisations envisage an increasingly complex progression of support toolset, HMI, ATS infrastructure and operational procedures. At present these organisations are defined at a high level, so it is likely that the ISTF will have to fill in the gaps by making assumptions.

#### **3.4.2 Current Organisations**

Currently three organisations have been defined, Org 0, 1 and 2 [1]. These are to be refined to develop two study organisations, as described in section 3.4.3.

##### **3.4.2.1 Org 0**

A Baseline scenario based on purely tactical control procedures and facilities will be used to act as a reference for measuring the benefits of the more advanced systems provided by the PD/3 configurations.

##### **3.4.2.2 Org 1**

The first advanced organisation will be oriented towards a “traffic organisation” strategy with Multi-Sector Planning including tools to allow working by anticipation. In particular this will involve the incorporation of several advanced software tools within the simulators and real-time message exchange between the tools being used at the different simulator sites.

##### **3.4.2.3 Org2**

The second organisation, advanced multi-sector planning will be oriented towards the “deconflicting organisation” concept requiring automatic support tools. This organisation will again require real-time message exchange between the tools being used at the different simulator sites.

#### **3.4.3 Study Organisations**

The IOCPs are to be used as a means of refining the current organisations into the two organisations for study.

##### **3.4.3.1 OrgA**

A Baseline scenario based on PD/1 and PD/2 will be used to act as a reference for measuring the benefits of the integrated PD/3 configuration.

#### **3.4.3.2 Org B**

The advanced organisation will be defined as a result of the exploratory work being carried out in the IOCP programme. It will include air-ground integration.

## **4. Communication Means and Protocols**

The PD/3 Demonstration Facility is proposed to be a distributed system. As such the communications means and protocols will be of great importance. This architecture will require new development for all the simulation facilities since previously they have generally only functioned on a single-site basis.

This section describes the conclusions which have been reached so far for providing communications, as follows:

- Overview of communications requirements in terms of the links and the agents
- Detailed requirements for voice communications
- Detailed requirements for data communications means and protocols

### **4.1 Overview of Communications Requirements**

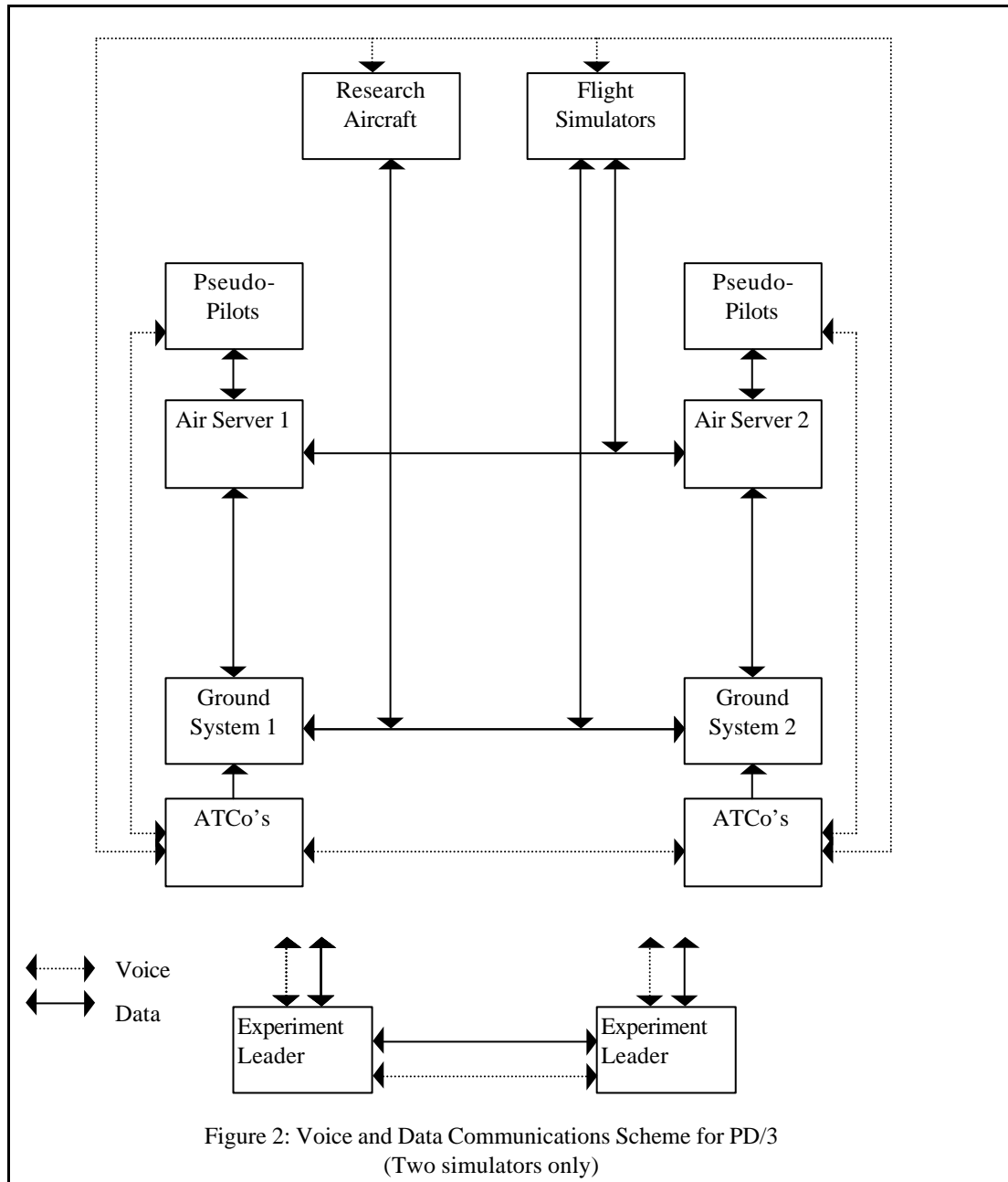
There are a number of different types of communication and different agents which will require provision of communications services. These various types and classes are summarized in the communications scheme shown in Figure 2 (in a simplified configuration of two simulators only).

Section 4.1.1 briefly describes the communication types shown in Figure 2 while section 4.1.2 describes the characteristics of the agents.

#### **4.1.1 Communications Types**

The required communications can be categorised in terms of their characteristics into several different communications classes as follows:

- Voice communication between Air and Ground participants in the simulation, i.e. between pseudo-pilots, flight simulator pilots, research aircraft pilots and ATC controllers, or between ATC controllers on different sites.
- Ground-ground data communication between different sites simulating the data which would be exchanged in real life, such as flight plans and coordination information.
- Simulated operational data link communications between ground and aircraft, though in reality between the pseudo-pilot and flight simulator HMIs, and the ground system.
- Real datalink communications between ground and research aircraft used in the simulations.
- Data communications which are required as part of the distributed simulation infrastructure. This will include aircraft state vector data needed for creating the radar picture within the ground system and data exchanged between air servers to achieve the continuous simulation of each aircraft as it transits the system.
- Voice and data communications for simulation management



#### 4.1.2 Requirements of Communicating Agents

A generic picture of the agents which shall participate in the PHARE PD/3 demonstration is shown in Figure 2 along with the required communication links.

The following decomposition of agents has been identified:

- Pseudo-Pilots
- Air Server
- Ground System
- Air Traffic Controllers
- Experiment Leader
- Flight Simulators

- Research Aircraft

The requirement for each of these will now be described.

#### **4.1.2.1 Pseudo-pilots**

Each pseudo-pilot will require voice links with one tactical controller only. These will represent air-ground voice links. It is assumed that there will be no requirement for voice links between pseudo-pilots and planners or multisector planners.

The tactical connection will represent the r/t of 10 to 20 aircraft under control of one tactical controller/planner team.

Each pseudo-pilot will require data links to one or more tactical controllers, planners and multi-sector planners, representing air-ground datalinks.

The interface between pseudo-pilot and air server should be directly via a computer terminal or, to reduce communication needs, indirectly via a front-end computer. This terminal or computer need not necessarily be located at the same site as the air server, which may lead to additional inter-site communication.

#### **4.1.2.2 Air Server**

The air server will require an interface to the pseudo-pilot for control of aircraft navigation. For PD/3 the air server will have to be equipped with digital datalink and 4D FMS functionality. It is planned that 70% of aircraft will be so-equipped.

#### **4.1.2.3 Ground System**

This system shall comprise the core ground system (including the kernel functionality, such as surveillance, flightplan processing and data distribution), PATs and GHMI.

The ground system simulators require simulation-specific communications (eg with the other ground system simulators for simulation control) and operational communications (between ground systems, and between ground and air).

Inter-site communication shall be specified in terms of communications between each ground system, rather than between the individual subsystems of each ground system.

#### **4.1.2.4 Air Traffic Controllers**

The following Air Traffic Controller's are identified for PD/3 [1]:

- En-route
  - Multi-Sector Planner (MPLC)
  - Planning Controller (EPLC)
  - Tactical Controller (ETC)
- ETMA
  - for Arrival phase:
    - Arrival Terminal Sector Planning Controller (TPLC)
    - Arrival Terminal Sector Tactical Controller (TTC)

- Initial Approach Controller (INI)
- Intermediate and Final Approach Controller (ITM)
- for Departure phase
  - Departure Terminal Sector Planning Controller (TPLC)
  - Departure Terminal Sector Tactical Controller (TTC)
  - Departure Controller (DEP)
  - Local Controller (LOC)

It is likely that, given the number of controllers who are likely to be deployed in experiments (see section 2.3) that not all these roles will be used or, alternatively, roles may be merged and carried out by a single controller. For the purposes of the estimation presented here the INI, ITM, DEP and LOC roles are not represented, and the Arrival and Departure TPLC and TTC roles in each ETMA sector will each be merged and carried out by an arrival and a departure controller.

Air Traffic Controllers communicate with their own Ground System functions via the HMI of a Controller Working Position (CWP) in order to perform their ATC tasks in their sector or multi sector planner's area.

Depending on their role, various Air Traffic Controller types will need local and intersite voice and data links with other Air Traffic Controller roles, and with local and remote pseudo-pilots, flight simulator and research aircraft crews.

#### **4.1.2.5 Experiment leader**

Each facility will have its own (local) experiment leader. Also RFS, Research aircraft and MCS may need their own (local) experiment leaders. The experiment leaders will control and operate their own facilities via a local supervisor interface. One experiment leader would be in control of the run to coordinate management and control experiments.

Experiment leaders of each simulator would need to be able to communicate with the other simulation experiment leaders. It may be sufficient for the flight simulator and research aircraft experiment leaders to communicate only locally with their own simulation leader, or it may be necessary for them to also communicate with the overall supervisor.

There shall also be an overall supervisor, or joint overall supervisory team, responsible for the PD/3 simulation. This overall supervisor would be responsible for taking decisions such as whether to end a simulation in which erroneous data had been found.

#### **4.1.2.6 Flight Simulators**

The RFS and MCS flight simulators are located at NLR and the EEC respectively. The crews shall need to communicate with experiment leaders and controllers, and to listen in on pseudo-pilot communication on the same frequency.

ISTRES facilities may also be included.

#### 4.1.2.7 Research Aircraft

These aircraft shall fly under control of a "real-world" ATC Centre. This requires simulated ATC, which shall not be in conflict with "real world" ATC. For the experiment communications for control of the flights would be based on the facility at NLR, DRA and NLR.

The research aircraft will require both voice and datalink communications services.

#### 4.2 Requirements for Voice Communications

This section will describe the general requirements for the PD/3 Demonstration Facility voice communications infrastructure and implementation, both in terms of the means of communication and the protocols.

The following subjects are addressed:

- Realism of communication links
- Physical means of communication
- Approximate sizing of required communication capacity
- Communication protocols, software and interfacing requirements
- Hardware and software requirements

##### 4.2.1 Realism of Voice Communications Links

This section reviews the required level of realism for the voice communications facilities provided for each participant in the simulation.

Pseudo-pilots, flight simulator and research aircraft crews shall be able to follow the conversation of all other aircraft on the same simulated frequency with their tactical controller, perhaps on a tele-conference configuration of telephones (using head-phones).

Combining a transfer of flight (to another (pseudo)-pilot) with a change of frequency is sufficient to maintain a voice communication network where all related flights, under the control of the same tactical controller, are present on the same frequency.

It is also desirable that only one person can speak on a frequency at one time since several people trying to talk on the same radio frequency at the same time should block each other. However, this constraint is not feasible with standards telephone circuits.

Ground-ground voice communication requires voice communications links able to simulate, to a realistic level, the links between sectors and between multi-sector planners and sectors.

The **multi-sector planner** and **planner** controllers shall be able to have open telephone lines with the Air Traffic Controllers of at least adjacent centres. In terms of realism, the use of point-to-point telephone lines would be sufficient.

It shall not be necessary to have voice communications links between tactical controllers and planners of one sector since they will be working as a team.

It will be important that all the voice links are well integrated in the appropriate HMIs. Different ground-ground and air-ground connections may be concerned. For example,

depending on the particular experiment, a given CWP may have to communicate with the pilot of a flight simulator (which may be situated locally or at a remote site) and one or more pseudo-pilots (normally at the local site except possibly at handover between centres), all on one simulated communications frequency. Consistent interfacing will be needed so that the controller's actions are the same whether he is working with a local or remote site. For example, if the touch-screen is used for establishing connections, both the local and remote voice links should be accessed through this screen.

#### **4.2.2 Physical Means of Communication**

This subsection reviews the possible physical means of communication.

In general, it will be important to minimise the number of open voice communications lines given that a typical scenario duration is three hours and the cost of keeping a international line open for a long time will be high. For this reason, dialup lines will probably be preferred.

##### **4.2.2.1 Air-Ground Voice Communication**

The infrastructure required for voice communications will be simpler and less costly to achieve if the parties which communicate most closely are co-located, thereby also minimizing disruption from the current hardware configurations. Hence pseudo-pilots shall be colocated with the controllers with whom they will spend most of the time communicating. When control of aircraft is transferred to another centre, a pseudo-pilot at the new centre will take on responsibility for the aircraft concerned.

The approach to integrating these various participants would depend on the particular characteristics of each voice communication system at each site.

However, executive controllers may have to communicate with flight simulators and research aircraft at remote locations.

A solution would be to start a tele-conference by telephone for each tactical controller and to connect MCS, RFS and the research aircraft, if necessary, and to connect the pseudo-pilots during the simulation. (The research aircraft will use, for example, VHF for air to ground communication and this communication channel would have to be relayed to one of the tele-conference configurations.). At least one air-ground VHF frequency will be needed for experiment management.

An alternative for standard telephone connections would be the use of ISDN [4]. In particular, if use of ISDN can be combined with some use of data communication applications, ISDN may also be cost effective.

##### **4.2.2.2 Ground-Ground Voice Communication**

Point-to-point remote telephone connections are required between pairs of:

- multi-sector planners
- planners

when these are located at different sites.

To reduce costs it would not be necessary for these links to be open at all times. Given that several international, long-distance links will be needed, this will be important. However, the links shall be quick to establish, preset dialing codes being a minimum.

#### 4.2.2.3 Experiment Control by Voice

The experiment leaders and overall supervisor(s) will need to coordinate their work. For this a tele-conference configuration or a set of point-to-point connections shall be provided.

#### 4.2.3 Approximate Sizing of Required Communication Capacity

The numbers of pseudo-pilots and controllers in each site will depend on the particular organisation being studied. For the purposes of sizing a general communications configuration has been adopted as representative of the experiment organisations, but this shall be taken as the best current estimate based on the information available.

The configuration has been based on the estimation made in section 2.3 and the controller roles identified in section 4.1.2.4. In particular it should be noted that several ETMA-related roles have been merged.

The possible voice communications topology for this general configuration is shown in Figure 3.

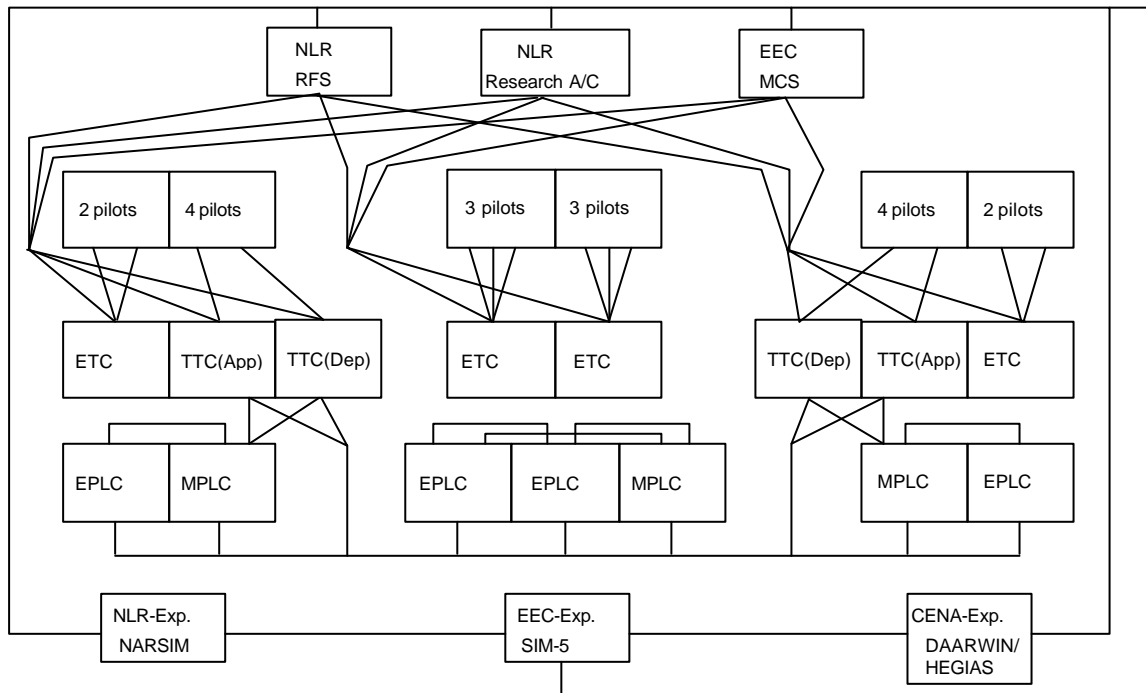


Figure 3 - Scheme of Voice Communication connections

The table overleaf expresses this configuration in terms of the assumed number of controllers and pseudo-pilots at each site:

Other positions may be required, such as feeder positions representing adjacent centres and/or Tower Control. In particular, some additional positions are mentioned in reference

[1], particularly for TMA functions, such as the local controller, although it is not clear whether these would be represented by real controllers. However, these potential requirements will be ignored for the moment given the practical difficulties in securing assistance from the number of ATC controllers implied by the table above.

	CENA	NLR	EEC
Experiment Leads	1	1	1
Multi Sector Planners (MPLC)	1	1	1
En-Route Planners (EPLC)	1	1	2
Tactical Controllers (ETC)	1	1	2
Approach (Tactical TTC)	1	1	0
Departure (Tactical TTC)	1	1	0
Pseudo-Pilots	6	6	6

The following table contains a list of estimated minimum required voice connections which need to be available at each site for each class of simulation participant (ie multiplanners at CENA require at least 3 internal and 7 external connections to other participants). The table excludes connections relating to the aircraft simulators and research aircraft:

	CENA		NLR		EEC	
	Internal	External	Internal	External	Internal	External
Experiment Leads	0	2	0	2	0	2
Multi Sector Planners (MPLC)	3	7	3	7	2	8
Planners	3	3	3	3	2*2	2*4
Tactical Controllers (ETC)	4	-	4	-	6	-
Approach (Tactical TTC)	2	2	2	2	-	-
Departure (Tactical TTC)	4	2	4	2	-	-
Pseudo-Pilots	4*1	-	4*1	-	6*1	-
Total	20	16	20	16	18	18

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Note that:

- experiment leads need to be able to communicate with all external sites. A tele-conference would be desirable between the experiment leaders. Communication with local participants is assumed to not require any special internal voice links since these can be achieved by face-to-face contact.
- the planner and executive controller work as teams with direct verbal communication, not requiring communications equipment between them and requiring only one set of voice communications equipment with the outside world.
- multi-sector planners talk to all other multi-sector planners, all planners, departure and arrival controllers. It has been assumed that the multi-sector planner to pseudo-pilots connections will be datalink only.
- planners talk to all multi-sector planners, planners, approach and departure controllers at the local and adjacent sectors.
- each tactical controller talks to one or more pseudo-pilot on one frequency.
- each approach and departure controller talks to one or more pseudo-pilot on one frequency, to the related departure and approach controllers, to the multi-sector planners and with the adjacent sector planner.
- pseudo-pilots talk to only one local planner/tactical controller team or the approach and departure controllers.
- the number of connections shown in the table is the number of connections required at a site - since there are two ends to each link, the number of links should be found by dividing the number stated by 2 to avoid double counts.
- internal switching may help to reduce the number of external voice connections.

Connections to pilots of flight simulators and research aircraft need to be variable to accommodate changes in the controlling site (for example the simulator pilot will need to talk to the tactical controller who on some occasions will be local (eg RFS when in airspace simulated by NLR) or remote (eg RFS when in airspace simulated by EEC or CENA).

The table overleaf summarises the additional links necessary for flight simulators and research aircraft.

The table does not include allowance for voice connections arising from use of ISTRES facilities.

To clarify the derivation of the figures in the analysis, consider the following example - RFS leader needs to talk to local experiment leader and CENA/EEC experiment leaders (both remote); RFS pilot needs to be able to talk to RFS leader and possibly a local tactical/arrival/departure controller (local) and/or CENA or EEC tactical controllers, or CENA arrival/departure controllers (remote).

	CENA		NLR		EEC	
	Internal	External	Internal	External	Internal	External
Experiment Leads	-	3	2	1	1	2
Multi Planners	-	-	-	-	-	-
Planners	-	-	-	-	-	-
Tactical Controllers	-	3	1	2	2*1	2*2
Approach	-	3	2	1	-	-
Departure	-	3	2	1	-	-
Pseudo-Pilots	*	*	*	*	*	*
RFS - pilot	-	-	3	5	-	-
RFS - leader	-	-	1	2	-	-
MCS - pilot	-	-	-	-	2	6
MCS - leader	-	-	-	-	1	2
Real A/c - pilot	-	-	-	8	-	-
Real A/c - leader	-	-	1	2	-	-
Total	-	12	12	22	5	14

\* If the pseudo-pilots are to be “on-net” with the simulators and research aircraft, additional links will be required.

In preparing this table, it has been assumed that:

- A separate leader is required for each of the MCS, RFS and research aircraft, and he/she will have to talk with the local leaders at each site as well as the corresponding pilot.
- MCS is located at EEC and is therefore internal to EEC.
- RFS is located at NLR and is therefore internal to NLR.
- One research aircraft is assumed, external for every site, but the aircraft experiment leader is internal to NLR.
- The tactical controllers will also have to talk with RFS, MCS and research aircraft.

Since the figures allow for the simulator or research aircraft representing a flight in different centres, except in a worse case of the simulators and research aircraft all working with a site at a given time, the number of links required concurrently would normally be lower at a given site.

#### **4.2.4 Hardware and Software Requirements**

Individual voice communications switching systems will be site specific. Additional investment may be required to enhance the respective voice communications systems since in general the current facilities are anticipated to be inadequate. If procurement is necessary, this needs to be initiated early in the programme to allow time for delivery and installation.

If point-to-point telephone lines are used, normal telephone equipment would form the basis of the facilities, combined with a suitable switching system. However, if other approaches, such as ISDN or teleconferencing are used, use of special lines will need to be obtained. At present the choice between the possible solutions requires further investigation by appropriate specialists.

The partners will need to ensure that:

- sufficient external lines are available and can be held open for the duration of the experiment runs
- line technology provides a simulation of radio and conventional telephone links
- the cost can be accommodated within the relevant budget(s)
- lists of line numbers and correspondents are supplied well in advance to allow the simulators to be set up accordingly

### 4.3 Requirements for Data Communications

This section will describe the general requirements for the PD/3 Demonstration Facility data communications infrastructure and implementation, both in terms of the means of communication and the protocols.

The following subjects are addressed:

- Realism of communication links
- Physical means of communication
- Approximate sizing of required communication capacity
- Communication protocols, software and interfacing requirements
- Hardware and software requirements

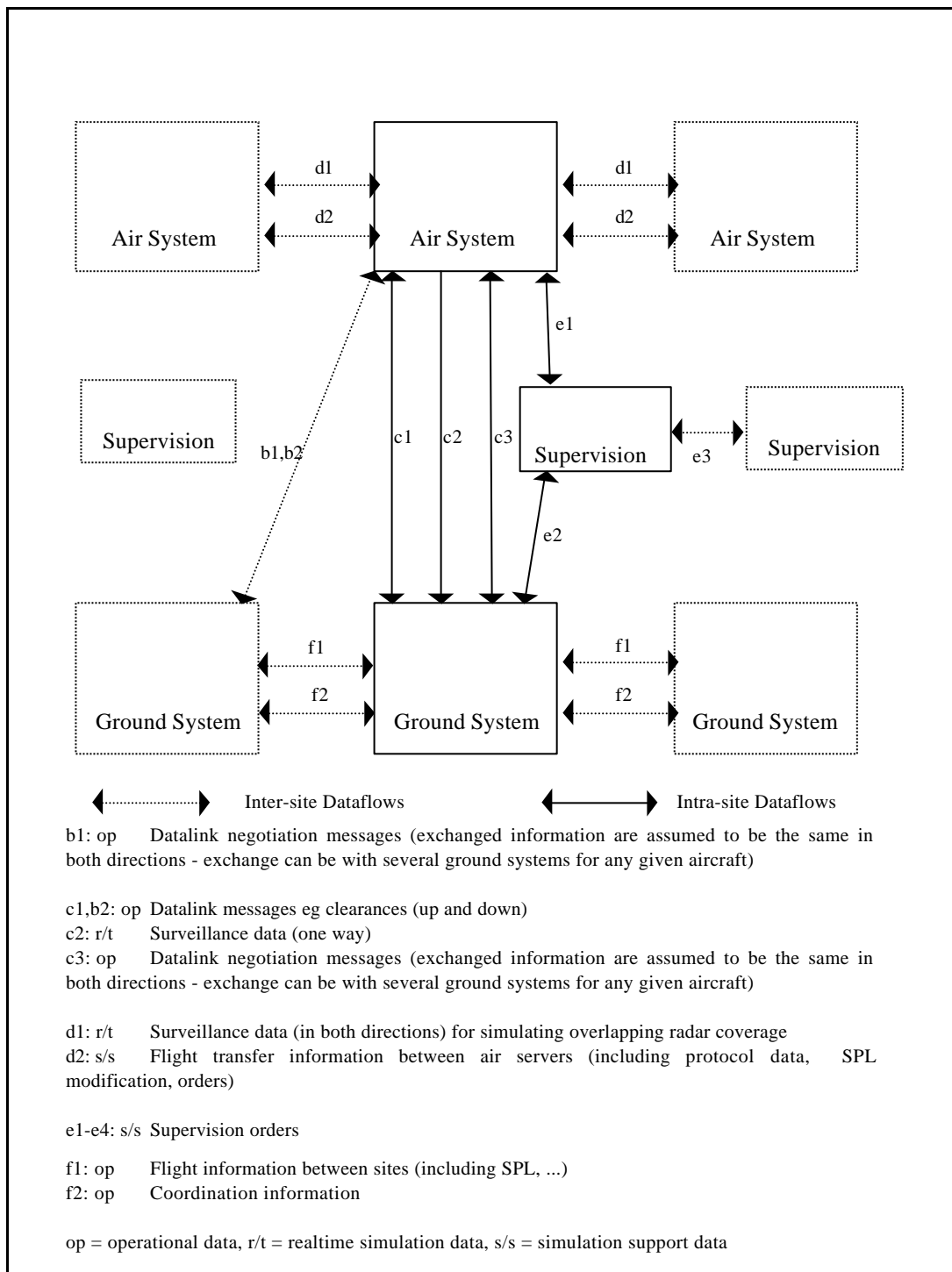
#### 4.3.1 Realism of Communication Links

Three classes of digital data communication requirements between the components of the PD/3 demonstration configuration have been identified:

- **ATN experimental or “operational” communications.** Some components and classes of data communications shall use an ATN, such as ground-air communications between controllers and pilots. Hence PD/3 will require either simulation of or access to an ATN.
- **Real-time simulation data.** This class covers data communications required for real-time simulation of the representation of real-world conditions. Typically this class concerns data such as the state vectors reported by the air server to the radar simulation.
- **Simulation support communications.** This class covers, for example,
  - Control of the simulation process (start, stop commands).
  - Control of individual flights (start, stop, transfer of flights between air servers).
  - Monitoring data, concerning the overall simulation process.
  - Logging of events and time-periodic data for post-processing.

Figure 4 presents a simplified view of the different communications links which are required in the PD/3 simulation, and indicates which of the links corresponds to which of the above classes. For convenience only the communications between one site (air and ground systems) and the others are considered.

Note that flows c1, c2, c3, e1, e2 are dataflows internal to a given site whereas dataflows b1, d1, d2, e3, e4, f1 and f2 are dataflows between sites. This section focuses on the latter group of dataflows since dataflows internal to a site over the local LAN should be much less difficult to achieve.



The required realism of these groups of communications is as described below in sections 4.3.1.1 to 4.3.1.3

#### 4.3.1.1 ATN Experimental Communication.

ATN communication is part of the multi-site simulation. The main requirements imposed in order to achieve realism are:

- The performance demonstrated on the network should comply with the expected operational performance of a future ATN. If, in operational sense, a compliant network is selected (eg PATN), then this will promote realism. At the same time, to accommodate future network performance enhancements, it shall be possible to configure the system to use simulated links which will provide better than current day performances. This will require the capability to simulate air-ground communications via ground-ground means and WAN communications via LANs.
- The selected network should be able to work with the expected response performances of a future ATN. Because the simulated traffic density on the ATN is less than under future operational conditions, an additional workload may have to be imposed in order to achieve sufficient realism. Moreover, because most of the Air-Ground datalinks are in fact intra-simulator data transfers or intersite Ground-Ground communications, it is required that appropriate simulation of transmission delays is available, at least for Air-Ground communications.
- Because pseudo-pilots will not be able to cope with all the required manually performed dialogues, (because of the number of simultaneous controlled flights), it may be required to treat part of the airborne side of the dialogues automatically, simulating manual treatment. This leads to an extra delay modelling requirement, imposed on the network transactions, for simulated pilot responses, which will be put as an additional requirement to the air server.

ATN covers ground-ground communication as well as air-ground communication. Ground-ground datalink communication is concerned with planning and coordination. For these exchanges precise timing responses will not be of critical importance except if interactive tools are involved.

Air-ground datalink communication is concerned partly with tactical control. This is time-critical with respect to both the HMI aspects and the requirements of responses for reliable and proper functioning of tools and algorithms. The most time-critical phase of the flight is the approach phase. Applications of optimizing approach sequencing are very sensitive to response times as well for automatic tools as for human control functions. These applications will probably only be able to use datalink communication if short message transmission delays are achieved [1].

Considering delays due to transmission and workload congestion, in the strategic phase delays up to about 1 minute may be acceptable, while in the en-route tactical phase delays in the order of 30 seconds may be acceptable, if, at most, datalink is used only as additional communication medium. However, in the approach phase maximum responses of only a few seconds are required.

#### **4.3.1.2 Real-time Simulation Data Communication.**

The largest contributor to this communications data class is surveillance information.

Surveillance information must comply with two requirements:

- Surveillance data, after tracking, shall represent a tracked trajectory, that is sufficient realistic to be recognized by the air traffic controller as an (almost) research aircraft.

- Surveillance data, after tracking, shall be realistic enough to allow tools and algorithms to function in a proper way.

Primarily this imposes requirements to the Air Server (see section 5) and secondly requirements on (intersite) data communication.

With respect to data communication capacity, this implies, firstly, that, for the tracking processes, it will be sufficient if new flight status data, e.g. position, speed and heading, are available each 3 to 10 seconds. Secondly, that only surveillance data of flights within coverage of the simulated radar(s), are to be communicated.

With respect to data communication delays, a delay in the order of magnitude of a few seconds are acceptable, because it is of the same order of magnitude as the precision of the flight trajectory predictions and it simulates the transmission delays in a real world system.

The data processing within a real system may allow for extrapolation of time-stamped positions. The surveillance module, simulating radar surveillance and tracking, shall also allow this by providing extrapolation of observed aircraft positions using the time-stamped message data.

Special flights, such as those flown by RFS and MCS, are essentially not different with respect to their contribution to the surveillance information. Provision must be made in the appropriate simulator interfaces for regular reporting of positions using similar formats to the standard air servers.

- RFS and MCS will require surveillance information from air servers in support of the visual representation of traffic visible in the direct vicinity of the aircraft (less than 10 NM).

It is possible that this information will be considered essential because it may be judged as replacement for the loss of "third party" information" if tactical control via datalink is used.

Further special processing is required for the research aircraft. Because "real-world" surveillance information will not be available easily and/or not usable, it will be required for this aircraft to determine its position itself (using e.g. the pressure altitude, a GPS receiver or an INS, or using the position and altitude, determined by EFMS), to relay its flight status information to the Ground Station at NLR (by satellite, VHF or SSR mode-S), and for special software to communicate these data afterwards as surveillance data to the Ground Systems. The surveillance information generated in this way will conform the principle of ADS.

Overall, therefore, attention needs to be paid to any significant differences in the delays in communicating positional information to the respective ground systems from each of the platforms providing the air system representation (ie air servers, flight simulators and research aircraft).

#### **4.3.1.3 Simulation Support Communications**

Simulation control data communications should not normally have a significant impact on the realism of the simulations. There is one very significant exception to this: control messages must ensure that the simulators remain in sufficiently close step with each other that events in different simulators retain the proper sequences.

A further exception is the control of flights simulated by flight simulators and research aircraft. If flights are to be properly integrated with the air server traffic it will be important that a flight can be initiated at a precisely defined real and simulated time and place. In addition to the problems of communication delays, this requirement imposes some demands on the efficiency of the start-up procedures of MCS and RFS.

Proper flight start-up procedures will become even more important, if the approach of transferring flight capability between an Air Server and MCS or RFS is required (as well between two Air Servers).

Flight start-up procedures of the research aircraft will be difficult to manage in a realistic and timely way.

### 4.3.2 Approximate Sizings

#### 4.3.2.1 Approximate Sizing of Required Communications Capacity

This section contains a first estimation of the minimum required communication capacity, based on initial assumptions for message flows, sizes and timings. The reasoning for the table contents (eg Security Factor) is given in sections 4.3.2.1.1 to 4.3.2.1.9.

Figure 4 showed the key data flows in the proposed architecture and the table below shows the approximate data exchange requirements.

##### 1. Intra-site

{PRI VAT E }Flow F	Purpose	Size [bits/message]	Freq. [Hz]	No. of Flights	Security Factor	Bandwidth [kbits/sec]
c1:	Datalink	400	≤1	1	4	1.6
c2:	Surveillance	640	0.1	280	2	35.8
c3:	Datalink negotiation	1000	0.007	196	4	6.1
e1-2:	Supervision	300	0.01	1	2	0.6

## 2. Intersite

{PRIVATE}Flow F	Purpose	Size [bits/message]	Freq. [Hz]	No. of Flights	Security Factor	Bandwidth [kbits/sec]
b1:	Datalink negotiation	1000	0.007	196	4	6.1
b2:	Data link	400	≤1	1	4	1.6
d1:	Surveillance	640	0.1	280	2	35.8
d2:	Flight transfer	6000	0.05	1	10	3.0
e3:	Supervision	300	0.01	1	2	0.6
f1:	SPL	5000	0.008	100	4	16.6
f2:	Coordination	5000	0.2	1	4	4.0

A distinction is made between intra and intersite flows, since while being logically equivalent, the practicalities of intersite data flows will be more complex with, for example, a rather lower data capacity. Therefore the following requirement concentrates on intersite communications bandwidth requirements.

The Frequency is the average number of messages of the given type sent per second, and the “Number of Flights” allows for the cases where this frequency relates to one flight but information on several flights has to be sent. A “Security Factor” is introduced to permit some, albeit crude, allowance for messages being sent in bursts rather than a regular stream. It is likely that there will frequently be a simultaneous occurrence of messages, resulting in peaks in the flow. For the more constant flows of data (e.g. surveillance data) a low “security” factor or multiplier has been applied. For bursty traffic (e.g. negotiation data) a high “security” factor of around ten has been applied.

The Bandwidth is the number of bits which need to be transferred across the network per second, and is equal to Message Size x Security Factor x Frequency x No. of Flights.

Some further definitions of these parameters are given in Annex B.

No specific transit delay time, or maximum delivery time for a message, has been imposed on the calculation at this stage of the analysis. The message transit delay time will be a function of the intrinsic network delay, the message size and the network bandwidth. It is likely that some messages will have specific message transit delay requirements, for example:

- simulation control messages need to arrive within 2 seconds of message dispatch (otherwise there will be a danger of the simulators not being synchronised)

- surveillance messages (LAN & WAN data flows) will need to arrive within 5-10 seconds of distribution (otherwise the surveillance picture will become very stale)
- some very low frequency messages (eg d2, f1) will have a maximum delay of 5-10 seconds.

These transit delay requirements will make additional demands on the solution for intersite communications.

Since it may be necessary to send data over the network in parallel (eg d1 and d2 messages may be competing for resources), the actual required bandwidth would be a combination of the data sent over any given link, adjusted to take into account allowances for “bursty” data.

The calculations are based on a link between just two simulator sites. Data which has to be distributed to the third site will demand additional communications bandwidth.

Overall these figures imply a considerable intersite communications bandwidth requirement. There may be scope for techniques such as extrapolation, filtering or data compression to reduce information exchange requirements, but counterbalancing this no allowance has yet been made for:

- the message packaging associated with the protocol employed (eg message headers, setting up connections)
- additional load caused by any need to re-send messages (eg in event of message loss)
- handshaking messages associated with message flows (eg confirmation of delivery)
- data exchange requirements which have not yet been identified but which are likely to appear during the PD/3 preparation work

In addition, the sizing does not fully take into account the requirement for a real multi-sector planning activity (ie all the flights which are controlled or about to enter the multisector planning area are not navigated. See Annex C for further details on the scenario employed.)

**Considering the requirements in terms of intersite operational and simulation communications, on the basis of the estimates contained in the table, the data to be exchanged is estimated to require:**

**operational communications (b1,b2,f1,f2) - 28.3 kilobits/second**

**simulation-specific communications (d1,d2,e3) - 39.4 kilobits/second**

**Assuming a margin of 50% to cover the additional requirements of message protocol overheads and unforeseen requirements, the bandwidth requirement would be 40 kilobits/second for operational data communications and 60 kilobits/second for simulation-specific data communications.**

Sections 4.3.2.1.1 to 4.3.2.1.9 provide a description of how the estimates have been derived.

#### 4.3.2.1.1 Flow c1,b2: Datalink Information

This flow is considered as symmetrical (up-link and down-link information size are similar). It represents local intra-site data which would be passed over each simulator's LAN.

The datalink messages covered are assumed to be position reports, clearances etc. An average message length of 400 bits is assumed.

#### 4.3.2.1.2 Flow c2: Surveillance Data.

This flow represents the surveillance data for all flights relevant to the site, also called the site extended view. It is assumed here that all aircraft will be reported every 10 seconds, although the update rate could be as high as every 3 seconds. Annex C should be consulted for the model of data flows between sites.

The number of flights reported to each site will be as determined by the following.

- ni: number of aircraft concurrently controlled by a site
- n1: number of aircraft concurrently controlled at NLR site = 50
- n2: number of aircraft concurrently controlled at EEC site = 60
- n3: number of aircraft concurrently controlled at CENA site = 50
- Ni: number of aircraft navigated in a site. This is the total of aircraft controlled by the site plus aircraft about to enter the airspace simulated in the site from non-simulated airspace and the number simulated in feeder sectors.
- N1: number of aircraft navigated in NLR site = 90
- N2: number of aircraft navigated in EEC site = 100
- N3: number of aircraft navigated in CENA site = 90
- $\alpha$ : percentage of flights of other sites belonging to site extended view. This is the proportion of flights in other sites which are in the domain of interest of a given site (see section 5 for further information). This factor may vary from site to site but is essentially dependent on the operational requirements for data exchange, such as for the Multi Sector Planning. It is assumed here that Multi Sector Planning will require that a given site has surveillance data on all flights within 40 minutes of the site. Since the Paris-Amsterdam flight duration is around 40 minutes, it is therefore assumed that  $\alpha$  should be 100% (see also Annex C for further information).
- E1: number of flights seen in NLR site =  $N1 + \alpha*(N2+N3) = 280$
- E2: number of flights seen in EEC site =  $N2 + \alpha*(N1+N3) = 280$
- E3: number of flights seen in CENA site =  $N3 + \alpha*(N1+N2) = 280$

The surveillance data messages are assumed to be of intermediate size:

- S: size of surveillance information:
  - minimum            576 bits            Horizontal position+mode A, C and ID

intermediate	640 bits	Minimum + ROCD, speed and track heading
maximum	1536 bits	Intermediate + correlation data + time + quality + tendencies

Thus, the total amount of data downlinked locally for one set of state vectors is of the order of  $E_i \cdot S$ , that is  $280 \cdot 640$  bits = 179.2 kbits.

These message sizes assume a worst case with no compression will be assumed on the basis that data compression means additional processing must be carried out at each end of the communications links, increasing end-to-end delivery times for data.

#### **4.3.2.1.3 Flows b1, c3: Datalink Negotiation data.**

The negotiation data has been considered separately from the other data-link information because of likely message size. Also multisector planning means that datalink negotiation could take place with any of the three sites at any time, so the message exchanges could be local or remote between air and ground.

Negotiation normally concerns the next 20 minutes of the flight at least. Because of potential re-negotiations due to unexpected events, the flights will be considered to need to re-negotiate their trajectories every C minutes. Assume C is 15 minutes.

The EFMS negotiation scenario assumes a maximum message size of 10kbits. Normally much less data than this will need to be exchanged. Hence it is assumed that a message length, L, of 1000 bits will be typical.

Each negotiation implies exchange of N messages. From the average EFMS-based negotiation dialogue, a typical sequence would be two downlinked trajectories, an uplinked constraint list and an uplinked tube. Taking into account dialogue management messages (eg acknowledgements), normally N will be approximately 7 per C minutes.

The multisector planning concept means that datalink negotiation may take place with any of the aircraft seen at a site. The number of datalink equipped aircraft will be 70% of the total number of aircraft seen at a site. Therefore, T, the number of aircraft so-equipped will be 70% of 280 aircraft, or 196 aircraft.

The security factor S will depend on the number of controllers carrying out negotiation (ie Multi-sector planners). 4 is assumed since the more negotiations that are carried out in parallel, the higher should be the “bursty” factor that should be taken into account.

These estimations give a peak bandwidth of:

$$S \cdot T \cdot (N \cdot L) / (C \cdot 60) \text{ bits/second} = 6098 \text{ bits/second.}$$

The frequency of messages is  $N / (C \cdot 60) = 0.007 \text{ Hz}$

#### **4.3.2.1.4 Flow d1: Surveillance data.**

It is assumed that each site will send all its surveillance information to the other sites’ air servers in the form of state vectors. The receiving air servers will filter and sort the received data according to their radar surveillance capability and construct the domain extended view for their respective ground systems.

This approach maximises the distribution of surveillance information and is a worst case view. It is believed to be a reasonable assumption because multi-sector planning is likely to demand a comprehensive picture of events at least forty minutes ahead of the current time.

The data sent is the same as for flow c2, except that

- it only concerns the aircraft managed in one site
- it is bi-directional (sending to other air servers and receiving from them)

Each of the three air servers will send out  $N_i$ . Adding the values of  $N_1$ ,  $N_2$  and  $N_3$ , the combined number of state vectors which will have to be sent across the communications networks is 280.

Transit delay requirements will affect the solution further by, for example, requiring provision of dedicated communications lines.

Note that an alternative approach to that shown here is to cross-tell the surveillance information between ground systems after down-telling the data from the respective air servers. If this were so the data flow would be ground-ground rather than air-air.

#### **4.3.2.1.5 Flow d2: Transfer of Flights Between Air Servers**

This allows for the data flows arising from transferring flights between air servers.

The estimated size for flight transfer between air servers is 6000 bits.

If it is considered that each site will transfer at most all its flights to the next site and the maximum flight duration within a site is 30 minutes, this results in a frequency of at most  $n_2$  (ie 90) transfers within 30 minutes.

However, controllers may (with the assistance of automated tools or not) transfer several flights at the same time when, for example, there is a build-up of traffic. In this case there is a high probability of simultaneous events, so a security factor of 10 is chosen.

Transit delay requirements will affect the solution further by, for example, requiring provision of dedicated communications lines.

#### **4.3.2.1.6 Flows e1,e2: Local Supervision.**

This flow will consist of incidental messages, each of size around 300 bits to the Air Server and Ground System at the local site.

#### **4.3.2.1.7 Flow e3: Distributed Supervision.**

This flow will consist of incidental messages required for supervision of the distributed simulation. Each message would be of around 300 bits, and messages would be distributed over the WAN.

#### **4.3.2.1.8 Flow f1: Flight Information Between Sites**

This message flow corresponds to the distribution of system flight plan information between sites. Master site data distribution is assumed in line with section 7.2 and PATs shall gain

access to flight data by calling up the local database rather than making direct, cross-network data requests.

Normally, updates would be sent out whenever the data is changed. It is assumed that five updates will occur once per flight per ten minutes. At a given time  $N_i$  flights will be controlled concurrently at a particular site, giving 90-100 SPLs to transfer in a given traffic set.

A security factor of 4 is selected since the controller may make several changes close together.

Standard SPL traffic is assumed to require a message size of approximately 5 kilobits.

Transit delay requirements will affect the solution further by, for example, requiring provision of dedicated communications lines.

#### 4.3.2.1.9 Flow f2: Coordination Information

This represents the flows for exchanging messages to set up and coordinate flight transfers between sectors and to perform the ground-to-ground part of the negotiation process. On the basis of the estimated traffic flows (see Annex C) 180 coordination tasks would have to be made per hour per sector. Assuming two sectors per site, the coordination frequency will be about 0.2Hz.

A security factor of 4 is selected since the controller may choose to make several coordination actions in one go. The volume of data transferred is set at 5000 bits corresponding to the estimated SPL size.

#### 4.3.2.2 Approximate Capacities of Different Communications Links

For the communication links, several links are candidates for use in PD/3. Some of these use networks with routing services (eg PATN) while others are dedicated point-to-point links (eg "plain old telephone system" or POTS).

The table below shows some approximate current day capacity measurements. In the table, "min" is the lowest value measured, "max" is the largest measured. Only the variable costs are given (per link, based on international rates) as network connections are already available to all participants.

{PRIVATE }Carrier	Bandwidth [kbits/sec]			Delay [ms]			Cost
	min	avg	max	min	avg	max	ECU/hour
Internet		±40	160?	±70	±150	±700	?
ISDN	64	64	64		20	30?	±60
POTS <sup>4</sup>	9.6	±14.4	28.8		20	30?	±30

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<sup>4</sup> POTS stands for "plain old telephone system".

PATN (X.25 g/g subnet)		±1.8	19.2	±100	±150	±1000	?
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For details of the measurements, see Annex B.

Further measurements need to be made to confirm the results. For example, the maximum bandwidth figures are based on measured general international Internet traffic routing (eg including the United States); it is anticipated that due to the Internet implementation within Europe such a maximum bandwidth is not currently available between all the three sites. In particular, it is thought that there is a physical limit of 64 kbits/s on CENA Toulouse Internet access, and this may significantly reduce the practical upper limit for Internet capacity.

**However, when compared with the likely capacity requirements given in section 4.3.2.1 these measurements suggest that for an acceptable simulation performance to be achieved, some of the following steps need to be taken:**

- Use of multiple access lines in parallel (eg multiple ISDN) with the data flows spread across them.
- Buying additional capacity for, for example, PATN from the underlying network service providers, such as SITA.
- Using a mix of communications service providers, such as PATN for simulation of operational services and point-to-point connections for simulation data.

### 4.3.3 Physical Means of Communications

Three classes of digital data communication were identified between the components of the PD/3 demonstration configuration (section 4.3.1):

- Operational ATN communications.
- Real-time simulation data.
- Simulation support communications.

The possible physical means of data communication for these three groups of communication are described below.

#### 4.3.3.1 Operational ATN Communications

The experimental objectives of PD/3 propose that PATN is used to provide the datalink network for ATN communication [3].

PATN is an implementation of a network. It provides:

- physical means of communication
- routing, error recovery and quality of service software
- application software.

Possible physical means of communication are :

- Satellite (mobile sub-networks)

- SSR mode-S (mobile sub-networks)
  
- X.25 WAN (fixed ground sub-networks)
- Ethernet (fixed ground sub-networks)

In the context of PD/3 the ground-ground sub-networks used by PATN would be required to simulate:

- ground-ground communications, such as simulation of centre-to-centre message exchange
- air-ground communication, such as for simulation of datalink transactions between controllers and aircraft simulated in the air server.

For the simulated air-ground links a capability to introduce variable delays will be required in order to simulate the lower and variable transmission rate of the equivalent real world communications systems.

The ground-air sub-networks Mode S or Satcom accessible through PATN should be used for the research aircraft integrated into the simulation. The operational concept for the usage of these links will need to take into account their much lower performance.

The use of PATN has the advantage of using an implementation that anticipates the possible future use of such a system. The benefit may be a more realistic simulation for the end-users, although a realistic software implementation of the ATN is not necessarily relevant for the success of PD/3.

The ability of the PATN to meet the needs of PD/3 are, as yet, unproved. The carrier currently exists in a prototype form - it is as yet unproved whether it can comply with timing, capacity and robustness demands. At this time the PATN provides only some very basic communications applications for information exchange. Hence the partners will have to adapt the applications supplied or develop new applications using the lower level services provided by PATN. For example, this would include up-link of clearances and down-linking of flight parameters.

If the PATN software proves too difficult to develop, or the performance and reliability are inadequate an alternative solution will have to be sought. Such a possible alternative solution would be to use a commercial off-the-shelf router (such as that available from Retix), providing equivalent functionality to PATN for ground-ground links. As with PATN, this fallback solution would require the development of the required operational applications.

It may be possible to reuse the air-ground datalink protocols defined in PD/1 and PD/2 in an adapted or enhanced form.

#### **4.3.3.2 Real-time Simulation Data Communication**

This class of communications must meet the following requirements:

- strict limitations on worst case delays (so that, for example, the simulation management messages arrive in a timely way)
- carry high volumes of data (approximately 50kbits/s based on current assumptions)

Possible solutions for delay problems and bandwidth restrictions are:

- Develop simulation support software based on a network such as PATN
- Use a separate, supporting communications system, based on dedicated communications

PATN ground-ground paths could be used for simulation data, sharing communication capacity with the (simulated) operational use of PATN. In this case it would be required that these communications have priority and that no hindrance is caused by the operational communications or other, third party activity loading the communications lines. This solution could compromise any measurements of the use of the PATN network as a real communications system.

Therefore, since in general there is no control on an average or even a maximum delay over networks, the favoured solution for this class of communications is a separate communications system based on dedicated point-to-point connections such as ISDN.

#### **4.3.3.3 Simulation Support Communications**

Provided that logging is kept off-line, this class of communications has the following characteristics:

- strict maximum delay requirements.
- relatively low intensity.

Any of the data communication facilities described in 4.3.2.2 could be used to provide a solution. As discussed in section 4.3.3.2 to avoid the problems of sharing network access with third party users, it would be best to implement this class of communications on a dedicated system.

#### **4.3.4 Communications Applications Protocols**

This section addresses the communications protocols which shall be applied to the PD/3 inter-site simulation.

The communications protocols are the messages, the sequences of fields constituting those messages and the message sequences which are to be implemented. The operational communications applications (see section 4.3.3.1) and the simulation-specific communications will both require implementation of appropriate protocols.

The following criteria shall be applied when selecting a preferred protocol:

- expandability to meet future requirements
- support for techniques for reducing bandwidth requirements
- portability/reusability for other future applications
- existing standards

Different protocols shall be required for the operational communications services and the simulation communications services. A number of different approaches to providing the protocols are described here.

#### **4.3.4.1 Operational Communications Services**

Two main approaches to providing the operational communications services are identified:

- use of existing standards on an arbitrary carrier
- use of ATN-compliant PATN software and hardware

##### **4.3.4.1.1 Existing Standard Communications Protocols**

There are existing standard ATM communications protocols, such as OLDI/SYSCO, ASTERIX and ADEXP for ground/ground communication and ICAO4444 for air/ground communication.

Since these are only the protocols, they only provide part of the necessary solution. In general, they would require implementation of access to a communications network.

It would be desirable to make use of these where possible to promote future activities. However, if they were used, either existing libraries would have to be used or specific developments made.

Existing libraries would not have been designed for simulation work, and seem likely to impose an overhead on the interfacing software in the simulators. New developments would introduce a significant development load on PD/3 for which no plans have been foreseen.

A further disadvantage is the existing standards are not complete for the PD/3 scenario so they would require some extension.

##### **4.3.4.1.2 PATN**

It is the objective of PD/3 to demonstrate the use of PATN [1], and the objective of the PATN is to provide an operational ATN, so the PATN shall provide operational communications in PD/3.

PATN will be an implementation of an ATN-type communications system. The PATN should provide both communications software and access to communications networks. It is presently proposed by the PATN team that application specific programming interfaces are defined at the application entity level, which would provide the PATN users with specific services. Thus far, two simple message passing applications having been developed as demonstrations.

Most applications specification work in international standards organisations has addressed air-ground datalinks. Little work has been done on ground-ground datalinks. If PATN provides all operational communications services, appropriate ground-ground applications will have to be defined, perhaps based on standards such as OLDI/SYSCO.

For efficiency in development of software for PD/3 it will be important that sufficient flexibility is built into the applications and the interfaces to ensure that modifications to the application functionality (eg message sequences, message contents) shall be possible by the PATN users

#### 4.3.4.2 Simulation Communications Services

Two main options are identified for providing simulation communications services:

- use of an ad-hoc protocol developed specifically for PD/3
- use of an existing protocol, the example being DIS

##### 4.3.4.2.1 Basic Ad-Hoc Protocols

Because of the relative independence of the simulators participating in PD/3 an interface can be defined on a relatively low level. Where necessary, each establishment would write their own software interface, dependent on the local system architecture.

The lowest level interface depends on the network used (see section 4.3.3). Assuming that all link types support at least a simple byte-stream protocol, a possible approach to communication protocols would be asynchronous message passing using a low level standard such as ASCII or XDR (eXternal Data Representation), a public-domain package from SUN Microsystems.

Message types and message formats would need to be defined. A surveillance message could for example be encoded as "SV 65 3471 520534 0044358 270" meaning: SurVeillance, track 65, SSR mode-A 3471, latitude 52°05'34", longitude 4°43'58", SSR mode-C 270. The advantage of a package such as XDR over ASCII would be that using XDR would normally result in smaller messages compared to simple equivalent ASCII messages, XDR has a predefined format for complex messages, and the XDR encoding requires less computation.

The resulting message protocol would be an ad-hoc solution, produced specifically for PD/3 and with a resulting lack of portability to other applications. Also it would not profit from existing standards, communications libraries and software.

##### 4.3.4.2.1 DIS

An IEEE standard communication protocol is being developed for communication and control of multi-site simulations: DIS (Distributive Interactive Simulation, [5] and [6]). This communication protocol is supported by commercially available software packages which are focused on military applications. Groups in the US FAA are extending the protocol to ATC applications and there is an existing DIS interface to the MCS flight simulator (amongst others).

The use of the DIS standard could be profitable to PD/3 when viewed at a number of levels of abstraction:

- It provides a general standard for intersite simulation communications. Additional functionality could be introduced as necessary using existing stubs.
- Standardization of conventions for simulation control (start, stop, resume and freeze).
- Standardization of representations and conversions of data.

Use of DIS would have the advantage of making an existing standard in use in the simulation community. This would have the additional advantage of being useful for future simulation work with other DIS users.

#### **4.3.5 Hardware Requirements**

Hardware requirements are closely related to the underlying carrier. These requirements have not yet been investigated in detail.

The PATN requires the following:

- SUN workstations to provide Routers
- SUN workstations to provide End Systems
- For air-ground communications, Satcom and/or Mode-S equipment
- For ground-ground communications, interface cards to the appropriate data carriers (X.25 WAN etc.). These would be installed in the workstations.

It should be possible to secure use of this equipment once EURATN development has been completed. However, the number and configuration of workstations required for a simulation of the size of PD/3 is unknown since experiments to date have been very limited in scope.

The PATN system is hardware-dependent, so the software cannot immediately be transferred to, for example, HP workstations. However, it may be feasible to port the software.

## 5. Air System

This section addresses the intersite aspects of the air system. As such it does not address issues such as FMS and trajectory predictor implementation since these are not intersite simulation issues and are more properly dealt with by each site.

The section describes the requirements for the air server system of the PD/3 demonstration facility. It assumes a distributed approach to implementation of the server, as described in section 2.

The section also addresses the integration of flight simulators and research aircraft.

The section has the following structure:

- Requirements for distributed air system of the PD/3 demonstration facility
- Possible approach to implementation of distributed air system
- Air server implementation requirements
- Flight simulators integration requirements
- Research aircraft integration requirements

### 5.1 Requirements for Distributed Air System

This section describes the requirements for the distribution of the air server over the three sites of PD/3. The corresponding data flow is d2 in Figure 4 above. The consequences of distribution and the corresponding proposed solutions are described, addressing message exchange requirements and the mechanism for transfer of aircraft flights between servers.

Various distribution strategies have been considered [2]. The result of this analysis has been to select the most distributed option in which each air server is in charge of a set of aircraft for a certain period of the flight. Each air server navigates the flight for part of the flight plan, with transfer of responsibility between air servers. The air server responsibility area and the area controlled by the site are the same.

#### 5.1.1 Continuity of Traffic between Two Contiguous Air Servers

This is the major point when speaking about distribution over several sites. However it contains more than the dynamic synchronization of position, speed of each aircraft at transfer time. It must also reflect the possible modification of routes resulting from previous ground system controllers instructions or from previous air server pilots requests.

For example, if the pilot requests a new route, the next air server has to be informed that the aircraft will follow a quite different route from the planned one, except if modifications impacting other air servers are forbidden, which is not very realistic. This will entail either the ability for air servers to change dynamically the route or other flight plan information (speed, levels, arrival ...) or the ability to create dynamically flights according to information given by a previous air server.

A transfer of responsibility for the flight between two air servers has to be envisaged. This transfer must be at least synchronous with the flight handover between the sectors controlled

by the two associated sites and shall be a consequence of coordination action by the controller staff but transparent to them.

This transfer has also to be "public": it has to be exported to other applications at least for message routing. This might be done in a transparent way to the end applications through the ATN services.

### **5.1.2 Diffusion of Air Server Results (Mainly Tracks) Over Different Sites**

The diffusion of the air server results is also necessary because ground systems need access to more traffic than they currently have control responsibility. For example, the controllers will need radar information several minutes before the traffic actually enters their airspace and the PATs at each site will require frequent access to flight data from outside the area of control responsibility of the appropriate server.

The solution where the two contiguous air servers navigate the same flight during a certain period of time seems unacceptable because of the resulting divergences (cf. first section) and the difficulty to identify which air server is in charge of the data link applications.

The different tracks coming from different air servers are then to be merged in order to build a site extended view of the traffic, that is, all the aircraft navigated by the local air server plus the aircraft navigated by the other air servers that may be locally relevant. This last solution is the most realistic : it corresponds to a real site radar coverage.

In all cases the volume of exchanged data has to be taken into account. The messages, the periodicity of which is 3-10 seconds, contain at least all positions for a given air server. This will be detailed in the subsequent section.

## **5.2 Foreseen Solutions**

Two main elements are foreseen in the solution to the distributed air server:

- maintaining continuity of traffic
- distribution of surveillance data (or "building a site extended view")

These are described below in sections 5.2.1 and 5.2.2.

### **5.2.1 Continuity of Traffic**

Achievement of traffic continuity requires that the following are provided:

- mechanisms for responsibility transfer between air servers,
- propagation of flight data context,
- export of the current responsible air server for a given flight (at least to the appropriate ATN service).
- supervision and monitoring

These are addressed below in sections 5.2.1.1 to 5.2.1.4.

### 5.2.1.1 Mechanism for the transfer of responsibility between air servers

In this section the scenario describing the way of transferring a given flight between two distinct and distant air servers is proposed, highlighting in particular the transfer triggering conditions.

The cases of an aircraft to be transferred to and transferred from a distant air server are considered.

Due to the necessity of co-location between the pseudo-pilots and the controllers dedicated to a given sector, the transfer between two air servers must be synchronized with and initiated by the hand-over of a flight between two sectors associated with two different sites.

When a given aircraft is about to enter a new air server "jurisdiction" (each PD/3 Site Air Server is assumed to be in charge of a specific control area which will be divided into a set of control sectors), the pseudo-pilot currently in charge of this flight shall transfer the guidance to another pseudo-pilot logged in the relevant distant air server. This transfer shall normally occur only after the pseudo-pilot currently in charge of the flight has received from the controller (who is currently in charge of the flight control and is located on the same PD/3 site) radio-frequency change instructions. The case of radio-frequency change handled by data-link applications is to be considered while eventually even the replay of events could be dealt with.

In any case, two possibilities can be considered :

- either the new frequency is associated to a sector handled by the same site and in this case there is no transfer action between distinct air servers to be considered ( the only action which may be considered is the transfer of the flight to a different local pseudo-pilot in charge of this new radio frequency)
- or the radio frequency is associated with a control sector handled in a different site : in this case the current air server shall check that the transfer decision is meaningful i.e. whether considering the current aircraft position, tendencies (heading , flight level) and flight plan, the flight is supposed to exit the current sector and to enter this new sector managed. The transfer instruction shall be allowed only if meaningful. This checking process will also be useful to warn the currently in-charge pseudo-pilot that a given aircraft will soon reach the current sector limits and is supposed to be soon transferred to another air server (case of non data-link aircraft). If this check fails then the radio-frequency change shall be considered as an erroneous control instruction but the transfer final decision may be forced by the pseudo-pilot. If this check is successful, the transfer is authorized i.e. the frequency radio is effectively changed and therefore the aircraft is automatically transferred to the distant air server: the pseudo-pilot who has just transferred the flight shall be able to see the track on his radar display until it definitely leaves his geographical zone of interest, but is no longer able to guide it.

As far as entering aircraft are concerned (i.e. transferred flights), the future in-charge air server and only this air server (the pseudo-pilots working on the other distant air servers not being bothered by irrelevant traffic) will have to display the expected aircraft to all its local pseudo-pilots radar displays, even before the hand-over : i.e. all the pseudo-pilots (and the controllers) attached to the new Air Server shall be able to see on their radar display, the

future incoming traffic but while this incoming traffic has not been actually transferred, these pseudo-pilots will not be allowed to give it guidance instructions. As soon as the incoming aircraft have been transferred, then the newly responsible air server shall automatically select a pseudo-pilot and only then will the newly selected pseudo-pilot be allowed to give orders to the transferred flight.

It is anticipated that during the handover period, no guidance on the flight will be allowed from previous and future pseudo-pilots.

### **5.2.1.2 Propagation of flight data context**

As it has been described, the first requirement to meet for a distributed air server facility is that any air server shall be able to take into account (i.e. creates and activates ) a transferred aircraft the flight plan description and flight data context of which are incomplete at start time and are dynamically (i.e. at run-time) provided by a distant air server.

Such an air server shall be able to navigate a part of the complete route i.e. only a few segments of the route defined as the intersection of the current route and the control area managed by the site. This truncated route is defined from an initial position (defined at run-time in terms of latitude, longitude and altitude whenever the flight is actually transferred ) to a final position which is either the flight plan final point if the flight plan is supposed to end in the site itself or a next "transfer point", for instance in the case of a flight taking off from Amsterdam, landing at Paris Charles de Gaulle and therefore crossing the control area under the responsibility of EEC.

Furthermore the current flight context of the transferred aircraft must be made available to the future in charge air server.

Let us describe the list of the main flight data information necessary to the distant air server in order to initialize at run-time a transferred aircraft. If we suppose that every air server is aware of all the flight plans participating in a PD3 simulation, the following data are supposed to be at least necessary (but may be not sufficient) to the different PD3 air servers to achieve such an initialization at run-time :

- the current simulation time.
- the new selected radio frequency : this parameter will enable the air servers to clearly identify whether he has to manage the transferred aircraft . The transfer message (i.e. the message which contains the flight data context) itself shall be determined locally using a site/sector/frequency lookup table. The air server shall also discriminate the radio frequencies in order to distinguish a local frequency change (involving local pseudo-pilot and controller) from a frequency change instruction involving a distant site, with a distant controller and a distant pseudo-pilot.
- the last updated route information e.g. the list of all the remaining beacons to over-fly defined with their position, name , estimated time of over-flight for 4D FMS equipped aircraft, etc. with some optional description if the aircraft is supposed to execute a final approach (e.g. STAR description.....)

- the last trajectory position and flight conditional data; the same data as required to initialize a flight to an Initial Condition (IC) for loading into the air server. This corresponds to the last navigation sensors data (current position, current heading, current speed, current rate of climb or descent, current weight...). Some of these parameters are specific to the type of aircraft model used by an air server ( e.g. Mass is using a TEM model, other traffic generator may use EROCOA/PARZOC models or different models needing only part of these parameters), so the air servers will need to be able to translate from the common inter-air-server protocol to their internal formats and data.
- the current navigation objectives (such as the last speed law, the last selected flight level, heading, rate of climb or descent objective to be captured ) which are related to previous guidance orders and which were not achieved at transfer time.
- the current aerodynamic configuration (such as brakes, spoilers and flaps current configuration) in order to be able to consider a consistent drag behavior (once again some or all of these parameters may be useless for some models)
- the avionics equipment current state ( e.g. Datalink equipment may be inoperative, or a transponder code may have changed).
- the temporary results and states of Data-link applications (such as trajectory negotiation, flight level change clearances, meteo data exchanges, etc.)
- data equivalent to the initial condition data such as, for example, the current weight, and weight of fuel and fuel used.

This is an initial list of necessary information which is not exhaustive and must be completed.

Another requirement is that the PD3 air servers shall be able to determine that an aircraft is about to leave the control area associated to the site and that some action shall take place to transfer this aircraft to one of the distant air servers (i.e. warning message shall be issued to the pseudo-pilot display or specific transfer clearance shall be asked). The pseudo-pilot shall only have to handle radio frequencies and the determination of the future air server shall be transparent to him.

To summarize, the flight data context propagation implies that the air servers will have to offer entry points enabling them to create and activate aircraft at run-time from the use of a common flight data context, the format of which must be specified and adopted by all the PD3 air servers.

### **5.2.1.3 Export of the current responsible air server for a given aircraft**

Some external applications, such as ATN applications, will need to identify at any time which air server is currently in charge of a given aircraft in order to establish connection with the aircraft or to go on exchanging data and messages.

PD/3 air servers shall provide a facility (eg. a specific API entry point or event) enabling external applications to know whether or not a given aircraft is currently navigated by a given air server.

For instance, at transfer time, a specific event and message could be propagated by the air server achieving the transfer to external applications and contain in particular the new selected radio frequency. Radio frequency mapping (every air server being supposed to be associated with distinct sets of radio frequencies) could be used to identify the air server currently responsible for the aircraft.

#### **5.2.1.4 Supervision and Monitoring Aspects**

The overall message exchange sequence of aircraft transfer would follow the following general dialogue:

- Following an initiative of the pseudo-pilot or after receiving a flight transfer event, a handover message is sent to the selected site.
- After completion of the transfer, a positive acknowledge is sent back. Also a logging event is sent to the supervisor.
- In case of acceptance problems if, for example, the specified frequency is not recognized, an error diagnostic reply would need to be generated and control of the flight returned to the original air server. A possible solution would be to reactivate the flight and to inform the pseudo-pilot.

#### **5.2.2 Building the Site Extended View**

The second main requirement is the need to build a site radar extended view for the site pseudo-pilots and controllers.

On one hand, the pseudo-pilots and the controllers should be aware of the incoming traffic some minutes before the transfer action has been achieved and on the other hand they should also see the outgoing aircraft some minutes after they have been transferred.

These operational requirements imply that every air server must merge its local tracks (i.e. the tracks related to the aircraft actually navigated by the air server itself) with some external tracks (i.e. tracks related to aircraft being navigated by a distant air server) in order to build and display to the pseudo-pilots and controllers, a so-called "site extended view". This shall be achieved using the distributed surveillance information.

Every air server shall filter the tracks of interest, merging the "external" tracks with its local tracks in order to display consistent radar traffic to all its local pseudo-pilots.

Synchronization of local and remote tracks will require that every track data message is time stamped and identified in order to be able to merge consistent tracks. Also a common track data interfacing format will need to be specified and adopted by all the PD/3 air servers.

### **5.3 Flight Simulator Integration**

This section will describe the conclusions reached regarding the inclusion of flight simulators in the experiments.

The objective of including flight simulators is to provide more realistic aircraft behaviour than can be achieved using a MASS-type air server:

- more realism can be expected from a 6-degrees of freedom model than a 3-degrees of freedom point mass model
- realistic autopilot, FCS and autothrottle modelling
- capability for manual control
- high realism of airborne HMI environment
- realistic pilot responses

Also, their use will allow real pilots to participate in the experiments and give their feedback concerning the procedures and technology being investigated.

### 5.3.1 Participants

A number of aircraft simulators have been proposed as participants in the simulation. These are:

- EEC MCS. This simulator would be integrated into the distributed simulation facility using the CAPO Air System network [7].

A number of functional enhancements will be required to bring the MCS up to the level required for PD/3.

- NLR RFS. The NLR Research Flight Simulator (RFS) will be able to participate in the PD/3 demonstrations as an equipped aircraft. The simulator can perform flights as a B747, Fokker-100, Swearingen-Metro and a Citation-II. For performing flights or parts of flights as an equipped aircraft, the following enhancements are anticipated:
  - equipment of RFS with EFMS, and HMI facilities for trajectory negotiation
  - full capability of datalink handling, including PATN and HMI
  - capability of handover flights, including flightplan handling
  - access to the simulation playing area, eg for navigation purposes, and actual weather information
  - access to surveillance data in the immediate surroundings for TCAS
  - facilities for r/t, participating in teleconferencing circuits, and options to switch r/t within the context of the simulation
- ISTRES. Aircraft simulators from their ISTRES facility participate in the experiments.

### 5.3.2 Integration within Air System

A flight simulator or research aircraft can be considered, from the scope of its external communications, to operate as an air server, simulating one aircraft. These could be used to simulate aircraft for full flights or only segments of their flights.

### 5.3.2.1 Full-Flight Simulations

The objective of simulating a full flight would be to demonstrate that such a flight can be performed with respect to all its required procedural actions in the cockpit. A possible application to be tested in this way is trajectory negotiation and the use of datalink and PATN.

The technical advantage of simulating full flights is:

- One flightplan, one simulated flight and a maximum of realism towards the pilots.

The disadvantages are:

- Switching from centre to centre and from sector to sector, with a complicated system of voice communication. However, relayed controlled switching is possible with RFS.
- Full flights are performed with advanced 6-degree-of-freedom models, while large parts of the flight are dynamically not significant.

### 5.3.2.2 Partial Flight Simulations

It is also desirable that it should be possible to use a flight for only a part of an aircraft's flight, enabling experimenters to concentrate on the areas of flight where the aircraft simulator provides greatest advantage in realism over the air server. This means there would need to be switching of the simulation of an aircraft between an air server and an aircraft simulator.

Alternatively this approach could be realised by having a flight simulator start up outside the simulated area and fly into one of the centres.

The objective of simulating a part of a flight can be to demonstrate that a model critical part or a procedural critical part of a flight can be performed with respect to the behaviour of the aircraft and the pilot. A typical application is the approach sequencing and the coordination between airborne software and the Arrival Manager.

The technical advantage of simulating part of a flight is:

- The r/t communication can be restricted to communication within the context of one ATC simulator and therefore one site.
- More flights can be performed during one simulation, which may lead possibly to more significant results.

The disadvantage is:

- Transfer of flights between air servers and flight simulators is required.
- The flight simulator has to be able to start without long initialization processes. The feasibility of this needs to be investigated.

The handover of a flight to and from the flight simulator could be achieved as follows, provided that the delay for initialisation of the simulator software was not more than a few seconds. The PD/3 supervision process shall manage the flight simulation. The flight simulator transfer would be selected as a special event, created manually through supervision or by an indication in the flightplan or the scenario file, subject to trajectory changes in the scenario run. At handover time, the flight simulator would be initialized with the appropriate

state data transferred from the air server. The flight simulator run would then be initiated by the supervisor.

Transfer of a flight from the flight simulator to an air server would again be managed by the supervisor and would be initiated in response to a change of frequency. On selecting a frequency, it is anticipated that the flight would normally be transferred to an air server.

### **5.3.3 Communications Protocols and Procedures**

The inclusion of aircraft simulators will mean that appropriate communications links to the ATC centre simulators will be required. These links will need to be both voice and data and will be complex. For example, if an aircraft simulator moves from the control of one centre to another, voice input will have to come from a controller at another physical location. The feasibility of this depends on the characteristics of the appropriate voice communication systems.

The pilot(s) of the simulators will have to perform the operational tasks which are, in an air server performed or simulated by the system. This will enable actions dealing with manual control of air-ground datalink handling to be tested under realistic conditions.

### **5.4 Research Aircraft**

There is a proposal to include research aircraft in the PD/3 simulation. This is for reasons of the extra realism of having real pilots participate in experiments, to allow assessment of trajectory predictor accuracy and for publicity.

This requirement is still being investigated within the PD/3 participants so, pending a firm decision to use the aircraft, a detailed technical solution has not yet been prepared.

There are a number of significant problems to be resolved. A research aircraft cannot be controlled by start stop and freeze actions. Moreover, it is difficult to position the aircraft at a required time at a required position. Therefore, the research aircraft could not participate in handover procedures.

For a research aircraft live use of the ATN air-ground mobile sub-network is possible. Therefore simulation of such a sub-network has to be supported for air servers, while at the same time a real sub-network is to be used for the research aircraft. The shared workload has to be taken into account, but extra network loads could also be added.

## 6. Operational Communications Applications

This section identifies an initial set of possible ATN operational communications applications for PD/3 with the objective of providing a baseline for the communications sizing assessment in section 4. The required set applications will be defined separately within PD/3.

To complete the CNS set, Navigation and Surveillance issues will also need to be addressed.

### 6.1 Data Communications Applications

#### 6.1.1 Air-Ground Data Communication

This section summarises the datalink functionality which will be required to be handled in the multisite simulation. It also addresses implications for the ATN used to support the experiments.

Air-ground datalink applications are partly replacing and reducing r/t. During the scenario era, evolution towards more datalink oriented airborne systems will continue. According to the PHARE Medium-term Scenario [8], transmission of data between Air and Ground will either be automatic between air and ground computers (informative data) or will involve pilots or controllers actions (decisions, clearances etc.). Datalink communications will be available within PATN through SSR Mode S and/or satellite and possibly through VHF. The generic types of applications are considered in the FANSTIC II [9] and EATCHIP III [10], ODIAC and ADSP work.

It must be stressed that fully-fledged ATN standard-compliant applications are not required for PD/3 since PD/3 is purely an experimental environment.

The following categories of datalink applications are required for PD/3 [1]:

- Strategic ATC communication:
  - Trajectory negotiation, negotiating on trajectory "contracts" for a medium-term time-scale.
- Tactical ATC communication (Controller-Pilot Datalink Communications or CPDLC):
  - Part of the tactical clearances may be (non-time critical) communicated by datalink instead of R/T.
  - Requests for clearances may be supplied by pilots via datalink.
  - Frequency changes and initial contact calls are good examples of non-time critical clearances to be performed via datalink.
- Informative communication in support of ATC (Downlink of Aircraft Parameters or DAP):
  - Flight management data, e.g. in flight position report, start of tactical manoeuvre indication.

- Flight status data, e.g. actual weight, altitude, rates of climb, descent, turn and selected flightlevel, heading and speed. This information will be supplied mainly in support of ground-based automatic tools.
- Airfield/Airspace and NOTAM information.
- Weather information:
  - Weather forecast information, uplinked.
  - Actual weather information, downlinked.

The trajectory negotiation application is complicated and the precise dialogue is still to be determined. Moreover, the air-ground dialogue is tightly coupled to ground-ground dialogues between different Air Traffic Controller's.

The tactical clearances can be implemented with a simulated pilot acceptance by air servers, while a pilot in a flight simulator shall accept the message himself and shall respond appropriately. The dialogue will consist of an exchange of a message and an appropriate acknowledgment. A frequency change can be implemented in the same way. However, the frequency change asks for some additional actions, like establishing the connection and a verification of a proper connection.

Down-linking aircraft status information is essential for PD/3 and it is a requirement for correct functioning of the automatic PATs. The required dialogue is simple and consists of a message and an acknowledge by the ground system. There is no manual interaction required.

There are four so-called Quality-Of-Services of an ATN: throughput, maximum transfer delay, reliability and priority. It is assumed that modelling of delays, combined with the generation of workload will account for realism with respect to throughput and maximum transfer delays [11]. Priority handling is supported by PATN, while the reliability issue has to be modelled separately.

The air-ground datalink will make use of the PATN. For air traffic simulated in an ATC air server, this means that a simulated air-ground communication link will be used, based on ground-ground physical communications links. The simulation of such a datalink places some requirements on PATN:

- An air-ground datalink has to be simulated within PATN, which includes:
  - simulation of dynamic rerouting (for research aircraft and for transfer of aircraft simulations between air servers at different sites while maintaining air-ground applications)
  - simulation of delays due to the physical medium
  - simulation of delays due to the expected workload
  - simulation of expected transmission failures
- Pilot responses have to be simulated:
  - simulation of pilot delays, if in an air server pilot responses on manual controlled dialogues are simulated.

- A large number of air-ground connections are to be supported. Typically a number of 100 to 200 equipped aircraft are flying during the same simulation and sharing of simulated physical nodes has to be supported by PATN.

It is proposed to use ground-ground communications links for the simulation of air-ground datalinks. For this, the air-ground datalink model will need to include a parameterisation capability such that the following can be achieved:

- introduction of a variable delay to message availability at the destination
- introduction of a systematic, constant delay to message availability at the destination
- call setup/closedown delays

These options shall be separately or jointly selectable.

### **6.1.2 Ground-Ground Data Communication Applications**

Almost all ground-ground communication will be performed by using datalink user processes with access to real or simulated ATN datalink applications. Communication applications, supported by PATN, shall perform point-to-point communications as well as broadcast distribution of information.

Examples of the applicable ground-ground communication processes are (selected with respect to the context of the demonstrations for PD/3 only):

- System management information:  
The allocation of tasks and functions and the associated areas and sectors.
- Aeronautical information services (AIS):  
In the context of PD/3, this in principle broad class of communications can be limited to the identification of the configuration (sectors and frequencies), the routes in use and the use of airfield, runways, SID's and STAR's.
- Meteo exchange:  
Updates on weather forecasts.
- Aircraft performance database update:  
The actual status information of aircraft will be distributed after downlinking this information via air-ground communication.
- System Flightplan database updates:  
All updates on flightplans due to Controllers actions and/or updates as result of automatic procedures.
- Planning coordination:  
All communicating activities concerning the coordination between different sectors and/or areas. Included are informative data exchanges as well as information exchanges via dialogues. The status of a flight may change as result of an automatic signalling process, but also as result of a manually supplied indication, while dialogues may be on request of any controller, affecting any planning or tactical control activity.

- 4D trajectory negotiation:

A special case of planning and coordination is the medium-term planning, in which an air-ground trajectory negotiation process is involved. Coordination is required between several Sector Planners and one or more Multi-sector planners.

These ground-ground datalink services would be provided by PATN. Although the data exchanges of all aforementioned communication applications may be considerable, in practice most of these data exchanges will need to be simplified and/or emulated. The applications, that are a bare minimum and that are essential for PD/3, are:

- System Flightplan database updates.
- Planning coordination.
- 4D trajectory negotiation.

## 7. Ground System Integration

This chapter will first provide in section 7.1 a review of high level requirements for the multisite aspects of the PD/3 ground systems based on general assumptions and discussion of possible approaches to implementation as well as operational features. Section 7.2 discusses a possible approach and implementation issues are then be addressed in section 7.3.

### 7.1 Requirements Placed on the Ground System

The requirements placed on the ground system of each site by their users, essentially the tools and HMIs, may be summarised by the “timely provision of functional services on the required set of objects, and more specifically on the required set of flights and the requested set of environmental objects, with the required level of consistency”.

#### 7.1.1 Functional Services

Using the services approach of CMS [12] as an example, a set of required service types may be defined according to the following main groups:

- Environment services and their associated APIs, which aims at providing relevant information related to the ATM environment, i.e. airspace structure, current and forecast meteorological data, description of aircraft performance and airlines mode of operation.
- Flight Plan, System Plan and Surveillance services and APIs, providing different and complementary views of the flight, such as filed flight plan, constraints, trajectory, deviation and surveillance data.
- Context services and APIs, aiming at providing the services requested to perform what-if functions.
- Simulation services and their associated APIs, enabling services which aims at providing information necessary to use the available ground system services and to monitor and control the system.
- Operational ground configuration services and APIs enabling a dynamic mapping of the sectors onto control units.

The first two groups are related closely to the ground-ground communications applications described in section 6, whereas the third and fourth groups are more closely related to simulation-specific aspects. The last group is not considered to be relevant to the PD/3 ground system integration, being more closely related to local simulator configuration, and hence will not be considered further.

The first four groups will be detailed in the following subsections.

##### 7.1.1.1 Environment Services

The environment services include :

- the airspace services providing static and dynamic data which define the airspace structure and status. Examples of static data are navigation points, holds, SID and STARs; dynamic data are mainly related to the status of runways, military areas, etc.

- the meteo services, providing both general information (e.g. current temperature, pressure, wind) over the whole airspace and more detailed information (e.g. visibility, ceiling, meteo forecast) for specific location like airports.
- the aircraft services providing performance information about the different aircraft types as well as airlines policies.

#### **7.1.1.2 Flight Plan, System Plan and Surveillance Services**

These services include :

- delivery of information related to flight plan initially filed by the pilot or the airlines (e.g. type of aircraft, requested route and flight level, departure and arrival airports, etc.)
- management of information computed or captured by the Air Traffic Control systems :
  - constraints to be applied to the flight route and profile (direct, heading, speed, SID, STAR, etc.),
  - trajectory, as a set of 4D points,
  - deviations detected between predicted trajectories and actual aircraft positions,
  - list of sectors planned to be crossed by the flight,
  - co-ordination information defining the status of the flight vis-à-vis each sector (this enable to handle co-ordination and hand-over process),
  - surveillance information (current position, mode A, flight level, speed, heading, etc.).

#### **7.1.1.3 Context Services**

These services propose a set of facilities suitable to perform what-if functions (creation of a simulated flight on which can be applied a lot of standard services already available for real flights like constraint definition and trajectory computation, activation of a simulated flight resulting in a replacement by the simulated flight of the previous corresponding current flight)

#### **7.1.1.4 Simulation Services**

They provide facilities to :

- manage the location of the services (registration, provision of an available service address),
- monitor and control the ground facility (e.g. start, stop, freeze, unfreeze, etc.),
- synchronisation between elements of the system (e.g. get time).

#### **7.1.1.5 Required Services**

It is anticipated that the first four groups of services (i.e. environment services, flight plan, system plan and surveillance services, context services, and simulation services) form the basis for the set of services necessary for the tools and HMI integration and operation in PD/3.

For example,

- the multi-sector planning tools envisioned for the different organisations [1] will need to access the flight plan, constraints, trajectory, list of sectors, co-ordination, context and environment services.
- the trajectory predictor will need to access to flight plan, constraints and environment services
- the conflict probe will need to access to the trajectory services
- the problem solver will need to access the trajectory, constraint, context and environment services

### 7.1.2 Set of Objects

According to the operational scenario, each operator (controller, multi-site planner), and consequently the HMIs and tools assisting these operators, will need to be able to assess the traffic and the associate environmental constraints in an area which will generally exceed its proper area of responsibility (sector for controller, planning area for multi sector planner). Indeed, in the specifications for operational scenario Org2 [1], it is stated that the multi-sector planners of two adjacent areas must be able to judge the traffic in both areas and to be aware of the restrictions to be applied in those areas.

Therefore, as far as flights are concerned, for each site, the availability of functional services will very likely be requested as follows for :

- the flights currently flying within the airspace associated to the site.
- the flights likely to enter the airspace associated to the site with a specific notice. It is anticipated that the services available for these flights may be reduced according to the reading and writing access policy scenarios and allow final adaptation when adjusting the software facilities.
- the flights flying or planned to fly close to the airspace associated to the site, in some specific case. Indeed, as exemplified above for multi-site planning purpose in the advanced operational scenarios, this kind of information will be necessary for some of the tools. In order not to impose undue restriction onto the operational scenarios this last requirement needs to be taken into account up to the moment when it is confirmed or invalidated by the detailed specifications of such tools.

Similarly, for environment object, it is anticipated that tools and HMIs of each site will need to have access to objects related to their own site as well as part of the objects belonging to adjacent sites, e.g. airspace data for part of the airspace of the adjacent centres. This part will probably vary according to the operational scenario.

The time horizon may also be a requirement strongly impacting the ground system implementation. A time horizon may be associated to some of the services, for example, for the trajectory a time horizon of forty minutes may be requested for the part of the trajectory within the centre (i.e. a trajectory needs to be computed for the next 40 minutes) and this time horizon may be restricted to an area overlapping the adjacent centres area for the part of the trajectory external to the centre.

### 7.1.3 Timely Provision of the Services

Timely provision of services means at least that the services related to flights need to be available with a specific notice before the actual entrance of the flight in the airspace controlled by the site. This notice will very likely depend on the operational scenario and may be subject to change or tuning up to the very last moment before the demonstrations themselves. The value of the notice is therefore required to be flexible enough to accommodate these different scenarios. Nevertheless, from the draft version of PD/3 operational specifications, a range of values from 20 to 40 minutes seems appropriate. This will comply with the probably most demanding requirement of PD/3 which is the objective for the multi sector planning controller to plan for a period of at least 20 to 30 minutes ahead of time.

### 7.1.4 Policy for Access to the Services

#### 7.1.4.1 Access Requirements

According to the PD/3 operational requirements :

- Some flight data items must be accessed, at least in read mode, by more than one site.

*For example, tools in site A will be interested in reading trajectories of flights currently flying in site B (of course tools of site B also need to access these trajectories) which are close to the A-B boundary, to be able to perform conflict detection between these flights and other flights that A plans to transfer to B.*

- For a given flight, and at a given moment, some data items need to be accessed in write mode by more than one site's tools and HMIs

*For example, an executive controller of site A (where the flight is currently located) may need to modify the part of the route data inside A area (e.g. for some unexpected reason), while a multi-planner controller in site B may need to modify another downstream part of the route data in order to organise in advance the traffic in its own area of jurisdiction.*

For efficiency reasons, each site will probably need to maintain a local copy of the shared items. A common basis for exchanging these, such as CMS flight data types definitions, will need to be agreed.

#### 7.1.4.2 Flight Data Ownership

##### 7.1.4.2.1 Presentation

The previous section has shown that some flight data items need to be physically present in more than one site's ground system. There is no valid reason, at least in a PHARE demonstration context, to protect flight data managed by a given site from being accessed in read mode (read operations or event receptions) by another site, whatever the data is. Concerning write accesses, it is not a safe solution to allow several ground systems to modify their own copy of a given common flight data item without an agreed flight data management policy, because it could lead to inconsistency problems. To help solving this issue, four approaches will be considered : symmetrical roles, data splitting, master site, and modification token.

#### **7.1.4.2.2 Symmetrical roles**

All the sites play a symmetrical role from an applicative point of view. Special middleware mechanisms need to be defined and agreed which ensure that each modification of a flight by a ground site is an atomic operation. This is to avoid inconsistent results in the event of concurrent accesses to the same flight data. Some write access restrictions may be applied, based on geographical or operational criteria.

This approach is attractive from an applicative point of view, because concurrency problems are solved in a transparent manner for applications. But it seems unreasonable to follow this approach in the PD/3 time frame, because it involves the definition of a complex low-level protocol between ground systems, and quite surely a major redesign of the existing platforms. As a consequence, the following approaches concentrate on more applicative solutions.

#### **7.1.4.2.3 Data Splitting**

Flight data items covering several site areas (route, local constraints, profile, ...) are logically split into smaller items, each one covering a unique site area. Each data item is owned by a nominated site, and other sites are not allowed to modify this item. General flight data (e.g. SSR\_CODE) are owned by the site currently controlling the flight, according to the co-ordination status.

*For example, the route object may be divided in route parts, each part being related to a given site area. Write access rights to a given route part could be distinct according to 1) the site area the route part belongs to, 2) the origin (which site, which controller function, ...) of the write order, and 3) if necessary the flight progress or the co-ordination status. In this case, the executive controller in charge of a given sector has write access to the corresponding part of the route, while a multi-planner controller can modify the route part corresponding to its area of jurisdiction.*

This solution appears well suited to managing list-typed data items such as planned route or trajectory. Indeed even for multi-planning activities, as described in the current PD/3 operational specifications, modifications issued by a multi-sector planner of a flight transit plan (which will probably have to be expressed as a set of constraints and trajectory data) will be restricted to the own multi-sector planning area which does not overlap with other multi-sector areas. In addition, this policy avoids the need for a given site to get the whole environmental data.

However, this approach would require a close coupling of the simulators, which is at odds with the principle of independent development. Hence a less tightly coupled approach, master site, is also considered.

#### **7.1.4.2.4 Master site**

The multiple ground systems interested in accessing specific flight data in write mode play an asymmetrical role : for each flight, a master site is elected, which is granted rights to modify the data items of this flight. The other sites are not allowed to modify this flight's data themselves. Instead they must send their modification request to the master site.

The role of the master site is to put write accesses to a given flight in serial order, to verify access rights according to flight status and modification origin, and if necessary to compute the modifications. The local copies of other interested sites may then be updated.

The master site is chosen according to static criteria (e.g. each site plays the master role for a non overlapping sub-set of the total set of flights, this sub-set been agreed off-line), or dynamic criteria (e.g. criteria related to a co-ordination status). Static criteria are easier to implement (no need of a complex hand-off protocol), but less efficient than dynamic ones, because for a given flight the subset of the most write-demanding sites follows the flight progression.

Dynamic criteria may be either geographic (e.g. related to the physical position of the flight) or operational (e.g. related to the co-ordination status).

A major problem with dynamic criteria is the managing of the ownership changing phase, where a flight previously owned by a site A passes under control of another site B. Before B modifies the flight, it must be sure that its own local copy of the flight data is up to date. This may be done either by a synchronisation protocol, which ensures that every modification event generated by A has been correctly received and taken into account by B, or by a complete read of flight data at site A followed by a complete write at site B. The latter method provides greater robustness, but the transition phase is longer and the data exchange capacity needs to be increased significantly.

#### **7.1.4.2.5 Modification Token**

A special case of the master site policy with dynamic criteria is an approach based on a modification token. Write concurrency problems are solved by applicative negotiation protocols between involved sites. The role of these protocols is to assign, for a given flight and at a given moment, a unique modification token to the set of interested sites. It should be noted that the token ownership may frequently change, e.g. when a multi-planning activity is performed by a site distinct from the site where the flight currently is located.

#### **7.1.5 Level of Consistency**

Some flight data items will be present on more than one ground system, these systems being separated by a WAN. Therefore the problem of consistency between these multiple copies needs to be considered. Very roughly two levels of consistency between the data provided by the services on each site may be envisioned :

- A so-called weak consistency between two sites, where a site plays a master role for a given piece of data : when a modification is performed on a given piece of data, there is a finite delay during which one user in the master site sees the new value of this piece of data while the other in the other site sees the old value. If no further modification is made, both sites will provide at the end the same response.

*For example, a multi-planning tool of site A may be advised of a flight trajectory modification a bit later than the ground system of the site B currently in charge of the flight. It is not a major problem, because multi-planning activities can suffer longer delays than executive ones, as they work in a longer time-frame.*

- A strong consistency will be provided on the contrary if the responses to the same query in the two sites at the same moment are identical, because the copies of the data in each site are updated symmetrically.

The main advantage of strong consistency is the systematic maintaining freshness of local data copies. But the mechanisms needed to ensure strong consistency are more resource

consuming. Moreover, complex mechanisms and protocols need to be defined and agreed among ground systems designers to implement the symmetrical updates, and major redesign of existing platforms may be necessary.

Since this approach is unlikely to be feasible in the context of PD/3, the approach of weak consistency is preferred.

## **7.2 Review of Elements towards a Solution**

### **7.2.1 Presentation of Possible Solution**

This section provides a more detailed study of a possible solution, based on what seems the simplest flight data ownership policy, namely the master site policy.

Each flight is managed at a given moment by one site, the site currently controlling this flight. Therefore the master site role is defined according to the coordination status. The choice of this criterion allows unambiguous election of one and only one site as owner of the data. This is straightforward since the coordination status is present at each site interested in the flight. An operational criterion such as this is preferred to a geographical criterion, because it seems better from an operational point of view that consequences of master site changes (e.g. access rights) are synchronized with the controller decisions (e.g. flight transfer commands).

Normally the master site shall distribute data updates on the flights for which it has responsibility to all other sites. The data would then be available, if somewhat out of date, for use by the tools at these other sites.

When a given flight is under control of a given site A, which other sites are interested in modifying this flight's data ? Firstly, we can consider that upstream sites do not need to apply control actions on this flight once they have granted the control transfer to the downstream site. Concerning the downstream sites, their planning and multi-sector planning controllers may be interested in applying operational changes to the planned trajectories to prepare the delivery of air traffic to the sectors.

In the context of a master site policy, every flight modification has to be verified and either accepted or rejected by the master site, before it is taken into account. When a non-master site proposes a modification, it may use an optimistic data delivery policy (i.e. distributing the new flight data locally without waiting for the master site's acknowledgment, and applying appropriate actions whenever the master site refuses the modification), or it may wait for the acknowledgment. This choice is to be resolved.

### **7.2.2 Flight Data Exchanges**

The major flight data exchanges between sites are the following :

- Flight data transfer, during the master role changing phase, from the transferring site to the receiving site.
- Modification propositions, sent from a downstream site to the master site (with some access rights restrictions, see below).
- Update notifications, sent by the master site to the other interested sites, especially the downstream sites which previously asked for modifications.

What is the data set that need to be transferred during the master role changing phase ? Flight data may be divided into input data subset (e.g. current flight plan, tactical constraints, observations of flight progression) and computed data subset (e.g. planned trajectory, list of crossed or interested sectors). Input data shall obviously be part of the transfer. It is not necessary to transfer computed data assuming that the corresponding tools (e.g. trajectory predictor, sector list computation) are present at the receiving site. Similarly, only input data exchanges are necessary in the two others inter-sites flight data exchange types, i.e. modification propositions and update notifications.

If the implementation of the tools are different at two different sites, the results of the computation may be more or less different, for example because of differences between the models used in both sites. In best cases, these differences may remain undetectable neither by controllers nor by tools. But in the worst case, the presence of variations in computations may induce major differences of some flight data. For example, a small variation in the time estimates of a planned trajectory may rise a conflicting situation not identically detected in both sites.

Flight data transfer will probably need to be considered in the context of inter-center coordination procedures, such as those identified in CMS/PARADISE and SYSCO.

### **7.2.3 Access Rights Policy**

No restrictions shall apply to read accesses.

Concerning write accesses, the master site may apply modifications on the whole downstream part of the planned flight path, while the downstream sites may be limited to a geographical subset of the path beginning from the requesting site's area up to the planned destination. Compliance with these restrictions shall be checked by the master site, according to the origin of the demand, before it updates the database to reflect the modification request.

### **7.2.4 Master Role Changing Phase**

One of the main problems related to the master role changing phase is the way flight data modifications proposed during this phase are treated. Several policies may be envisioned, but the simplest one which does not seem to be too restrictive for the applications is that flight data modifications are rejected (by both transferring and receiving sites) during the transfer phase.

A protocol between sites need to be defined to start and stop the transfer phase, thus passing the master site token from the transferring to the receiving site. This protocol may use communications facilities such as those provided by the CMS/PARADISE environment, i.e. operations and events, and might be based on inter-center coordination procedures.

## **7.3 Implementation Issues**

This section addresses issues associated with implementation of ground system integration in the context of PD/3.

### **7.3.1 CMS**

The PD3CG has made a strong recommendation that the local simulators should be adapted to meet CMS principles and APIs [12]. A first version of most of the CMS services has already been discussed, defined and implemented [13].

A given ground system may provide either all the services described by the CMS specifications or only part of them. Nevertheless, it is anticipated that a minimum set of services would be required to enable a correct operation of the distributed PD/3 platform, and more specifically of the different tools.

From an implementation point of view, provided that the external behaviour of the systems and especially the provision of services complies with the CMS specification, it is not required from the different ground systems to identically implement these services. This will allow the different sites to use their existing facilities, e.g. NARSIM, SIM5+ or DAARWIN, which will have to be adapted to provide external CMS interfaces as required by the PD/3 PATs, tools etc.

### **7.3.2 Data Formats for Intersite Information Exchange**

This section addresses the data structures which should be employed for ground-ground integration.

Where possible these shall correspond to existing international standards, amended according to the constraints of the simulator platforms. For example, it would not be reasonable to employ the complete international standard flight plan syntax - instead a suitably limited version should be adopted. The approach of generally conforming to international standards would have the significant advantage of easing future distributed simulation using other simulators or integration with live systems.

However, existing standards are based on current and near future systems. Additional data formats and interfaces will be required to address the more advanced elements of the ATM system, such as the PATs, to be simulated in PD/3.

#### **7.3.2.1 Common Coordinate System**

Valid data exchange will require the use of a consistent coordinate system by the three simulators. Several different coordinate systems are used internally by different parts of each simulator, so appropriate transformation software will be required to convert between formats.

In general it is therefore anticipated that all positions and displacements would be represented in latitude/longitude coordinates.

Many of the simulator components employ orthogonal x,y,z coordinate systems internally. This may lead to distortion and hence incorrect mapping towards the edges of the simulation playing area. The internal conversions to and from latitude/longitude may lead to errors. While these effects are normally unimportant, they may begin to have an effect in the intersite environment, perhaps with discontinuities between the airspace represented by centres. Further investigation of the magnitude of any effect may need to be carried out.

### **7.3.2.2 Common Airspace Structure**

A common definition of the airspace will be needed for data preparation and on-line interchange. This shall include features such as coordinates of airfields, airways and beacons.

This shall correspond to an international standard, such as ARINC 424.

### **7.3.3.3 Common Flight Plan Definition**

A common definition of flight plan information is required to ensure consistency between sites. A logical basis would be the international standard ICAO 4444 or the IFPS standard, ADEXP. It is likely that ADEXP would be the more powerful to use.

## **8. Tools**

### **8.1 Introduction**

Requirements placed on the tools in the PD/3 environment are similar to those placed on the ground systems.

It is anticipated that the CMS interfaces could be used, and extended to support new cases associated with new tools.

### **8.2 Interfacing PATs**

The existing individual PATs have been implemented according to agreed APIs. Each simulator should provide corresponding interfaces to these PATs to enable interfacing. Interfaces for the following will be required:

- trajectory predictor (TP)
- flight path monitor (FPM)
- conflict probe (CP)
- (highly interactive) problem solver (PS)
- arrival manager (AM)
- departure manager (DM)
- cooperative tools (CT) services comprising presentation of conflict situations and agenda/reminder facility
- multi-sector planning tools comprising on-line traffic complexity analysis, workload estimation and “lookahead” analysis of future situation in response to strategic decisions (TLS)
- negotiation manager (NM)

### **8.3 Intersite Aspects to Integration of Tools**

Once the tools have been interfaced, there will be a need to set up appropriate controls within the underlying software to ensure they are integrated together and with the controller HMI. In order to achieve this the experiences of PD/1 and PD/2 for the logical and sequencing relationships between the tools should be investigated closely.

## **9. Demonstration Monitoring and Supervision**

This section describes the facilities required for monitoring and supervision of PD/3 simulations. It consists of the following sections:

- Purpose of demonstration monitoring and supervision facilities
- Strategy for monitoring and supervision
- Monitoring data
- Supervision data
- Monitoring and supervision messages and their processing

This section concentrates on the aspects of monitoring and supervision peculiar to intersite simulation. It does not address local simulation management aspects.

### **9.1 Purpose of Supervision and Monitoring**

The Supervision and Monitoring subsystems shall contain the functions necessary for defining, controlling and observing the operational and technical aspects of a simulation run.

The facilities shall allow simulation managers to monitor the progress of the simulation as represented by the local simulator and remote simulators. In this context the local simulator is the simulation facility with which the given Supervision facility is geographically collocated, while remote simulators are all physically distinct facilities located at different geographical sites.

The Supervision facility shall be used by two distinct user groups:

- simulation managers responsible for the technical aspects of the simulation
- operational supervisors responsible for the operational aspects of the simulation

### **9.2 Monitoring and Supervision Strategy**

#### **9.2.1 Functionality**

The supervision facilities of the simulators shall have the functions of the existing simulator supervision facilities and, in addition, shall be extended to make them compatible for PD/3. These extensions shall permit operation in the distributed environment.

The requirements set presented here shall assume that the distributed simulation facility is constructed in such a way that each simulator can run as a standalone entity and each simulator “affiliates” to the distributed simulation when it is ready to do so. It also assumes that a Supervision and Monitoring component is present in each of the simulators.

It shall only be feasible to run one distributed simulation exercise at a time, although the simulator facilities themselves may be capable of running several simulation exercise in parallel.

In general terms the approach to distributed supervision shall be as follows:

- Each of the simulators shall be able to run standalone for local testing.
- There shall be no “master” simulator upon which the whole system relies since this could cause difficulties for testing. Each simulator shall be allowed to initiate a run and be the “master” for that run by providing a coordinating role.
- It shall be possible to “log on” and “log off” the collective simulation facility by transmission and receipt of appropriate messages.
- A synchronisation mechanism shall allow the simulators to work to a common timebase and keep in step.

Due to the complexity of the information required to recreate the simulation state, it shall not be a requirement to resume a distributed simulation which fails partway through a run. However, where possible simulators should be constructed with sufficiently resilient structures that if a component which is not crucial to data or communications integrity should fail, the local site should be able to continue and restart the component without causing the whole run to fail.

### **9.2.2 Implementation**

The Supervision and Monitoring facility functionality must be compatible and able to interact with the corresponding facilities of the simulators comprising the PD/3 multi-site demonstration facility. Possible implementation approaches will be to:

- Construct a software package specific for the distributed Supervision and Monitoring services and to set this up at each site, working through new interfaces to each of the existing Supervision and Monitoring facilities.
- Integrate the distributed Supervision and Monitoring services into the existing Supervision and Monitoring facilities at each site.

The Supervision facility implementation shall interact with the other Supervision facilities to obtain the monitoring data and to coordinate, and hence it will also be necessary to implement an agreed message set.

The Supervision subsystem shall respond to enquiries from the user very quickly, ideally well within 0.5 second. To achieve this communications delays must be small. Where possible copies of data shall be held locally and regular updates passed over the networks so that reasonably up-to-date information is constantly available at each site (rather than the Supervision subsystem calling for data each time, which could give a slow response to the user).

Data preparation file formats shall be needed to permit exchange of data between simulators. Standalone filter programs may be required to convert files into the formats required by each simulator.

## **9.3 Monitoring Functions**

This section describes the monitoring functions which shall be required.

The distributed simulation description and current status shall be made available at each of the simulator sites. This shall be done by having Supervision facility create and maintain a database holding the last reported information on the status of each component of the distributed simulation. This information shall include for each component of the simulation:

- “in wait”/ “running”/down/ status unknown
- last reported simulator time
- communications status
- hardware status
- traffic sample reference
- for each aircraft, which air server or flight simulator has control

The database will also include more general information such as which clock is the master clock for the simulator, how many simulated aircraft are presently active and sectors which are configured in each centre.

The database at a simulator site should be initialised when a simulator is started up. The Supervisor at any site will automatically initiate queries to its own and to the other sites in order to update this database at regular, user-defined intervals. This may mean that the data is slightly out of date between updates, so the update rate shall be sufficiently frequent to avoid significant discrepancies (while also avoiding communication network load).

The Supervisor system at a site will provide a user interface enabling interrogation of this database. A summary of key information will always be on display on the simulation managers terminal(s) during the run.

#### **9.4 Supervision Functions**

The functions required for multisite simulation supervision should be as follows:

- Start/Resume. Proceed from current stopped/frozen state.
- Freeze. Temporarily halt, maintaining the context.
- Resume. Restart from the saved context.
- Stop. Terminate the current simulation run.
- Electronic Messaging and Voice Communications Facilities. For communication with other partner’s Supervision teams.

Common operating procedures shall be defined by the three partners to enable common understanding of how to use the Supervision functionality to manage the distributed simulator.



## **10. Data Preparation and Analysis**

### **10.1 Data Preparation**

It will be of great importance that a consistent, common data set is provided for the three simulators when they are set up since a frequent cause of simulation crashes is incorrect data being supplied to the simulator. A possible approach will be to have a master data source. Programs would then be used to convert the data into the formats and fields required for the respective simulator.

Data required for multisite preparation to ensure commonality will include:

- Exercise configuration data, such as timing information, number of controller positions etc.
- Airspace environment data, such as routes, sectorisation and meteorological data.
- Aircraft performance data for input to air system.
- Flight plan data, constituting the traffic scenario.
- Surveillance environment data, such as locations of radars and their intersite connectivity.
- Distributed system configuration data, such as communications organisation and parameters used to configure each site's support tools.

### **10.2 Data Gathering and Analysis**

Data gathering is, likewise, extremely important and needs to be harmonized across the three simulators in order that a single set of programs can be employed to extract statistics for reporting. Again it is likely to be preferred that utility programs are prepared to bring each of the three sets of data to a common format, enabling the data to be loaded into a single analysis program or database.

Tool support and data gathering requirements will be assumed to be provided by the VAL group.

## **11. Configuration Management**

Configuration management shall be required to reduce the likelihood of problems arising at runtime. The following shall be required:

- a process shall be required to circulate and monitor changes in the software, hardware and documentation distributed across the participating sites. This process will have to be able to take into account the local amendments to software at each site.
- a static configuration control process shall be required to enable manual checks and confirmation that the software builds of each simulator for an experiment contain the correct software and the correct versions of that software
- a dynamic configuration control process should provide a protocol at initial connect time which will check the version and build status of the connecting system is acceptable to continue

## **12. Technical Risk Areas**

This section contains a summary of the technical risk areas which have been identified in the course of the preparation of this document.

This section does not attempt to address the organisational risks, such as resourcing for PD/3 and the difficulties of coordinating multiple, distributed developments managed from several different locations.

Key technical risk areas are as follows:

### **12.1 Robustness of Integration**

#### **12.1.1 Risk Description**

There is a general risk that, given the experimental nature of the communications and distributed simulation environment, the simulation may not be robust simply because there is insufficient time to develop mature communications products.

#### **12.1.2 Risk Impact**

If such problems arose, they would have a serious impact on the operational success of the simulations.

#### **12.1.3 Possible Risk Reduction/Avoidance Measures**

1. Carry out early prototyping to examine feasibility under PD/3-level loads
2. Carry out progressive integration and testing of the distributed simulators, avoiding a “big bang solution”
3. Keep in mind potential fallbacks, such as commercial off-the-shelf solutions which would provide less functionality but with greater reliability

### **12.2 PATN**

#### **12.2.1 Risk Description**

There are a number of risks associated with PATN. The principal risk areas are:

- capacity of the links. It should be possible to reduce this risk by purchasing additional capacity from the underlying network service providers, but this may be expensive.
- time and effort required to develop software applications. At present there is little experience of developing applications for PATN. The amount of time and effort available for producing and integrating the applications required for PD/3 may be inadequate.

Since PATN is required, as an objective of PD/3, to be at the heart of the distributed system, the risks described here pose a significant danger to meeting the project objectives.

### **12.2.2 Risk Impact**

Failure of PD/3 to reach objective of demonstrating use of PATN.

### **12.2.3 Risk Reduction/Avoidance Measures**

1. Ensure inclusion of a prototyping programme to demonstrate as early as possible that PATN is a viable solution
2. PD3CG should maintain a high degree of awareness of activity on the PATN project, perhaps through its own assessment team

## **12.3 Upgrade of Simulators**

### **12.3.1 Risk Description**

There is a general risk that the parallel upgrade of the three simulators will provide too difficult to achieve. All three simulators must undergo significant enhancements in functionality, and this may not be achievable in the time and with the resources available.

Furthermore, there is a need for the three simulators to have very similar functionality. This may not be achievable in practice due to the differing structures, interfaces, software and tools of the facilities.

### **12.3.2 Risk Impact**

Possible impacts are inability of the simulators to provide the required functionality, late availability of simulator capability and difficulties in integrating externally provided tools (eg PATs).

### **12.3.3 Risk Reduction/Avoidance Measures**

1. Finalise and elaborate the organisation, operational and partners' participation requirements to enable preparation, as soon as possible, of an overall PD/3 system design specification taking into account the different features of the different simulators.
2. Realistic planning, and continuous monitoring and reporting by each site of the progress of simulator adaptation.

## **12.4 Implementation of Distributed Air Server**

### **12.4.1 Risk Description**

The distributed air server is a significant risk area since the approach is untried and existing work has demonstrated some of the difficulties. Problems to be solved include the difficulty of modifying the different air servers to allow transfer of aircraft and the difficulty of implementing this solution over the communications networks in a reliable and robust way.

### **12.4.2 Risk Impact**

Problems may be experienced with the simulation of aircraft in the PD/3 simulations.

### **12.4.3 Risk Reduction/Avoidance Measures**

1. Critical review of the approach by the PD/3 Air Server task force.
2. Prototyping of solution.

## **12.5 Initialisation of Flight Simulators**

### **12.5.1 Risk Description**

The difficulties of initialising flight simulators to work coherently as part of the simulation were discussed in section 5. These may well mean that the flight simulators bring little practical benefit in terms of results while adding significant complexity and cost to, for example, the communications environment.

### **12.5.2 Risk Impact**

The additional costs and complexity may outweigh the benefits obtained by including the flight simulators in the experiments. In particular, the air system may become so complicated that it cannot operate properly or is late in being made ready.

### **12.5.3 Risk Reduction/Avoidance Measures**

1. Consider different options for including the flight simulators in experiments, such as using them in separate smaller-scale experiments
2. Consider only having the flight simulators fly short trajectories from outside the simulated area into the airspace modelled by the site with which they are colocated (eg RFS into NLR).

## **12.6 Simulation Data**

### **12.6.1 Risk Description**

Consistency and coherence of simulation data is a serious problem to be solved for PD/3. Each site has different data requirements which have not yet been documented and the tools for converting between formats not planned or developed.

### **12.6.2 Risk Impact**

Failure of experiment run.

### **12.6.3 Risk Reduction/Avoidance Measures**

1. Adopt a solution minimising replication of data.
2. Develop and use automated cross-checking and validation tools.
3. Ensure that the plan includes sufficient allowance for data preparation and for validating preparation data.

## **12.7 Voice Communications**

### **12.7.1 Risk Description**

The difficulty of providing the necessary voice communications is easily underestimated. Particular areas of concern are accuracy of estimates, procurement delays for new equipment and costs of implementation.

### **12.7.2 Risk Impact**

Unavailability of suitable communications equipment will prevent the experiments from taking place. Unsuitable equipment will compromise results.

### **12.7.3 Risk Reduction/Avoidance Measures**

1. Include specific tasks for providing the voice communications facilities in the plan to be carried out early in the project

## **12.8 Integration of Inputs from other PHARE Projects**

### **12.8.1 Risk Description**

It is proposed that other PHARE projects participate in PD/3 by provision of validated software components and documentation to defined specifications.

The resulting software components will then need to be integrated locally at each site, and then, for multisite components (eg tools supporting multisector planning) across the whole simulation facility.

There is a high risk of incompatibility through, for example, misunderstanding of specifications, difficulties porting across computer languages or hardware and differences in appreciation of objectives. Given the diverse range of teams carrying out these projects, the likelihood of a failure of coordination is high.

### **12.8.2 Risk Impact**

The risk is that some aspects of the simulators will not function properly, or there will be delays in availability of the simulators.

### **12.8.3 Risk Reduction/Avoidance Measures**

1. Produce an overall PD/3 system design specification to identify clearly how each team's contribution fits into the system.
2. Allocate well-defined tasks to the PHARE projects.
3. Apply effective acceptance procedures

## **12.9 Differences Between Local Implementations**

### **12.9.1 Risk Description**

Each site will make use of local implementations of, for example, trajectory calculations in air servers. This creates the risk that while the implementations may be similar, there may be significant discrepancies. As an example of the type of problem this might cause, it could be imagined that on crossing the boundary between centres, aircraft might start to behave differently.

### **12.2.2 Risk Impact**

The likely impact is that unexpected and unrealistic behaviour may occur. This may compromise the results.

### **12.2.3 Risk Reduction/Avoidance Measures**

1. Include work in the programme to compare the local site implementations for differences and to determine the impacts of these differences.

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## Glossary & Abbreviations

ACC	Air traffic Control Centre
ADEXP	ATS Data Exchange Presentation
AIS	Aeronautical Information Services
API	Application Programming Interface
Architecture	Concepts for large scale structure of a system
ASTERIX	All Purpose Structured Eurocontrol Radar Information Exchange
ATIS	Air Traffic Information Services
CMS	Common Modular Simulator
CNS	Communications, Navigation, Surveillance
CPDLC	Controller-Pilot Datalink Communications
DAARWIN	CENA Simulation Facility
DAP	Downlink of Aircraft Parameters
DIS	Distributed Interactive Simulation
DLARD	Datalink Application Requirements Document
DLCRD	Datalink Communications Requirements Document
Experiment Leader	Person at each site responsible for running simulator
FMS	Flight Management System
GHMI	Ground Human Machine Interface
ISTF	PD/3 Intersite Simulation Task Force
ISTRES	
LAN	Local Area Network
MASS	Multi Aircraft Simulator System
MCS	EEC flight simulator
Multi Sector Planner	Controller responsible for planning flights to 40 minutes ahead
NARSIM	NLR Air Traffic Simulation Facility
NOTAM	Notification to Airmen
OLDI	Online Data Interchange
OTF	PD/3 Operational Task Force
Overall Supervisor	Team or individual responsible for runs of whole simulation
PAT	PHARE Advanced Tool
PATN	PHARE Aeronautical Telecommunications Environment

PD	PHARE Demonstration
PD/3	PHARE Demonstration 3
PD3CG	PD/3 Coordination Group
PHARE	Programme for Harmonised ATC Research in Europe
Pseudo-Pilot	Air server operator. Mimics the responses of several pilots
QoS	Quality of Service
RFS	Research flight simulator
r/t	radio telecommunications
SID	System Instrument Departure
SIM5+	EEC Simulation Facility
site extended view	Aircraft state vectors needed by a site to build its radar picture
STAR	Standard Arrival Route
SYSCO	System Supported Cooperation.
WAN	Wide Area Network

## **Appendix A: Requirements to PATN**

### **A.1 Introduction**

A part of the PD/3 preparation activity is to identify and take into account the results of a number technical issues.

This paper identifies the requirements for PATN capability assessment. It is an initial draft to be refined further.

To provide background to this requirement, this paper also describes the anticipated implementation requirements which will be placed on PATN by PD/3.

### **A.2. Objective of Prototyping/Proving PATN for PD/3**

An objective of PD/3 is to examine the use of PATN in a large scale but still experimental environment. However, PATN is incomplete, and PD/3 also requires new and additional functionality of PATN. Only a very limited subset of applications is foreseen to be implemented in PATN Phase 0/1, while PD/3 puts specific requirements on the simulation of sub-networks. It is the objective of this requirement paper to define what validation of PATN is needed before a decision can be taken to use it for PD/3.

Of particular importance to PD/3 at this stage is the need to demonstrate the feasibility and costs of integrating PATN with available ATC simulators and the costs and time of implementing basic datalink capability, user processes and application processes for datalink communication. If these costs prove to be excessive, or the demonstrated performance and reliability are insufficient for PD/3, then alternative or complementary solutions will have to be sought quickly. It is for this reason that a fast response to these requirements is essential.

### **A.3. Background - Likely Requirements of PD3 on PATN**

This section summarises the anticipated requirements which will have to be introduced into PATN if it is to meet PD/3 requirements. These requirements are in the process of refinement and shall be viewed as indicative of the anticipated requirement rather than stating the precise requirement at this time. The section shall serve to demonstrate the likely needs of PD/3 for support from PATN and to put into context the specific prototyping exercises described in section 4. These requirements will need to be implemented and be available in time for intersite integration in 96-97.

It is understood that a PATN prototype exists which has been demonstrated and site deployment will soon start. The PATN developers state that the product is debugged and available for use.

It is currently the objective of PD/3 to integrate the various air and ground systems by interconnecting them through PATN. The possible inclusion of simulation communications is believed to be different from previous expectations of the PATN team which are believed to be more oriented towards real ATN applications - the implications of this are unknown at present.

The following general requirements are foreseen:

- Quality of communications:

PATN should cope with the qualitative communication requirements of an ATN, such as following the ISO-OSI standards.

- The average throughput of data is likely to be of the order of:

- operational datalink air-ground approx. 8 kilobits/s  
(CPDLC + DAP + ATIS + negotiation)

- operational datalink ground-ground approx. 21 kilobits/s  
(flightplan updates + negotiation)

There is no allowance for message headers and other overheads in these estimates.

- The maximum transfer delay is typically of the order of 10 seconds. Datalink applications with large messages (5000 bits?) such as trajectory negotiation may tolerate longer delays of 20-30 seconds.

- It is essential that the communications service reliability is very high and robust (ie no message loss, no link failures during a 2-3 hour simulation run)

- Priority is high for operational applications in sequence: CPDLC, DAP, trajectory negotiation, and ATIS, and then simulation support data.

- Air-Ground simulation data connectivity:

PATN shall be able to serve 400 air-ground flights reliably. Almost all these flights are simulated flights performed in three (distributed) ATC simulation facilities.

Controlled simulated aircraft and flight simulators shall use real ground-ground links.

These simulated flights shall have access to the ATC simulation software in a transparent way, to PATN, using an appropriately simulated network. Data would be exchanged between the different ATC centres, via access to PATN simulated in the different ground systems of the ATC simulation facilities. Simulated flights will be transferred from site to site and accordingly also the routing within PATN shall be transferred.

Because datalink response is critical for certain air-ground applications, such as CPDLC, it is important that actual transfer times simulating air-ground links are corrected to foreseen real-world message transfer times. (Moreover, it is important to be able to select simulated response times better than actually current day responses because future datalink performance improvements may be expected within the PD/3 timeframe.)

Thus the simulated air-ground datalink shall include:

- simulation of dynamic rerouting
- simulation of delays due to the physical medium
- simulation of delays due to the expected workload
- simulation of expected transmission failures

In addition to the aircraft simulated by ATC simulators, there are also flight simulators, such as RFS and MCS, participating in PD/3 and research aircraft, such as the NLR Citation. The real flying research aircraft shall use a real air-ground mobile communication sub-network.

- ATN communication applications:

The following categories of datalink processes are expected to be required for PD/3:

- Strategic ATC communication:

- Trajectory negotiation, negotiating on trajectory "contracts" for a medium-term time-scale.

- Tactical ATC communication (CPDLC):

- Part of the tactical clearances may be (non-time critical) communicated by datalink instead of R/T.
- Requests for clearances may be supplied by pilots via datalink.
- Frequency changes and initial contact calls are good examples of non-time critical clearances to be performed via datalink.

- Informative communication in support of ATC (DAP):

- Flight management data, e.g. in flight position report, start of tactical manoeuvre indication.
- Flight status data, e.g. actual weight, altitude, rates of climb, descent, turn and selected flightlevel, heading and speed. This information will be supplied mainly in support of ground-based automatic tools.

- Airfield/Airspace and NOTAM information.

- Weather information:

- Weather forecast information, uplinked.
- Actual weather information, downlinked.

- Ground-ground connectivity:

Each Controller Working Position (CWP), including planners as well as tactical controllers, must be able to communicate with each other via PATN. Tasks include coordination and flight plan data. Moreover, every controller shall be able to establish a connection with each equipped flight, when this is appropriate.

- Documentation:

Hardware and software documentation shall be supplied for:

- overall design
- router/carrier specifications
- applications specifications, including interfaces
- integration details

- running PATN hardware and software
- maintenance

For example, documentation must be supplied which is sufficient to use and access the network configuration and to select and to use and understand the implementations of the different datalink applications.

- Support

Support will be required for the validation, integration and running of the software and hardware.

- Implementation requirements:

The implementation of applications shall be flexible, modular and extendable. The implemented applications shall be accompanied by representative test sets, which are able to validate the complete functionality as supported, demonstrating the correct working of all available options.

Overall PATN will have to be adapted and extended to meet the needs of PD/3. In parallel to this the ATC simulators being used will have to be adapted and extended.

#### **A.4. PATN Validation/Proving Requirements**

PD/3 considers that the following topics should be investigated and proven through production for the multi-site simulation facility by PATN:

- Concerns of PD/3 are the impact of the overhead of the PATN on simulator performance, its robustness against problems such as random failures, and the ease of expansion of the PATN to a scenario of the size of PD/3. An early programme of experiments/prototyping using the PATN is essential to enable the PATN team to demonstrate that PATN works adequately under loads typical of PD/3, and hence to allow PD/3 to determine how to use PATN.
- For use of PATN within an ATC simulation environment, specific simulation requirements such as delivery of messages within specific time delays are applicable. These are not yet foreseen in PATN Phase 1. The ability of PATN to support this functionality needs to be proven.
- Different application processes, required for PD/3, such as trajectory negotiation, direct clearances (CPDLC) and downlinking flight parameters (DAP), are not implemented in Phase 1 of PATN. The costs and difficulties of developing these types of applications under PATN needs to be proven.

Overall, for a proper integration of PATN in a multisite simulation environment, a practical proving or assessment is necessary.

#### **A.5. Proposed Work Plan for Prototyping/Proving PATN**

Given the importance of communications within PD/3, it is recommended that all three PD/3 partners work closely with the PATN team in this proving exercise in order that all become familiar with the use and capabilities of the PATN.

The following experimental tasks are proposed:

- Task 1.

Establish site-site links, coupled to the different ATC simulators, to prove PATN site-site communication between and integrated with simulators is feasible in technical, time and cost terms. This will ensure the compatibility of the software and hardware at each of the sites. Both ground-ground and air-ground links shall be established (using the X.25 and Satcom sub-networks respectively).

Given the existing installations, this exercise shall be straightforward and shall have been done by the end of 95.

Hardware to run the routers will be required at the EEC for this exercise.

- Task 2.

Implement some simple new user and application processes to exchange data between sites using the OSI protocols. These processes could be comparable in terms of complexity with the MET application already available. The implementation of the DAP application process and some DAP user processes (regular update of weight, fuel and other AC status parameters, and mode-of-flight indicators (e.g. a turn indicator)).

- Task 3.

Use these new processes to examine ATN performance under a range of loadings and for the different sub-networks which might be used (ie. ground-ground X.25 and air-ground Satcom). The objective would be to measure transfer times when the network is placed under PD/3-type loads (eg. peak loads of at least several hundred messages per second and mean loads of a few hundred messages per second, requiring bandwidths of 20-40 kbits/s for ATN applications).

- Task 4.

Report results obtained and draw up conclusions on whether the PATN can accommodate the predicted required loads, the rates of message loss, and robustness with respect to factors like loading and message size. Also report on the costs and difficulties of implementing software application and user processes to interface to the core PATN developed under Phase 1.

#### **A.6. Timescale for Prototyping/Proving PATN**

PATN Phase 1 is underway with a demonstration facility being available and installed but distribution to sites is still to be carried out.

A validation of some air-ground aspects (Mode S) will be carried out by Eurocontrol, ending September 95.

Hence it shall be feasible to design and plan experiments in Q3 95 and to execute those experiments in Q4 95.

This would allow time for a go/no go decision on use of PATN in PD/3 by early 96, in time before software development of PD/3 communications applications has been begun in earnest.

This prototyping shall be in addition to the planning and design for the development of communications applications.

## **Annex B. Communications Measurements**

### **B.1 Definitions**

Network performance should be considered with characteristics concerning the quality-of-service. On a rather low level, the transport layer, one discerns the following QoS parameters [14]:

- 1 - Throughput
- 2 - Transit delay
- 3 - Residual error rate
- 4 - Protection
- 5 - Priority
- 6 - Transfer failure probability
- 7 - Connection establishment failure probability
- 8 - Connection release failure probability
- 9 - Connection establishment delay
- 10 - Connection release delay
- 11 - Connection resilience

Not all of these are relevant, and on a high level the relevant parameters to be considered, are:

- 1 - Transit delay
- 2 - Residual error rate
- 3 - Service loss reporting
- 4 - Throughput

For the discussion on the required capacity, the transit delay characteristics and the throughput characteristics are the determining factors. The calculated required bandwidth between two sites identifies the average or even the minimum required throughput capacity.

- **Frequency of messages:** The average number of messages sent per second. When flow of messages is erratic it will be desirable to use a peak frequency next to the normal frequency.
- **Network delay:** The time a bit of information takes to travel across the network. For complex networks (e.g. Internet, SITA) the network delay should be characterized by a distribution function giving the chance the network delay is below x seconds at any time.

- Transit delay: The elapsed time between sending and receiving a message. The transit delay depends on the intrinsic network delay, the message size, and the network bandwidth.
- Bandwidth: The average number of bits per second that can travel across the network from one given point to another given point.

There are no simple relations between any of the quantities given above.

More natural is to calculate the required bandwidth as:

Bandwidth = size x security factor x frequency of sending dataset x number of messages in dataset

where the security factor is an allowance principally for bursty, or simultaneous traffic demands on the communications network. It can also be considered to include some allowance for communications overhead, unexpected network delays and the inevitable inaccuracies in the communications forecasts.

If the delay is used instead of the frequency it is assumed that an extra security factor is required. This extra factor enlarges the bandwidth, but does not reduce necessarily the delay time. Therefore it seems better to keep the basic network requirements separated, and to keep the required bandwidth separated from the specified maximum acceptable delay.

## **B.2 Internet**

Performance measurements on Internet were made as follows. It should be noted that nothing is said about the overall performance of the network and about the average capacity available for PD/3 on critical connections or timing factors. Therefore, it is difficult to comment on the stability of delays.

The Internet measurements have been done on 11 and 12 October 1994 using binary ftp to transfer a large file from ftp.cenatls.cena.dgac.fr and from mcs.eurocontrol.fr to a host at NLR (ftp.nlr.nl).

The delay numbers are all derived from actual measurements using the UNIX ping utility to send 100 packets between two sites and measure the delay.

The average bandwidth between the establishments has been measured during daytime. The maximum bandwidth figures are based on general international Internet traffic, disregarding possible bottlenecks resulting from low-bandwidth connections from an establishment to the Internet provider.

A small tool used in the Annette project to measure Internet bandwidth between establishments has been used, yielding these results:

```
$ bandwidth -t10 ftp.cenatls.cena.dgac.fr  
chargen TCP: bufsize=1024, running ..  
running time = 10 sec
```

---

	characters	bit rate	Byte rate
recv	69706	55.76 Kb/sec	6.81 KB/sec

---

```
$ bandwidth -t10 capo.eurocontrol.fr  
chargen TCP: bufsize=1024, running ..  
running time = 10 sec
```

---

	characters	bit rate	Byte rate
recv	52910	42.33 Kb/sec	5.17 KB/sec

---

Taking into account the actual connections from the establishment to the Internet provider the maximum bandwidth between the establishments is approximately 64kb/sec. Within EEC discussions about a possible upgrade are in progress. NLR currently has a 2Mb/sec link to Internet, soon to be upgraded to 34Mb/sec.

The possible bandwidth between, for example, nlr.nl and inria.fr is show below:

```
$ bandwidth -t10 ftp.inria.fr  
chargen TCP: bufsize=1024, running ..  
running time = 10 sec
```

---

	characters	bit rate	Byte rate
recv	235798	188.64 Kb/sec	23.03 KB/sec

---

## B.2 PATN

Preliminary PATN measurements over the SITA X.25 network were made between NLR and CENA. These measurements have been made by direct access to the SITA network, not using any particular part of PATN network software. A large file was transferred several times on different times of the day. Worst case results were achieved at lunch hours. Timing figures were achieved by simple manual timing and by calculating the effective throughput.

More figures concerning general throughput data, including the working of the PATN network protocol, may be achievable using the Presentation Service Traffic Generator (PSTG) of PATN.

## Annex C. Estimated Traffic Sample

The traffic sample can be thought of in terms of a set of flows of aircraft between controllers, as shown below:

=> DEP CENA => ER CENA => ER1 EEC => ER2 EEC => ER NLR => ARR NLR  
<== ARR <== <== <== <== <== DEP

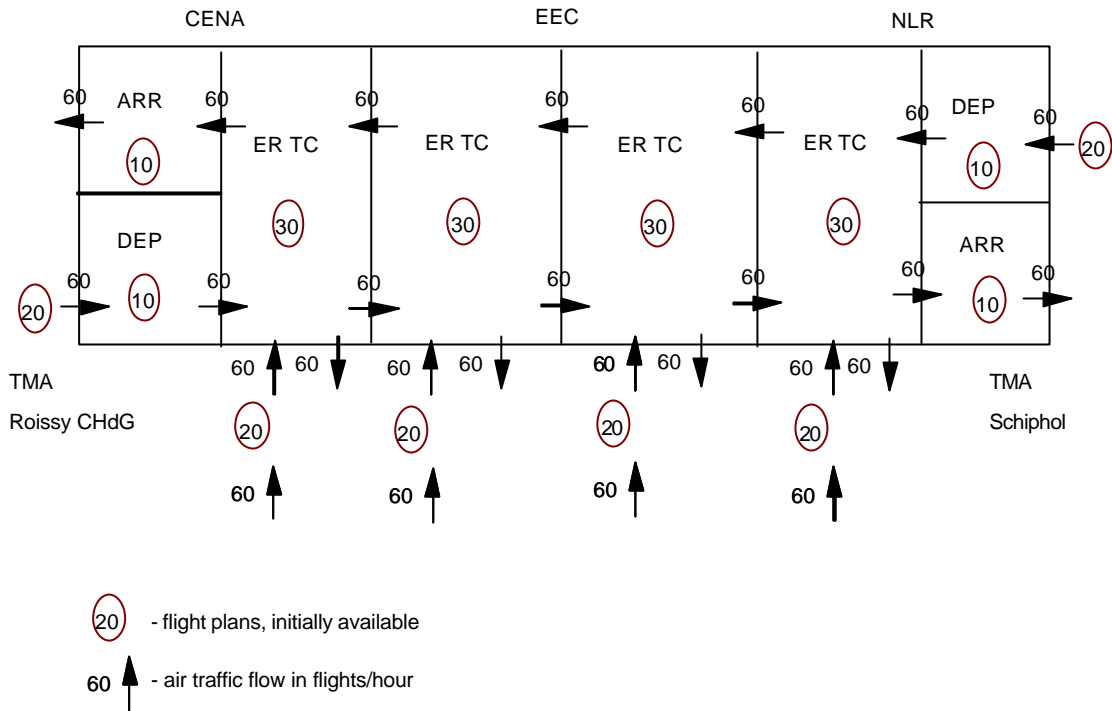
This assumes the configuration shown in section 4.2.3 with departure (DEP) and arrival (ARR) tactical controllers, and one en-route (ER) tactical controller at each of CENA and NLR, and two en-route tactical controllers (ER) at EEC.

Supposing that the ER tactical controller will control 30 flights at a time and that an aircraft will spend 10 minutes on average in an en-route sector, then every 10 minutes 30 new aircraft will be handled by the sector. The result is that the flow in and out of an en-route sector is 180 per hour.

Supposing that 60 flights per hour will arrive and depart to and from a TMA. In that case 120 per hour will be dissipated from the CENA/NLR en-route sectors to other en-route sectors.

Supposing that the traffic sample is such that 50% goes to EEC adjacent en-route sectors, then 60 per hour flow to and from CENA/NLR to and from EEC. The result is that there is a remaining feeder stream to and from each EEC en-route sector of 60 flights, because we have 180 per hour fed into the EEC en-route sectors without any TMA traffic, directly into the EEC area and EEC is fed by 120 AC to and from the 2 sectors.

The resulting possible traffic sample is shown below:



In more detail, the flows and numbers in each of the sectors would be as follows:

CENA	EEC	NLR	
30+10+10	30+30	30+10+10	a/c under tactical control
40	40	40	a/c in feed sectors
180 per hour	240 per hour	180 per hour	out/in-flows

Allowing for planning up to one hour in advance will require the following capacity in each simulator system, calculated from the sum of the individual contributions:

270 flights      340 flights      270 flights

In practice the actual requirement should be slightly less than this number since the multisector planning window is currently approximately forty minutes.

The creation of new flights feeds the simulation at the following rates:

120 fl/hour    120 fl/hour    120 fl/hour

The simulation navigates in each site:

90 flights    100 flights    90 flights

and over the three hour simulation the following number of flights will need to be created in each site:

360 flights 360 flights 360 flights

and to receive from adjacent areas:

180 flights 360 flights 180 flights

This results in the following total requirements for a full three hours simulation:

Processing:

630 flights 820 flights 630 flights

Initializing:

450 flights 460 flights 450 flights

And the following peak loads:

Ground system capacity (flights actively recorded in a ground system database at a given time):

270 flights 340 flights 270 flights

Air system capacity (flights actively simulated in an air server at a given time):

90 flights 100 flights 90 flights