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ACCESS

ATN Compliant Communications

European Strategy Study

Performance Analysis and Dimensioning

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EXECUTIVE SUMMARY

Of the vast amount of work which has been performed to date on the ATN (including that done within the ACCESS study), most of it can be classified as "qualitative" or "logical design". This report is one of the few documents known to the authors which takes a **quantitative look at the network**.[1]

The primary goal of this work package is to set up a framework for specifying quantitative parameters of network components of the ATN in the ACCESS area depending on a number of "boundary conditions" and the time frame under consideration. Because of the lack of suitable existing material on the subject, it has been necessary to carry out **original research** which is reported in this document. It has become apparent that there is little, if any, research nor experience in dimensioning data networks similar to the ATN in a consistent way.

The problem of predicting and analysing ATN performance and specifying parameters of ATN components is a **multidimensional design task** which seeks to optimise a number of mutually conflicting aspects:

- topology
- throughput capacity,
- transit delay times,
- accuracy,
- availability and
- costs.

The particular problems encountered in the design task are due to the unique technical and administrative characteristics of the ATN. Although the Internet, as the world's largest (inter)network, has many similarities to the ATN, **studying the Internet is no help** in a quantitative analysis of the ATN. This is due to the history and development of the Internet and to the radically different demands placed on it.

Any quantitative analysis of the ATN is necessarily confronted by a **large number of assumptions** which have to be made. Within the ACCESS context, much valuable work has been done in narrowing down this inherent uncertainty in the "environment" of the European ATN. The initial requirement in terms of applications, architecture, locations and subnetworks has been defined in the ACCESS Work Packages 202 to 205. However the authors have chosen not to restrict themselves only to the ACCESS environment because of the general lack of quantitative ATN investigations. Therefore the results presented here are **valid for the ATN in general** and not just for the ATN in the ACCESS area. This approach has the advantage that the methods developed will be useful not just in the initial design stages of the European ATN and not just within the European Region.

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[1] A notable exception is the quantitative work which needed to be performed on protocols for the A/G data link because of the limited bandwidth on some mobile subnetworks. However no *overall* quantitative analysis exists as yet.

Given the above facts, it is evident that this area is a necessary **basic research topic**, and all methods must be specified in the absence of supporting external research. It would seem that this report is starting from scratch in a number of senses, and can only outline procedures to progress the ATN design, but cannot yet actually produce the design itself because of insufficient information. It fulfils the requirements of the task description for this Work Package, to "… **set up a framework** for analysing, predicting and planning the quantitative parameters of the network …".

The framework consists of a **series of activities** to be carried out when performance analysing and dimensioning the ATN. There are two distinct ways of approaching this task:

- assume a topology, and analyse it to dimension the components accordingly, and
- assume only the requirements (throughput, time delay, etc.) and compute an optimal cost topology.

It is concluded that the **topology must be input** to the task as a given fact and that it is unrealistic to expect the analysis to yield a topology: it is felt that this is best carried out manually. This is in keeping with the ACCESS methodology: WPs 203, 204 and 205 provide the necessary input. The framework does therefore not propose a method for designing specific topologies.

The framework contains analytic and simulation activities. The **analytic approach,** which is emphasised in this report, will be fast, but not totally reliable because certain dynamic aspects of the ATN cannot be analytically modelled (e.g. interaction between routers). For this reason, the analytic methods should be verified by either a **simulation model** or by a **pilot implementation**. There are three tasks which must be carried out prior to using the analytic approach of the framework:

- establish the application data traffic overhead for each class of application which the ATN must handle;
- obtain the throughput and transit delay characteristics, MTBF and MTTR of each subnetwork and router product proposed for use in the ATN;
- specify (in terms of locations, subnetworks etc.) the ATN topologies which are to be analysed.

This approach is largely consistent with the simulation activities being performed by the ATN Implementation Task Force, [ATNITF1].

In addition, the following information must be determined:

- application analysis - a survey to identify each end system location and the applications it supports,
- for each application supported by an end system, the number and average/peak length of data items it will generate for transfer through the ATN,
- the priority setting and classification for each application,
- a detailed survey of ground subnetworks involved,
- a detailed survey of air/ground subnetworks involved,
- topography (geographic locations) of end systems and any constraints on location of routers, connectivity of subnetworks, subnetwork traffic types,
- analysis of profiles of traffic due to mobile hosts.

Assuming that the above information is available, the calculations in this framework can be used to determine appropriate **subnetwork, router and communications circuit sizes** and the **associated costs**. This analytic approach may be used to eliminate obviously undesirable designs prior to running simulation tests on those designs which seem acceptable.

The results must, however, be interpreted in the light of the **following restrictions**:

- The designs will indicate the minimum requirements of routers, subnetworks, switches and communications links which are able to handle peak traffic loads, under the assumption that all of the ATN components operate at their most efficient. The requirements must be multiplied by a factor to ensure that abnormal loads and component outages can be dealt with;
- The designs do not take into consideration the requirement for duplications of ATN components to minimise the impact of component failures. Appropriate duplications must be included in the design of any proposed ATN topology;

As a result of this investigation, the following **recommendations** can be made:

1. Manually design trial ATN topologies and test them with the analytic tools outlined in this report;
2. Subsequently test the designs by simulation;
3. Develop analytic tools based on spreadsheet models for the ATN;
4. Use existing proprietary tools for subnetworks and routers where they are available;
5. Initiate research into actual application requirements in terms of expected data traffic flows, peak data volumes, transit time peak maxima and timings and other parameters for each application. Determine the overall constraints for each application. This is a significant and large task, the results of which are used in both analytic modelling and in simulation.
6. Initiate research into the availability of subnetwork capacity and router capacity available from the market, and determine their throughput/transit time delay characteristics;
7. Establish an Operational Context for the ACCESS region which specifies precise throughput, scope and transit time delay requirements;
8. Establish a framework for allocation of target parameter values (e.g. maximum allowed transit time delays) among the ATN operational authorities.

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1. Introduction

1.1 Scope

Following the specification of the ACCESS architecture (routing architecture: WP203, subnetworks: WPs 204 and 205), this document adds a quantitative dimension to the design of the European ATN in the time frame 2010. By means of the methods developed here, appropriate capacities of network components can be estimated.

1.2 Purpose of Document

According to the task description for this Work Package, the document shall "… set up a framework for analysing, predicting and planning the quantitative parameters of the network." In order to accomplish this, the following steps are to be followed:

1. Identify all relevant quantitative parameters to describe the network;
2. Describe feasible methods for measuring dynamic parameter values, e.g. throughput;
3. Set up and justify a list of desirable values for the parameters;
4. Derive consequences for the dimensioning of network components.

The results presented here are not restricted to the European ATN in the ACCESS terms of reference. Because of the general nature of the problems involved and the lack of suitable existing research material, the solutions proposed are applicable to the ATN in general.

1.3 Document Structure

The report has the following structure:

Chapter 2 is a statement of the problem, formulating the scope and objectives of a quantitative analysis of the ATN.

The following chapters move successively from a general discussion to the specific activities necessary for the European ATN:

Chapter 3 looks at the performance analysis and dimensioning problem for internetworks in general.

Chapter 4 treats techniques for the analysis and dimensioning of CLNP networks.

Chapter 5 details aspects of analytical modelling (by comparison with simulation or pilot trialing of networks) which is recommended here as initially being the most useful modelling technique.

Appendix A gives an outline of a possible further development of the analytical model developed in the body of the report.

Appendix B introduces features which are specific to the ATN (by comparison with CLNP networks in general). Without attempting to be complete, it discusses aspects which need to be considered when developing the analytical model.

The approach and contents of this report have been strongly influenced by [SPO1].

1.4 References

	Reference	Title
1	[SPO1]	Spohn, David, "Data Network Design", Second Edition, McGraw Hill
2	[Axxx]	ACCESS WP xxx
3	[ATNITF1]	Eurocontrol ATN Implementation Task Force, "Software Simulations for the Planning of the European ATN Network, Call for Tender"
4	[CEC8]	EOLIA Project Deliverables - 30/08/1996
5	[EURsim]	Results of Eurocontrol/CENA IDRP simulations conducted in 1996 & 1997 in the context of the ATNP SARPs validation activities

1.5 Acronym List

A-DATA Application Level Data

AAFPP Airborne Application Flight Phase Profile

ACSE Association Control Service Element

ADS Automatic Dependent Surveillance

AIDC ATS Inter-facility Data Communications

AMHS ATS Message Handling System

APDE Application Protocol Data Unit

APO Application Protocol Overhead

ASN.1 Abstract Syntax Notation 1

CASA Computer Aided Slot Allocation

CFMU Central Flow Management Unit,

CLNP Connectionless Network Protocol

COTS Connection Oriented Transport Service

CPDLC Controller-Pilot Data Link Communications

FIS Flight Information Services

IDRP Inter Domain Routing Protocol

ISO	International Organization for Standardization
LAN	Local Area Network
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
P-DATA	Presentation Level Data
PDU	Protocol Data Unit
PSN	Packet Switching (Switched) Network
S-DATA	Session Level Data
SARPs	(ICAO) Standards and Recommended Practices
SNDCF	Subnetwork Dependent Convergence Function
T-DATA	Transport Level Data
TACT	Tactical Planning Application
TCP/IP	Internet transport and network protocols
TPDU	Transport Protocol Data Unit
TSDU	Transport Service Data Unit
WAN	Wide Area Network

2. Objectives of Performance Analysis and Dimensioning

2.1 Background

This section gathers the background facts which are of importance to the task of performance analysis and dimensioning of an ATN.

2.1.1 Sources of Requirements

The requirements of the ATN are specified in a number of different documents including:

- the **SARPs -** which specify the functional requirements of a range of ATN applications and communications technologies and services used to support the application data communications requirements;
- a set of **Operational Requirements** for each application, which specifies the ***overall*** target parameters of each application type as far as the application's users are concerned;
- an **Operational Context**, which provides a plan for utilisation of the ATN to meet ATC operational requirements. This will impact and refine the global Operational Requirements for a specific region of the ATN.

2.1.2 Relevant Features

From the point of view of system dimensioning and performance, the ATN:

- is a ConnectionLess internetwork using standard ISO CLNP and routing protocols to support a number of different air/ground and ground/ground communications applications.
- connects a wide range of end system types, each of which may support one or more of the ATN applications.
- is based on a free running connectionless packet switching systems consisting of various types of subnetworks interconnected by means of routers. This implies a high degree of resource sharing, and no provision for resource reservation for specific data traffic flows;
- must support mobile subnetworks (in aircraft) and their attached end systems and applications;
- supports ATN applications which communicate with each other using the OSI Connection Oriented Transport Service (COTS) using Transport Protocol Data Units of up to 64Kb;
- is safety critical;
- must support strict traffic transit time delay, accuracy and availability appropriate to each application;
- has (assumed) well behaved congestion and traffic flow control mechanisms to avoid excessive congestion delays and to give a level of fairness to different traffic flows;
- has a powerful traffic prioritisation mechanism which can be used to select routes for traffic dependent on the applications from which the traffic originated. This includes

the ability to inhibit certain traffic from using particular routes and can also be used to selectively dump low priority application data traffic in cases where overload traffic conditions are approached;

- it can be assumed that end applications obey an appropriate flow control regime and present traffic to the ATN in a ‘considerate’ manner (e.g. in that lower priority applications pace the transfer of large quantities of data and do not ‘flood’ the network, and that they also obey the ATN flow and congestion control mechanisms);
- resets (i.e. packet discarding) are supposed to happen in only the most catastrophic of situations, if at all;

In such connectionless networks:

- time delays through routers, subnetworks and subnetwork switches vary as a function of traffic load;
- an adaptive/alternate routing strategy introduces the need for TSDU re-constitution and this will tend to increase the average overall traffic delay for TSDU.

CLNP Internetworks and their component subnetworks and routers can operate in a reasonably predictable and stable manner only when traffic loads are kept reasonably low with respect to their theoretical maximum throughputs, however their throughput and time delay characteristics generally worsen as the traffic load is increased, and can go into ‘chaotic decline’ (i.e. approach zero) at extreme loads. It is therefore necessary to assume that the ATN must be operated at less than its theoretical maximum throughput. This implies that the ATN must be oversized by a certain factor with respect to its expected peak traffic loads to ensure that congestion and reduction of quality of service never arise apart from during exceptional conditions.

2.1.3 Constraints

There are some other constraints placed on the ATN which are relevant to its design:

- Various national and regional networks will be integrated into the ATN. These may have exiting traffic loads which are not due to ATN applications;
- It is not possible to consider the ACCESS ATN in isolation from other regional ATNs if the ***global*** transit delay times specified in the operational requirements are to be met. In general there will be complex relationships between regional and global traffic patterns.
- The ACCESS ATN may also be required to carry transit traffic between other regions, and its end systems will also be the source or sink if information flowing to or from other non-ACCESS regions;
- The actual traffic throughput requirements have yet to be estimated for the ACCESS region. Whereas some traffic flows can easily be determined (e.g. for AFTN and Radar), some applications are not yet ‘live’ and estimates must be based on current levels of the equivalent voice communications interchanges (e.g. CPDLC and AIDC). Others have no operational precedents, so therefore they must be roughly estimated (e.g. ADS, D-FIS), and perhaps restricted during the initial phases of the ATN to protect it whilst assessing the actual demand;
- Each ATN application has separate throughput and target maximum transit delay requirements;

- Applications supported by the Access ATN will require data flows between and across ATN facilities operated by different national ATC services. However, the ATN throughput and maximum transit delays must be achieved on a 'global' basis - end to end across the whole of the ATN. This implies that the maximum allowed transit delay times must be shared between the different operating agencies, such that the total transit delays do not exceed the application's maximum allowed value. It would seem essential that each organisation operating a part of the ATN should agree to maintain their individual transit delays within their allocated targets. The way in which transit delay targets are allocated are presumably to be derived from the Operational Context.

The design of the ACCESS region's ATN must take into consideration all of the above aspects.

Important material on the likely future applications using the European ATN has been derived from [A202]. Although the treatment here is independent of a particular network architecture, all recommendations made are consistent with the architecture proposed in [A203]. The treatment of subnetworks is consistent with the proposals made in [A204] and [A205].

2.1.4 The Relevance of the Internet

The Internet is the worlds largest internetwork which might be compared to the ATN, however, to date, it is fundamentally different in a number of aspects and even if research had been available it would be largely irrelevant because:

- The Internet is not regarded as safety critical. Because of this, it has grown and been upgraded only as and when demand has reached critical levels with respect to the Internet's capability and it has already endangered its operational integrity (i.e. with its customers complaining);
- It is a TCP/IP network which does not support such sophisticated congestion management, traffic priority schemes and flow control mechanisms as those available to the ATN;
- There has been little attempt to model the Internet to date, however this is now changing.

2.2 The Design Process

The primary necessity of the performance analysis and dimensioning task is to ensure that the ACCESS ATN is capable of meeting the requirements of the SARPS, Operational Requirements and the Operational Context for the applications that it must support.

2.2.1 Performance Target Parameters

In real terms, the factors of major importance to the ATN users are the following **requirements** of performance for the whole network. They must be met by the ATN overall on an end-to-end basis including all end systems, subnetworks and routers:

- **data volume throughput capability** to ensure that data volumes produced by end systems can be delivered. This is an absolute requirement which will be dictated by the number, type and distribution of applications actually connected by the ATN;

- **data transit delays**, which should be minimised to values specified by the ATN SARPS, Operational Requirements and the Operational Context of the ATN applications. This parameter is very sensitive to the traffic loading of the ATN, and generally increases with increments in traffic volumes;
- **data accuracy**, which should meet the criteria specified in the ATN Operational Requirements. This is generally ensured by inclusion of appropriate redundancy checks in application TPDUs;
- **connection establishment delay**, which should be minimised and should not compromise the transit delay times. This parameter depends directly on the number of subnetworks and routers, and the number of subnetwork switches which must be traversed by connection establishment TPDUs. This parameter is effectively dependent on the transit delay through the ATN, but will have higher values due to end system delays;
- **availability**, the values of which are specified in the ATN SARPs, Operational Requirements and the Operational Context. This parameter depends on the reliability of each component of the ATN and the provisions made in its design for alternative routes and provision of redundant (replicated) systems;
- **consistency of flow** (i.e. variance in the transit time delay which is important for some types of data stream such as real time video/voice). However, the requirements and applications do not indicate strong requirements for this, and an ATN solution would not give adequate performance, so a requirement for consistency of flow is not assumed in this work.

Of these**, throughput, transit delay and connection delay** are all interrelated and depend directly on the design and components of the ATN. Accuracy and availability are also important, but represent significantly easier design problems which can be dealt with once an initial design and sizing of the ATN has been made.

2.2.2 Tasks to be Performed

In the following, it is assumed that the overall design process will consist of several phases:

1. Data gathering from SARPs, Operational Requirements, Operational Contexts, Topography of the area and all the information to determine expected traffic flows;
2. Proposal of a trial topology of an ATN which specifies a topology of how subnetworks, routers and switches are to be connected, and also specifies what application data can be transferred over each component. A trial topology is proposed by some manual or automatic design process; this task has already been performed within the scope of ACCESS [A202] to [A205].
3. Performance Analysis, to determine the traffic loadings, transit delays and other performance parameters implied by use of the trial topology. This phase is essentially a test of the proposed ATN design;
4. Simulation of a selected trial topology with appropriately dimensioned components;
5. Pilot trials.

This work package is concerned with phases 1 and 3 of the overall process.

2.2.3 ATN Performance Analysis

Figure 1 outlines the ATN Performance Analysis Process which is explained in the text following the figure.

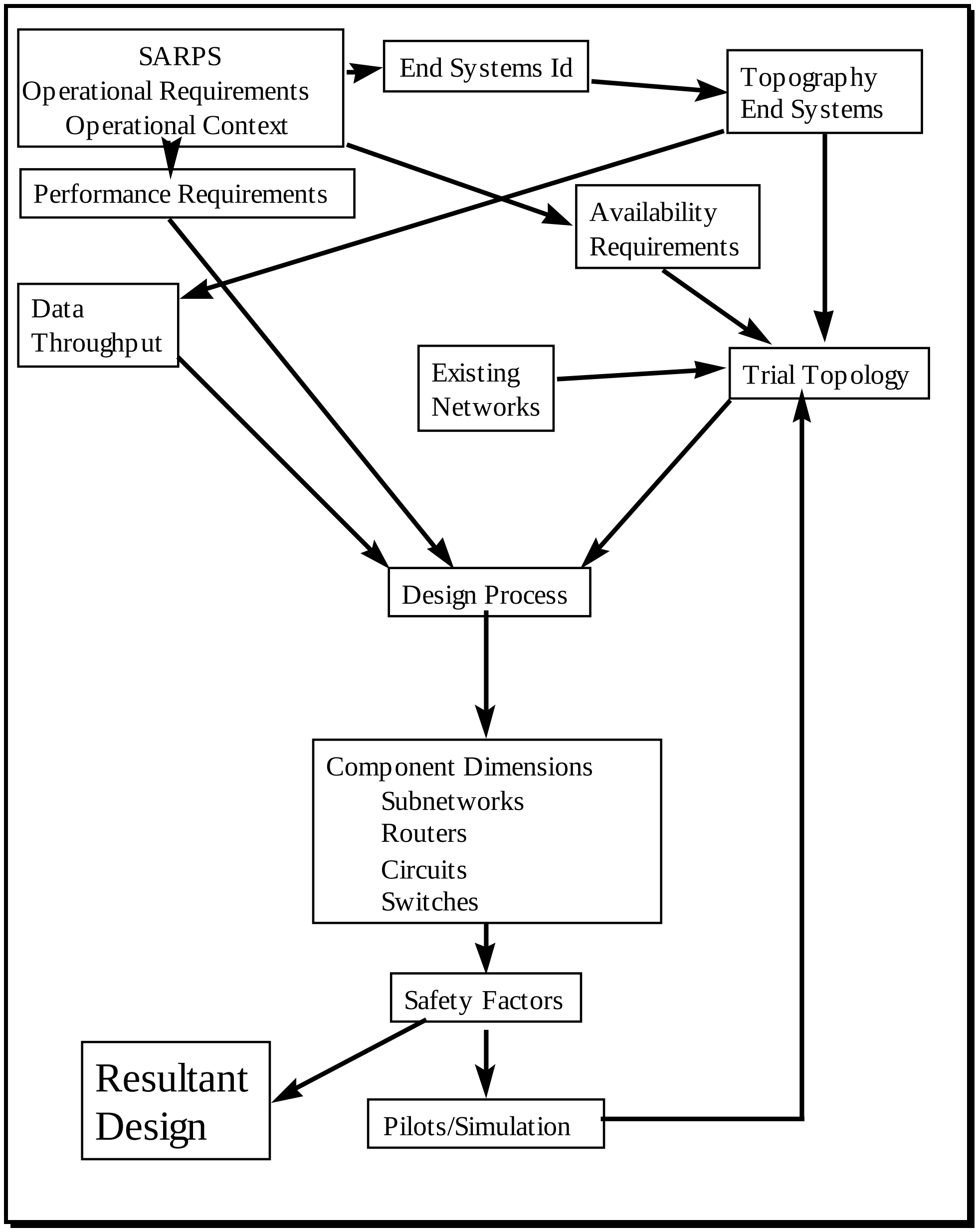


Figure 1: The ATN Performance Analysis Process

2.2.3.1 Define Performance Requirements

Given the SARPs and Operational Requirements, the next step is to design a concrete part of the 'global' ATN specified by the requirements of the Operational Context e.g. as defined for the ACCESS region.

The performance requirements and applications to be implemented are determined from the combination of SARPs, Operational Requirements and Operational Context. From these, the ***peak*** end to end data throughput for each application, the identity of end systems and their topography, system availability and overall performance requirements can be derived. (Note that estimating the peak data throughput volume requirements represent a significant task, and the results must represent each individual data flow through the ATN).

2.2.3.2 Carry Out Network Design and Dimensioning

The role of existing networks and the ATN availability requirements are then used to generate one or more 'trial' ATN topologies, each of which can be examined by the performance analysis process. Within the scope of ACCESS, the results of [A203], [A204] and [A205] provide this information.

The results of the Performance Analysis Process will indicate the ***minimum*** traffic loads which ***must*** be handled by each component of the trial topology and the expected transit delay times across each component (under the assumption that the components are operating in an un-congested state). From these computations, the actual load, in terms of packets per second throughput for routers and subnetwork switches, and the actual required bandwidth of each communications circuit can be determined.

The computed dimensions represent the actual loads presented to the trial topology. In order to ensure that the components do operate satisfactorily under peak loads, the dimensions of each component must be multiplied by a suitable factor (e.g. 4). At this point, it will be possible to cost the individual components and provide an overall cost when data concerning router, switch and circuit prices are known.

The trial topology can then be subject to simulations and possibly pilot trials to verify the dimensioning. The results of these simulations can in turn be used to fine tune the performance analysis procedures by modifying the trial topology and presumed characteristics of the ATN components.

2.2.3.3 Perform Further Iterations

However, ATN performance analysis cannot be regarded as a one-off process, since it is evident that the ACCESS ATN will grow both geographically, in terms of the number of end systems it supports, and in scope, in terms of the types of applications it is required to support. It will also eventually be interconnected with ATN systems in other regions (e.g. N. America/Far East). These will all increase the traffic loads and extend the topology and geographical coverage of the initial ACCESS ATN. For these reasons, the ATN must be '**incrementally designed'**. This means that for each new application or extension in scope, the analysis process must be re-run to identify any changes in traffic patterns which may require enhancement to ATN components. It must also allow the consequences of component outages on traffic distribution and transit delays to be investigated. This is really the justification for building and fine-tuning the performance analysis tools to be able to repetitively run and re-run to test different topologies quickly prior to selecting one or more for simulation or pilot trials.

The design must also take into consideration any **pre-existing components** (subnetworks, routers) such as the use of existing national X.25 PSNs and LANs which are required to be integrated into the ATN.

Also, in view of the safety aspects of the ATN, the design must be a **predictive process** which results in a high degree of assurance of the designed ATN being able to support the requirements and which, except in extreme and catastrophic situations, cannot fail to meet the operational requirements under its predicted peak traffic loads. It cannot be a retrospective design process which is so often used in commercial networks[2], where network capacity is added as and when the service provided by a network degrades due to increases in traffic load.

2.3 How the Objectives are Reached

2.3.1 Design Tools

During the ATN design process the following design tools will be of use:

- **To determine the traffic loads** introduced by each application at each end system and deducing the resultant packet loading;
- **To test proposed ATN designs** against the requirements to support a proposed set of end systems and traffic load;
- **To determine the required size of the components of a trial topology** e.g. to determine communications circuit bandwidth, subnetwork throughput capability and router requirements to meet the performance target parameters within the constraints of a given ATN topology;
- **To determine the transit delays** introduced by each ATN component;
- **To predict the impact of a change of an ATN design or its application load on an existing ATN design** to meet the demands of additional application loads;
- **To determine the effects of transient disruption to traffic** caused by an outage (i.e. router failure) or other re-routing incident (e.g. convergence delay for mobile subnetworks);
- **To estimate the costs** of proposed ATN designs;

Most of these can be achieved by means of a computational model supported by spreadsheets.

2.3.2 What this paper proposes

There are some **limits** to the what can be achieved in terms of concrete design at the time of writing this report because:

- The detailed design of the ATN is dependent on the Operational Context of the ACCESS region and this is not currently available;
- In order to complete a design, a large amount of information needs to be collected regarding the initial applications, the traffic loads they will place on the ATN, the location of end systems to be integrated and the identity, connectivity and characteristics of all pre-existing and market available subnetworks and routers which are to form the ATN.

[2] There are many reasons why other networks can adopt this approach, one of which is that they actually support applications and number of users which are unpredictable. This is not the case with the ATN, where we have a predictable number of applications and predictable peak throughput.

For these reasons, the output of this WP should be regarded as a ***framework*** to facilitate the initial design process, and to aid in modifying an existing ATN design to support further requirements.

What does the framework have to provide?:

1. facilitate the design of the initial ATN and its component routers and subnetworks to meet the data transfer requirements of air traffic management and supporting data communications applications. The output of this design to be specifications of the capacity/capabilities of routers, subnetworks and communications links;

2. predict the impact and further requirements of the ATN in the following circumstances:

    - Addition of further application traffic;

    - Extension of the ATN with further subnetworks and routers;

    - major multiple router and subnetwork failures (outages);

In doing this the design must ensure that the ATN can deal with any expected peaks in demand as well as single component failures with a high degree of certainty.

This report essentially provides a framework from which it will be possible to develop spreadsheet tools - see Appendix A. The further proposals outlined in this paper are:

- to specify a regime which clearly allocates responsibilities to the various operating authorities to provide ATN services with adequate resources to meet the required throughput and maximum transit time delays. This is necessary because different parts of the ATN will be operated by different organisations, and each organisation must agree to meet appropriate local targets to ensure that the overall end to end characteristics of the ATN meets its operational requirement;
- Tools for an analytic approach to the initial design and 'incremental design' of the ATN followed by;
- Tools for a simulation approach, to verify the results of the analytic approach, and maybe to adjust the analytic approach;
- pilot trials to verify the previous analytic and simulation approaches.

In this way, the initial design and the effects of subsequent modifications can be closely investigated before the ATN or any of its extensions becomes operational. The four phase approach is suggested because:

- An analytic approach will be far more useful and faster at testing different designs, but it is likely to render only approximate results;
- Simulation is a more arduous task in terms of raw computing power and time to set up the simulation but it is generally more accurate.

Once the analysis, simulation and pilots agree, then the level of confidence in the analytic approach can be raised, and it can be used more readily to quickly assess the impact of changes to the ATN.

2.3.3 Further Necessary Steps

This report develops the framework for analysing ATN performance in general and specifies the requirements for spreadsheet tools. However, it does not develop them. It can be applied to the qualitative results delivered by ACCESS in WP202 to WP205. More concrete work needs to be done to provide:

- the spreadsheets and simulation tools;
- an Operational Context to specify a list of ATN applications, identify and locate each individual end system and to be able to determine appropriate trial topologies and traffic throughput requirements;
- identity and characteristics of existing subnetworks which must be integrated into the proposed ATN and applications which can be run on them;
- the actual expected data flows for all applications;
- the data transfer characteristics of each component router, subnetwork and communications link supporting the ATN;

before the modelling tools proposed by this report can be effectively used.

The framework thus provides only the first step in the quantitative design of the ATN. It will enable ATN designers to estimate the requirements of initial ATN designs, however, the accuracy of those designs and sizings will only be an approximation, and the work will have to be verified by use of simulation and pilot trials before the ATN can be brought into operation. After quantitative work has been performed, the qualitative results may have to be reconsidered and thus an iterative process may be necessary. In the case of ACCESS, quantitative work may have an effect on the qualitative results in WP202 to WP205.

3. General Solutions for Internetworks

This section gives a general overview of performance analysis and dimensioning of internetworks such as the ATN. The specifics of the ATN architecture are dealt with in the next section.

3.1 Gaps in Existing Research

Literature research has not revealed a ***complete*** theory or method for designing a COTS/CLNP internetwork as envisaged for the ATN in a ***predictive*** manner. The reason for this is probably that most data network implementation are either based on a common (single) technology or they use TCP/IP in the same fashion as the Internet. However, there are a number of partial solutions which are of use.

Examples of where CLNP networks have been designed have resorted to static modelling of traffic patterns and multiplying the estimated required bandwidths and throughputs by a suitably high factor (e.g. *4). This approach can be used in a static environment, and indeed may well be of use in the initial designs of the first phase of the ATN. However, the ATN will grow and become a general purpose datanet eventually supporting a wide mix of ground/ground and air/ground traffic types. Its topology will extend and change. A major requirement through all these changes is that it must remain under control and be predictable even under adverse conditions of traffic load peaks and router/subnetwork failures.

3.2 Relevance of the Internet

Although, at first sight, the ‘design’ process used for the Internet (a very large connectionless internetwork) may be considered to be a potential pioneering endeavour in this field, the Internet’s goals, applications and technology differ considerably from that of the ATN. The Internet:

- does not handle safety critical traffic in the same sense as the ATN. Its design and engineering is performed by over specification of bandwidth and router capacity, and upgrades generally happen only in response to traffic throughput limitations;
- its traffic is growing at a very rapid pace, and the applications placed on it are essentially not enumerable (i.e. unlimited);

The internet approach cannot be adopted for the ATN. ATN designers must at least have an initial idea of the amount of traffic to be supported. Traffic loads are more predictable in ATN because of its limited environment and controlled and identifiable applications. (Note: At the time of writing, extensions are proposed for the Internet which will bring it closer to CLNP by providing resource management and data traffic priorities, however, any results of the use of these tools will be too late to be taken into consideration in this work).

3.3 Partial Solutions

So, given that there are no complete solutions, what does exist? What does exist are a number of basic performance analysis and dimensioning methods which have been used in the past:

- **Standard traffic analysis -** Traditional ‘Erlang’ analysis has been used for many years for circuit switched networks, however it is limited to circuit switched technologies in which a ‘connection’ reserves resources throughout the network for the duration of the connection. Since one of the principle techniques used in connectionless Internetworks is statistical multiplexing, in which resources are shared among many uses, Erlang analysis is not of use;

- **Subnetwork Switch Performance Analysis and Dimensioning Tools** are available for most Subnetwork types (i.e. X.25, Frame Relay, LANs etc.). However, this is not the case for the Internet nor Intranet technology, to which the ATN is allied.
- **Queuing theory** and **Packet switching analysis** is used to analyse individual message, packet, frame and cell switches, and is often used as the basis for dimensioning of individual switches. It is most appropriate for CLNP but it cannot be applied to collections of switches supporting a network.;
- **Simulations** are generally purpose built and are appropriate for small networks and can give relatively accurate results given accurate traffic forecasts; However, they become increasingly difficult with increasing network complexity. Before a simulation is started, there needs to be a high a degree of confidence that a proposed network design is not fundamentally flawed - hence there is a requirement for an analytic approach to determine which designs might be acceptable;
- **Traffic matrices -** which are used to model traffic flows between network nodes (and end systems) are often used to determine and document the actual traffic flows between end systems;
- Methods to **estimate traffic distributions** through a network would be useful, however, no general approach is available. An ATN specific method would have to take into account the particular ATN characteristics and mode of operation with the use of priority mechanisms, alternate routing and flow control mechanisms;
- **Analytic Models -** a general complete analytic modelling approach is not available, however many components such as Traffic Matrices, subnetwork switch performance tool etc. are available;
- The **traffic handling characteristics** of most commercial data switches and routers can be obtained from most manufacturers. These can form the basis of modelling switches and routers in the ATN

3.4 Relevance of Other CLNP projects

Other CLNP projects (such as within the Military) appear to have resorted to manual calculations to estimate traffic loads and distributions and have then ‘over engineered’ the resultant networks by a certain factor of safety.

3.5 Relevant Eurocontrol Projects

- **MADAM** and MoMo **-** research into the data throughput, transit and connection delays in the Mode-S subnetwork. These will provide the throughput characteristics of the Mode-S Network in the context of the wider ATN performance analysis;
- Study of **CLNP Network congestion control -** is only of marginal importance to ATN performance analysis, since it modelled the use of the ATN congestion control mechanisms, and reached conclusions about the way in which applications should make use of the ATN to avoid provoking congestive traffic patterns. An ATN performance analysis will have to assume that applications do operate in a ‘considerate manner’;

- **IDRP** Convergence Modelling Study (by simulation) of distributing information concerning routes to mobile subnetworks through the ATN routers. Its main results were determination of the convergence delay (time to ensure that a route was modified). The results of this could form a particularly important aspect of the ATN performance, however, the results of this and any other similar study will be very dependent on a particular ATN topology. This implies that the same simulations must be re-run as and when the ATN topology is designed and adapted.

3.6 Conclusion

The conclusion must be that there are no precedents to follow which give a complete solution to predictive design of a CLNP internetwork. Partial solutions for individual components (e.g. routers, packet switches, LANs and communications circuits) are available, however solutions for complete subnetworks and internetworks are not available. The design of the ATN must therefore start afresh from the basic principles which are further outlined in this section and use those tools which are available.

4. Models for CLNP Internetworks

4.1 Possible approaches

There are three approaches which might be taken to performance analysis and dimensioning of the ATN:

- An Analytic Approach;
- Simulations;
- Pilot trials.

These are evaluated over the following subsections.

4.2 Analytic Approach

Analytic approaches can be relatively fast, they can be based on spreadsheets, and are relatively easy to use once the baseline spreadsheets have been created and all of the necessary data has been captured. Such an approach could give a 'what if capability' so that ATN designers could investigate the effects of changes to topology, traffic loads and system outages. However, there are certain difficulties with an analytic approach:

- they must assume independence of the actions of ATN routers and switches from each other. In reality this can only be assumed at low traffic levels, and it cannot be assumed when high traffic loads are applied;
- they make assumptions about the interaction between routers and other aspects of the ATN operation. Because of this they introduce errors and are not regarded as particularly accurate.
- They can only model the 'static' aspects of a network by modelling the bandwidth requirements of communications circuits and the required 'packets per second' capability of each router and packet switch.

Because of these assumptions, the results can only be approximate, and the dynamic aspects of the network (e.g. how it deals with unusual peaks in traffic) cannot be predicted. An analytic approach would therefore have to be verified either by simulations or pilot trials or both;

4.3 Simulation Approach

Simulations are generally more accurate than analytic approaches, however, they are much more costly to implement and run. They also become very complex with large networks and require large computing resources and take a long time to run individual simulations.

A simulation model would be very similar to that outlined below for the analytic model except that predicting the traffic flows through Network/Subnetwork Components would have to be simulated by emulating packets transferred through routers and switches in a simulated real time environment.

4.4 Pilot-trials

Pilot trials of an ATN design are the ultimate test and produce reliable results. However, they are costly to implement and require many resources to run. A pilot trial could be made for an initial implementation of the ACCESS ATN, based on the actual ATN itself prior to it being commissioned. However, trials for extensions to the ATN would not be feasible after the ATN is processing live traffic.

4.5 Conclusion on approach

Design of the ATN Internetwork will not be a one-off event. There is a need to do performance checks on an ***ongoing*** basis as the ATN evolves. This implies that pilot trials are not feasible in the longer term unless a parallel trial network is maintained. Analytic and simulation tools will be needed to assess the impact of any changes to the operational network.

However, a pilot trial on the initial ATN design can be used to verify the results of the analytic and simulation approaches. This could be used to make sure that analytic and simulated results do agree with the actual ATN by modifying the models as a result of experience. So, the approach suggested is:

1. Develop analytic and simulation models;
2. Design (*or redesign*) the ATN topology (in ACCESS already performed within the scope of [A202] to [A205]);
3. Run the analytic model to determine whether the design is acceptable, if not then repeat 2;
4. Run the simulation model;
5. Adjust the analytic model according to the simulation model until they converge;
6. If the design does not meet the ATN requirements, re-run from 2 above;
7. Build a pilot ATN and run pilot trials (examples of pilot trials which have been performed are ATIF and ProATN/EOLIA, [CEC8]);
8. Adjust the analytic and simulation models to agree with the pilot; - at this stage, a degree of confidence can be placed on the analytic and simulation models;
9. For each modification of the ATN, perform procedures 2 to 6 before incorporating the modification into the live ATN;
10. Monitor the effect of each modification on the actual ATN performance and modify the analytic model and simulation model to agree.

In this way, designers can use the analytic approach to assess many different topologies and select only those which appear to meet the requirements. Simulations are then applied to the those topologies to select the most appropriate design before modification of the actual ATN.

Designers would not normally need to apply the modelling to the whole of the ATN, nor would it be practicable. They should be able to apply the analytic model to parts of the ATN, and to individual subnetworks or parts of large subnetworks.

5. Analytic Modelling

5.1 A 2-Level Approach

Since the ATN will be a very complex network involving many component routers subnetworks and (which themselves may be complexes of switches and communications circuits) it is useful to be able to approach the design and analysis of the ATN at two levels:

- At the ATN level, where the performance of routers and whole subnetworks is considered (each subnetwork is treated as a 'connector' between two or more routers). No attempt to analyse the network is made, except to quantify the data throughput requirements between each pair of subnetwork addresses. This will provide an analysis of the performance and dimensioning requirements of each router, and any communications circuits used to directly connect two routers;
- A refinement at the subnetwork level, where the individual subnetwork switches and communications circuits are analysed with respect to the traffic loads calculated from the overall ATN analysis. This will provide an analysis of the performance and dimensioning requirements of each subnetwork switch, and the communications circuits used to directly connect subnetwork switches;

It is also useful to be able to analyse ***parts*** of the ATN (e.g. ACCESS or a part of access) independently of the rest of the ATN, but taking into account the external data traffic flows which the part must carry.

At each level, the following procedure can be used to determine the traffic load of each component:

1. Determine the traffic flow and throughput requirement introduced by each end system and external traffic flow (end system for the ATN will support applications, and end system for a subnetwork will either be a real 'end system' supporting applications or a router);
2. Produce a Traffic Matrix describing the traffic flows between each end system;
3. Compute the traffic flows through each ATN or subnetwork component from the traffic matrix for each application, taking into consideration the traffic priority, traffic type and the route selection mechanism of each router and subnetwork switch;
4. Compute the total traffic flow through each ATN component for all applications;
5. Compare the computed throughput requirement with either existing products (to select an appropriate one) or with the existing ATN component to (to determine whether it will be overloaded). If the existing component is overloaded then it must either be replaced, or the ATN design must be changed to re-route traffic around the component. If an appropriate product exists, then it should be specified for procurement; if one does not, then the ATN design must be changed to avoid the potential bottleneck;
6. When the design is finalised, compute the transit delays due to the total traffic load for each component from its known characteristics;

The following subsections outline a computational model connectionless networks which could be applied to the ATN.

5.2 General Computational Models

5.2.1 Abstraction

The ATN is considered to be an internetwork of subnetworks connected to each other by routers as shown in Figure 2.

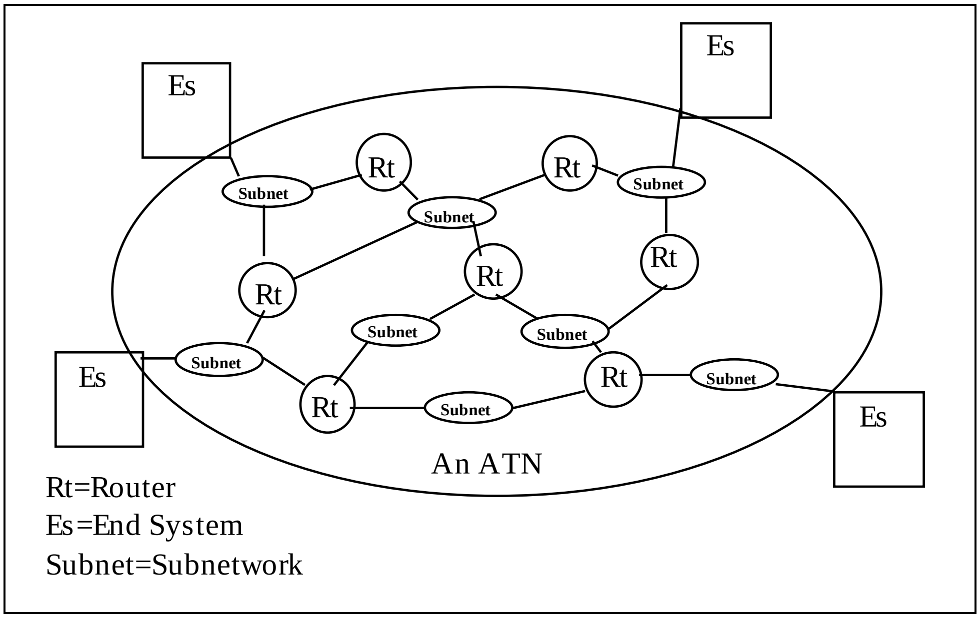


Figure 2: Abstraction of the ATN for computational purposes

5.2.2 General Dynamic Characteristics

Free running CLNP networks (and all other similar networks and subnetworks and their components) have a traffic load/throughput/time delay characteristic which are generalised in Figure 3 and Figure 4.

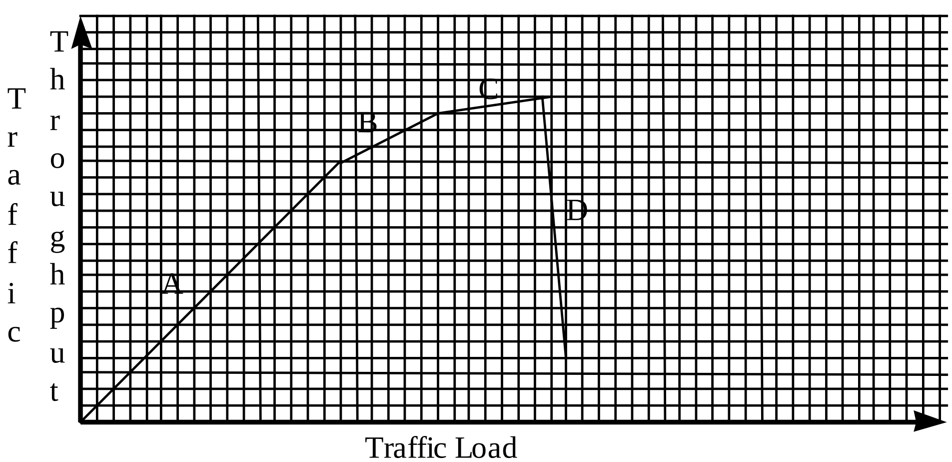


Figure 3: Free Running "Packet" Network Traffic Throughput/Load Characteristic

In Figure 3:

- Section A indicates a rise in throughput as the load increases for relatively low loads for the network or subnetwork;
- Section B indicates that when the load reaches a certain point, the traffic queues and associated transit delays begin to increase significantly. Traffic begins arriving faster than the switch can route and pass it on;
- Section C indicates a transition to a state where incoming traffic streams are being stopped because of congestion and potential packet buffer shortage;
- Section D illustrates what happens when buffer space in the network becomes insufficient. This is a catastrophic congestion during which switches/routers etc. may ‘reset’ and discard traffic to prevent wider congestion. This precipitates Transport Layer re-transmission of the traffic which can again cause the same overload situation at some later time.

Clearly, the ATN and its components ***ought*** to be operating under the loads of Sections A. Section B should only be entered for transient peaks. Section C should cause inhibition of certain classes of source traffic. Section D should never happen or even be approached.

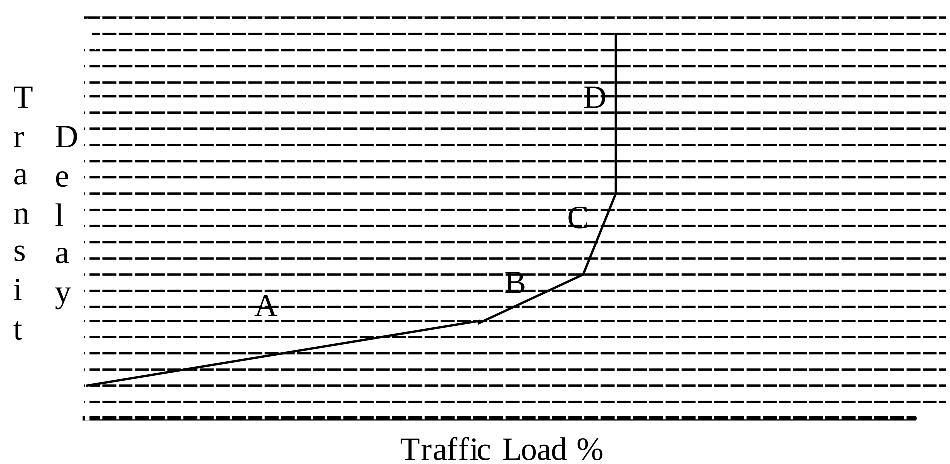


Figure 4: Traffic Transit Delay/ Traffic Load Characteristic

Figure 4 illustrates the corresponding effect on transit time delays through networks.

In reality, of course, the segments outlined in the two diagrams will be continuous curves. The conclusions to be drawn from these diagrams are:

- A network’s throughput tends to vary in a linear fashion with the traffic load it is presented with over a certain range of loads;
- Overload conditions should be triggered when B is reached;
- Selective load shedding should be initiated when C is reached;
- Each network and network component will have a different characteristic;
- Connectionless networks which do not have strict control over resource allocation may tend towards chaotic degradation when overloaded with traffic;

- These characteristics apply to the ATN as a whole and individually to any free running connectionless network within the ATN (e.g. to an X.25 subnetwork based on datagram technology or an IP network).

The throughput and transit delay characteristics for communications circuits are directly dependent on the bandwidth, the protocols used and the probability of transmission errors. The effects of traffic load can therefore be calculated directly. The throughput and transit delay characteristics of end systems, routers, and subnetwork switches can usually be obtained from manufacturers or determined by trials. These circuit and router/switch characteristics can be used to determine the suitability of a each component in a particular role in the ATN.

Fortunately, the ATN is a CLNP network which has the benefit of congestion control and traffic priority control which, if used and tuned appropriately with adequately dimensioned ATN Components, can avoid operation in the sections marked C and D in the diagrams. The following computations therefore assume that each subnetwork and the ATN itself acts in a well behaved manner in sections A and B (i.e. cannot 'lock up' with buffer deadlocks, and is being used at a peak loading which does not dramatically downgrade throughput). This suggests that the ATN and its component end systems, routers, switches and circuits must be oversized by an appropriate amount to prevent overloading.

A topic not treated in this report is deadlock avoidance, i.e. the avoidance of situations in which little useful work is done by the network. This is achieved by not overloading the network and is obviously connected with the discussion above.

A further topic not treated is the collection of raw performance data by means of suitable network monitoring systems. This functional area is included in the Performance Management functional area of network management and is outside the scope of this report.

5.3 Partitioning into Separate Models

5.3.1 Internetwork Model

The following scheme can be used to model the performance of a section of the ATN as a whole under presented traffic loads, whilst hiding the complexity of individual subnetworks.

1. Identify the topology of router interconnection, end systems and the subnetwork connectivity between routers and routers and end systems;
2. Identify the TSDU traffic for each application from each source to each sink. This data is determined from the **End Systems Model**;
3. Identify the initial packet load for each source and sink, taking into account the end systems subnetwork of attachment and its respective protocol overhead and the SNDCF overheads introduced by the particular subnetwork that each end system connects to;
4. Identify the application traffic loads from each source end system to each sink end system and construct a traffic matrix;
5. Identify the ***probable*** traffic dispersion over Routers/Subnetworks to derive the traffic load applied to each source/sink pair on each of the ATN components. This must reflect each ATN component's routing policy and route choice probabilities (where alternate routes exist in a connectionless environment);

6. At this stage, it is possible to identify the total ATN traffic for each subnetwork and router component by summing the traffic loads for each component over each of the individual application loads;
7. Compare the traffic throughput characteristics of each ATN router and subnetwork component with the applied throughput as a function of delay time, and determine whether any component is overloaded;
8. Calculate the traffic delay attributable to each ATN component using the throughput/time delay characteristic of each end system, subnetwork and router.
9. From this, a computation of the total expected time delays on an end to end basis can be computed using assumptions about the relative priorities (e.g. high priority traffic will have shortest delays, and low priority traffic will have longest delays); This calculation will highlight any 'hot spots' where overload can be expected.

5.3.2 Subnetwork Model

Within a model which is to be used for dimensioning purposes, the subnetworks, especially ground subnetworks, can be treated as "black boxes" whose internal working and dimensioning are not immediately relevant. In principle, only the quality of service under a variety of load situations provided at the service boundary of the subnetworks is of interest. However it is interesting to note, as is done in this subsection, that the principles developed in previous sections for the ATN internet can also be applied to the subnetworks.

Subnetworks can be dealt with in almost the same way as portions of the ATN. Each subnetwork consists of data switches connected by communications channels as shown in Figure 5.

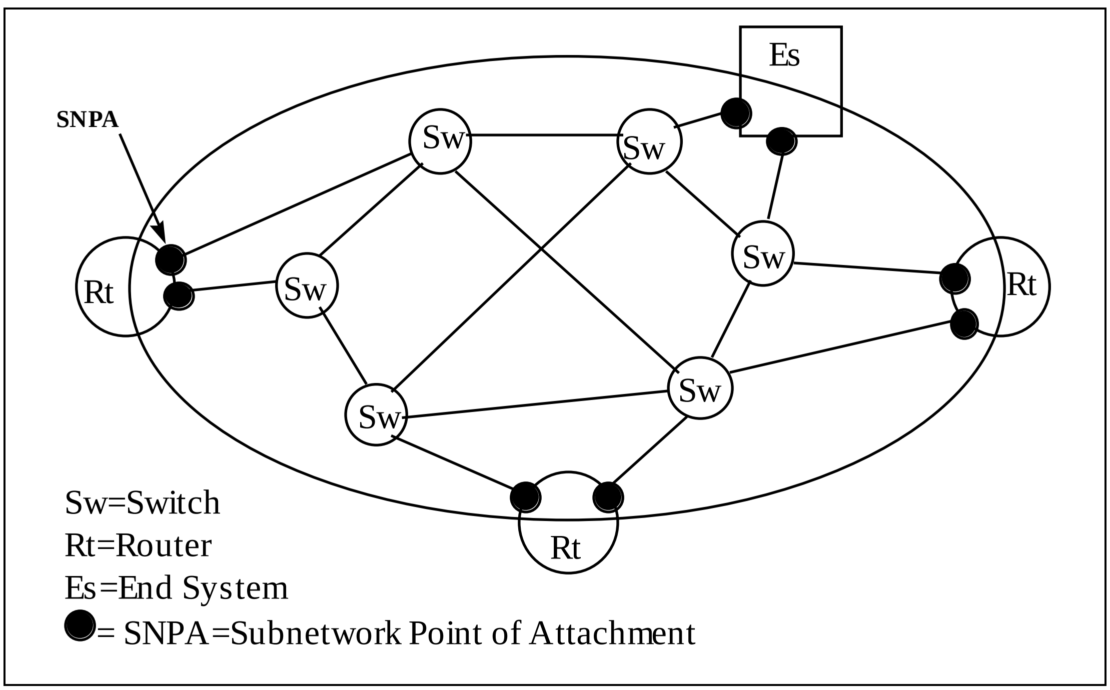


Figure 5: WAN Subnetwork Topology

The traffic throughput and consequent transit delays across the subnetwork are dependent on:

- The actual route taken through subnetwork switches and communications links between routers. This may be a single hop or multiple hops dependent on the subnetwork's topology and routing algorithm;
- The bandwidth of each circuit which must be traversed;
- The traffic queue delays encountered at each switch (which depends on the switches traffic load originating from all connected end systems and routers, and on the switches processing capacity in packets/sec.);

Figure 6 illustrates the important aspects of WAN subnetworks which affect performance:

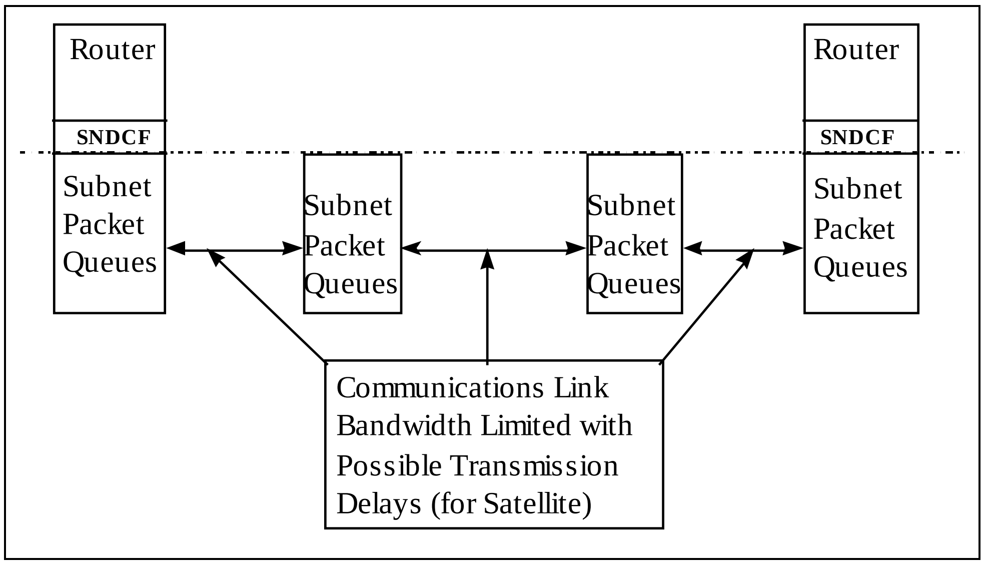


Figure 6: ATN subnetwork structure

From an analysis point of view, LANs differ only in the technology which replaces the subnetwork and that only a single communications link will usually connect ATN routers. Multiple LANs connected by repeaters will have a similar scheme to that above. Also, instead of packet queue delays, LANs will have contention delays.

The following calculations can only be carried out when the traffic loads between each address of the subnetwork (including addresses used for non-ATN traffic) is known. This might be done by the following method, but in many cases, design tools for specific subnetwork types are available and may be better suited to the task. The calculation will reveal any 'hot spots' in the subnetwork, and will indicate whether the subnet as a whole is liable to overload. This knowledge may be re-used to re-size the subnet to deal with the load, or it might be used to change route choice probabilities in the ATN computation to route around the subnetwork (which will have to be subsequently re-calculated);

1. Identify the aggregate CLNP packet flows and lengths between each pair of the subnetwork's points of attachment;
2. Multiply each aggregate packet flow by a factor representing the local SNDCF protocol mapping and protocol overheads; Estimate the SNDCF overheads associated with mapping the CLNP packets onto subnetwork packets/frames (if any) in attached end systems and routers. These overheads may cause an increment in the number of CLNP packets and an increment in the total amount of data to be transported dependent on the type of subnetwork involved;

3. Generate a traffic matrix indicating the required flows of subnetwork packet traffic between each router and End System attached to the subnetwork;
4. Identify the dispersion of these individual traffic flows over communications links and switches based on the subnetworks routing policy and traffic priorities; In connectionless subnetworks, a single traffic flow may be dispersed over a number of different routes: In a connection oriented subnetwork, a single traffic flow will flow over a single route; This should identify the number of packets to be transferred and the total volume of data;
5. Compare the traffic throughput characteristics of each switch and communications link with the applied throughput requirement and determine whether any component is overloaded;
6. Calculate the traffic delay attributable to each component using the throughput/time delay characteristic of each switch and communications link;
7. From this, a computation of the total expected time delays on an end to end basis across the subnetwork can be computed using assumptions about the relative priorities (e.g. high priority traffic will have shortest delays, and low priority traffic will have longest delays); This calculation will highlight any 'hot spots' where overload can be expected.
8. Calculate the transit time delays of the subnetwork from the individual switch, communications link and SNDCF delays.

Steps 6, 7 and 8 identify any components which are either redundant or overloaded. In both cases, the designer may choose to upgrade/downgrade or remove components, or apply routing restrictions into the subnetwork as a whole to reduce its traffic load. The latter action will necessarily involve re-application of the ATN level computations to deal with the implied re-distribution of traffic away from that subnetwork.

5.3.3 Application and End System Model

Figure 7 outlines a hypothetical end system supporting applications**:**

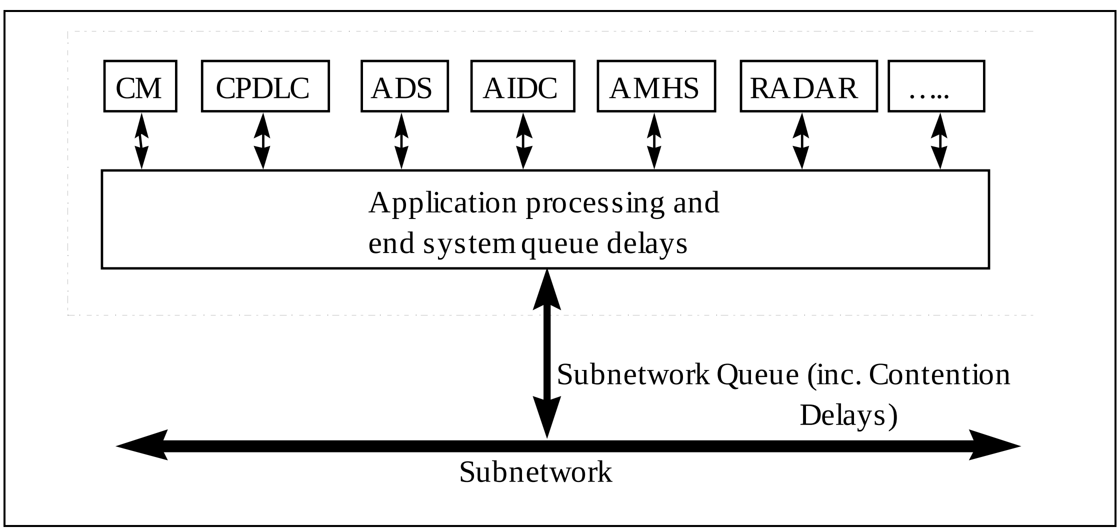


Figure 7: End System and Application Structure

Each application in an end system may have zero or more traffic flows to and from different distant end systems. The model must include all aspects of the following:

- Presentation delay/queuing on receipt;
- Local transmission delays in Operating System and other subsystems involved in the transport and upper layers, and the initial network layer processing;
- Local reception delays plus a factor to cover TPDU recovery due to delayed (re-routed or re-transmitted) packets;
- Upper Layer Protocol overheads.

For each end system, the following calculations must be made to determine the ***peak minute*** source/sink traffic volumes and local end system time delays:

1. Estimate the number and lengths of TSDUs per unit second for each application using the same end system according to the **application model**;
2. Estimate the number and lengths of TSDUs per second being received by each application supported by the end system;
3. Estimate the total number and lengths of TSDUs over all applications supported by the End System;
4. Estimate the number and lengths of CLNP packets per TSDU sent or received; This result is used to determine the throughput requirements of the subnetwork and end system to deal with data originating/arriving at the end system;
5. Estimate the time delays and queue delays in the local application for both sent and received TSDUs. This will determine any local end system delays;
6. Determine the destination end systems for all traffic flows being sent, and the source end system for all traffic flows received.

The results will be:

- source data volume for each application;
- the sink data volume for each application;
- The total source and sink data volumes for the end system;
- Output time delay;
- Receipt time delay.

It is essential to record this information on a ***per application*** basis to be able to model the effect of routers distributing the traffic over different subnets based on each application's class and priority.

Each non-ATN or transit/arriving/departing traffic flow which passes through a component of the modelled internetwork must be represented as an 'end system' i.e. as a source or sink of traffic.

Each application will have a characteristic traffic pattern which must be determined for use in the end system and application model. Typical traffic patterns which may arise in ATC are:

- Continuous, repetitive, constant rate,
- Bulk, low priority,
- Sporadic, short and interactive.

For each application on each end system, it is important to establish the overall throughput requirements, the peak minute throughput, and the length of TSDUs produced. These results are used to calculate the number and length of TSDUs generated by the end system.

5.3.4 Switch/Router Model

Models of switches/routers should be obtained from manufacturers or test laboratories for each system type and customised to their expected configuration with the following factors taken into consideration:

1. Switch Processing time (dependent on switching Platform/Operating System used);
2. Bandwidth of each trunk to other end system, router or subnetwork switch;

5.3.5 Communications Circuit Model

For ground sectors it is possible to assume that throughput is limited only by the bandwidth and error rate and that there is a zero propagation delay. Estimate the average packet size, taking into account framing and other link level protocol overheads. This can be used to estimate the average maximum packets/sec possible to deal with traffic peaks.

For satellite sectors one must assume the same as for ground sectors but a time delay factor must be added to simulate the satellite uplink/downlink round trip delays;

5.4 Traffic Matrix

Once all of the traffic loads presented by each end system attached to the network/subnetwork are known, a traffic matrix is developed and used to predict the traffic flows between each pair of end systems.

5.4.1 An Example

Table 1 shows a hypothetical traffic matrix.

from **to->**	**A**	**B**	**C**
A	1	5	4
B	5	2	10
C	4	1	1

Table 1: An example traffic matrix

End systems are identified in the header column and row (A, B, C). The number of CLNP Packets passing from a source to a sink are represented by the integers. Number on the diagonal represent local traffic within an end system.

This traffic matrix can be used as a guide to the manual (or automatic) process of designing a topology - e.g. from the above, a direct high bandwidth path between B and C would seem to be required, but not between A and B.

In addition to the “production” traffic illustrated in the example, i.e. traffic originating in and destined for end systems, the ATN internet handles internal traffic such as routing updates and systems management data. Ideally this traffic, as an internal overhead incurred in running the network, should be a small proportion of the production traffic. It can be considered to consist of a fixed component, independent of the amount of production traffic, and a component which depends on the production traffic (or more correctly, the number of communicating end systems and changes in routing and communication relationships). It appears to be sensible to model the internal traffic in this way as a function of the production traffic.

5.4.2 Implementation of the Models

This process seeks to determine the traffic load on each network/subnetwork component given the traffic flows from a source to a sink through a (sub)network. This is dependent on the distribution of traffic towards its destination by the route choice mechanism in each individual switch or router, and depends on:

- Link availability (by traffic class or outage);
- Minimal hops - minimal time delay;
- Traffic priority;
- Alternative routing strategy;
- Traffic loading of outgoing links from the node (e.g. measured by traffic queues).

The route choice mechanism is modelled for a switch/router by means of allocating proportions of each application’s traffic flow to outgoing routes depending on the probabilities of those particular routes being chosen by the switches/routers route choice mechanism. This is an approximation which will lead to a degree of error, but which can be improved upon by using the results of simulations and pilot trials. However, it will give an idea of the likely traffic distributions through the network and serve to identify potential (obvious) bottlenecks.

This basic scheme has to be calculated for each source sink pair and for each application. A summary calculation can then be made to assess the whole (sub)network for all applications. This summary will indicate the traffic loading for each (sub)network component.

Re-runs can then be made to model circuit/router/switch and end system outages, different topologies etc.

One could imagine an n-plane spreadsheet where each plane 1-n represents the (sub-)networks topology, for a particular application; plane 0 represents the traffic sums of planes 1-n; plane -1 represents the transit delay due to each component; etc.). Databases for component pricing, component characteristics and end systems traffic loads would also be required.

The way this calculation is done is critical, and here the approach used for an analytic model differs significantly from the approach taken for a simulated model.

In an analytical model, the computations are made on the basis of statically assigning traffic to paths through networks based on knowledge of the probabilities of certain routes being chosen by routers/switches for each application’s traffic load;

In simulations, the distribution must be done iteratively on the basis of individual CLNP packets with each source gradually increasing its load in turn to simulate a gradual traffic build up. The route choice mechanisms at each router are emulated for each CLNP packet, and real time must be simulated to approach an accurate result. Allowing one source to increase traffic instantaneously will bias the overall result dependent on the order in which sources traffic loads are introduced.

Simulation is clearly more complex to implement and costly to run than the analytic approach. For this reason it is probably of benefit to develop the analytic approach as well as the simulation approach so that designers can first experiment with analytic results before undertaking simulations.

5.5 Quantitative Parameter List

The parameters of primary concern are:

- Throughput;
- Data Transit Delay;
- Connection Delay;
- Routing Convergence Delay;
- Availability;
- Accuracy.

Throughput, Data Transit Delay and Connection Delay are all highly interrelated, and their treatment forms the larger part of this report.

Routing Convergence delay is the subject of current Eurocontrol simulation investigations, and is not explicitly dealt with in this report apart from noting that it will constitute a significant data traffic overhead.

Availability is subject to the topology and configuration of the ATN topology, and certain design principles should be used in proposed ATN topologies to ensure the required availability targets are achievable. These principles should include:

- Duplication of Routers, Switches and communications links;
- Dual connection of end systems.;
- Selection of equipment and communications circuits with appropriate guarantees of MTBF and MTTR.

Accuracy can be controlled by Transport Layer checksums. The effects of errors will be both a temporary increase in transit delays and traffic load of the ATN.

The primary characteristics are governed by a variety of **secondary parameters** of various ATN component subnetworks, end systems and routers. These are:

- MTBF - mean time between failures;
- MTTR - mean time to repair;
- bit error rates of each component;
- data loss rates;

- data replication probability - (wasted bandwidth);
- queue delays in subnetwork switches and ATN Routers;
- contention delays in media access protocols (e.g. LANs);
- transmission delays over communications circuits - related directly to bandwidth;
- routing convergence delay times;
- protocol overhead (increases data volume);
- protocol recovery times and tuning.

5.5.1 Communications Links/Protocols

Basic Bandwidth	what you pay for
Protocol overhead	losses because of the protocol operation itself
Effective bandwidth	difference between the above two - what you get
Transit delays	across the link - low for terrestrial, higher for satellite
Data Losses	due to line errors and recovery procedures
Link Duplication	required for availability
Load characteristics	describing how the link acts under different traffic loads

5.5.2 Switch/Routers

Switching delay	Packet/frame/cell processing time
Queuing delays	average, maximum waits in queues
Router Translation delays	processing/translating data and protocol header contents
Load characteristics	describing how the switch/router acts under different traffic loads

5.5.3 Network and Subnetwork Characteristics

In some instances, where the networks are already operational, the characteristics should be determined by the operators. The modelling outlined in this paper may suggest that an existing network may be deficient.

Where they do not exist, the modelling suggested in this paper will suggest appropriate parameters.

Hops	average and maximum number of hops across the network
Maximum Transit Delay	across a particular network
Switch/router Transit Delay	time between complete reception and complete dispatch
Switch/router buffer capacity	important not to underestimate in terms of congestion control/avoidance
Topology/connectivity	of nodes through communications links
Management overhead traffic	used to administer the (sub)network's operation
Flow characteristic	constant rate, fluctuating
Re-routing delay	time to arrange an alternative path to avoid congestion/faults/outages
Re-routing alternatives	Number of alternative routes between any two addresses
Congestion control characteristics	the impact of congestion on various parameters - throughput, loss, transit delays
Flow control characteristics	
Traffic prioritisation characteristics	
Current load/loading characteristics	

5.5.4 End System Characteristics

The following information is required to estimate the characteristics of end systems, but it can only be obtained from manufacturers or determined from pilot products.

Queuing delays	
Processing delays	
Access link time delay	

Access link throughput	
Current load/loading characteristics	

5.5.5 Application Data Transfer Requirements

These characteristics may be derived from the ATN Applications Operational Requirements for each application.

Maximum allowable Transit Delay	
Throughput Required	
Traffic Peaks	
Flow jitter requirements (AVI files, real time speech/video)	Generally none.
Availability	
Allowable loss	
Priority	
Networked flows - map of individual flows per application type	

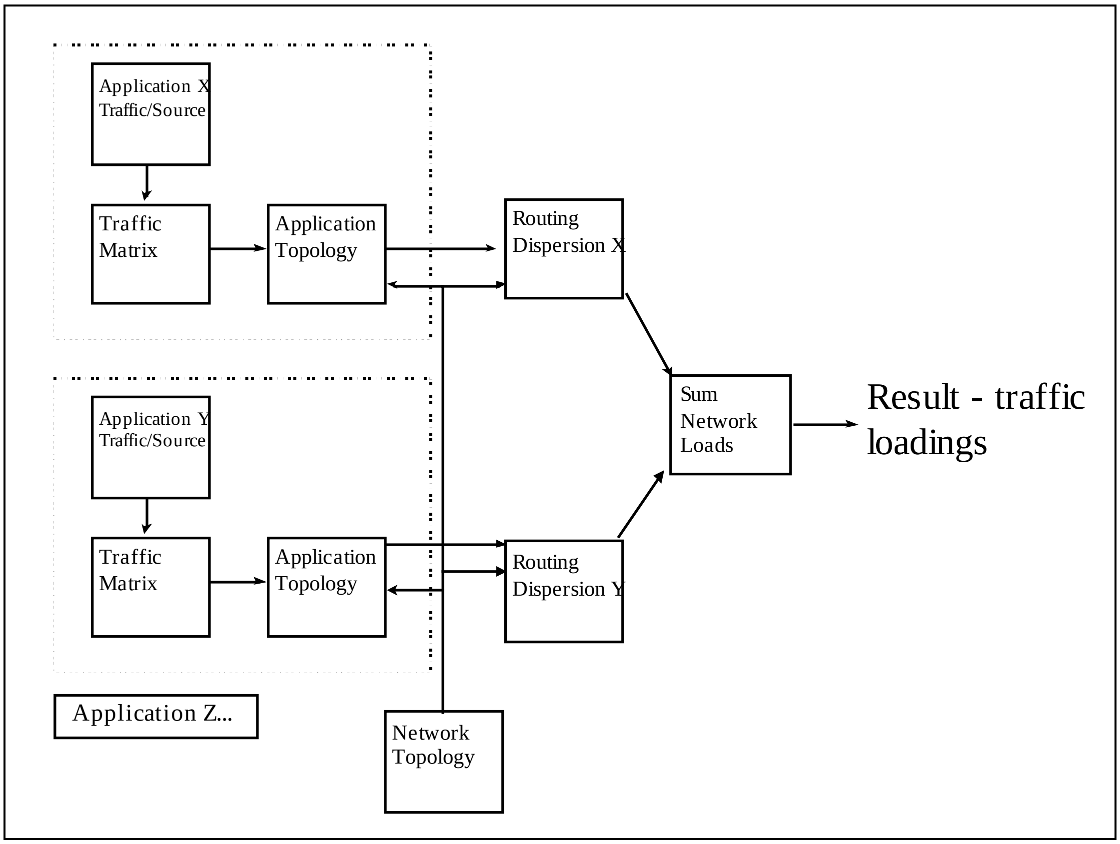
Appendix A:

Outline of Traffic Modelling Organisation

Outline of Traffic Modelling Organisation

This appendix gives a short, schematic description of the organisation of a possible approach to analytically modelling ATN traffic patterns. The organisation of the approach is shown by means of the structure of spreadsheets in the model.

In the following diagram, each box represents a set of spreadsheets with a specific content and function. The relationships among the sets of spreadsheets are shown by the arrows, with the direction of the arrow meaning "provides input data to". This model could be applied to the complete ATN or any subset of it such as that restricted to given applications, sets of nodes, communication channels through subnetworks, etc.



The individual types of spreadsheets are explained briefly in the following.

1. **Application X/Y/...** data are one-dimensional source/sink data volumes for given applications organised according to locations. One spreadsheet must be completed for each entry/exit point on the ATN area being modelled. These must represent accurate CPDLS, D-FIS, AIS applications, Routing overheads, and traffic from all other sources;

2. **Traffic Matrix** is, in each case, a two-dimensional matrix which states the amount of traffic flowing from each ATN source to each ATN destination supporting a particular application;

3. **Network Topology** provides a connectivity map of the region of the ATN serving the applications, and must include all communications links and switching nodes; It might ultimately allow specification of maximum throughput for each component;

4. **Application topology** states the topology of ATN connectivity which is available from the ATN for that application (allowing some resources to be reserved exclusively for certain applications). It is effectively a mapping of the application-specific traffic matrix to the network topology;

5. **Routing Dispersion X/Y...** This spreadsheet emulates the ATN routing characteristics for that application (e.g. based on priorities), and which distributes an appropriate amount of throughput over the application topologies. This spreadsheet effectively contains information on ATN routing strategies. Its structure is not yet entirely clear.

6. **Sum Network Loads**. The sums of all application traffic loads are summarised across all ATN switches and communications links to provide the final resulting load on each ATN component.

Clearly, the spreadsheet can be built to operate in either a static way to determine approximate traffic loadings, or is can be built to operate in an incremental mode, where traffic is 'introduced' incrementally. This might give a better picture of the dynamics and effects of the routing dispersion function.

Appendix B:

ATN Specific Features of the Analytic Model

ATN Specific Features of the Analytic Model

In this appendix, the models developed in section 5 of ACCESS WP207 are further developed. More detail is provided on some aspects of the analytical model. It is recognised that the treatment is incomplete and that further work is necessary.

B.1 Functional View

The ATN is formed from a collection of end systems generating a certain pattern of data traffic between OSI end systems. This traffic is passed over a number of data subnetworks interconnected by routers between the end systems. The applications supported by the end systems are safety critical tasks and it is therefore necessary to ensure that any design and configuration of the ATN will meet certain requirements specified in the SARPs, Operational Requirements and the particular Operational Context of the area for which the ATN is being implemented. These requirements primarily concern, data traffic throughput, connection and transit time delays, accuracy and availability.

Figure 8 is a functional diagram of the ATN, consisting of Airborne Subnetworks, Air/Ground Subnetworks, Wide Area Subnetworks and Routers.

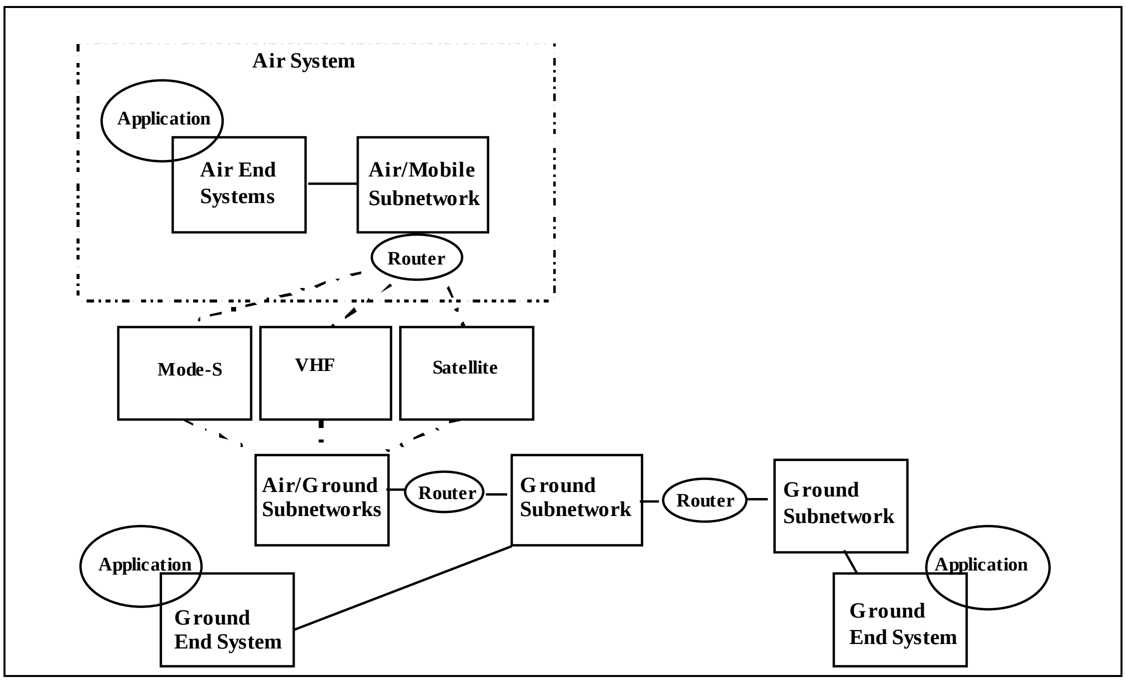


Figure 8: ATN Dimensioning Overview

B.2 Application Data Volume Estimation

B.2.1 The Problem

One of the major tasks in preparation for any analytic approach or simulation traffic modelling, is to estimate the actual traffic volumes and profiles introduced into the ATN. This section develops approaches to that task, however it cannot be drawn to a complete conclusion because many factors are simply unknown at this time e.g.:

- Number and topography of air/ground link transreceivers (Mode-S, Satellite, VHF receivers) and how they connect into the ATN;
- Characteristics of the Air/Ground communications links (throughput, delays, contention delays etc.);
- Baseline traffic flowing within airborne subnetworks (“airborne” or “air-based” applications);
- Traffic patterns of a number of air/ground applications (CM, ADS);

This suggests that an investigation is required to gather and evaluate information related to these factors. The following suggests an approach which can be made to the estimation task once these facts are known.

Each application can be considered to introduce a ***characteristic traffic pattern*** to the ATN, initiated by ATC operational events. Each event will invoke generation of an Application Protocol Data Unit (APDUs) which must be conveyed by the ATN. Some events will also invoke a response PDU from the recipient of the APDU.

In order to estimate the volume of application data to be transferred, the following information must be collected for each application so that the ***peak*** requirement of bandwidth and resultant number of CLNP packets per second for transfer through the ATN can be calculated:

- The mean length of each application communications message;
- The peak frequency of APDU invocations;
- The destinations of the APDUs.

These are all very application dependent, so they have to be estimated on **a per application basis.**

B.2.2 Ground Application Traffic Estimation

The current ground to ground applications are already reasonably well understood, and it is possible to specify a method for Radar, AMHS and AIDC because they all have existing precedents from which traffic volumes can be estimated. These estimations are outlined in the respective sections on AIDC and AMHS applications later.

Note that this does not mean that for the ground applications, the traffic volumes will be *the same* as in the corsponding existing applications. Due to different transfer syntaxes and protocol behaviour, these may be quite different. However the existing applications provide a good starting point for deriving the ATN traffic volumes.

B.2.3 Air/Ground Application Traffic Estimation

Little is known about traffic flows for prototype Air to Ground applications with which there is no current experience (e.g. ADS, CM, D-FIS and CPDLC), and which have the added complexity of mobility, which *alters the topology of the ATN* subnetworks in a certain sense. This section seeks to identify a method for estimating such traffic loads.

A traffic model of airborne applications should reflect a number of aspects:

- The profile of some application's data traffic (e.g. CPDLC and ADS) will change dependent on the phase of a flight (at Gate, Taxiing, Take-off, Transit, Approach, Landing, Controller hand over etc.);
- It is not known whether an application's traffic profile will be similar for all geographical regions, or for all air/ground subnetwork types. It might change due to particular regional requirements (this implies that the profile might actually be constrained by the region dependent on air traffic separation, flight frequency, air/ground communications subnetworks implemented and actually operational). A study of the operational realities throughout the ACCESS region is required to determine whether a 'standardised' AAFPP can be identified. This would greatly simplify the traffic estimation process);
- It is not clear that a particular application will always be mapped over a particular air/ground subnetwork type;
- It should be possible to estimate the peak traffic load introduced by each Air/Ground subnetwork link given the number flights being consecutively handled by each subnetwork;
- It must provide estimates of traffic volumes introduced to each part of the ATN based on the specific air/ground sub-network and duration and activity of each airborne application.

These lead to an application actually having a number of different traffic profiles. Each traffic profile will specify:

- Probability of invocation of each APDU type per unit time;
- Length of APDUs;

To approach the dynamic aspects it is useful to define a new traffic source type called the **Airborne-Application-Flight-Phase-Profile (AAFPP)** for use in traffic volume calculations. An AAFPP is the traffic profile that an incarnation of a particular airborne application in a particular phase of flight introduces to the ATN when it is communicating with the ground application component via an identified (concrete) air/ground subnetwork ground receiver. The profiles will depend directly on the operational constraints of the region for which they are defined (e.g. Mode-S can only be used where appropriately equipped radar is available). AAFPPs relate application flows to particular ground subnetwork reception points.

If accurate AAFPPs can be developed, the flight traffic patterns of the region covered by each air/ground subnetwork can be used to determine the peak number of AAFPP **sources** attached at any time, their types and the duration of their attachment. From this it is possible to provide an estimate of the likely traffic load introduced at each air/ground subnetwork receiver.

The data acquired for this can also be used for estimating the number, frequency and distribution of ATN-IDRP routing updates introduced by each air/ground subnetwork receiver.

As the mobile host approaches the region covered by a particular air/ground communications link, a data connection is formed between the airborne subnetwork and the air/ground subnetwork is attached to and a traffic pattern is introduced as specified by the AAFPP; as the mobile host leaves the region, the link between the airborne subnetwork and the air/ground subnetwork and the traffic pattern ceases. Each such change results in an IDRP update

B.2.4 Conclusion

This section has presented one way of approaching the task of estimating the traffic loads which must be carried by an operational ATN. However, there is a shortfall of information available to complete the task. A good deal of information has yet to be collected and analysed before an adequate traffic throughput requirement of the ATN can be established. The following information needs to be collected:

- Location and subnetwork/ATN Internet appearance of each air/ground network;
- AAFPPs for each air/ground subnetwork;
- Current traffic loads introduced by OLDI (for AIDC), CPDLC, ATIS and AMHS.
- Guidelines for the traffic which will be generated by ADS, CM, Administration, IDRP.

B.3 Protocol Overhead Considerations

This section gives guidance on how to assess the data volumes and number of packets/second for each type of protocol, and when to apply them. Protocol overheads occur at the following places for a particular application:

- to the application data, which is extended by Application, Presentation and Session PDU overheads to produce the actual Transport Service Data Unit Traffic;
- TPDU traffic conversion into CLNP traffic;
- CLNP overhead and SNDCF compression mechanisms (particularly on the eir-ground data link) - not discussed further here,
- For each subnetwork traversed, the ratio of CLNP packets to Subnetwork packets and the associated subnetwork overheads.

B.3.1 Application Protocol Overhead

Each application will also introduce a *characteristic application protocol overhead* which is dependent directly on:

- Whether ASN.1 Basic or Packed Encoding Rules are used;
- The application itself, and the complexity of its APDU ASN.1 structures (i.e. the more ASN.1 typed fields it contains, the greater the % overhead);
- The way that the information is encoded (i.e. as bits or as textual strings).

When these are known, the Application protocol overhead (AP_O) can be calculated.

B.3.2 Dialogue Control Function Protocol Data Value Overheads

Table 2 gives values for the overheads in octets.

Connect request	0 octets	DC_1

Connect response	0	DC_2
Terminate Request	3	DC_3
Terminate Response	3	DC_4
Data Transfer	3	D_O

Table 2: Dialogue control function protocol data value overheads

D_O for data transfer, must be added to each message which uses an established Dialogue Service. The sum of DC_1 to DC_4, called D_C, are the connection data.

B.3.3 Application Control Service Element - ACSE Overheads

The ACSE is always used during the connection phase, and introduces a fixed overhead as shown in Table 3[3].

Connect	7 octets	8 optional extra for addressing
Connect Response	9	8 optional extra for addressing
Release Request	1	8 optional extra for addressing

Table 3: Application Control Service Element Overheads

This is referred to as A_C, which must be added to the application data to determine the length of the corresponding TSDU.

ACSE is also used during connection release and abort (ACSE APDUs AARL and ABRT are sent and acknowledged).

B.3.4 Presentation Overheads

There are two variants:

- Where the application relies on the Fast Byte stack;
- Where the full OSI stack is used.

Except for CF, where the application relies on the Fast Byte stack defined in the SARPs, P-data is not used (A-Data is mapped directly into T-data) and there is therefore no overhead. Where P-DATA request is used by the CF, the Fast Byte option of the Presentation protocol maps this primitive onto the S-DATA request.

[3] Taken from SARPs Guidance Material.

The overhead introduced in the P-Connect is a single octet in each direction.

P_C = 1 octet for each direction

Where the application uses the full OSI Stack i.e. for AMHS. In this case the presentation header will be added for all APDUs. The overheads (referred to as P_O) shown in Table 4 occur for each message.

Presentation Data	2 octets per message
All other services map directly to Session PDU fields	-

Table 4: Presentation overheads for transfer phase

B.3.5 Session Overheads

There are two variants:

- Where the application relies on the Fast Byte stack, uses the SARPs defined Dialogue Service and/or the 'OSI skinny stack', and
- where the full OSI stack is used.

S-DATA request is used by the Fast Byte Presentation protocol machine. The Fast Byte option of he Session protocol maps this primitive onto the T-DATA request. The overhead introduced by S-Connect/Disconnect is two PDUs, each of a single octet: For Dialogue Service based applications;

(S_C) = 2 PDUs, each introducing 2 octets overhead for each direction

Where the application uses the full OSI Stack (i.e. for AMHS), the Session header will be added to all APDUs. The overheads (referred to as S_O) shown in Table 5 occur in the data transfer phase.

Session Data	+2 octets per SDU
Minor Synchronisation point	Dependent on implementation configuration, 4 octets per synchronisation
Activity	+4 octets per Message (Start and end)

Table 5: Session overheads in the data transfer phase

However, the precise number of the above which are used depends on the configuration of UA, MTA and MS implementations, in which the rate of occurrence of S-Minor Synch points will be specified.

Other Session functions:

- Token Management;
- Exception reporting:
- Resynchronisation;

Occur only sporadically and may be ignored for the purpose of traffic modelling.

B.3.6 Transport Overheads

B.3.6.1 General

The Transport Protocol is always used and introduces overheads outlined in this section. The ATN Transport layer connect request can transport up to 32 octets of User Data. However, if the user data presented is more than 32 octets, then all of the user data is retained and mapped into a separate TSDU. Since it is unlikely that any application will generate messages of less than 32 octets, it must be assumed that each connection will also result in a separate TSDU carrying the user's data.

This has the consequence that the initial application data will have an extra transit delay imposed by the connection establishment. This will effectively extend the transit delay of the initial data between applications by an amount equivalent to the connection establishment delay. ***This could be of critical importance for some instances of the ADS 'Emergency Contract' services where a current dialogue does not exist, particularly since the TSDU will be trapped on a potentially vulnerable mobile end system.***

The following subsections outline the individual overheads associated with each TPDU. The sum of all of these overheads is T_O - the transport overhead.

B.3.6.2 Connect Request TPDU

Length	1 octets
TPDU Code	1
Checksum	4
Dest. (Address)	4
SRC Ref	4
Class	1
TSAP	2
DST Ref	2
TPDU size	3
Ack Time	4
Priority	4

Inactivity Time	6
User Data (SPDU)	up to 32 octets
Total max	128 octets

Table 6: Transport overhead for Connect Request TPDU

B.3.6.3 Connect Confirm TPDU

Length	1 octets
CC/CDT	1
Dest Ref	2
SRC Ref.	4
Class	1
User Data (SPDU)	up to 32

Table 7: Transport overhead for Connect Confirm TPDU

B.3.6.4 Disconnect Request TPDU

Len	1 octets
DR	1
DST Ref	2
SRC Ref	2
Reason	1
Checksum	4
User Data (SPDU)	up to 64

Table 8: Transport overhead for Disconnect Request TPDU

B.3.6.5 Disconnect Confirm TPDU

Len	1 octets
DC	1

DST Ref	2
SRC Ref	2
Checksum	4

Table 9: Transport overhead for Disconnect Confirm TPDU

B.3.6.6 Data TPDU

Len	1 octets
DT	1
DST-Ref	2
TPDU-Nr & Eot	4
Checksum	4
User Data (SPDU)	up to the the negociated TPDU size - the DT TPDU header size

Table 10: Transport overhead for Data TPDU

The number of Data TPDUs can be assumed to be determined from the length of the message, and the maximum specified TPDU length of 64 Kbits.

B.3.6.7 Expedited Data TPDU

Not used.

B.3.6.8 Data Acknowledgement TPDU

Len	1 octets
AK	1
DST-Ref	2
Yr-Tu-Nr	5
Checksum	3
Flow control confirmation	10

Table 11: Transport overhead for Data Acknowledgement TPDU

B.3.6.9 Expedited Data Acknowledgement TPDU

Not Used.

B.3.6.10 Reject TPDU

Len	1 octets
RJ	1
DST-Ref	2
Yr-Tu-Nr	4
CDT	2

Table 12: Transport overhead for Reject TPDU

These can be considered to be sporadic only, and not a source of real traffic.

B.3.6.11 TPDU Error TPDU

Len	1 octets
Er	1
DST-Ref	2
Reject Cause	1
Invalid TPDU	? - as long as the largest TPDU!
Checksum	3

Table 13: Transport overhead for TPDU Error TPDU

These can be considered to be sporadic only, and not a source of real traffic.

B.3.7 TSDU sizes

It will only be possible to calculate TSDU sizes accurately when the design and configuration of the ATN is finalised to the extent that all the parameters are known. However, once they are known the following formulae can be applied to determine the expected Transport traffic.

For AMHS, which uses the full OSI stack, the size of each TSDU, in octets, is provided by the following expression:

Application Data Length + AP_O + P_O + S_O

For the case of the Dialogue Service and use of the 'skinny stack' the resultant overhead is:

$AP_O + D_O$ - for message data;

Each OSI connect phase will generate:

Two packets, each of length:

$ACSE_C + P_C + S_C + T_C$

TPDUs are limited in size to 64 Kbits. Most APDUs will result in single TSDUs This is likely to remain the case until advanced, high volume applications such as AMHS and the transmission of detailed weather maps etc. are in use.

B.3.8 Network (s)

The throughput requirements of the ATN are expressed in terms of the number and length of CLNP packets. The maximum CLNP packet length must be determined from the design of the ATN, and is denoted by $N_{L..}$

The number of CLNP packets generated by a TSDU is calculated as follows:

- Connection establishment/disconnection (2 for each connection, 2 for each disconnection;
- Data conveying, dependent on the size of TSDUs and the CLNP Packet Length.

B.3.9 Subnetworks

Each Subnetwork will introduce a number of overheads:

1. Subnetwork Packet and Framing Overheads;
2. Circuit connection and disconnection overheads
3. Potential further packets if a CLNP packet does not fit into the subnetworks defined maximum packet length.

If (3) above does occur, then it may be the case that the subnetwork does not perform CLNP packet re-assembly, and the number of CLNP packets within the ATN multiplies (which of course introduces further protocol overheads).

Because of the many unknowns, and the wide number of subnetwork types and respective configuration possibilities, subnetwork dimensioning should be done on a case by case basis. Design tools are available for many subnetwork types which should be used for this task.

B.4 Applications Traffic Patterns

The following subsections analyse each application in terms of their characteristic traffic patterns.

B.4.1 Administrative Applications

It is currently not possible to estimate the traffic properties of AOC applications.

B.4.2 AFTN - AMHS

Traffic volume source: Part of this can be judged from the existing traffic loads between existing locations. It is assumed that the traffic would appear as the AMHS application. However, the AMHS traffic is likely to increase unpredictably because of its general purpose nature.

Protocol Overheads: The full AMHS application, presentation and session layer protocol overheads should be added to the application traffic to determine the number and length of TSDUs. Because of the complexity of AMHS messages, it will be difficult and perhaps pointless to try to provide accurate estimates of the actual traffic volumes it produces. It is therefore suggested that a nominal 25% overhead is added to the application data volume determined from existing sources.

It should also be noted that AMHS uses the ATN at a lowish priority, and would therefore be one of the first sources to be inhibited in any potential overload situation.

Dialogue overheads: The overheads will be impacted by the policy of establishing and clearing OSI associations between UAs, MTAs, MSs and Gateways (i.e. Are associations established 'on demand' for each message, or is a virtual network of associations established to permanently interconnect them?). Also, in the event of a non-delivery occurring, a report (a single TSDU) would be generated for each message recipient in failure.

Number and size of TSDUs and CLNP packets: For messages, it is unlikely that the 64Kbit TPDU length will be exceeded by current AMHS, however the number of CLNP packets must be judged from a profile of AMHS message lengths and their respective protocol overheads.

B.4.3 ADS

This application has no predecessors and there is no operational experience for it. Will depend on:

- Number and Location of Mode -S Radars;
- Number and Location of Satellite antenna/reception systems;
- Number and location of VHF transmitter/Receivers;
- Number of Aircraft communicating through each Mode-S, Satellite link and VHF transreceiver;
- Frequency of ADS reports generated by each aircraft;
- Actual content of ADS reports and the 'traffic profile';
- Number and location of air/ground routers,
- Phase of flight.

Traffic Volume source: There are actually two types of ADS information:

1. 'Operational' ADS messages which are of direct use in the ATC operations, there may be several destinations for each such ADS message. These must be associated with the tight maximum allowable transit time delay requirements specified in the operational requirements;

2. ‘Administrative’ ADS messages (e.g. aircraft position reports to airline offices) which are not of an operational nature and are typically bound for non ATC destinations. (It is suggested that these do not have to meet the strict Operational Requirements of maximum transit time delay).

ADS messages are all specified in the SARPs, and from this source, one can obtain a good idea of the length and variance of length of messages.

Protocol Overheads:

ADS uses the Dialogue Service and the fast byte stack specified in the SARPs - see the tables in section “Protocol Overhead Considerations” (Some figures are given on the application generated overhead in the CAMAL (Guidance Material, part III - application)).

Dialogue overheads:

For the dialogue overheads see the tables in section “Protocol Overhead Considerations”.

Number and size of TSDUs and CLNP packets:

Currently no information is available.

B.4.4 AIDC

This application is already in operation in Europe (at least partially) and is currently supported by dedicated network connections (OLDI) and Voice communications.

Traffic Volume source:

OLDI constitutes only parts of the controller traffic dialogue, and estimates of the traffic volume to support the aircraft handover dialogue must be judged from the current controller’s voice dialogue. All of the controller’s standard dialogue messages are specified in the SARPs, their length is therefore known. Free text messages are also possible, but will generally be of a length limited by the input capabilities of the controllers - i.e. short!

Protocol Overheads:

AIDC uses OSI in a ***similar way*** to the Dialogue Service and uses the fast byte stack specified in the SARPs. From the point of view of traffic dimensioning, only two packets with two octets overhead need to be added to the application data volume (one for session, and one for presentation) which are be carried in the Connect TPDU. There is no session/presentation overhead for data TPDUs.

Dialogue overheads:

Each AIDC Message results in an acknowledgement, the length of which is specified in the SARPs.

Number and size of TSDUs and CLNP packets:

This must be estimated from the number and size of each message, and the acknowledgements for each individual controller-controller communications link.

B.4.5 ATN Routing Updates

Routing Update traffic has the following dependencies:

- Number and Location of Mode-S Radars;
- Number and Location of Satellite antenna/reception systems;
- Number and location of VHF transmitter/receivers;
- The rate at which aircraft become reachable (or unreachable) through each of the air/ground subnetworks (dependent on the progress of the aircraft through airspace);
- Number and location of air/ground routers,
- The topology, configuration and selected architecture of the routing update system chosen for a particular region.

No ATN application for Routing Updates is specified, it is introduced as CLNP packet data as part of the network management overheads, however, it must be considered as a significant source of ATN packet level traffic.

Traffic Volume source:

Eurocontrol has conducted the ***MoMo*** [EURsim] simulation studies that have produced some results related to ***particular*** routing update architectures which describe the routing convergence delays, however there are no known sources of traffic estimates.

Until a concrete routing strategy and routing update flow is selected for implementation it will not be possible to estimate the amount and distribution of traffic it will introduce to the ATN.

B.4.6 CFMU CASA

The application traffic volumes for this are already well documented. If CASA is to be transferred to the ATN, then the actual traffic volumes will have to be re-evaluated in terms of the full OSI protocol stack using the application traffic volumes.

Traffic Volume source:

– to be added –

Protocol Overheads:

– to be added –

Dialogue overheads:

– to be added –

Number and size of TSDUs and CLNP packets:

– to be added –

B.4.7 Context Management

This application has no predecessors and there is no operational experience for it. Will depend on:

- Number and Location of Mode -S Radars;
- Number and Location of Satellite antenna/reception systems;
- Number and location of VHF transmitter/receivers;
- Number of Aircraft communicating through each Mode-S, Satellite link and VHF transreceiver;
- Frequency and destination of CM events generated by each aircraft;
- Number and location of air/ground routers,
- Phase of flight.

Traffic Volume source:

The content and length of CM application messages are specified in the SARPs.

Protocol Overheads:

CM uses the Dialogue Service and the fast byte stack specified in the SARPs - see the tables in the section “Protocol Overhead Considerations”

Dialogue overheads:

For the dialogue overheads see the tables in section “Protocol Overhead Considerations”.

Number and size of TSDUs and CLNP packets:

CM interactions only occur when an aircraft establishes or clears contact with an ATC. ***Update CM interactions will probably be rare!*** So, the number and frequency of CM messages (and responses) can only be judged from the number of aircraft handled at a particular point in the ATN and the number of ATC centres that each aircraft establishes contact with.

B.4.8 CPDLC

This application is already in operation and is currently supported by voice communications. An estimation of the traffic volumes it introduces to the ATN can therefore be obtained from a statistical analysis of real dialogues.

Traffic Volume source:

An equivalent CPDLC message for each standard voice message is specified in the CPDLC SARPs. Free form textual messages can also be exchanged, however these are expected to be comparatively rare and limited in length to the input capability of the pilot/controller.

Protocol Overheads:

CPDLC uses the Dialogue Service and the fast byte stack specified in the SARPs. - see the tables in the section “Protocol Overhead Considerations”.

Dialogue overheads:

For the dialogue overheads see the tables in section “Protocol Overhead Considerations”.

Number and size of TSDUs and CLNP packets:

The number and frequency of CPDLC messages (and responses) can only be judged from the number of aircraft handled at a particular point in the ATN and the number of ATC centres that each aircraft establishes contact with (assuming that pilots do use CPDLC to communicate with downstream ATCs). The profile of each ongoing dialogue (i.e. per aircraft/controller relationship) must be estimated from the current voice interchanges. It might be possible to identify a ‘standard profile’ for this to simplify all calculations.

However, it is not certain whether the dialogue ‘profiles’ will differ significantly with geographic region. Nor is it known whether there a significant difference between the CPDLC dialogue contents for takeoff, approach and transit (phase of flight). If there is, the estimation task may need to be modified appropriately.

B.4.9 D-FIS

This application has no predecessors and there is no operational experience for it. Estimations will depend on:

- Number and Location of Mode -S Radars;
- Number and Location of Satellite antenna/reception systems;
- Number and location of VHF transmitter/receivers;
- Number of Aircraft communicating through each Mode-S, Satellite link and VHF transreceiver;
- Frequency and destination of D-FIS requests generated by each aircraft;
- Number and location of air/ground routers,
- Phase of flight.

Traffic Volume source:

It can be expected that D-FIS traffic will be very sporadic, and the actual length of messages will vary a great deal dependent on local conditions, also it will change with time (e.g. particularly with rapidly changing weather conditions);

Protocol Overheads:

D-FIS uses the Dialogue Service and the fast byte stack specified in the SARPs - see the tables in the section “Protocol Overhead Considerations”.

Dialogue overheads:

For the dialogue overheads see the tables in section “Protocol Overhead Considerations”.

Number and size of TSDUs and CLNP packets:

Unknown

B.4.10 Radar

No ATN application for radar has yet been specified. However, if it should ever be considered as a candidate ATN application, the following should be taken into consideration:

- The traffic profile requires a high throughput, and has very tight time constraints.
- Use of the Transport Service will be highly inefficient, since it would require generation of very many small TSDUs with their associated overheads.
- Whilst traversal of a single subnetwork may be possible for radar packets, traversal of several, including intervening routers would probably add too much transit delay to be acceptable;
- It will probably be defined as a point to multipoint data traffic flow using the connectionless transport service.

It might be preferable to either consider radar as a totally separate network, or only as an external traffic flow which places a known, constant packet load on underlying subnetworks.

Traffic Volume source:

If it becomes an ATN application, then its traffic patterns and flows will be quite predictable and relatively constant.

Protocol Overheads:

Can be assessed from the ASTERIX format.

Dialogue overheads:

Virtually no dialogue traffic exists.

Number and size of TSDUs and CLNP packets:

This can be quite accurately determined from the installation and configuration of Radar data streams from antenna, and their respective destinations.

B.4.11 Systems Management

Traffic volumes for this are unknown, since it is not yet clear how the systems are going to be managed. Perhaps there should be a fixed estimated traffic flow per network component based on the needs to monitor and adjust each component.

B.4.12 CFMU TACT

There is no ATN application defined for TACT at the moment, however, if one should be defined, the applications traffic patterns can be determined by examination of the existing TACT operation. The resultant application traffic volumes would have to be treated in the context of an OSI application using the full OSI protocol stack.

B.5 Measuring Traffic Characteristics

Table 14 shows sources of information on application traffic characteristics.

Application	**Traffic estimation**
AFTN	Known Traffic flows can be measured
CFMU	Known Traffic flows can be measured
TACT	Known Traffic flows can be measured
CASA	Known Traffic flows can be measured
Radar	Known Traffic flows can be measured
CPDLC	Must be estimated from current Pilot/Controller voice communications per flight.
Context Management	Must be estimated taking into account: the number of logons each aircraft will make during a flight through ACCESS region, and ground station contacted
ADS	Must be estimated since no current similar service is in operation.
AIS	Must be estimated - no current similar service in operation - there are few indicators of quantity
D-FIS	Must be estimated - no current similar services are in operation - there are few indicators of quantity
A-MHS	May be estimable from a portion of the current AFTN traffic
AIDC	Known Traffic can be estimated from current controller voice dialogues per flight
Subnetwork management	Must be estimated, but there are a few precedents
Network Management	Must be estimated, but there are a few precedents
Air traffic routing maintenance (dynamic)	Must be estimated. However it is dependent on the ultimate routing topology chosen. Results of simulations are necessary here to be confident of reasonable results.
Administration	Not possible to estimate. Which administrative tasks are planned for the ATN

Application	**Traffic estimation**
External Traffic Flows (where National resources are being shared e.g. routers or subnetworks).	Source, sink and quantities should be declared by administrations.
External traffic arriving from other ATNs	cannot yet be estimated.
Transit Traffic Flows	Between other ATN regions - cannot yet be estimated.

Table 14: Sources of information on application traffic characteristics

B.6 ATN Traffic Load Rationalisation

Given the individual traffic flows for each application specified in section 0, it might be possible to identify certain similarities in the traffic introduced by certain applications irrespective of their geographical location - i.e. if the CM application traffic profile is similar at each CM supporting end system, then this value could be used throughout the ATN loading calculations to simplify the task.

If no similarities exist, then the ATN traffic loading calculations will have to deal individually with each instance of the application at each geographical location, and derive each individual traffic flow.

B.7 End System Traffic - Determining The Traffic Matrix

The traffic flows for each application (or their rationalised flows identified in section 6.4) and for each end system may then be summed to determine the data volume throughput requirement and packets/second flows for each end system.

The results for all end systems in the part of the ATN being dimensioned are then compiled into a traffic matrix, and the methods outlined in section 5 for determining the traffic load distribution through the proposed ATN are applied to determine the required dimensions of each ATN Router, Subnetwork and communications circuit for the proposed ATN topology.

B.8 Transit Delay Time Targets

The transit time delays introduced by each ATN component router, subnetwork and communications circuit can be derived from the results of the traffic load distributions with reference to characteristics of the installed components. The delays must be calculated for each application data stream between each pair of end systems, and must include the individual delays introduced by each end system, router and subnetwork in the path.

Alternatively, the computed traffic load can be used to select an appropriate size of component to meet the required maximum traffic delay allowed, based on the characteristics of components available on the market.

In the context of the many national administrations which co-operate to provide and operate the ATN within the strict maximum transit delay times specified in the Operational Requirements, it would seem necessary to impose constraints on how much time each national operator can introduce (this form of regime is also imposed by PTTs etc. in provision of global service to known quality of service targets). The following table suggests how the responsibility for meeting the maximum global transit delay times may be specified as shown in Table 15[4]:.

Target Maximum Time Delays for application X		
System part	Responsibility	Max. allowable Time Delay for each sector under peak load (e.g. for RADAR is max. 4 seconds), allocated as follows:
End system	National	0.5
airborne LAN	National	0.1
WAN sector	National	0.5
ATN router +subnet hops	Multilateral agreement	1
WAN sector	National	0.5
airborne LAN	National	0.1
End System	National	0.5

Table 15: Target maximum time delays for applications

These constraints set overall targets for the ATN for each application and allocate agreed responsibilities to the various parties involved. It will probably be necessary to classify groups of applications into classes, where the classes are each associated with a CLNP Priority, and perform all modelling and simulation according to classes as opposed to distinct applications. Priorities are defined in ATN SARPs.

B.9 Possible Rationalisations

Chapter 5.5 has so far outlined a quite complex method of determining the traffic volumes and flows through proposed ATN topologies which will require extensive further work to determine the actual data flows. However, it might be possible to identify common or standard configurations for various aspects e.g.:

[4] However, the precise figures will obviously need to be negotiated.

- Air/Ground ATN Application - Airborne End system, ARINC LAN, Mobile Router, air/ground communications link (Mode-S, Satellite, VHF), ground link, WAN 1, WAN 2?, ATC LAN, ATC End System.
- Ground-Ground System - ATC LAN, WAN 1, WAN 2, ATC LAN.

So it would be useful to factor out three types of air/ground links for separate models:

- Airborne End system, ARINC LAN, Mobile Router, air/ground communications link (Mode-S);
- Airborne End system, ARINC LAN, Mobile Router, air/ground communications link (Satellite);
- Air/Ground ATN Application - Airborne End system, ARINC LAN, Mobile Router, air/ground communications link (VHF);

and one ground to ground, model:

- Ground End System, LAN, WAN, WAN?, LAN, Ground End System;

It might be possible to evaluate the air/ground segments for each type (Mode-S, Satellite and VHF) and establish standard transit delays and throughput requirements for each which could be 'plugged in' to the overall ATN model.

Each application is also going to generate a standard 'peak' traffic load per connection (what are the maximum number of connections expected for each application - are there natural limits?)