# TECHNICAL RESEARCH REPORT

Hybrid Network Architectures; A Framework for Comparative Analysis

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## HYBRID NETWORK ARCHITECTURES; A FRAMEWORK FOR COMPARATIVE ANALYSIS


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### Abstract

The Global Information Infrastructure of the future will include a great variety of heterogeneous, seamlessly interconnected networks. There are strong variety of heterogeneous, seamlessly interconnected networks. There are strong technical and economic reasons predicating the emergence of these hybrid networks which will include many diverse terrestrial (tethered or wireless) and satellite networks in an interoperating configuration. This paper critically analyzes the basis for these new architectures and examines the various possibilities that will emerge in various phases in the future. A summary view is presented for these emerging hybrid architectures, the alternative components and subsystems available and the trade-offs that must be considered. The role of satellites is carefully analyzed and several conclusions are drawn. This paper will present a summary of the work and views of the Center for Satellite and Hybrid Communication Networks todate, in this important area. Specific design and performance evaluation tools being developed will also be described.


### INTRODUCTION

The mission of the Center for Satellite and Hybrid Communication Networks (CSHCN) is the advancement of space-based communications with a thematic emphasis on hybrid networks. This statement is intended to include each of the following as properly within the domain of CSHCN activities: education; research and development; national policy, NASA and otherwise, as regards the satellite industry and other efforts for the general advancement of the industry as a whole. The role of the Center in the latter two cases is primarily that of a catalyst to promote the development and deployment of networking technologies and services based on satellite and *hybrid* network capabilities. This mission is critical to the lasting leadership of the U.S. communications satellite industry, and to a rapid and cost-effective deployment of an advanced NII and GII.

The hybrid communication network theme appears throughout our work and plans, and is a unique distinguishing characteristic of this Center. It is based on the proposition that certain industry forces are driving the convergence of satellite and terrestrial communications technologies and industries just as over the past decade we witnessed the convergence of computers and communications. And similar to the convergence of computers and communications, it is projected that the convergence of satellite and terrestrial telecommunication technologies will be a phenomenon of immense proportions.

The concept of the hybrid network as used here goes well beyond the traditional application of interconnecting a satellite hop with a terrestrial gateway. As opposed to the "fiber to the home" concept of a single fiber providing the full array of transmission services to the customer, the hybrid network implies diversity of media and consumer choices. It implies a cost effective, balanced migration to a market-demand-driven NII. It also implies a new industry structure built around diversity and no longer constrained by the old barriers to entry. Control of the ubiquitous copper pair will no longer define control of the market. In a very real sense the architecture of the network will reflect the structure of the industry which itself is on the verge of a major redefinition. Current legislation in the Congress is proposing to rewrite both the Communications ACT of 1934 and the Modified Final Judgement (MFJ). The result will create a new set of dynamics for the industry with the fundamental impact of introducing competition into the provision of local loop services. Ironically, as the telephone companies advertise a future of a single fiber supporting all services new legislation is being written that implies diversity in the local loop. If the satellite industry is alert and motivated that diversity can include hybrid satellite-terrestrial transport services.

In this context it becomes apparent that a key component for the long-term viability of the communications satellite industry will be the integration of satellite technology into traditional and developing terrestrial networks. Satellite technology can support the full complement of network services offered today and projected for the future.

But in all major markets integration with other modes: existing analog plant of the public switched network, ISDN, cellular mobile, PCS, Internet, private networks, etc. is essential to the viable business case. The underlying theme is the migration of satellite services into the mainstream of mass market consumer network services. And that migration must take the form of integration with terrestrial modes. In this way the satellite industry will remain a potent and growing force in the evolving national and international telecommunications infrastructures.

The strategic plan of the CSHCN is founded on seven concurrent and timely interconnected components: 1) Development and implementation of network interfaces between personal communication, satellite and high data rate terrestrial networks; 2) Development of PCN terminals with terrestrial and satellite connectivity; 3) Development of on-board fast-packet switching for satellites; 4) Development of active aperture antenna technology for multiple high-gain spot beams for satellites; 5) Development of high data rate low cost VSATs; 6) Development and demonstration of network management to provide seamless operation of the hybrid information infrastructure; 7) Demonstration of the end-to-end seamless operation of the hybrid infrastructure through the ACTS satellite and other commercial satellites.

This focus and concentration is clearly reflected on the current commercialization projects. This plan is organized so as to gradually increase the commercial markets, and thus induce further investment and productization and at the same time, decrease the required government investment.

The commercialization project selection of the CSHCN is critically timed to enhance and help Government efforts to establish universal access to information highways by bringing together a team of leading companies from industry sectors that otherwise may pursue individually and in an antagonistic fashion only one of the proposed interconnected components (PCN, ATM networks or satellite networks). The CSHCN represents a unique and concerted effort to end the fragmentation of the U.S. telecommunications industry. The CSHCN program will accelerate the development and deployment of global information networking by providing Information Age capabilities to the masses using a "trickle-up" marketing of high technology. This will be accomplished by the simultaneous introduction of advanced networking capabilities with inexpensive mass-market products. The dovetailed higher technologies pursued in the CSHCN projects are needed to hide or make transparent from the user the staggering complexity of future information infrastructures. Otherwise the benefits will be confined to an information elite and to small markets that cannot sustain the development needed in a cost affordable manner. The integrated system proposed enlarges the potential set of end-users in an extreme sense by combining in a multiplicity of ways the users of the individual component networks. This results in a well defined and sustainable productization plan, based on a phased approach of market expansion and the associated exceptional cost reduction of communication components and services.

It is important to emphasize that the commercial product of the CSHCN program is the “hybrid network,” or the “hybrid information infrastructure.” We plan to productize and commercialize components of this system, which can be used interoperably in the market. Our major focus is on the required interfaces and systems engineering rather than on specific hardware components and/or devices.

## COMPARATIVE ANALYSIS USING HYBRID NETWORK SIMULATION

As the complexity and diversity of networks have grown, simulation has proved to be an important tool in their design, analysis, testing and performance estimation. A typical hybrid communication scenario is shown in Figure 1. Hybrid networks involve a variety of network elements - both terrestrial and satellite with their associated protocols, and the services they provide, like commercial video and radio transmissions, voice, data and image transmission services. Because of their complex nature, design and evaluation of hybrid networks is a particularly complicated and challenging task.

A number of tools are available for the simulation of communication networks. Some of these are general-purpose simulation packages like BONeS DESIGNER, GPSS/H, MODSIM II, SIMSCRIPT II.5, SES/workbench, SIMAN/Cinema V and SLAMSYSTEM; others like OPNET Modeler provide a communication network simulation language; and yet others are specialized communication network simulators like BONeS PlanNet, COMNET III, NETWORK II.5 and L•NET II.5. For the simulation of communication networks, a dedicated communication network simulator offers advantages over a general purpose simulator, namely, speed of network modeling, a library of predefined network components and perhaps, automatic computation/display and analysis of the key communication-related performance statistics. A general-purpose simulator, on the other hand, has the flexibility to model almost any discrete-event system, though, as the generality of the simulator increases, typically, so does the effort required.

The simulation of a complex hybrid communication network offers a unique challenge to simulation tools. Because systems to be simulated are complex and diverse, constructing a system model using a general-purpose simulator would be too time-consuming. On the other hand, most of the current network-simulation tools are not designed to visualize or simulate such complex networks. The deficiencies in simulating hybrid communication networks with conventional communication network tools are (i) difficulty in modeling the system in sufficient detail and accuracy, (ii) difficulty in capturing the entire communication scenario, (iii) slow speed of execution, (iv) inadequate network performance monitoring/evaluation support both during and at the end of a simulation run.

A number of issues are involved in the simulation of hybrid networks. While being of interest in the simulation of conventional networks, they gain critical status for the simulation of hybrid networks because of the unique demands placed by the complexity and diversity of these networks. They in turn place stringent demands on the simulation tools and motivate the development of new tools tailored to the simulation of these complex systems.

## A Complex Network Paradigm

To get an idea of the complexity, let us consider the proposed Teledesic satellite network for the provision of global telecommunication services. The proposed system configuration consists of 840--900 satellites in a 21 low-earth orbital plane configuration, with a possibility of ATM support. The capacity of this system is in excess of 2,000,000 simultaneous full duplex 16kbps channels. With the small data-segment size of ATM packets, the simulation of this system operating even at 1% capacity would require the processing of over 10 million packets per second of simulated time. At 100% capacity, a processing rate of over a billion packets a second would be required.

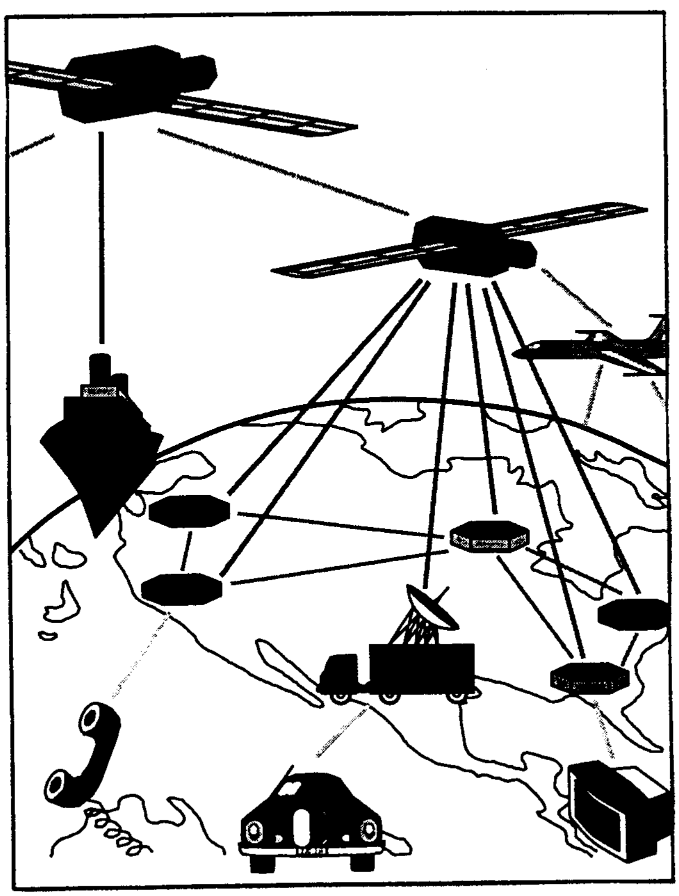

FIGURE 1. A Hybrid Network Scenario.

Assuming the simulation of the life of a packet (generation, end-to-end transfer and consumption) to generate on the order of 100 events (conservative, considering that a typical packet path would involve several satellites), an event based simulator trying to simulate this system would have to process on the order of a billion (1% utilization) to a 100 billion events (100% utilization) for every second of time simulated. With the current technology, even the world most powerful computers would creep through the event-based simulation of such a system---and we haven't even considered the simulation of the terrestrial network that would interact with the Teledesic satellite network, or the work required to simulate the dynamic nature of the satellite/terrestrial network.

Conventional event-driven simulation has been found to be quite efficient for the simulation of conventional networks. However, as the complexity of the system being simulated grows, the vast number of events being generated and required to be individually simulated presents a bottle-neck on the speed of simulation. The back-of-the-envelop calculations we presented for the Teledesic network simulation scenario demonstrate the immensity of the problem. Clearly, a more effective simulation paradigm is required for the simulation of hybrid networks, one that takes advantage of the inherent structure within the sub-systems that make up the complex network. In the hybrid simulation tool, we adapt a multi-tier model based approach -- the network system is modeled in terms of a few large functional blocks, which may be recursively defined in terms of smaller functional blocks. The more detailed the model, the more accurate the simulation, and the higher the simulation complexity. This scheme allows a few small, critical blocks to be simulated more accurately, while allowing the other simulation blocks to be replaced by equivalent aggregate parameters, thereby reducing simulation complexity.

### Flexibility and Adaptability

A hybrid network, by its very definition, is a diverse system that brings together in a single system, different means of communication, each with its own array of network components, protocols and control strategies. It is not possible for the creator of a simulation tool to provide a model for every possible component that may be required to be simulated. Even if it were, advances in technology and changes in networking ideologies would result in new building blocks that would be required to be simulated, rendering such an effort useless. It is therefore, very important that a hybrid network simulation tool be designed from the bottom-up to allow easy creation of user-defined components and their efficient integration into the simulation software.

### Data Management, Databases and Network Management

During a simulation run, vast quantities of data may be generated. Typically, this data would be simply dumped into a file, and accessed later for post-simulation analysis. A more efficient approach is to structure the data on the fly by storing it in a database. This allows simulation data to be manipulated and utilized much more easily during the post-simulation phase. More importantly, it allows access to this data while the simulation is being performed, allowing dynamic computation and display of network performance statistics. The database also serves as an interface point for intelligent network management tools that could use the simulated network as a model to predict the long-term behavior of a real network, and use the performance data generated by the simulator to formulate long-term network management policies.

### Object-Oriented Programming

Object-oriented programming is an advanced approach to structured programming. It is ideally suited to hybrid network simulation for all the reasons that makes it ideal for most complex software efforts: a clean software structure, software and effort reuse, flexibility and adaptability, ease of documentation, and with the availability of modern object-oriented programming languages, efficiency. Object-oriented programming is used to define network nodes; a top-level generic node captures those features common to all nodes, and more specialized node structures are constructed through inheritance and specialization from more general class structures.

## SOME TYPICAL APPLICATIONS

Using effective simulation tools for hybrid networks and fast algorithms for performance evaluation, we can perform efficiently the systems engineering analysis and trade-off studies required for hybrid architectures evaluation. For instance one can carefully and quantitatively evaluate the performance vs. cost of various architectures including: the type of satellite, the number of satellites, the type of terrestrial networks, the type and composition of traffic, the value of a particular interface, the selection of transfer modes, compression, etc.

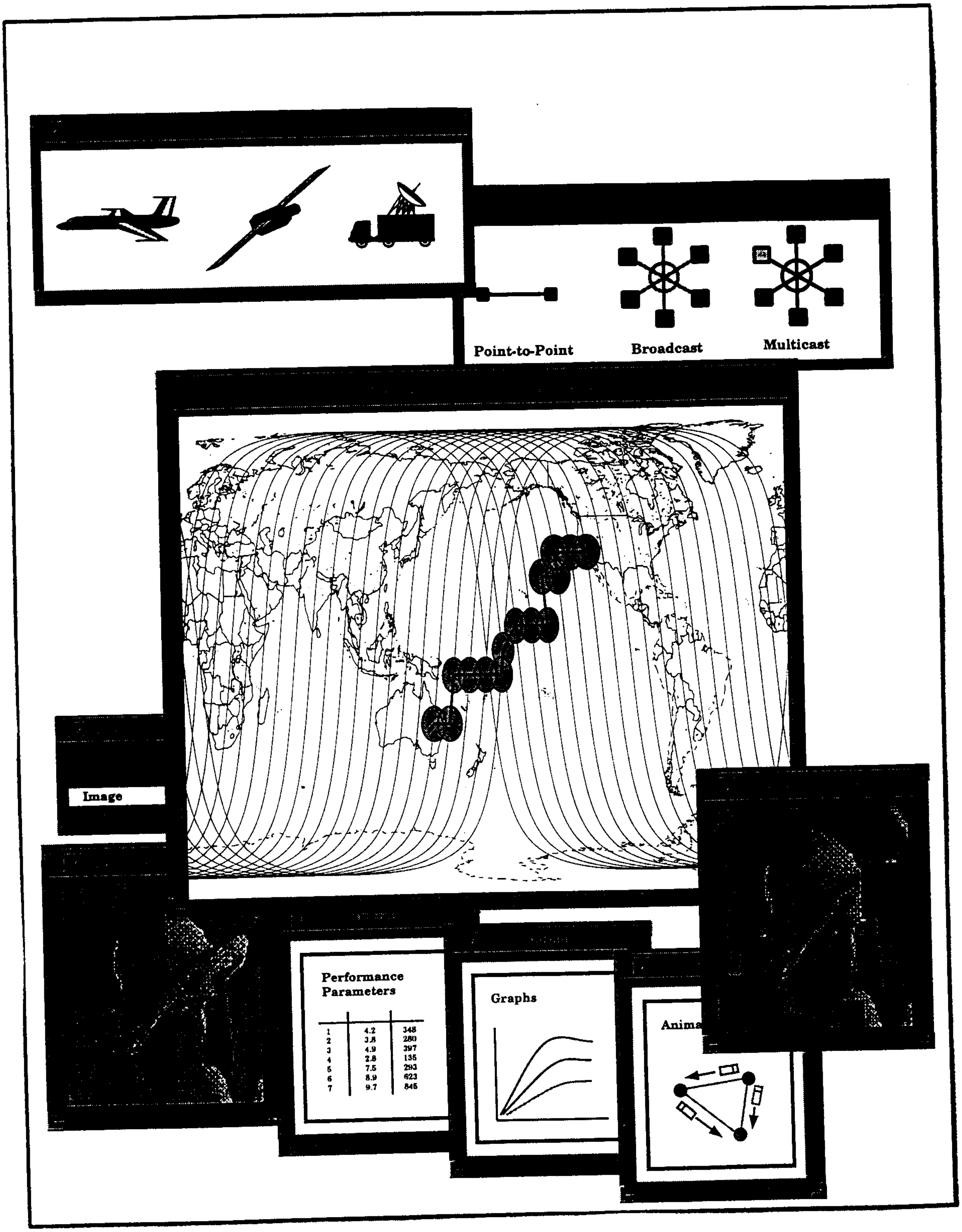


FIGURE 2. Visualization of a Satellite Constellation and Related Parameters.

In this section, we describe two typical applications of the object-oriented distributed hybrid network simulation software. The first application tries to highlight some of the network visualization capabilities, which are essential for trade-off studies. The second application is an illustration of how the software may be used as a tool for network management and therefore performance evaluation.

## Satellite Constellation Network Simulation

With proposals to provide global communication coverage (telephone/cellular) through a constellation of low-earth orbit (LEO) and medium-earth orbit (MEO) satellites arranged in multiple orbits around the globe, for example, Iridium, Teledesic and Globalstar, the simulation of satellite networks has suddenly gained prominence. Because of the dynamic nature of satellite networks, both visualization and simulation of such networks presents unique problems. Recognizing their importance, the hybrid network simulator provides a special interface to handle the simulation and visualization of satellites and satellite constellations and their relationship with the earth. The specialized satellite constellation GUI provided by the software incorporates (i) definition of multiple orbits and the positioning of multiple satellites within each orbit; (ii) definition of satellite and earth-station communications parameters; (iii) visualization of the satellite constellation -- logically (showing connectivity) and spatially against the globe and on a flat map; (iv) selecting the visual context with respect to a satellite, a point on the globe, or some inertial frame of reference; (v) visualization of end-to-end connection paths, and associated path metrics; (vi) definition and visualization of cell patterns and antenna beam patterns associated with a satellite as it moves around the earth; and (vii) incorporation and visualization of climatic activity and population behavior models.

Fig. 2 shows how some of this information is presented on the GUI. Multiple visualization models are required to effectively visualize the network; for every piece of information, there is a model of visualization that represents it best. In Fig. 2, only the flat-map visualization is shown. The figure shows a communication path between Australia and California over the proposed Teledesic network, and illustrates how the communication path crosses the constellation seam. The path itself is depicted as a bold line, and the shaded ovals represent each satellite's computed footprint (assuming a minimum antenna elevation angle of 40 degrees) projected on the flat map. Other information like beam patterns, connectivity and relative satellite positions can also be effectively visualized on the flat map.

Other visualizations of the satellite constellation network, for example, a globe-based 3D visualization and a logical view showing communication path and satellite performance related statistics are also available (not shown) to more effectively visualize the network.

Additionally, Figure 2 also illustrates symbolically, how a network may be assembled using nodes and links and also shows how performance-related data may be viewed dynamically. Finally, the figure also shows an actual distributed image application running on the simulated network (using the software interface feature).

## Intelligent Network Management

The flexible interface and the incorporation of a database prepare the hybrid network simulation software as a tool for network management in a closed loop with a network management software. In a typical network, network monitor functions gather data on network performance, and store it in distributed databases. Some of this data is used for short-term network management and fault resolution directly, using dedicated network management functions. Additionally, as part of the intelligent management of the network, this data is used to drive the simulation (which runs in parallel with the actual network and mimics its behavior). The long-term behavior of the simulated network now acts as a predictor of the long-term behavior of the network, and may be used to better manage the long-tem network performance. The effect of particular network policies can be safely judged by testing them on the simulated network, before they are applied to the running network. For example, in current work, we are developing fast versions of the simulation to provide online feedback advise for hybrid network configuration and fault management. Working in this fashion one can evaluate various proposed hybrid architectures.

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