

Integration of Space and Terrestrial PCS in the Information Infrastructure

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ABSTRACT The emergence of National and Global Information Infrastructures (NII/GII) has been receiving considerable attention and emphasis across many domains, including both technical and political communities. This paper examines considerations for efficient integration of satellite and terrestrial PCS into the fabric of the NII and GII, with emphasis on interoperability among wireless systems themselves as well as with the other elements of the infrastructure. The objective architecture should constitute a seamless hybrid network.

Introduction

The information infrastructure will be a complex "network of networks" which will dramatically transform society and its many elements such as education and health care systems, libraries, and business and Government information systems. Key properties which the objective architecture should have are universal service including services for mobile users; a healthy competitive environment based on the principle of universal access; and widespread interoperability among the various heterogeneous elements of the infrastructure.

The concept of a widespread information infrastructure has received considerable attention and emphasis and has been embraced by the Clinton Administration as an important enabler of continued US global leadership into the next century.

Transmission systems (a.k.a. "bitways") will be the foundation upon which the information infrastructure will be built. Bitways may be classified as tethered networks (interconnected by fiber optic and coaxial cables, wirelines, etc) and untethered (linked by various types of wireless and satellite systems). It is critically important to successful achievement of the NII vision that the tethered and untethered elements of the infrastructure be simultaneously developed in a coherently phased manner. Although the tethered backbone will transport most of the bits flowing through the information infrastructure, the wireless links will be essential in terms of the utility provided to consumers. The NII vision states that the "network of networks" will provide all Americans with the information they need in a meaningfully useful form, when and where they need it, and at an affordable price. Ubiquitous service, even for mobile users, is a goal which requires emphasis on untethered transmission systems.

Foundational Principles

Vice President Gore has embodied the foundational principles behind development of a National Information Infrastructure in a set of 5 principles:

- encourage private investment
- promote competition
- flexible regulatory framework that can keep pace with rapid technological and market changes
- open access to the network for all information providers; and
- ensure universal service

Wireless and satellite services will provide various competitive alternatives for consumers to consider, and these untethered transmission systems will be absolutely essential to achieve the important objective of affordable universal service to all Americans. US companies presently have significant competitive advantages in wireless and satellite technologies and systems in the global marketplace, and exports in these industries will have positive impact on our balance of trade in the future.

Vice President Gore recently extended these principles to apply to development of the Global Information Infrastructure, or GII, which will be key to economic growth for the international economy. The International Telecommunications Union (ITU), in its Declaration from the 1994 Plenipotentiary Conference in Buenos Aires, has embraced these principles as key to successful development of the GII.

In his speech to the ITU in Buenos Aires, the Vice President pledged our nation's vigorous, continued participation in development of a Global Information Infrastructure, which promises to improve the quality of life and preserve freedom and democracy around the world. In particular, the Vice President emphasized the important role which low cost mobile satellite communications systems can play in accelerating the development of a telecommunications infrastructure within developing nations, as well as providing a link for these countries into the fabric of the GII.

The Role of Untethered Networks

Both the National and the Global Information Infrastructures will be based around high speed tethered backbone networks, or "information superhighways." Wireless and satellite systems will contribute to these high speed backbones. For example, ARPA and NASA will be performing seminal demonstrations of reliable, 2-way interactive high speed satellite communications using the ACTS spacecraft. Using antennas in the size regime of conventional (Ku band) VSATs (Very Small Aperture Terminals, typically 1 to 3 meter diameters), the ACTS experiments will demonstrate high speed (up to OC-12, or 622 MBps) fiber optic input to a satellite terminal using the SONET/ATM protocol, and networking at these data rates among terminals separated by thousands of miles.

Nonetheless, it is important to recognize that the information infrastructure will actually encompass much more than just the high speed backbones, and in fact such backbone networks will have little utility for consumers without an adequate system of tributaries to

feed the "superhighway." It is in this aspect of the NII and GII that wireless and satellite systems will play essential roles.

Untethered systems have great potential to make universal service both practical and affordable. These components of the infrastructure will provide high productivity leverage for all Americans by enabling ubiquitous access to the information arsenal even from isolated and remote regions, and areas of low population density. Mobile users, including pedestrians and people travelling in various platforms such as cars, aircraft, and ships, can only be integrated into the information infrastructure by untethered systems. The diverse set of Personal Communications Services (PCS) which will emerge over the next few years will make critically important contributions to achieving the goals of affordable universal service and access to the infrastructure by mobile users.

It is imperative that the NII and GII evolve as balanced architectures. As noted above, significant utilization of the information infrastructure will take place through untethered connectivity. As the high speed backbone networks are developed, the tributaries must also be developed on a commensurate timescale. The alternative is deployment of a highly capable backbone which will have limited utility until the feeder systems are put in place. Such a course of action is clearly undesirable and would have unwanted economic implications.

Wireless and satellite PCS connectivity will be a critical enabler for many future applications. Capital formation to develop these applications could be seriously impeded without progress in developing the underlying PCS transmission fabric. Given the deployment times required to establish physical infrastructure for wireless and satellite systems, the ultimate delivery of services to consumers and to business could be greatly delayed if we are slow to begin development and deployment of the PCS infrastructure. Investors, manufacturers, and service providers will also be encouraged by a regulatory environment conducive to investment in wireless and satellite systems.

The Synergistic Union of Space and Terrestrial PCS Networks

Concerns have been expressed by some that space and terrestrial PCS systems may be duplicative and compete for the same markets, and therefore one or the other will "win out" and dominate the untethered components of the information infrastructure. Quite the contrary, a clear understanding of the attributes of these systems and the diverse markets they will capture show that the relationship between the space and terrestrial elements of the grid will be synergistic, and both will find economic validation in the marketplace.

Terrestrial systems will be established initially in those areas offering greatest market demand - primarily metropolitan areas around major cities. In these areas, the diversity of PCS services will be greatest, including networks in the newly opened bands at 2 GHz as well as perhaps expanded service offerings by existing cellular carriers operating in the 800 MHz band. It appears that proliferation of cellular coverage regions will extend out from metropolitan areas only as far as can be justified economically (in terms of capital expenditures for infrastructure and operational/maintenance costs versus derived revenues).

By their very nature, satellite systems will be able to provide services over very large areas, with most proposed space-based PCS systems offering near global coverage. Given the heavy capital outlays to establish a space-based infrastructure, these systems may not be price-competitive with terrestrial systems for sessions between parties in the same geographic region (same metropolitan area, for example). However, for long-distance and/or international connections, the network route through space may be competitive, and in cases where one or more participants in a session cannot be reached via tethered or terrestrial untethered modes, then a space link will be essential. Thus, economic factors will compel space and terrestrial PCS to be utilized synergistically, with each mode offering certain unique advantages over the other.

The development of a Global Information Infrastructure will also motivate synergistic coupling between space and terrestrial networks. The concept of a satellite ground terminal being co-located with a terrestrial wireless hub offers an attractive and potentially least cost approach to establishing an information infrastructure in regions of the world where even a basic telecommunications system is today non-existent. A unified space-terrestrial PCS approach may provide the quickest and most economical way to tie the vast elements of the global population in Third World nations into the GII.

Competitive Heterogeneity vs Interoperability

The disparity between free and open competition and the need for standardization and interoperability is a dilemma which recurs throughout the vision of an integrated information infrastructure. "Technology-neutral" and "vendor-neutral" are frequently cited as important elements of a competitive climate in the development of the NII. Many vendors consider design freedom to be a key element of their competitive positioning. For wireless systems, including satellite communications, system specifications include frequency tuning range, bandwidth, modulation format and networking protocols, coding, antenna beam profile, receiver sensitivity and selectivity, transmitter spurious emissions, and so on. Currently "hot issues" in wireless communications reflect competing approaches among various vendors, such as the use of CDMA or TDMA networking protocols for digital cellular systems. While maximum diversity in vendor products should be fostered, interoperability and the economic implications of large volume manufacturing are also important considerations.

There are several approaches to achieving interoperability. The canonical approach is to develop one (or a set of) standard(s) which ensure compatible characteristics across a class of system equipment. The advantages in the use of standards include clearly established specifications to the level deemed appropriate for achieving the desired degree of technical interoperability. Of course, standardization always implicitly (or explicitly!) restricts design alternatives and therefore tends to "homogenize" rather than promote heterogeneous diversity.

Perhaps the other "extreme" from the standardization approach is the "kluge" approach in which there are few if any restrictions on the designer, and specific interfaces are created for all incompatible systems in order to force interoperability on them. The dilemma here is that one creates a problem of order N^2 , where N is the number of

incompatible systems. This is clearly an inefficient approach to interoperability when N is anything but a small number (which it likely will not be for the information infrastructure).

There is a newly emerging concept for interoperability which is based on leading edge technologies and the intelligence they can bring to a systems environment. The basic concept is that a common interface is developed which can serve as a "translator" among diverse, heterogeneous elements of a system. For the PCS world, this interface will likely be a programmable multi-band radio architecture operating under the control of a parallel processing computer acting as the node controller.

Programmable multi-band radios are currently under development by ARPA for the defense community as well as some private companies. Essentially, this new paradigm for radio system design centers around the use of powerful digital signal processors. Since Marconi's pioneering work in the late 1890's, radios have been designed essentially as "stovepipe" systems - able to talk only to their clones. But today, the application of advanced microelectronics and computing technologies with radio systems engineering is about to break this century-old paradigm. Now, instead of information being impressed on a carrier by means of hardwired modems and radios which are limited to fairly narrow tuning ranges, we will have systems which feature broad multi-band operating capability and direct generation of a modulated waveform by means of digital signal processing operations on a baseband signal. In other words, the new paradigm is that of the programmable, software controlled radio.

As an illustration of the impact of this technology for interoperability in the PCS domain, consider cellular nodes which are based on a programmable radio architecture. A diverse set of waveforms and protocols can now be supported by the cell, since the base station can support any waveform/protocol that it has emulation software to support. Using a parallel processing architecture for the base station's computer facilitates each link being allocated a processor to handle the specific waveform/protocol which the end-user's equipment utilizes. The processors would be allocated by a node controller after receiving a service request on a common signalling channel (which would be the only standardization requirement placed on the end-user equipment). The bank of processors would share a software library to call-up emulation packages as needed to program the signal processing engine and set the up/down conversion chains to the appropriate frequencies. Layers 1 through 4 (Physical, Data Link, Network, and Transport) of the OSI Reference Model could be addressed by such an approach to interoperability among wireless systems.

Summary

Space-based and terrestrial PCS will make important contributions to the emerging National and Global Information Infrastructures. Rather than being purely competitive wireless alternatives, satellite and terrestrial modes will operate synergistically to yield ubiquitous accessibility in a cost-effective manner on a worldwide basis. Interoperability among diverse heterogeneous wireless systems is a significant challenge facing the developers of the untethered portions of the NII and GII. Programmable multi-band radio architectures may offer an approach for wireless systems interoperability without greatly restricting the design characteristics of end-user equipment.