Cross-Industry
Working Team

The Cross-Industry Working Team (XIWT) is pleased to provide to you a copy of "Nomadicity in the National Information Infrastructure" (NII).

The White Paper advances the goal of making information services and applications ubiquitous and flexibly available to people on the move. It provides a vision to guide the evolution of underlying technologies, shape new uses, and accelerate the on-going revolution in information technology applications. The paper is the product of XIWT's Nomadicity Working Team, led by Leonard Kleinrock, Chairman of the Department of Computer Science at UCLA and a member of the XIWT Science Council.

According to Kleinrock, "Nomadic computing and communications will dramatically change the way people access information– and a paradigm shift in thinking about applications of the technologies involved. It exploits the advanced technologies of wireless, the Internet, global positioning systems, portable and distributed computing to provide anytime, anywhere access. It is begining to happen, but it makes everything much harder for the vendors."

"Nomadicity," in this White Paper, means that people can easily access services, other people, and content while they are on the move, at intermediate stops, and at arbitrary destinations. Realizing this capability and integrating it into the rapid evolution of the NII presents a daunting set of technical challenges to meet requirements such as interoperability, security and flexibility.

The underlying mechanisms of nomadic computing and communications must support traditionally understood requirements of mobility, portability, and wireless communications, such as data transport, user authentication and privacy. There will also be new requirements. Among the most challenging are: 1) supporting the multiple roles desired by a user and dealing with varying sets of technologies, services and data, and; 2) configuring data to maintain critical content characteristics across the varying media the nomad encounters or commands as he or she moves about.

The underlying technologies for these requirements are often quite distinct, but must work together seamlessly and reliably to create the broad benefits of tomorrow's NII. XIWT will refine the concepts and technical challenges identified in the White Paper through additional study and experimentation.

For additional information on this White Paper and on XIWT please contact me. Text versions of this and other documents are on the Internet at: http://www.cnri.reston.va.us/xiwt

Sincerely

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Nomadicity in the NII

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XIWT

The Cross-Industry Working Team (*XIWT*), is a membership organization consisting of a diverse group of communications, computer system, information and service providers who have joined together to develop a common technical vision for the National Information Infrastructure (NII).

Among our activities, *XIWT* publishes White Papers intended to improve the quality and accelerate the evolution of the NII by establishing common understanding about technical issues among those involved with its development and use. White Papers will evolve along with our understanding and be reissued from time to time. Subsequent papers will delve more deeply into many of the issues identified herein.

XIWT activities have a technical focus, and may have broader implications. Hence we expect this series of papers will be of interest to policy makers, to others contemplating activity in the NII, and to the general public, and we invite comment and suggestions.

To obtain reports or for more information about *XIWT*, please contact:

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Cross-Industry
Working Team

Nomadicity in the NII

Contents

2.0 Underpinnings of Nomadicity

Some things are designed with nomadicity as their central focus. Hand-held cellular phones are one notable example, the newspaper *USA Today* is another. Some things are evenly balanced between catering to the nomad and serving other needs: The electronic appointment book and the automated teller machine (ATM) fall into this category. Some things are not nomadic. The stand-alone desktop personal computer is such a device.

The central characteristic of nomadicity is support of the nomad. In this section we explore some of the defining motivations, challenges, and concepts of nomadicity.

2.1 What Motivates Nomadicity?

In the past, people traveled because they had no choice. If they wanted to transact business or converse with friends they *had* to meet in person. However, transportation costs made certain meetings and activities prohibitive. A long series of technological developments — including the pony express, railroads, automobiles, and the telephone — have aimed at lowering the costs associated with transaction and conversation. Computer-mediated communications are just the most recent development in that progression. Even so, people still travel and still meet in person. This section explores some of the reasons why.

Increased productivity — In many situations, the expenses associated with hiring, integrating, and developing staff account for much of the total cost entailed in deploying a given organizational capability. Thus, if an organization needs hands-on contact at a location, it is increasingly more effective to provide the capability with a centrally located person who travels rather than with a person in-place at the site. Customer service is an obvious example. If service can be provided without an on-site engineer, costs are lowered. The more expensive the engineer, the more pressure to have one person serve many customers.

"The personal touch" — Another motivator is the social requirement for personal contact. The salesperson goes to the customer, shakes hands, and looks at the facilities. Workers in different groups travel to the staff meetings of their colleagues to establish rapport. Friends get together for dinner. In all these situations the requirement for movement is rooted in the desire to meet, take the measure of, and enjoy the company of others.

Personal environment — The many parts of our lives — our family life, business life, personal social life, business social life, etc. — each frequently involves a different physical location. People move between these places as they move between the different aspects of their lives. They go to their children's school to meet with the teacher, they go to the country club to have a round of golf with a new prospect. Doing the appropriate thing in the appropriate place is key to the way many people organize their lives.

Interactivity — Much of the communication in intense human interactions is nonverbal and therefore requires face-to-face contact. There are certain situations where the give and take goes beyond words. The personnel evaluation meeting in business, the town meeting in government, and the family meeting to decide on a vacation destination are all common examples of the need for interactivity.

Setting — For various reasons, people frequently carry out business in locations other than in their own office. Some of these locations are preferable to others: A winter meeting in Florida probably will be better attended than one in Nova Scotia. On the other hand, people sometimes simply find themselves, in the midst of a chance encounter, with a business transaction opportunity.

2.2 *Challenges Presented by Nomadicity*

Nomadicity, and the motivations underlying it, create a series of high-level requirements, or challenges, for NII communications. These requirements, which both motivate individuals to be nomadic and define ideals for technologically mediated human communication, are, as discussed above,

- greater productivity for mobile individuals,
- personal contact,
- individuals partitioning their lives,
- the full range of human communication modalities, and
- personal location preference.

This section describes the NII requirements implied by nomadicity.

Location independence — Today we communicate with individuals in terms of the location of their communications instruments; for instance, the nearest telephone or fax machine. If, as the NII develops, it takes over the worries related to finding the individuals with whom we wish to communicate, transparently directing our communications to the appropriate device at the appropriate location, it will create an environment in which people are communicating with other *people*, not with the *devices* they use. People will be calling their mother, not their parents' kitchen. People will be writing to their business associates, not sending faxes to the XYZ company fax machine.

A significant challenge for the NII is to make the process of establishing communications with a nomad largely transparent to both the nomad and her correspondent, regardless of which one initiates the exchange. The NII must therefore supply an ubiquitous and reliable implementation of location independence which places no special burdens on the nomad.

With location independence, an individual can do what he wants to do where he wants to do it. It is the character of the nomad that he needs to do his job irrespective of location. Consequently, anything that supports nomadicity must be useful in as broad a range of locations as possible.

Device independence — Being a nomad means not always accessing the NII from the same place or through the same device. So communication with the nomad may be through a device — for example, a borrowed telephone or a portable phone — that has quite different capabilities than the one he commonly uses when at home. Thus, the NII must support device independence: It must be able to match people to devices with different capabilities, at different locations, through different access paths, and under different access conditions.

Widespread access — Because an essential component of nomadicity is that individuals remain as connected as they desire from wherever they desire, the communications devices and channels on which connectivity depends must allow for widespread access.

Security — Nomadicity imposes special security requirements, particularly with regard to identification, certification, and billing. Because the device is not the person, technology can hide the identities of the communicating parties. Ensuring that the individual at the other end of the communications channel is whom she says she is is critical to establishing effective access. Similarly, when the individual is in motion, switching between devices and locations, many other security issues are exacerbated.

Adaptability to new technologies — The prevalence of cellular phones has conditioned the public to expect totally tetherless access in the near future. And the rapid development of wireless transmission technology, as evidenced by low-orbital satellite systems with global span and digital systems with throughput capability measured in megabits and gigabits, has forced reconsideration of the choice between wired and wireless systems. The rapid pace of technological change challenges the NII to adapt continuously to new technologies. System components supporting nomadicity are likely to be among those changing most rapidly.

Friendly interface — Public acceptance of new technology is largely based on the extent to which this technology is familiar and consistent with other technologies — that is, similar to models users already know. So the success of the cellular phone, for example, is partly due to the fact that the image the system presents to a user is consistent regardless of location, and the fact that the technology is quite familiar, since it is almost the same as that of the wired telephone. The complex interface devices and services that will probably characterize the NII make realization of this friendly interface somewhat difficult. Nomadicity adds further complexity with its requirements for specialized devices and more complex connections.

Partitioning — Movement between individual social contexts will impose special requirements on the NII. In other words, a given person may use the same device (or set of devices) for accessing the NII in various separate personal environments — business, family, etc. Users will want to keep those environments separate: They will not want business calls intruding on a family weekend. The communications environment must be partitioned so that the user can filter and manage incoming communications.

One method for partitioning would be to provide each user with several NII identifiers (the equivalent of telephone numbers). These identifiers would partition that user's communications space into different environments — for instance, home, office, family, and leisure. Another way might be to create a richer connection dialog, one which takes the environments of the communicating parties more fully into account.

2.3 *Concepts Defining Nomadicity*

In this section, we examine some concepts that will help in understanding and responding to the requirements posed by nomadicity.

2.3.1 Context

Every environment has several alternative contexts. These contexts are based on people's various perceptions and expectations of that environment. So, for instance, most people perceive a shopping mall as a central location for buying a wide range of goods: This is the **normal** — or overt — **context** of a mall. But a police officer's **dominant context**, or primary focus, for a mall might be as a crime scene. For a teenage couple, the dominant context might be as a place for a romantic rendezvous.

People are aware of alternative contexts, but generally focus on the context most significant to them. However, one context might override another. Having a romantic interlude at a crime scene might seem the wrong thing to do. Also, time of day or history may change the normal context of a location. After nightfall, the normal context for a warehouse could change from "place to do shipping" to "dangerous place to be avoided." Thus, all contexts are group-social phenomena which affect an individual's ability to pursue his own activities.

When a person enters a given environment, she may wish to focus on a context not well-supported by that place. It could be difficult to balance a checkbook in the dentist's office or to order heating oil while stuck in rush hour traffic. Nomadicity can be thought of as providing the ability to maintain an individual's chosen context regardless of the normal context of the environment presently occupied. In this way, context speaks directly to motivations arising from increased productivity, individual environment, and setting. It also addresses the requirements of location independence and partitioning of the communications environment.[1]

It is possible for people at different locations to share a context. This results in a **distributed context**. The video conference is a first step toward modern system support of distributed contexts. The combination of a shared computer link and a simultaneous telephone connection is another such step. Distributed contexts that persist over time without continuous participant interaction form the basis for **virtual communities**. The traditional mail system provides basic support for virtual communities, as does the traditional telephone system. These aspects of context speak to the nomadic motivations of maintaining a personal touch, greater interactivity, and an individual environment in communications.

The characteristics of contexts that interact most strongly with the nomad are

- the communications and information access mechanisms present;
- the type of interaction those mechanisms must support — immediate, delayed, or both;
- the physical relationship between the participants the mechanisms support — co-located, separated, or both; and
- the requirements for participant authentication and privacy.

[1]Note that this ability to superimpose a favored context on the current normal context has been a cornerstone of value added for some time. The travel industry has been especially sensitive to it: Hotels that are "just like home" or that provide an "office on the road" exemplify this idea.

2.3.2 Degree of Proximity

Not only do nomads carry on their lives in many locations, they also move between the locations. One important class of contexts, then, involves physical motion. Further, these contexts fall into two categories: vehicles and personal movement. The difference between these two categories can be explained by **degree of proximity**.

For example, vehicles maintain consistent contexts for an individual because the proximity of things relative to the individual and each other is maintained within them. Support of nomadicity in this situation means keeping everything functioning in the same way even though the vehicle is in motion. Cellular telephones do this reasonably well in automobiles. Radio stations do this within range of the transmitter.

Things are **nearby** if a person does not have to change location significantly to use them. Things are **co-located** if a person does not have to change location at all to use them. The phone on the desk is co-located with the personal computer on the desk. The fax in the next room is nearby.

2.3.3 Proximity, Movement, and Context

Context may, from the user's point of view, move with her. The interplay of movement and context exposes another dimension of nomadicity, the **moving context**. There are two types of moving contexts:

- **A group of individuals moving together** — Examples of this type are two people walking down the street or a military squad in the field. In these cases, the combined communications mechanisms carried by the group create a context that is made up of nearby, moving components. The burden of support for nomadicity in this situation is to maintain the local context while the group moves.
- **A distributed context with individually moving participants** — In this case, the requirement is for establishing the context of the virtual community for all the participants in their various locations.

2.3.4 User Device Independence

A computer network or telephone system does not recognize the existence of human beings per se; it instead recognizes the devices they use. These devices are presumed to be controlled by a particular person at a particular time, and authentication techniques work to ensure that the association between user and device is maintained. When nomadicity is involved, these assumptions present special problems. Each location may contain many communications devices: telephones, fax machines, networked computers, television sets, etc. It is reasonable for all the individuals in the locations sharing a context to want access to all the communications devices available. They do not want to be dependent upon only those devices they can carry around with them. Thus, the dynamic association of devices and individuals is central to nomadicity.

The issues are as much social as technological. The awkwardness of having to ask someone to use the telephone on his desk is often more of a limitation than is getting an outside line. If there is a device that is inherently single user in a location, how does it get associated with a particular user? Who decides?

3.0 Elements of a Nomadicity Model

This section presents the elements of a model of nomadicity that takes into account

- the motivations for nomadicity,
- some high-level requirements derived from those motivations, and
- various concepts that help organize our thinking about nomadicity.

Development of this model will help in understanding, discussing, and responding to the issues posed by nomadicity.

3.1 Locations

Locations are defined relative to individuals. Everything in proximity, everything that is co-located or nearby, is in the same location.

3.2 Location Coordinators

Location coordinators keep track of the individuals, devices, and communications system capabilities at a given location as they change. They implement the concept of proximity, allowing assumptions to be made about which individuals are at a location and what capabilities are available to them.

A location coordinator knows the characteristics and "addresses" of all the devices at a location. It is responsible for identifying the individuals and mobile devices that enter and leave the location. In an office example, a location coordinator would know the phone number of the office phone, the TCP/IP address of the personal computer in the office, and the phone number of the fax machine around the corner. It would know the physical relationship of the phone, fax machine, and personal computer; and it would know the capabilities of the devices. And, if an individual made it known that he was co-located with any of the devices, the location coordinator would be able to infer that the other devices could be at his disposal as well.

3.3 Destinations of Communications

At the "far end of the pipe" are destinations of communications. Clearly, there is overlap between this and other elements of the model.

The most common example of a communications destination is another person, but it could as easily be something standing in for a person, such as an answering machine. A person getting messages from her own answering machine is asking her stand-in to pass the message along. Other "stand-in" communications destinations include the bank computer at the other end of the line from the ATM, the voice response system at the power company, and the computerized information service at the stockbroker.

It is possible for both the communications destination *and* origin to be non-human. The automated system at the bank that validates a check for the check authentication system computer is an example.

3.4 People Who Move

Because people are nomads, the NII must — in delivering communications and information services to individuals — take into account that people move both in space and through the various aspects of their lives.

3.5 Access Devices

The many access devices with which a user directly interacts are the things that communicate. These devices are the portals between the user's physical world and the electronic world of the NII. Telephones, fax machines, computers, television sets, ATMs, and pagers are examples of things that communicate.

Access devices can move. Some are designed to; some move only rarely. A pager is designed to move; the office printer moves only when it is relocated.

Some access devices move with people, while some are only in occasional proximity to them. The cellular phone will often move with the individual; the office fax machine will only be near the person when he is in the office. No device (even implanted heart monitors) can be guaranteed to be in one-to-one correspondence with an individual.

Devices are either tethered — that is, in a fixed location because of physical attachment to a communications channel — or untethered. In either case, a location must be defined for the device if it is to be integrated into a context. Current networks provide only inexact location information. A device like a large printer, which moves infrequently, can have its location stored in a static database. But an active cellular phone, without triangulation, can be located no more exactly than within a cell capture area. Under any circumstances, the underlying systems of the NII must be supplemented by mechanisms to associate physical location and electronic location.

Untethered devices carried by individuals and associated with them can be an effective way for associating individuals with places — provided, of course, that authentication appropriate to the context is supported. A smart card that only responds to a challenge/response sequence when a particular person has her right thumb on its sensor provides reasonable validation of a person's location and identity.

3.6 Services

In our model, services are the individuals or things with which a person communicates. One may exchange information with these services or get them to act on one's behalf. When communication is with another person, the "service" may be the individual and will be mediated — that is, facilitated and/or limited — by the device(s) available to the individual.

In a broad sense, there are at least three types of services:

- those in support of the communications system (e.g., routing, link-level service);
- those that may serve both the communications system and end users (e.g., encryption, location brokerage); and
- those that serve only the end user (e.g., electronic banking).

3.7 The Communications System

Everything between the representatives of the communicating parties forms a communications system, which provides connectivity between devices and services. The NII will provide many different communications paths. Within it, users will be able to choose among these alternatives based on their cost, performance, coverage area, and other characteristics.

Nomadicity adds the dimension of dynamic movement within communications systems and among systems available at a particular location if a user's needs change. To facilitate that capability, the various systems will need mechanisms for managing quality of service, communication of service capabilities, and coordinated inter-enterprise interaction. At a higher level, the alternatives will have to be communicated to the user in some manner so that he can choose among them.

Under some circumstances, the definition of the communications system is thought to be complicated because elements considered to be internal to the system are made available to end users. Examples are the billing, directory, configuration management, and maintenance subsystems which, although used primarily by the communications system provider to keep the system running, can be of value to its customers as well.

We believe the definition of communications systems can ignore this distinction. If an internal system component is unavailable to the user, it is still part of the communications system. If it is packaged so the user can get at it through the system provider, it is a service as well. And, if the same service is provided by someone other than the communications system provider, it is a service but not part of the communications system at all.

3.8 Context

A context, as part of the model, is made up of at least one location, the devices at the location(s), the individuals at the location(s), and the activities those individuals wish to pursue. A person's integration with the other elements of the context are characterized by psychological factors (social expectations, setting, requirements for security, etc.) and physical factors (level of interactivity, level of proximity, etc.). Nomadicity requires that the user's dominant context be maintained as the user environment changes.

3.9 Aliases

An alias is an abstraction of an electronic entity that represents the user in the electronic world while managing communications with her in the real world. Rudimentary present-day examples of aliases are the answering machine and the electronic mail (e-mail) system. These stand in for the individual when he is not available. As they have evolved, both these systems have started to differentiate themselves, offering user configurability and additional functions.

For example, the answering system may notify a pager of an incoming call. This is a form of media translation and abstraction. The medium through which the message is delivered is changed, and the message is abstracted to its simplest form: notification that it occurred. In the case of computer-controlled answering machine-modem-fax machine combinations, a person can receive a message via e-mail and have it faxed to her current location. The fax number is specified via a call to the answering machine.

Thus, while not well-integrated at this time, many of the elements of an alias exist within current electronic environments: maintenance of status information regarding the individual, acting as a contact point for the individual, translation and abstraction of information for the individual, delivery of information to the individual on demand, and support for the individual's ability to control access.

Note that a person may have several aliases representing various aspects of his life and interests. Similarly, an alias could be formed to represent the aspects and interests of entities other than individuals. Groups, departments, or temporary associations might be actualized with an alias.

4.0 Nomadicity and Traditional System Issues

This section covers those concerns that every computer system must address and which nomadicity brings into sharp relief. This discussion ties the motivations and high-level requirements associated with nomadicity to these traditional concerns. It also addresses the relationship between traditional system concerns and nomadicity's concerns for location and context.

4.1 Security

Security is broadly divided into **authentication** and **privacy**. Authentication means certification that the parties in an exchange are whom they represent themselves to be and that the message received is the same as the message sent. Privacy means limiting information about an exchange to the intended parties.

Security requirements in computer systems are often met by a mix of administrative controls, cryptography, and physical security measures. In current systems, these mechanisms are usually organized into administrative domains associated with organizations and constrained by geographic areas. Universities on their campuses and businesses at particular sites are examples of security domains.

People can access their systems from beyond their normal work locations, generally through connections that terminate at the system they normally use — for example, by dialing in via a modem. In this situation, the remote access device and communications path almost certainly fall outside the security domain maintained by their organization. Consequently, one impact of device and location independence on security systems is that secure communications paths and devices cannot be assumed. While moving, intermediary devices (e.g., cell sites) change. Thus, a second impact of nomadicity on security is that motion independence must be taken into account.

The dynamic nature of communications paths and the lack of physical security inherent in nomadicity affect the most basic security issues. How does one ensure that a person is whom he says? How can one be sure previous conversations have not been monitored and passwords compromised? How can one guard against the unsecured parts of the communications systems being compromised? When a person deals with multiple security domains, how do you maintain security without making her personal management issues excruciatingly complex?

This last case is illustrated by the multiple password problem, an aspect of the requirement for a friendly interface. A person has voice mail at work, an answering machine at home, a bank card, a telephone card, and an office computer — all of which have different personal identification numbers (PINs) and passwords for access. Some of these devices have different remote and local access protocols; often, a person cannot access his computer away from the office in the same way he accesses it at his desk.

There are solutions to these individual issues, including smart cards, end-to-end encryption, and voice prints. But these technologies are not widely deployed or uniformly accepted. Neither are they static: New technologies continue to emerge. The NII will have to adapt to these new technologies if nomadicity security requirements are to be satisfied.

The new technology issue can also be viewed as another dimension of device independence. Security systems must be flexible enough to accommodate not only new technologies but simultaneous use of differing, current technologies.

Technological considerations are not the only aspects of nomadicity that interact with security. Calling home to ask if anyone needs something from the grocery store clearly requires a different level of security than transferring money for the house payment. At work, the special project has different security requirements than an expense report.

These are examples of the association of context and security. Further, when a context contains individuals from different (and perhaps competing) organizations, maintenance of the distributed context must take into account the varying security requirements of the participants. If individuals form virtual communities, those communities may become the basis of security domains.

4.2 Distribution and Synchronization

User requirements for location, motion, and device independence affect decisions regarding distribution and synchronization. If a person always wants his phone book with him, how and how often does he reconcile that phone book with backup copies or with a corporate phone book which may have updated numbers? If the person wants to access phone numbers stored on a personal digital assistant (PDA) while at his desk, how will the storage on the device be integrated with the fax system in the desktop computer? If the person buys a new PDA from a different manufacturer, how will the new device fit in? These examples show how decisions regarding distribution and synchronization are affected by user preference, dynamic environments, and technological change when nomadicity becomes a design consideration. Traditional designs — where most elements are under the developer's control — will fail for nomads.

If a person is at home balancing her checkbook and wants to look up a phone number, should her phone book look in her private phone numbers first? If she is at the office working on the XYZ account, should it first look up numbers associated with that account? Moving between contexts could affect data access decisions. When the person is in a distributed conference, should the system first display information on the other participants and their organizations? The interaction between distributed contexts and information access must be addressed by any system supporting nomadicity. It is a small step to see that virtual communities might provide an organizing principle for data and data distribution decisions. With knowledge of the likely locations of context or community members, costs might be minimized through relocation of data or processing. If the participants are moving, the various impacts of moving contexts will change distribution and resynchronization decisions.

Nomadic individuals are likely to draw on a variety of communications, computation, and information systems simultaneously. This creates the potential for parallel content in those systems. A common example is a phone number in a written personal phone book, programmed into a phone book on a personal computer, in memory on a cellular phone, and in a PDA. When the number changes, how do they all get updated? Intersystem synchronization issues exacerbate intrasystem issues such as temporary disconnection, update latency, failed transactions, and cancellation of updates. Both inter- and intrasystem synchronization requirements must be addressed.

4.3 Location

Nomadicity has uncoupled individuals from places. With that uncoupling, the implicit binding of access capabilities to individuals has been broken. "I'll send him a fax" now has new dimensions of uncertainty. Where is he? How close is he to a fax machine?

What is its number? Does it need a special header for guests? Could a computer just print the message near him? When has the individual left the location?

Device independence interacts with the increasing use of mobile devices to complicate the notion of location even further. The variety and capability of devices individuals carry are increasing. Mechanisms are needed to define a location dynamically and to connect the user. As technology advances, the ability to adapt to new technologies must be built into any such location management system.

There are multiple communications paths into many locations (video cable, computer networks, telephone lines, broadcast media, etc.). These paths may terminate in a variety of devices (television sets, telephones, fax machines, pagers, cellular phones, computers, building control systems, etc.). They may also present varied and changing quality of service. As nomads and their devices move in and out of locations, a significant challenge is the dynamic coordination of communications channels and static devices with individuals.

Beyond the technical challenges posed above, there are personal and social issues. The demand for friendly user interfaces motivates removing the burden of managing all this complexity from the user. Resources must be allocated fairly when multiple individuals are present.

These issues cannot be addressed from the perspective of a single industry. A better cellular telephone interface will not by itself ease the burden of receiving a fax while in an airplane. Mechanisms that bridge different systems for the nomad are required. Such solutions must take into account that parallel systems will always exist. No one will use all of them, but all of them will be used by someone. The connections between systems must provide useful coordination while having enough flexibility to allow variation and change.

4.4 Context

For the nomad, any place he hangs his hat is home, office, or entertainment area. Any system that supports the nomad must help him maintain these various contexts. Such support for context maintenance must include

- identification of the context on which the individual wants to focus,
- maintenance of the state of the activities and information associated with the context,
- knowledge of the preferences the individual has for interaction with the context,
- application of those preferences to the location from which the context is being accessed, and
- simultaneous management of multiple contexts.

Context identification can be either specified — "I want to balance my checkbook now" — or implicit — "I've just placed a call to the Smith Industries' account manager." In any case, there must be support for reestablishing the state of the context. This may be complicated by the context's level of autonomy. Some contexts will be active even when the nomad is not in contact with them. An ongoing electronic meeting is an example. In that case, reestablishing the state of the context might involve some means of summarizing the portion of the meeting that the nomad was unable to attend.

For less autonomous contexts, e.g., periodic payment of a credit card bill, the charges would be posted to the account throughout the month and the individual would only examine them periodically. Reestablishing context in that case would be relatively simple. Another consideration regarding context identification is the fact that different people will choose to define more complex contexts. The person who does her books at the end of the month will have a context of checking, savings, bills, and credit cards all of which need to be organized in such a way that she can see the state of her finances. Supporting automated systems will therefore have to take into account varying levels of specification, autonomy, complexity, and the interactions among them.

This context scope is an example of individual preferences. People can be expected to have preferences for every aspect of their interactions with computer and communications systems. Those preferences will include the **permissible demotions** they will allow in different locations. An example of a permissible demotion is having an e-mail message read over the telephone. Graphic information is lost, but the message is conveyed. A further demotion might be having just the message's key words — drawn from a list of filtering key words, such as "call as soon as possible" — read over the phone. Other preferences might include what contexts could be established from what locations and what level of security would be involved. Perhaps an individual would only allow purchases of up to $50 to be authorized via phone, but would allow up to $300 to be authorized from an ATM.

These are examples of applying preferences to the communications channels and devices available at different locations. They illustrate the interaction between context, preferences, and location.

Finally, individuals certainly will want to maintain some interaction with several contexts simultaneously. The priority call that has to get through is one example. Any person who keeps several things going at once will have a requirement for maintaining multiple contexts.

While we expect that integrating the notion of context into traditional computer, communications, and information systems is necessary to support nomadicity in the NII, we also believe that integration will require significant alteration in system design. NII developers that use context as an organizing principle in their designs will probably have an advantage when addressing nomadic needs.

4.5 Operating Environments

Although the issues discussed thus far have been couched in application-level terms, support for them must lie at least in part in the operating systems and networks on which the applications run.

One concern in this regard is **application visibility**. Some classes of application may not need to be "aware" of the changing distributed environments in which they operate. System-level adaptations can maintain connectivity on the application's behalf. Early examples of this kind of support are operating systems supporting process migration and the X Window System. Process migration (ideally) is transparent to the application.

X allows users to decide where an application displays its output. In both these examples, conservative applications do not need to be modified in order to operate in dynamically changing environments. In other situations, the applications must be aware of and support distribution and synchronization. The phone book in the earlier example is one such application; most graphically demanding applications (e.g., window systems, imaging applications, design, etc.) are another.

Location services are just one example of system-level activities affected by nomadicity. The division of labor in the realm of security between computer system, communications network, and applications is another. So, there could be end-to-end security where only the devices carried by nomads were trusted. At the other extreme, internal computing and communications systems could take responsibility for all security.

The architectural boundaries within the NII are not yet fully defined. As the builders of the NII work out new industry and organizational boundaries, their activities will interact with technological considerations to establish the NII's architecture. A central challenge is to establish architectural boundaries that ensure interactivity between components of the emerging (and continually changing) system, while not limiting participation in it. With respect to nomadicity, architects and developers must additionally account for its central concepts — movement within physical space, social space, and channels of communication — when defining the new systems.

4.6 Applications

Arguably, operating environments (operating systems, network operating systems, middle-ware, etc.) are moving to support the distributed system capabilities which the NII requires. Applications software, however, is adapting more slowly — and, in some cases, only incrementally.

Many applications are designed to take into account only minimal distribution issues. They depend on reliable local capabilities and, if they take remote capabilities into account at all, they characterize them as either being fully available or fully unavailable. Issues of changing bandwidth, latency, or reliability are almost never considered.

Nomadicity complicates software requirements even further. Today's nomad may spread her computing and communications activities over many different devices and access many remote services. The applications she draws on need to adapt to her various environments. When she is working from a portable computer, her applications must be sensitive to the requirement for alternative communications paths and the computing capabilities of her machine. Thus, a mechanism must be developed for applications to sense and adapt to changing environments and user preferences.

Clearly, the distribution of function between applications and operating environments is not yet defined. Just as there will undoubtedly be many different capability sets within the NII's system components, some applications will deal with nomadicity issues internally and others will draw on services. The challenge in software is similar to the system component challenge: ensuring interoperability without restricting the potential for innovation.

We cannot hope, in this report, to explore all the systems issues associated with nomadicity. But note that for each application-level requirement outlined here, there is a set of system-level capabilities that underlies it.

5.0 Summary

Nomadicity — the ability to move easily from place to place and retain access to a rich set of information and communications services while moving, at intermediate stops, and at the destination — is a new paradigm for information processing and communications. Its basic characteristics include location independence, device independence, motion independence, widespread access, and ease of use. In order to design systems that will meet nomadicity requirements, we need to address these characteristics, as well as privacy and security — issues that are exacerbated in a nomadic environment.

Developing a model of nomadicity will help in designing systems that meet the requirements posed by nomadicity. Elements in this model include locations, communications destinations, the nomadic user, access devices, services, the communications system, and context. Another key model element is the **location coordinator** — an entity that keeps track of the individuals, devices, and communications system capabilities at a given location as they change. Location coordinators know the characteristics and "addresses" of all the devices at a location and are responsible for identifying the individuals and mobile devices that enter and leave the location. A final element is the **alias**, which is the electronic entity that represents the user in the electronic world while managing communications with him in the real world.

Simply stated, in this model, the location coordinators provide information to a user's alias about where she is and what capabilities are at the location. The alias then opens connections to her and establishes the desired contexts as completely as possible using available resources. On the service side, the alias is a reliable point of contact for services and other aliases. Issues of security, quality of service, and location are minimized for services with which the alias interacts. Knowing the user's capabilities, preferences, and requirements, communications between the alias and the user are better coordinated than if the exchanges were handled by each service individually.

Potential and actual nomadic applications are plentiful, as illustrated by the numerous examples cited in the appendix to this paper. Moreover, it is obvious that virtually all of us are already heavily engaged in such applications. The need for nomadicity in the NII is clear; it now remains for us to develop the principles, concepts, technology, and infrastructure to support it.

6.0 Next Steps

This is the first in a series of Cross-Industry Working Team papers on nomadicity. Other papers in the series will develop the architecture, address the technical issues, and discuss the potential roles of the various constituencies (e.g., industry, academia, and government).

We believe the components outlined in this paper can be incorporated into a model that materially simplifies the relationship between nomadic individuals and the services they access, while providing some enhancement to existing models of interaction in the NII. We call on reader expertise for comment on what we have done so far and help in setting the agenda for follow-on papers. Reader comments are particularly welcomed regarding those elements of the NII that may be affected by nomadicity and the issues that a nomadicity architecture must address.

Appendix: Examples of Nomadicity

There are many practical examples of nomadicity in the NII.[2] Several are presented in this section to illustrate the opportunities available to business and government to enhance the value of the NII by addressing nomadicity concerns.

i: The Portable Office

Both individuals and organizations are trying to squeeze the most out of available resources. The portable office will let people coordinate their business activities from anywhere. Today, the portable office represents both the least and most successful of the application areas discussed in this appendix. It is the most successful in that large numbers of people have already created some kind of portable office for themselves. By 1996, for example, laptop and notebook computers will account for one-quarter of all new computers sold in the United States.[3] On the other hand, the frustration faced by those who do establish portable offices points up the lack of infrastructure in place to support them.

The portable office is not just the 9-to-5, work-for-pay environment, but any place where a person assembles the tools necessary to carry out his work. For example:

- **Education** — Students as well as teachers maintain offices in a strict, although unconventional, sense. They travel between home and school, and work in both places. They are nomadic, and the NII must let students and teachers do their work regardless of location.
- **Manufacturing** — The manufacturing process has many stages, including product planning, design, forecasting, production, delivery, and service. Increasingly, these activities are geographically disbursed and centrally coordinated. One disadvantage of this coordination, however, is the inevitable need for a certain amount of travel. Productivity would be enhanced if the information infrastructure that supports the process took people's mobility into account.

ii: Financial Trading

For the financial trader, time is of the essence, and information is the staff of life. She may participate in transactions from anywhere — whether on the floor of the stock exchange or

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[2]The examples in this appendix are based on information in EDUCOM, *R&D for the NII: Technical Challenges,* C.10, "Portability, Mobility and Ubiquity" (Washington, DC: 1994), pp. 77-80.

[3]*PC Week* (June 27, 1994) reports that, in 1996, of all personal computers shipped in the United States — excluding servers and home use — 77.1 percent will be desktop and 22.9 percent will be portable. *Computer Retail Week* (June 20, 1994) reports that 28.6 percent of all personal computers shipped in 1996 will be portable versus 71.4 percent for desk-bound machines and servers. The latter article also gives the annual growth rate for portable sales through 1998 as 15.7 percent versus 3.8 percent for desktop sales.

while traveling to and from customer sites. The trader requires not only information such as client names, account balances, and price quotes, but interactive communications for customer contact and transaction initiation.

iii: Crisis Management

In a crisis people have to get on site fast, understand what's going on, and take effective action quickly. That means rapid installation of equipment, rapid access to information, and rapid prioritization and analysis. The situation at the site can be critically affected by access to information and communication with individuals at remote locations. By its very nature, a crisis management team is nomadic. The infrastructure that supports it must take that into account.

Several application areas where the NII must deal with the nomadic aspect of crisis management are:

- **The mobile clinic** — In emergencies such as train wrecks, earthquakes, or industrial accidents, mobile emergency rooms are deployed. If the NII supports remote consultation and analysis and automated patient records, these services will have to be available in these dynamically deployed environments.
- **The firefighter** — While the fire trucks are on the road, the dispatcher is relaying information to them, telling them where the fire is, what material the building is made from, if injuries have been reported. Once on site, the firefighters discover new problems and need new information. How close is the gas line to the building? What is the layout of the 23rd floor? Coordinating the team involves keeping track of both human and physical resources. If the command center can't get at the floorplan stored in the city's computer, a significant value of the NII will not be realized.

iv: Personal Services

Personal services support an individual's activities outside the work context. These are generally leisure and family or home maintenance activities. The NII will make possible a broad range of innovative personal services.

Currently, personal services for most people are supported by various communications media — the television, telephone, and post office. The NII must accommodate these delivery mechanisms, support new ones, and be able to deliver content (movies, shopping, banking, person-to-person communications, etc.) over combinations of them. The ability to switch messages between them will become increasingly important.

Nomadicity has implications for all personal service applications. The NII will have to support multimedia conversations when the participants are not only separated, but on the move, as well as delivering an individual's favorite television program when he is away on a trip.

These are not the only personal activities for which the NII will need to take nomadicity into account. Consider computer application sharing, computer conferencing, games, gambling, video messaging, voice messaging, e-mail, paging, information-on-demand, video-on-demand, home shopping, and voice communications.

People will want access to all of these services from different places, with different delivery capabilities, and with different preferences.

v: Distributed Measurement

While we have here focused on individuals as nomads, the NII cannot ignore the potential of *devices* as nomads. Distributed measurement involves the sensing, collection, analysis, and dissemination of data originating in remote locations. An NII that supports distributed measurement will allow small — possibly portable, possibly mobile — sensors to be integrated into the fabric of everyday life. Collected data can be transmitted to processing sites. At those sites, the data can be analyzed, stored, and acted upon either by individuals or automatic programs. Given a supporting infrastructure, important data can be collected with lower cost, higher integrity, greater longevity, and greater value than if each data collection system had to have specially designed communications mechanisms.

Ready examples of distributed measurement applications that would improve the quality and efficiency of people's lives follow:

- **Health care** — Distributed patient monitoring systems allow doctors to evaluate patients' conditions without costly office visits or hospitalization. Remote recording of vital signs enables a physician to monitor the progress of a recovering patient carefully, even though that patient has already left the hospital.
- **Environmental monitoring** — Sensors floating in rivers, sending back information on water quality, flow rate, and location, would allow for dynamic tracking of changing conditions. The ability to deploy sensors rapidly to remote locations would allow for quick response in dangerous situations.