Breaking Loose

The Internet's ultimate utility depends on our ability and willingness to make the network at least as pervasive, convenient, and invisible as electricity is today.

Leonard Kleinrock

THE INTERNET (FORMERLY KNOWN AS THE ARPANET) CAME to life in my laboratory September 2, 1969, when the first piece of networking equipment (a packet switch) first communicated with an operational piece of the outside world (my time-sharing computer at UCLA) (see www.lk.cs.ucla.edu/). Two months earlier, on July 3, 1969, UCLA issued a press release in which I presented my vision as to what this network would become (see www.lk.cs.ucla.edu/LK/Bib/REPORT/press.html). Basically, that vision was that the Internet would be ubiquitous, always available, always on, anyone would be able to plug in any device at any location, and would be invisible, just like electricity. The part I did not include in my forecast 32 years ago was that my 93-year-old mother would be on the Internet today.

Did the Internet get it right? Well, yes and no. It achieved my first three predictions—ubiquitous, always available, and always on—but has so far missed the last two—any device could be plugged in at any location and it would be as invisible as electricity. Basically, the mistake regarding anything being plugged in at any location was that the Internet's TCP/IP protocol assumed that end users and their devices and IP addresses would all be found in the same location and would all be tightly coupled. The fact is that end users today do not always access the Internet from fixed locations, do not always use the same device, and the IP address they use may not be one familiar to every subnetwork they encounter in their travels; indeed,

STEVEN ADLER

they may use different IP addresses when on the move. That is, users are nomads, and the issues associated with nomadic computing were not anticipated by the network protocols that grew up in the Internet.

Meanwhile, the problem with being as invisible as electricity is that the Internet is anything but invisible in the sense of being easy to use in ways that do not assault our human senses with irritating input and output interfaces.

Nomadicity may be defined as the system support needed to provide computing and communication capabilities and services to nomads as they move from place to place in A WAY THAT IS TRANSPARENT, INTEGRATED, CONVENIENT, AND ADAPTIVE.

Place in Communications History

But first, by way of introduction, I should observe that since the beginnings of telecommunication technology 100 years ago, we have witnessed a number of major shifts in the application of the related technologies to the needs of our society and industry. In that process, we have seen the marriage of wireline and wireless technologies, of analog and digital technologies, and of voice, data, video, image, fax, streaming media, and graphics to create a computer communications infrastructure spanning the globe and serving billions of people. The Internet is one of the latest of these developments.

We are now in the midst of an accelerating groundswell in this field of computer communications in its most visible and useful sense—not only the wires and networks but infrastructure, middleware, applications, uses, and users. The Internet is now a household word everywhere.

Most computer users have functioned, at least until the mid-1990s, in a world where their desktop computing appliances are connected through corporate or private networks to servers located elsewhere. They usually assume the connectivity provided by the network is reliable and delivers high bandwidth (typically megabits per second). But, in fact, most computer users are nomads, moving among office, home, airplane, train, hotel, automobile, branch office, conference room, and bedroom. We often find ourselves with significant variation in the computing platform to which we have access (possibly a workstation, Pentium-class PC, laptop, or handheld device), in the quality of the printers and displays that are available to us, in the communication device we use (Ethernet attachment, PCMCIA card, analog modem card, cellular digital packet data wireless data channel, or wireless LAN), as well as in the communication bandwidth available to us (wireless at 9.6Kbps, modem at 56Kbps, ISDN at 128Kbps, wireless LAN at 10–54Mbps, Ethernet at 10–100Mbps, ATM at 25–155Mbps). Moreover, we may choose to do computing and/or communication while we're literally on the move.

Today's variety of portable computers is impressive, including laptop computers, notebook computers, handheld devices, smart credit card devices, even wristwatch computers. In addition, the communications capability of these machines is advancing at a dramatic pace, ranging from high-speed modems, to PCMCIA modems, to email receivers on a card, to spread-spectrum handheld radios and cell phones, to cellular digital packet data transceivers, to portable GPS receivers, to gigabit satellite access.

The combination of portable computing and portable communications is changing the way even the casual home computer user thinks about information processing. Along with their business-user counterparts, they recognize that access to computing, communications, and services is necessary, not only from their home bases, but also while they're in transit and then upon reaching their destinations. Even without portable computers or communications, many people travel to numerous locations and thus require access to Internet services through equipment available when they arrive. Indeed, even moving from one's desk to a conference table in the same office constitutes a nomadic move, since the computing platforms and communications capability may differ considerably between the two locations.

A fundamental way in which nomadic computing differs from the conventional desktop is the huge variability in connectivity to the rest of the user's computing environment. That level of connectivity often includes extended periods of low bandwidth or no communication capacity at all. Since many users and programs alike make intermittent, but nevertheless essential, use of "off-machine" information and services, they are unable to operate effectively unless extraordinary steps (such as reconfiguring their IP addresses and changing their netmasks) are taken by sophisticated users or their network administrators. The goal of "transparent virtual networking" is precisely to permit users and programs to be as effective as possible and as unaffected as possible in this environment of uncertain connectivity. That is, transparent virtual networking makes the sometimes-connected computer operate in the same way and as effectively in standalone operation as when it is connected to the organization's information network.

These ideas represent the essence of a major shift to nomadic computing and communications, or "nomadicity." Nomadicity may be defined as the system support needed to provide a rich set of computing and communication capabilities and services to nomads as they move from place to place in a way that is transparent, integrated, convenient, and adaptive.

THE RESEARCHERS AND DEVELOPERS creating this invisible universal Internet infrastructure are deeply interested in the capabilities that must be put in place to support nomadicity. The necessary performance characteristics include independence of location, motion, computing platform, communication device, and communication bandwidth, along with the general availability of access to remote files, systems, and services. The notion of independence as I define it does not refer to the quality of service one receives, but to the perception of a computing environment that automatically adjusts to the processing, communications capabilities, and access available at the moment. For example, the bandwidth for moving data between a user and a remote server could vary from a few bits per second (in a noisy wireless environment) to hundreds of megabits per second (in a hard-wired ATM environment). The computing platform available to each user could vary from a low-powered handheld device while traveling to a powerful supercomputer in a climate-modeling science laboratory. Indeed, today's applications treat radically changing connectivity or bandwidth/latency values as exceptions or failures. In the nomadic environment, applications must treat these exceptions and failures as the usual case. Moreover, the ability to accept partial or incomplete results is an option that also must be made available in light of the uncertainties in the informatics infrastructure. That is, our applications must be nomadically enabled so as to function properly in these situations.

Nomadicity exacerbates a number of the problems users face every time they turn on their machines. The nomad experiences disconnectedness, variable connectivity due to voluntary changes (possibly traveling), unpredictable changes (possibly a noisy wireless connection), variable routes through a network (possibly changing virtual circuits), and variable processing requirements. The nomad also experiences resource replication (possibly copying files in multiple locations and devices), the need to be aware of the changing environment, the need for the environment to be aware of the nomad's presence and location, the need for adaptivity to accept the nomad in "alien" environments, and a general need to manage all kinds of distributed stuff, including applications, files, and other distributed resources. However, the complexity of networking should be hidden from the user and managed by intelligent technology at the edge of the network.

Many people view wireless communications as the enabler or even the formal characterization of nomadicity. But nomadicity includes far more than wirelessness; though wireless communications may be a component of nomadicity, it is not a necessary component. When people travel the world and check into a hotel, they have made a nomadic move as they attempt to connect their laptops via wireline analog modem or high-speed digital subscriber line modem to the network infrastructure; no wireless communication need be involved. Indeed, much of the action involved in nomadic computing takes place at the middleware level of the commonly accepted layered architecture. To optimize effectiveness and flexibility, network services should be separated from access and transport. Most of the functionality is found at the middleware level. However, some of the interfaces to the network technology substrate refer to functionality at the Open Data Network (ODN) Bearer Service level (see the figure here, as well as bob.nap.edu/readingroom/books/rtif/index.html).

Some key system parameters about which users must be concerned include bandwidth, latency, reliability, error rate, delay, storage, processing power, component-to-component interface, interoperability, user interface, and cost. These are typical concerns in any computer communication environment; what makes them of special interest in the context of nomadic computing and communications is that their values change dramatically (and sometimes suddenly) as the nomad moves from location to location. In addition, the nomad has some totally new and primary concerns, such as weight, size, battery life, loss, theft, and damage to portable devices.

A key way to provide the necessary flexibility is to PLACE INTELLIGENCE AT THE EDGE OF THE NETWORK so it adapts to nomadic users who appear at that edge, instead of asking the users to adapt to the network.

Given that broadband access is quickly becoming a commodity, service providers are focusing on dynamically providing access and delivering personalized, value-added services to the end user, including video-on-demand, firewalls, content filtering, voice-over-IP telephony, virtual private networks, business applications, and games.

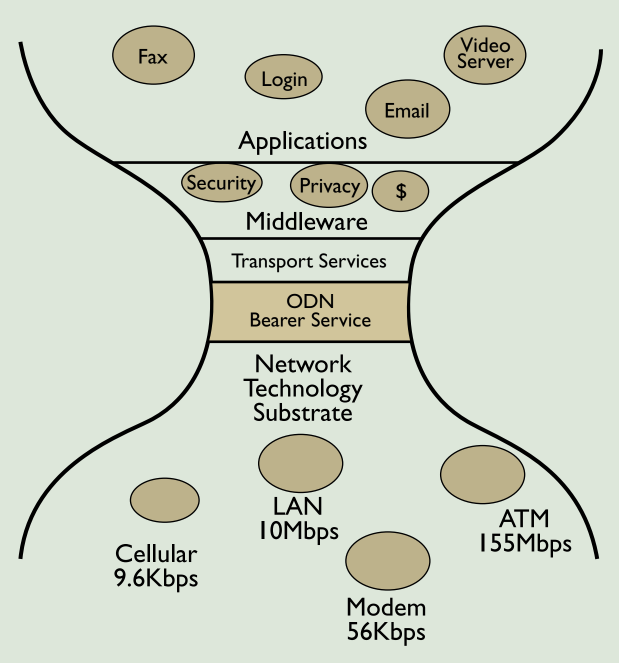
One of the most important enablers of nomadic computing is the availability of broadband access for homes and offices. Carriers have in recent years invested billions building this broadband communications infrastructure worldwide, with more spending planned for the future. While end users are willing to pay for broadband access, as well as the value-added content and services delivered over these networks, service providers have been unable to cost-effectively provide access to customers or "upsell" them value-added services, such as URL filtering, personalized content, and pay-per-view video.

The problems of high deployment costs and lack of upsell of add-on services have resulted in a slowdown of broadband deployment and the subsequent failure of some service-provider business models. To address the changing broadband marketplace, service providers must deploy value-added Web-based self-delivery and service-creation technologies in their networks. A key way to provide this necessary flexibility is to place intelligence at the edge of the network, so the network adapts to nomadic users who appear at that edge, instead of asking the users to adapt to the network. The edge may be defined in a number of ways, but perhaps the most effective is to recognize that it is that place in the network where the unmanaged collection of end-user devices (such as laptops, handhelds, email pagers, and IP-enabled cell phones) first meets the managed infrastructure of the Internet.

The method by which both access and value-added services are provided has therefore become a critical aspect of network architecture. To further this point, Paul Johnson, a senior technical analyst at the investment bank Robertson Stephens, told *Forbes Magazine* (April 2, 2001), "If this model is going to scale, I believe we will need a Web-based self-provisioning model, such that if you learn about a new application, you can go to the Web and say, 'This is how much bandwidth I need and for how long,' and sign up for the new application. This edge model requires not just a fat pipe, but a very fast and flexible provisioning process as well, which is as much of a software problem as it is a bandwidth problem."

BEYOND THE NOMADIC ENVIRONMENT is a larger vision that includes such concepts as intelligent rooms. Such a room has embedded in its walls, furniture, floor, and ceiling all manner of sensors (to detect who and what is in it), actuators, communicators, logic, storage, displays, speakers, microphones, and cameras. Indeed, one would hope to be able to walk into the room, have it know one had entered, and say to it, for example, "I need some books on the subject of spread-spectrum radios," and have, perhaps, three

The Open Data Network, showing the importance of the ODN Bearer Service where adaptivity for nomadic computing is often found.



books reply, possibly using some kind of synthetic voice system. The replies might offer to present each of their tables of contents, as well as their full text and even their graphics. The communication between the room and the human would take place as, perhaps, natural language speech, holograms, eyeglass displays, or other human-centered intuitive interface technologies. Moreover, the books would identify their locations in the room, and, if it were the case, might add that one of them is not actually in the room but three doors down the hall in a colleague's office.

Beyond the intelligent room, the vision evolves further into the more general notion of smart spaces.

Users today see cyberspace as trapped in the screens of their workstations. But few of them understand what is going on behind the screen, hence they view cyberspace as trapped in a netherworld. We will one day move out of this netherworld into the physical world of smart spaces. Most things in our physical real-world environment will be Internet-enabled via embedded technology. The environment all around us will be alive with technology—in the common surfaces and in our desks, clothes, eyeglasses, refrigerators, vehicles, hotel rooms, even our fingernails and other places in our bodies. We will likely have a "bodynet" connecting all the devices we are carrying; it will act as our surrogate in communicating with the bodynets of others, as well as with the rest of the smart spaces in which we will be immersed.

Another major development in this regard we can expect to see in the next five years involves the use of adaptive agents (also known as surrogates or proxies), whose purpose is to perform tasks on behalf of us nomads as we wander around the smart-space-enabled Internet. For example, an adaptive agent might decide to send a low-resolution black-and-white picture or perhaps an outline of a document to other nomads who are poorly connected, rather than, say, a full-resolution full-color picture or full-document text or hologram. An adaptive agent can act as an "impedance match" between the network and the things attached to it. In general, they would be there to support nomads, along with their applications, the network itself, servers, communication devices, and computing devices.

Viewed this way, Internet services will be ubiquitous, always available, always on, anyone will be able to plug in any device at any location transparently, and the Internet will be invisible in the same sense that electricity today is hidden from its users but is pervasive and easily accessible. Indeed, this environment is what I envisioned 32 years ago.

Conclusion

Nomadicity represents a new paradigm in the use of computer communications technology, including the Internet, and involves a number of challenging problems and some of their solutions. Nomadicity is an emerging fact of today's high tech life. Its needs are real; its issues are fascinating; its payoffs can be huge; and it complicates all the problems we face in computing and communications. It is clear that our existing physical and logical infrastructure must be extended to support nomadicity in many ways. The implication is that we must account for nomadicity at this relatively early stage in the development and deployment of our Internet-based networking infrastructure. Failure to do so will seriously inhibit the growth and functionality of nomadic computing and communications, as well as the growth of smart spaces. In addition to these issues, many more have not yet been identified; they'll arise only as we probe the frontiers. We cannot and should not ignore these challenges. C

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