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THE CYBORG SELF AND THE NETWORKED CITY

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The MIT Press Cambridge, Massachusetts London, England

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WIRELESS BIPEDS

As my networks extend ever outward, my circumscriptions multiply and expand like ripples in a pond. My cyborg self is structured—Linux-like—as a system of nested shells, with carefully articulated and controlled interconnections among the levels.

Under my epidermis there is a tightly packed, carbon-based kernel, mostly run by genetic code and my central nervous system but maybe augmented by implants. Then there is a wearable layer of cloth, leather, plastic, some metal, and a growing number of tiny machines and miniature electronic devices; to function as a coordinated system, these components need networking through my body or my clothing. When I travel in a vehicle, there is an additional, mostly metal layer, with its own increasingly sophisticated electronics, code structures, and interconnectivity. The architectural layers (which, of course, were Le Corbusier's idea of a *machine à habiter*) are generally composed of heavy materials, together with fixed-in-place machines and pipe, duct, and wire networks. Finally, the regional and global layers are formed by large-scale, long-distance infrastructure and geographically dispersed networks.

MIGRATION OF FUNCTIONS

Functions, and the artificial organs that provide them, may migrate back and forth among these layers as circumstances require. Consider protection and climate control, for example. If I need to keep warm, I can put on a sweater and rely upon body heat, or I can insulate the walls of my house and introduce a mechanical heating system. In the 1960s, Reyner Banham and François Dallegret dramatized this point in a famous project; their drawing showed them sitting, naked, in a transparent, plastic bubble that was inflated by the air-conditioning apparatus in the center. Buckminster Fuller went further and proposed a giant, climate-controlled, transparent dome over all of Manhattan. Marshall McLuhan hubristically trumped even that by suggesting that "global thermostats could by-pass those extensions of skin and body we call houses."[1]

For protection from the rain, I can use a portable umbrella or a permanent roof. If I worry about getting shot, I can bullet-proof my vest or the windows of my car, or I can post guards to take away guns at the door. When I ride in an automobile I depend upon the airbag in the dashboard, but that does not work on a motorcycle, so the airbag goes in my protective clothing. If I participate in a street protest, I can build a barricade or march behind a mobile shield. If I am an astronaut, I can have my life-support systems in a close-fitting space suit or in the infrastructure of a space station. For protection against SARS, I can wear a face mask, try to live in a clean room, or attempt to throw a quarantine cordon around my city.

Control points can also shift. In the days of simple mechanical controls, such as doorknobs and rack-and-pinion steering wheels, there was direct linkage of controlling device to controlled mechanism, and this severely limited spatial freedom. But the telegraph introduced the possibility of remote control; the motion of the transmission key induced corresponding motion in the reception device. Today, if I want to actuate some device I might find the switch on the wall, on the device itself (as with desk lamps and television sets), or on a hand-held remote. And, as increasingly many devices get network connections and IP addresses, anything can potentially be controlled from just about anywhere.

Less obviously, storage and processing nodes may migrate as well. My electric power supply may come from a button-sized battery or a tiny generator in my shoe, from a larger battery or generator in my automobile, from photovoltaic or fuel cell generators in the building I occupy, or from an electric grid extending over a wide geographic region and incorporating many large power plants. The light I require

to find my way may come from a ceiling fixture or a miner's helmet. If I am a scuba diver or spaceman, my oxygen is stored locally and circulated through wearable plumbing; if I am a motorist or airplane passenger, I rely upon an onboard air conditioning system; and if I inhabit a building, I depend upon natural air circulation from openings, upon a room air conditioner, or upon a central, ducted, air handling system.

For my information supply and processing power, I may access digital memory and processing capability in a wearable or portable device, I may get what I need from a personal computer or local network server, or I may download from a distant server to a "thin client."[2] I may fetch it directly from the supply point, or I may cache it at various intermediate storage locations for faster access.

Even sensing functions may shift. The temperature in a room I inhabit might be regulated by a sensor on the wall or by one on my body. If I want a health-monitoring system to know if I fall down, I might put motion detectors in the walls or accelerometers on my body. In early attempts to create intelligent environments, multiple sensors were connected to a single, central computer that processed inputs and responded; now it seems more effective to distribute processing power to the sensors themselves and to perform low-level interpretation tasks locally.

There is (as with many migrations) a strong sociopolitical dimension to all this. If you control temperature by adding and removing clothing layers, then you privilege autonomous individual choice, but if you go for Banham's plastic bubble, then you construct a situation in which the naked inhabitants have to negotiate with one another about the temperature setting. And Fuller probably did not consider the fact that the weather inside his Manhattan dome would become a matter of New York municipal politics.

SCALE AND RANGE

Scale matters. The independently moving subsystems that embed our biological bodies come in various sizes, and these sizes determine the potential locations of storage and processing sites—in inner, intermediate, or outer layers. Somewhere, there is a distinction between mobile subnetworks associated with our bodies and surrounding, fixed-in-place infrastructure networks.

The nomadic aborigines of the Australian desert represent one extreme.[3] For them, almost everything is in the peripheral layers—the natural infrastructure. They carry very little and wear almost nothing; this lightens and liberates the body, but it demands an extraordinary knowledge of the habitat, and a highly developed capacity to locate and exploit the water, food, shelter, and other resources that it offers. Nineteenth-century European explorers of the desert—equipped with camel-loads of supplies—did not have this capacity and frequently perished.[4]

Backpackers carry more than nomadic aborigines, but they still strictly limit themselves. They carefully calibrate their onboard storage capacity to provide themselves with sufficient independent means for survival between reconnection points. The bigger their pack, the greater their range, but they pay the penalty of increased effort and decreased agility.[5] Horses with saddlebags provide greater range again, but have significantly diminished flexibility; there are more places they cannot go. Wheelchairs for the sick and elderly offer more limited freedom of movement, but can provide room for sophisticated mechanisms and electronics, medical supplies, and even intravenous drips.

Mechanical transportation, providing the capacity to move larger packages of stuff around, shifts the balance still further. Compared to a horse, an automobile can accommodate many more storage and processing capabilities onboard, in inner layers, to create a larger and heavier zone of independence from surrounding resources and conditions. This is carried to extremes in SUVs with cupholders, limousines with bars, Winnebagos with kitchens and bathrooms, and dustbowl immigrants making for California in their overloaded jalopies. A modern jetliner is a flying restaurant and theater. A manned spacecraft, at roughly the scale of a house, carries everything it needs through the most hostile territory imaginable. An aircraft carrier is a slow-moving, independent system at the scale and complexity of a city. Ron Herron, in the 1960s, gleefully crafted *épater*-the-old-guys images of walking cities.

At the extreme are self-contained vehicles—from Noah's ark to the starship *Enterprise*—that must operate, for long periods, where there is *no* infrastructure to rely upon. The ships of seafaring explorers, such as James Cook, faced this condition. Cook's tiny vessel had to carry provisions for months at sea, along with antidotes for scurvy. Modern submarines are designed to operate for similar periods away from their bases. And spacecraft for Mars missions will need long-term, self-contained, recycling life support systems—designed in a particularly careful tradeoff of bulk and weight against capability and range.

LOCATIONAL OPTIONS

Given a particular scale and granularity of mobile cyborg systems, design decisions about where to locate storage and processing sites—in inner or outer layers, in the fixed infrastructure networks or the freely moving subnetworks—respond to many factors. Designers must consider intensity, urgency, and predictability of need, bulk and weight of storage containers, network speed and capacity, continuity or discontinuity of network connection, frequency of reconnection and resupply points, quantity and perishability of the resource being delivered, security requirements, and ease of duplication. There may be a need to achieve aggregation benefits and scale economies by locating sites where there is plenty of room. And there may be a political agenda—a desire to enhance individual autonomy by locating resources and functions in inner, personally managed layers, or conversely, to strengthen community by shifting them to outer, collectively managed layers.

Water is heavy and bulky, for example, and we usually don't need it instantly, so (fashionable young joggers and gym rats aside) we only carry around water bottles when there is no other option. Instead, we organize extensive systems of reservoirs and tanks, and deliver to points distributed densely throughout buildings and urban environments.[6] In many cultures, the activity of constructing, managing, and sustaining these systems has been a crucial focus of political activity and critical to social cohesion.

Electric power, on the other hand, is now required continuously to drive wearable and portable electronic devices, so many of us find ourselves carrying several miniaturized batteries. That's fine if we just need milliwatts or watts for a low-powered electronic device, but if we need kilowatts or megawatts for some big machine, we're probably stuck with a massive battery, a bulky generator, or a wire.

Stored digital information is different again; ease of duplication makes it convenient to keep portable local copies of files when network speed is limited. But when it is of a variety that quickly becomes out of date, and when it can be transferred almost instantaneously through high-bandwidth channels, it makes more sense to maintain it on central servers and deliver it where needed on demand. Or, as content delivery systems like that operated by Akamai have demonstrated, it may be efficient to duplicate and store content at numerous cache servers close to end users and use sophisticated optimization software to figure out the quickest delivery paths as requests are received from particular locations.[7]

If things you need frequently are too cumbersome to carry around, then you can sometimes rely upon grids of fixed access points. Thus public telephone boxes and booths were prominent features of many cities in pre-cellphone days; you could find one quickly when you needed to make a call. Today, we increasingly rely upon private, portable handsets, and these public access points have greatly diminished in importance. Conversely, many students on college campuses would rather check their email at public access points than carry relatively bulky wireless laptop computers to do so. And toilet training accomplishes a liberating shift from continual reliance upon wearable diapers to occasional use of the fixed infrastructure.

In general, if you make bigger moving boxes, you can carry around more stuff and mobilize more functions; you can pack more functionality into an SUV than a little two-seater, and more still into a mobile home. But the overall effect of recent technological development has been to shift the dividing line between highly functional stationary boxes (architecture) and less functional movable boxes—that is, vehicles, portable devices, wearables, and implants.[8] Miniaturization (particularly of electronic devices) allows designers to jam more functionality into small packages, and extensive networking

reduces the distances between replenishment points. Weapons designers were among the first to realize this; many of the early efforts to miniaturize electronics were driven by the desire to replace human pilots with missile guidance systems for the long-range delivery of destruction. In the early 1970s, Archigram's David Greene and Mike Barnard saw where miniaturization was leading more generally; they imagined the "electric aborigine," speculated about "the possible influence of miniaturized electric hardware on lifestyles," and proclaimed—a bit ahead of their time—that "people are walking architecture."[9]

This effect is most dramatically evident with artificial hearts and other organs. Once bulky bedside devices that kept users tightly attached to the nonwalking architecture at fixed locations, they migrated to backpacks and strap-on harnesses, and have now, in some cases, become small enough to implant. Step by step, the bodies of formerly tethered, immobilized patients have been liberated.

THE MISSING LINK

Until recently, however, there was a critical missing link. Interconnections across network layers worked reasonably well from the global scale down to the walls, but then there was a gap. Our bodies temporarily lost connection to larger networks when they got up and moved around.

Interim storage devices—water bottles, rechargeable batteries, and chamber pots—can expand the body's range from a fixed network connection point. (This only works within constraints of carrying capacity and expiration date.) So can flexible pipes and wires. A garden hose keeps you connected to the water supply system as you walk around your backyard, and a power cord keeps you connected to the electricity grid as you vacuum the floor. More dramatically, deep-sea divers depend upon their air hoses. But you cannot remain tethered to an outlet as you walk city streets, drive an automobile, or pilot an airplane. And you cannot link satellites to ground stations with wires. In these contexts you must rely upon wireless connections.

The possibility of continuous wireless linkage first emerged in the mid-nineteenth century, when James Clerk Maxwell theorized the existence of electromagnetic disturbances that might serve such a purpose.[10] By 1888 Heinrich Hertz had experimentally employed sparks to produce radio waves, and by the early 1890s William Crookes—in a classic piece of futurology—could speculate in the *Fortnightly Review* about a world of wireless intercommunication.[11] At the turn of the century, through the pioneering work of Guglielmo Marconi and others, the telegraph finally became the wireless telegraph. Ships at sea were soon maintaining continuous telegraphic contact with shore stations, and by the 1920s police cars and taxis were getting primitive radio telephones for voice communication.

In the mid-1940s, Bell Labs developed the idea of distributing low-powered transmitters over wide areas and handing off calls among them to provide continuous mobile service to large numbers of users. This was the beginning of the cellular telephone, but commercial cellular systems were not deployed until the late 1970s. Since then, the growth of cellular systems has been explosive; by 1990 there were about eleven million cellular users worldwide, by 1995 the number of new mobile phone subscribers each year was beginning to exceed the number of new fixed telephone subscribers, and by the early 2000s the number of users was heading into the billions.[12]

Early cellular systems employed analog signals and were intended primarily to handle voice communications. By the early 2000s, systems were going digital and increasingly shifting their emphasis from providing continuous, person-to-person voice connections to handling bursts of chip-to-chip data. This generated interest in broadband wireless systems that could deliver data not just at rates of kilobits per second, but at megabits, or even hundreds of megabits per second—as required, for example, by sophisticated multimedia.[13] Eventually, the differences between voice and data wireless systems began, messily and haltingly, to disappear.[14] We entered a world of GSM and G3 cellphone service, IEEE 802.11a and 802.11b[15] local-area networks (the "wireless Internet"), Bluetooth[16] networks to replace the serial and USB cables that had interconnected adjacent electronic devices, and high-speed UWB[17] networks. In research laboratories, many other alternatives were being explored. There was no single wireless network, and there were competing and conflicting standards, but seamless, global, wireless interconnectivity now seemed within our grasp.

THE LOGIC OF WIRELESS COVERAGE

The goal of a wireless transmitter is to provide satisfactory reception to suitable devices (either fixed or mobile) within some target area. This is essentially a matter of transmission antenna type and placement, signal strength, signal frequency, receiver design, the need to make efficient use of available spectrum, the requirement for sufficient spatial or temporal separation of signals that occupy the same parts of the spectrum, and policy governing spectrum use.[18] It turns out that there is a complex logic of wireless coverage, and that this logic has motivated the construction of wireless infrastructure "shells" encircling the earth at successively greater altitudes, like the layers of a rather messy and incomplete onion. The coverage areas of wireless systems overlap with one another, and with domains established by geographic and political boundaries, to strengthen some established social and political groupings while subverting and weakening others.

The smallest, lowest-powered, shortest-range systems communicate over distances of centimeters or meters. There is little need to regulate their use of spectrum, since they are not likely to create interference with other systems. They obviously aren't useful for person-to-person voice communication (your unaided voice probably carries further), but they provide a convenient, flexible way to interconnect tiny computing devices without physical networking—an idea that has been explored in the MIT Media Laboratory's "pushpin" and "paintable" computer projects. And they can be organized to provide multihop connections over longer distances—much as packets are routed from node to node through the Internet.

At a slightly larger scale, Bluetooth-enabled devices (which contain special microchips) can interconnect wirelessly on desktops or within rooms—over distances up to about ten meters. Bluetooth was originally developed in the mid-1990s to link laptop computers to mobile phones. But it also now serves to interconnect numerous other types of consumer devices, such as MP3 players, digital cameras, printers, and video projectors, and to link portable devices to stationary network access points. Most interestingly, a Bluetooth device can establish instant connection to any other Bluetooth device that comes within range—thus enabling, for example, ad hoc networking among laptops in a conference room or classroom. Essentially, Bluetooth and similar systems provide freedom of movement and flexibility of spatial arrangement within room-sized socio-technical systems. Bluetooth is not the only wireless technology suitable for this role, and it is likely that better alternatives will supplant it, but it has at least served to introduce short-range wireless connectivity.

At the next scale up, Wi-Fi (802.11) and similar wireless base stations typically have ranges of 100 meters or so, but their signals are easily blocked by walls and other obstructions.[19] Thus they are well suited to providing mobile coverage within private homes, businesses, cafés, gardens and parks, and so on. As these systems are deployed, our built environment is being populated, increasingly densely, with wireless points of presence that link low-powered, miniaturized, portable devices to high-speed, long-distance networks. Base stations and portable devices provide personal mobility, while wiring in the walls provides indefinitely expandable capacity.[20]

Since these base station systems provide coverage at room and building scale, they tend to strengthen interconnections within established occupant communities. If they are open to visitors, they also extend a new form of hospitality. By providing free Internet access, they can add a new dimension to public space; Midtown Manhattan's Bryant Park was one of the first public places to offer this amenity. And since the technology is relatively inexpensive, simple to install, and uses unlicensed spectrum (in most places, anyway), it encourages grassroots neighborhood networking.[21] With more powerful base stations, it is also well suited for municipal efforts by small towns and villages, electronically updating the communal role of the central church bell tower or the minaret; in 2002 the small Georgia town of Ellaville (population 1,700) pioneered this strategy by installing a broadband base station on its water tower, together with rooftop antennas, to provide Internet connectivity within a kilometer radius. The New Zealand city of Auckland deployed a larger-scale, demonstration network throughout its central business district. However, there is a price to pay for this electronic conviviality; since signals do not stop *precisely* at walls, there are also dangers of overlap and interference between coverage areas, of unauthorized appropriation of base station capacity by neighbors or passersby, and of electronic eavesdropping.

Outdoors, at city-block and urban neighborhood scales, cellular infrastructure, which makes use of licensed spectrum and centralized switching, typically begins to take over. The infrastructure (particularly for advanced digital service) is costly, so it is typically deployed and controlled by telecommunications companies rather than by grassroots groups. Each base station in the system comprises a transmitter, a receiver, and a control unit, and is located roughly at the center of a cell. Coverage areas consist of mosaics of such cells. Cells may be about ten kilometers across, but they will be subdivided into smaller cells (with correspondingly lower-powered transmitters) in areas of high usage. The base stations for the smallest microcells are found on lamp posts and other street furniture, those for larger cells are often mounted on small buildings and special towers, while those for the largest cells move to the tops of hills and skyscrapers. Since suitable base station locations are in limited supply, and since there are often competing cellular systems, there tends to be increasingly intense contention for cellular infrastructure sites.

Although the infrastructure of cellular grids has traditionally been deployed at fixed locations, mobile "cells on wheels" may be used for rapid disaster recovery (these were much in evidence in Lower Manhattan in the days following the World Trade Center attacks), and there has been growing interest in the possibility of ad hoc, towerless cellular networks that are carried by mobile handsets—and thus automatically follow users around and adjust for density.

Naturally enough, cellular providers have tended to concentrate their infrastructure in high-density urban areas, and along highly traveled transportation routes, where the payoff is greatest. In the developing world, and in sparsely populated areas, this has produced a pattern of urban wireless "islands" connected by long-distance links. Occasionally, as with GrameenPhone's GSM cellular system in Bangladesh, an explicit commitment to the welfare of the rural poor has generated more even coverage.[22]

The next scale of wireless infrastructure is that of high-powered, tower-based, licensed transmitters providing coverage over distances of tens, hundreds, or even thousands of kilometers. This type of infrastructure began to emerge very early, with the first wireless telegraph towers—which were thought of, for a while, as "electromagnetic lighthouses." These were followed by the towers of early mobile radio telephone systems, such as those used by taxis and police cars. And chains of microwave transmitter/receiver towers have sometimes been employed (particularly in difficult terrain) as an alternative to long-distance telecommunication cables.

Socially and politically, though, a more interesting use of high-powered, tower-based infrastructure is for radio and television broadcasting to urban, regional, national, and even global audiences. Where the industrial-era combination of machine-powered presses with rapid transportation had created urban mass audiences that were reachable within hours, this type of infrastructure provides synchronous access to such audiences at very low cost. Since electromagnetic spectrum is a finite resource, there can only be a limited number of broadcasters in a given geographic area without interference, so this type of infrastructure tends to hegemony—concentrating political power and cultural influence in the hands of those who control the towers.[23] Consequently, governments have generally sought either to retain direct control of the transmission towers themselves or to license control to a few broadcasters.[24] In general, the taller the transmission tower you control, and the more powerful its signal, the wider your broadcast coverage; thus the prominent towers that rise proudly from the tops of the tallest skyscrapers in cities like New York are not only instruments of broadcast dominance, they are visible announcements of it.

When a high-powered system is used for two-way communications within some group that is scattered across a wide geographic area, different speakers take turns occupying the limited number of available channels (often just a single channel). Shared, structured use of a common resource in this way provides cohesion to communities as diverse as those of the shortwave School of the Air in the Australian outback, truckers chatting on their CB radios, taxi drivers and patrolling police officers going about their business, and Afghan fighters exchanging taunts via their walkie-talkies. The commonly available spectrum acts as a social focus, much like the well in a traditional village.

THE SATELLITE ERA

When Sputnik began to transmit signals back to earth in 1957, the possibility emerged of extremely high-altitude transmission points, with correspondingly large "footprints." By 1960 NASA had launched Echo 1—a Mylar balloon satellite that could reflect signals back to earth. (This was a variant on the older idea of bouncing signals off the moon.) In July 1962, Telstar, the first active communication satellite, went aloft and carried the first live, transatlantic television transmission. Passage of the Communications Satellite Act by the U.S. Congress quickly followed, and COMSAT (Communications Satellite Corporation) was formed. Not coincidentally, Marshall McLuhan's phrase "the global village" began to resonate with the popular imagination. In the succeeding decades, the skies were gradually blanketed with satellites.

Not far beyond the Earth's ionosphere, in orbit at distances between 500 and 2,000 kilometers, there are now low-earth-orbit (LEO) telecommunication satellite systems. Satellites in a LEO system contain transponders that receive uplinks from transmitters on the ground, converting them into downlinks to receivers on the ground or handing them off to other satellites. (A transponder is a device that receives a signal and transmits some sort of signal back.) The Iridium and Globalstar LEO systems were first put in place with great fanfare (maybe a bit prematurely) in the 1990s to extend the idea of a cellular network to the skies and to provide wireless voice and data systems with global coverage. So-called Little LEO systems, such as Orbcomm, are designed for paging, tracking, and similar applications of small bursts of data. Big LEO systems, such as Globalstar, work at higher frequencies, support higher data rates, and can support voice and positioning services.

In order to provide service at desired locations on the earth's surface, LEO systems must extend coverage to the *entire* earth's surface. Thus they are particularly important to isolated and sparsely populated areas that are not readily served by other types of infrastructure. Furthermore, there is likely to be considerable excess capacity in these areas—capacity that might, at least in principle, be devoted to education and to supporting economic development.

Further out, orbiting at 5,000 to 12,000 kilometers, are medium-earth-orbit (MEO) satellite systems, such as ICO. These operate much like LEO systems, but find a different balance of technical tradeoffs. They require fewer handoffs but higher-powered signals, and they introduce longer delays due to the greater distances involved.

Furthest out, at about 35,000 kilometers, are the geostationary telecommunications satellites. Unlike LEO and MEO satellites, they are stationary relative to the earth—much like *very* tall transmission towers. They provide footprints covering very large areas of the earth's surface, which is very effective for television broadcasting but wasteful of spectrum (and therefore expensive) for point-to-point communications. They also introduce delays that are very noticeable in synchronous voice and video communication. Proposed by Arthur C. Clarke in 1945, the first of them (Intelsat 1) was launched in April 1965, and they have proliferated enormously since. They now cluster densely over the more populated parts of the earth, providing services such as voice communication, digital video (for example, via the DBS system), and Internet access through services such as DirectPC and Starband.

Obviously there is competition among the various different types of satellite systems, and between satellite systems and terrestrial wireless systems.[25] When a GEO satellite is in position, it provides instant coverage over a very wide area, with significant performance and capacity limitations. LEO satellite systems have very high initial costs, and take more time to deploy, but promise technical advantages. Terrestrial systems are relatively inexpensive and can be extended incrementally; if this happens rapidly while new satellite systems are being planned and deployed (as the planners of Iridium discovered, to their cost), much of the potential market for satellite service is lost. In the long run, satellite systems seem likely to occupy some important niches in wireless service (such as GPS, global paging, and service to sparsely populated rural areas), but not to provide a universal solution.

DEVELOPING THE HERTZIAN FRONTIER

From centimeter-range micro-wirelesses to broad-coverage geostationary satellites, the wireless world is weaving around itself an increasingly dense, multilayered cocoon of antennas, network access points, relay points, and channels. Different types of physical channels are increasingly being integrated, through telecommunication standards and protocols, into vast, seamless systems of bewildering complexity. Every point on the surface of the earth is now part of the Hertzian landscape—the product of innumerable transmissions and of the reflections and obstructions of those transmissions. The electromagnetic terrain that we have constructed, and continue to elaborate, consists of hotspots and deadspots, exposed areas and shielded areas, cells that get you through and overloaded cells that don't, signals (encoded in many different ways) that interfere with one another and signals that are cleverly multiplexed so that they don't interfere, jammed zones and Faraday cages, and the endless buzzes and bursts of electromagnetic noise.[26] It is an intricate, invisible landscape—one that is hinted at by the presence of antennas (sometimes, as well, by symbols warchalked in the street to indicate hotspots),[27] and can be made manifest by wardriving or warstrolling with a wireless laptop.

This landscape frames a complex geopolitics and political economy of wireless coverage. Within it, at every scale, there is competition for access to communities, for antenna sites, for timeslots, and for channel capacity.[28] Just as the kingdoms and empires of old struggled for control of terrestrial territory, those who seek power today increasingly contend for control of the airwaves.

One geopolitical strategy, with its roots in earlier traditions of telephone and broadcast communications, is to treat spectrum like frontier land. Governments chop it up and sell it—as in the spectrum auctions in many parts of the world that preceded introduction of G3 cellphone service. This facilitates comprehensive, top-down planning. However, it concentrates responsibility for providing coverage in the hands of a few license holders, and it encourages the development of centralized networks in which everything must flow through a few major switching centers, which become increasingly overloaded as the numbers of users grow. And it often slows down the extension of service, since spectrum auctions saddle license holders with huge debts.

A competing strategy, which draws upon the lessons of the Internet, is to think of spectrum as a communal resource, like the old village commons, or the land available to a squatter community. Anyone can use it, as long as they follow a few rules. This depends upon availability of unlicensed spectrum, and use of short-range, maybe multihop wireless technologies. It is messier, makes provision of adequate security harder, and risks overexploitation by a few at the expense of the many, but it has some important attractions. It allows the decentralized, bottom-up construction and interconnection of networks—much as packet switching and TCP/IP enabled the explosive, bottom-up formation of a global wired network. And it encourages a redundantly linked, decentralized network structure—which means that the addition of channels can enhance capacity without overloading central nodes.

There is, however, an additional twist. Since wireless spectrum is an immaterial, electronically managed resource, it can potentially (unlike land) be reallocated swiftly and automatically to meet changing demands. This opens up the possibility of dense wireless networks in which nodes cooperate dynamically to use available spectrum with maximum efficiency.[29] It seems likely that this will be the key to future expansion of wireless networks in densely populated areas.

At the extreme, deployment of wireless infrastructure can become a runaway, viral process. With very inexpensive wireless nodes, and a common standard such as 802.11, individuals can add nodes at will. With multihop technology, mobile and ad hoc wireless nodes can spontaneously form chains back to fixed infrastructure. And positive network externalities, supported by appropriate network architectures, can vigorously drive the expansion process; every node added to a network increases the value of existing nodes.

There is a close parallel, in all this, with strategies for real estate development. Governments can allocate land in a few large chunks for master-planned communities, or they can establish some general rules for land subdivision and development and encourage numerous smaller, independently initiated and controlled projects. Most often, in practice, urban form emerges from a complex combination of the two—and that is likely to be the future of the Hertzian landscape as well.

ELECTRONIC NOMADICITY

Gradually emerging from the messy but irresistible extension of wireless coverage is the possibility of a radically reimagined, reconstructed, electronic form of nomadicity—a form that is grounded not just in the terrain that nature gives us, but in sophisticated, well-integrated wireless infrastructure, combined with other networks, and deployed on a global scale. Leonard Kleinrock (one of the pioneers of the Internet) has defined this infrastructure 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."[30] This requires, as Kleinrock notes, "independence of location, motion, computing platform, communication device, and communication bandwidth, along with general availability of access to remote files, systems, and services." The technical challenges of achieving this are significant, but they will gradually be worked out, and as they do, the social and cultural implications of electronic nomadicity will become increasingly evident.[31]

Other types of networks—transportation, energy supply, water supply and waste disposal—cannot operate wirelessly (or pipelessly), of course. But by providing efficient summoning and locating capabilities, wireless connectivity links our mobile bodies much more effectively to these more traditional resource systems. If you want transportation, for example, you can call a taxi or ambulance with your cellphone. If you want to know when the next bus is coming, you can look at a bus stop display that wirelessly tracks the vehicles in the system. If you want to find a nearby vacant parking space, a drinking fountain, or a public toilet that's open and salubrious, you will increasingly be able to do so with your portable wireless devices. If you discover a restaurant with a great special on the menu, you can call your friends. In these sorts of ways, wireless systems reduce search and uncertainty, and minimize the time required to get what we need.

Furthermore, wireless interconnectivity mobilizes things as well as people. In wired networks, things such as desktop telephones and computers need to be physically plugged in to operate; they have relatively fixed and stable locations. But in wirelessly interconnected systems, components just need to be within range. If you add miniaturization and self-configuration capability (just stick a component anywhere, and it works) to wireless interconnectivity, networked systems become fluid and amorphous.[32] They are less like rigid things on boards or in boxes, less like buildings or cities, and more like the camps of nomads—ready to move around and reconfigure, at a moment's notice, as required.

The cumulative effect of these transformations is profound, and will become more so as wireless technology continues to develop and proliferate.[33] Wireless connections of fixed infrastructure to wearable and portable electronic devices, and among miniaturized wireless devices, are now completing the long project of seamlessly integrating our mobile biological bodies with globally extended systems of nodes and linkages. As a result, functions that were once served by architecture, furniture, and fixed equipment are now shifting to implanted, wearable, and portable devices. And activities that once depended upon close proximity to sites of accumulation—of water, food, raw materials, bank vaults, library books, or files of business information—now rely increasingly upon mobile connectivity to geographically extended delivery networks.

In an electronically nomadicized world I have become a two-legged terminal, an ambulatory IP address, maybe even a wireless router in an ad hoc mobile network. I am inscribed not within a single Vitruvian circle, but within radiating electromagnetic wavefronts.

ACCESS RULES

This new form of nomadicity is, of course, very different from that of ancient hunter-gatherer bands, which were forced by the sparse distribution of food, water, and other resources to range over wide areas. For them, mobility was not only a necessity but also a developmental constraint. They were limited by what they could carry around with them. The very possibility of further economic, social, and cultural development depended upon sedentarization, the accumulation and protection of food surpluses, the consequent ability to support non-food-producing specialists at sites of accumulation, and increasingly specialized division of labor within densely populated cities.[34] Today, large-scale networks support division of labor and specialization on a global rather than a merely urban scale, the possibility of non-food-producing specialization depends upon network access, and that access is—increasingly—available ubiquitously and continuously. You can get whatever advantages you may seek from mobility—wider intellectual and cultural horizons, global business opportunities, access to unique talents and resources, collaboration among geographically distributed specialists, the stimulus of diversity—with far fewer of the traditional costs.

Under these post-sedentary conditions, access capabilities and privileges are more important than traditional forms of ownership and control of property.[35] If you are sufficiently wealthy and privileged, for example, you can now travel very lightly—with credit card and passport, some portable electronic equipment, and a carry-on bag; you can take full advantage of the world's highly developed network infrastructure to access whatever you want, wherever you may need it. If you are a knowledge worker, a personal library of books accumulated in your study may now be less useful than mobile network access and acquisition of intellectual property rights to online information.

The time-honored way to invoke access privileges is to proffer a physical token that you carry in your pocket, such as a talisman, passport, metal key, or plastic card, so that a gatekeeping system can look for a match. With computer systems you proffer some bits that you carry in your head—a password or PIN—by explicitly typing or swiping. Now you can simply equip yourself with a wireless transponder that instantly, automatically, and unobtrusively supplies ID bits when interrogated by an electronic gatekeeping device. Thus automobiles with EZ-Pass transponders can gain access to toll roads without waiting at tollbooths, and access to gasoline pumps through Exxon Mobil's Speedpass, which is based upon similar RFID (radio frequency identification) technology. With further miniaturization, RFID devices shrink to tags that are tiny enough to carry on key chains, to be sewn into clothing, or even to be implanted under the skin; wireless nomads can become continuously, automatically self-identifying.[36] You don't even have to stop to identify yourself; electronic devices can suck the RFID bits from your body or your vehicle as you pass by.

From the viewpoint of service consumers, ubiquitous access capabilities and privileges assure you of getting what you want when and where you want it. From the marketer's perspective, that very same connectivity provides opportunities (subject to any privacy constraints that may be applied) to continuously track your behavior, draw inferences from it, and anticipate your needs. (Step up to buy a hamburger, and automatically have it your way.) Whenever and wherever you electronically invoke your access privileges, your action is likely to be recorded in a globally centralized database and, eventually, used as a data point in computing your creditworthiness and likely future consumption patterns, and in pinpoint marketing strategies.

In other words, the post-sedentary world represents the ultimate abstraction and mobilization of exchange capability—and therefore, of wealth and power.[37] In simple barter economies, wealth does you little good unless you have your accumulated goods nearby and can physically hand them over in exchange for other things you may want. Coins and banknotes emerged to serve as more abstract and mobile exchange tokens and supported the development of more complex and geographically extended systems of trade. Electronic telecommunication networks took abstraction and mobilization still further—allowing wealth to become electronically manifest at Western Union offices, ATM machines, or credit card charge terminals at points of sale. Now, globally negotiable, electronic exchange tokens (which may be complex, metalevel abstractions such as mortgages, options, and derivatives as well as straightforward cash equivalents) can move wirelessly, and show up wherever a mobile device can get reception.

Conversely, post-sedentary space also redefines the condition of homelessness—the plight of being placeless and marginalized in a sedentary society. Today, it isn't fundamentally a case of having no fixed abode. It's one of having no access privileges. If you cannot afford or obtain such privileges, if you get blacklisted, if you simply lose your cards or equipment, if you forget your passwords, if you have a RFID tagectomy, or even if your batteries just run out, you are—like those clueless colonial explorers in the Australian desert—surrounded by inaccessible abundance.

NODULAR SUBJECTIVITY

For good and ill, then, I am a not only a networked, spatially extended cyborg, but also a post-sedentary one—not because I have been bionically rebuilt (apart from a couple of replacement teeth, I still rely upon my slightly worn original equipment), but because I am continuously connected, even when in motion.[38] I am inseparable from my ever-expanding, ever-changing networks, but they do not tie me down. Not only are these networks essential to my physical survival, they also constitute and structure my channels of perception and agency—my means of knowing and acting upon the world. They continuously and inescapably mediate my entire social, economic, and cultural existence. And they are as crucial to cognition as my neurons.

Sometimes these extended flow systems demand that I disclose the identity of my mobile body, but at other times they introduce identity impedance. When I stop to pee into a urinal, I engage a gendered network node and thereby make a declaration of gender. When I pass through an airport security checkpoint or operate an ATM machine, I must declare my name and document my right to use it. If I carry a RFID tag or submit myself (maybe unknowingly) to biometric scrutiny, the labels that my body carries are observable. But if I wear a mask and gloves, identifying labels are obscured. And on the Internet, as has endlessly been remarked, nobody knows I'm a ____. As my body extends artificially from its fleshy core, its gender, race, and even species markers may fade.[39] It may acquire multiple, sometimes contradictory aliases, masks, and veils. Its agents and avatars in particular contexts may be ambiguous or deceptive—as when I choose an electronic skin to represent me in a videogame. Its very location may become indeterminate, and it may hide itself behind encryption schemes and proxy servers.[40]

We need more than McLuhanist extensionism, and certainly more than unregenerate dot-com boosterism, to make sense of all this. It isn't simply that our sensors and effectors command more territory, that our webs of interconnectivity are larger and more dynamic, or that our cellphones and pagers are always with us; we are experiencing a fundamental shift in subjectivity.[41] As Mark C. Taylor has succinctly summarized, "In emerging network culture, *subjectivity is nodular* . . . I am plugged into other objects and subjects in such a way that I become myself in and through them, even as they become themselves in and through me."[42] I do not have a fixed identity, nor do I exist as a discrete individual. My spatial and temporal coordinates are diffuse and indefinite. My network extensions intersect and overlap with those of others.

Humanist sages could complacently claim that the proper study of mankind was man. That ex-cathedra confidence looks misplaced in a post-whatever, ex-net era; "mankind" and "man" are clapped-out categories, and the idea of "studying" (in a study?) seems increasingly anachronistic. For networked scholars like me—constructing texts on our wireless laptops, writing on the run, continually shifting and multiplying our geographic and electronic vantage points, carrying digital cameras, surfing the Web for our sources, tracing through networks of citations, cross-references, and hyperlinks, sending out agents and spiders, poking around in the metadata, and attending to streams of email and instant messages as we go—the pertinent preoccupation is the electronomadic cyborg.[43]

Many may mourn the passing of the (presumably pre-TCP/IP, pre-HTTP, pre-RFID) liberal humanist subject and its celebrants. Heideggerians and other critics of modernism may kvetch about totalizing technology and the allegedly alienating qualities of the wireless cyborg condition. Students of gender, race, and political economy may remind us (quite properly) that we are not all networked to the same extent, in the same ways. Defense and security specialists may worry (quite understandably) about the increasing destructive potential of network crackers and hijackers. Those who just want a simpler life may choose to unplug, and to live off the grid in Idaho. But for this particular early-twenty-first-century nodular subject, disconnection would be amputation. I am part of the networks, and the networks are part of me. I show up in the directories. I am visible to Google. I link, therefore I am.

4

DOWNSIZED DRY GOODS

Even the humblest of everyday artifacts can suddenly gain utility, claim new roles, and form new spatial patterns when they are radically downsized or lightened. Ryszard Kapuscinski, for example, has pointed out the effect of the "cheap, light, plastic container" on African communities. Once, the women had to carry water in heavy clay or stone vessels on their heads. These vessels were valuable, so the women stood in line with them, for hours, at the spring. Now, plastic containers are light enough to be carried by children and inexpensive enough to be left in line while you find some shade or go off to perform other chores. Kapuscinski comments: "What a relief this is for the exhausted African woman! . . . How much more time she now has for herself, for her household!"[1]

Ironically, the affluent now also get their water in lightweight plastic containers—with labels like Evian. In this case, lightening the container helps the distributor to bypass local water supply systems and to deliver a branded product from a great distance. From the consumer's viewpoint, lightness has a different value; it provides the product with portability, therefore adding to its appeal to travelers and recreationists. Lightness is what you make of it, in some particular context.

Since the beginning of the industrial revolution—and at an accelerating pace over the last few decades—designers have exploited new technologies to make things smaller and lighter. As they have crossed certain dematerialization thresholds, many different types of machines that were parts of the architecture have become parts of