The Personal Node (PN)

Gregory G. Finn and Joe Touch
USC / Information Sciences Institute
{finn, touch}@isi.edu

Abstract

A Personal Node (PN) is a small, wallet-sized device that integrates people into the Internet. A PN incorporates wireless communication, limited user I/O, and local environmental telemetry to catalyze the coordination of other smart space (SS) and network devices for the user's benefit. By themselves SSs are not aware of the people in them and people are not be aware of what is in a SS. The PN allows the SS to interact continuously with a person, and a person to interact continuously with the space, mediating the interaction with the help of other devices throughout the system. A PN is an individual's networking focal point. As the user roams about, a PN persistently maintains user presence on the internetwork. This represents the final and missing link in SSs, bringing the user in as a system resource and participant.

1: Introduction

In the near future buildings, rooms and vehicles will evolve into *smart spaces* (SSs) containing varieties of wireless *smart devices*. As individuals roam they will swim in a virtual sea of such devices. Those spaces must become aware of the individuals in them and vice versa. A Personal Node (PN) is a small device that is continuously carried by an individual, **allowing the user to become a permanent part of the smart space**, and allowing the infrastructure ongoing access to the user for feedback and commands. The PN is the network corollary of the PC; it is a network node for the 'rest of us'.

A PN has promiscuous wireless interfaces to allow it to act as a networking catalyst. PNs also have telemetry sensors, such as location (GPS), temperature, and orientation. This allows a PN to be addressed by-interface, by-region, by-proximity or by-heading. Support for ad-hoc networks with multiple addressing modes benefits military, commercial and emergency services.

1.1: Need for a Sixth Sense

Wireless networks enable SSs and devices; key to the success of SS's will be their ease of use. People cannot directly interact with SSs. We are deaf, dumb and blind there, unaware of when we are in one or what's there. Conversely, SSs are unaware of our presence. This mutual unawareness must be overcome for SSs to be integrated into our daily lives.

In the distant future, SSs may have senses to be aware of and interact directly with us. It is currently easier for us to be aware of SSs and interact with them on their terms; to carry that sense with us. We need to acquire a sixth sense for us to continuously inhabit, to 'see and speak' in this wireless spectrum. One solution is the PN, to see and speak for us in the SS's wireless spectrum.

This document outlines our vision of the PN, and how it uniquely enables SS interaction via a continuous network presence for people. The rest of this document is organized as follows:

- Sec. 2: Defining a PN
- Sec. 3: Need for a PN
- Sec. 4: Research Issues
- Sec. 6: Related work
- Sec. 7: Implications
- Sec. 8: Summary

1.2: A vision of SSs

The following describes our vision of the future of SSs, and adding people to the continuous infrastructure. The vision is superficially similar to other SSs (e.g. Active Badges), but a PN is distinguished as the user's "eyes and ears" to the Internet (i.e. sixth sense). It is not a compute node, but rather the minimal I/O for a human to interact digitally.

> A user views a map in a monocular display. The monocular and its buttons provide primary I/O, while the PN provides location and orientation for the map to match the view.
>
> The user walks up to a truck, and the SS it signals a hand-off of the map view, to the heads-up display (HUD) or monitor at the seat the user enters, as he sits. The user drives off, and the map zooms out as the vehicle accelerates, to provide a more appropriate view.
>
> The user's rucksack, near his PN, is considered relevant by the truck's SS, and is checked for rations. A supply truck passes by, and the user's truck asks the supply truck for a refill of water, food, and batteries, which are dumped roadside with a smart, encrypted beacon. The HUD points to the refill pack as the user's truck approaches it, and the user's PN extends that function as a beacon-compass as

the user walks over to retrieve the sack. Many people in the same group have also recently retrieved rations, and that aggregate behavior schedules a shipment from the supply depot.

In this vision, the PN alerted the SS of the user's presence, and allowed another user (via the truck) to alert him an urgent query. This interaction also avoided external terminals, relying directly on the PN.

2: Defining a PN

A PN is a networking *vade mecum*[1] that is active whenever you are. It maintains your network presence, with enough I/O for bootstrapping other interactions.

2.1: Basic Assumptions

PNs require a number of conditions, most regard assumptions of Internet evolution, e.g.:

- Internet wireless services will be ubiquitous.
- Building nets will provide basic Mobile IP [18].
- Wireless nets provide different service levels.
- Smart-spaces will depend more on 'user state'.

2.2: Design Principle and Content

The main design principle of the PN is, "**have only those capabilities that cannot be moved elsewhere**":

- User I/O to bootstrap user-network interaction.
- All the I/O that's particular to the user's locale.
- Support, i.e., wireless links, processing and memory for local operations and bootstrapping, a battery that recharges "when the user does".

A PN is a hand-held sized device, including:

- A variety of wireless interfaces:
  - Fast IR, for Mbps desktop roaming
  - Wireless LAN for 1 Mbps office roaming
  - Cellular for 100 Kbps MAN roaming
  - Satellite wireless for WAN roaming
- A limited amount of user I/O:
  - microphone, speaker
  - small LCD (PDA or smaller), buttons (3-4)
- As much telemetry I/O as possible:
  - orientation: GPS, accelerometers, compass
  - environment: temperature, humidity, light / IR, sound, camera, EMI, pH
  - personal biometry: pulse, respiration (via sound proc.), blood pressure, fingerprint

A PN is not a full computer. It does not include:

- File storage
- Traditional I/O (keyboard and display)

1. *vade mecum* (latin) - lit. "go with me"

A PN mediates for its user with SSs that it encounters, making these SSs aware of the user and the user's environment. Conversely, a PN becomes aware of what is in the SS environments. A PN also caches information of immediate or local relevance on behalf of the user.

To achieve these objectives, PNs must be carried by their users most of the time, like a pager or cellular phone. As a result, a PN must be small and lightweight; this precludes a standard keyboard or display. Unlike a wearable computer or laptop, a PN is not intended to replace a workstation [24]. We assume that a user's primary computing and storage is located elsewhere, and the PN acts as a bootstrap to catalyze their coordination.

Compared to a PDA, a PN is smaller, intended for simpler network-to-user interactions, but with more advanced sensors and network access. A typical PDA is the size of a deck of cards, and limits its I/O to a fairly large display, stroke-based text input, and audio output.

A PN contains I/O peripherals intrinsic to an individual that cannot effectively be located elsewhere. This includes user I/O, including microphone and speaker, control keys, and a limited display, eventually packaged the size of a large wristwatch (Figure 1). It includes sensors that monitor you and your environment, such as GPS, electronic compass, accelerometer, photometer, barometer and biometry. Unlike PDAs, PNs are IP-addressable, operate continuously and autonomously, and communicate with their wireless environment.

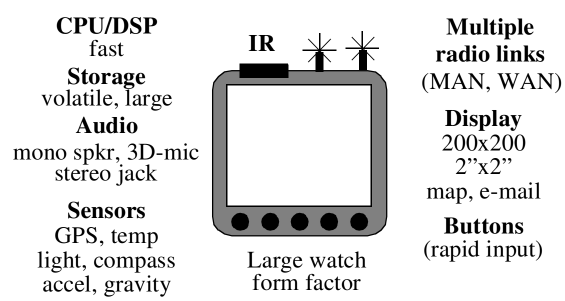

FIG. 1. PN characteristics

There are a variety of research issues in the PN. Primary is power conservation, which drives both hardware and protocols design. Continuous connectivity also challenges the traditional model of a node (host) [4].

2.3: How is a PN different?

The PN is related to the ParcTab, but differs as it:

- Supports continuous internetwork presence
- Is I/O rich: wireless, audio, and instruments

The PN extends SSs, enabling participants outside their conventional range. Continuous inclusion of the user as a node in the global infrastructure uniquely distinguishes the PN. These differences are summarized in Table 1.

property	PDA	PN
on time	mins/mo	100% on high-duty days/mo
usage	primary when disconnected	always secondary (catalyst)
num conns	1	2-3 (for handoff)
output	display, min. speaker	display, stereo spkr
input	keystrokes (primary) buttons, mic	mic (primary) buttons
other I/O	as peripherals	integrated GPS, temp, light accel...

Table 1: Comparing PDAs and PNs

3: Need for a PN

As noted, a PN integrates people with the network, enabling new uses for SSs. This section elaborates on the extension of SSs to enable new capabilities.

3.1: PN as a "Smart Spaces Device"

Since the early ARPANet, networking assumed two kinds of nodes - hosts and routers [4] [6]. This is modestly extended via Mobile IP and DHCP to support hosts that relocate periodically, such as laptops. IP telephony adds another node type, i.e. the IP telephone.

New devices extend this model further. The aggregation of host- and router-like devices is the basis of desktop area networks and network of workstations (DAN [1], Viewstation [10]). The current model of host as a single, terminal node is insufficient for these cases.

Even so, many emerging network devices remain expressible in this model. Wearable computers are modeled as laptops, since they not used continuously, and relocate only sporadically. They are alternate hosts, replacing a PC, but otherwise the same kind of node.

By analogy to telephones, the PN fills a gap in the node design space (Figure 2). Earlier attempts addressed this 'non-host, non-router' role [21]. In early telephony, limited resources drove party line use (e.g., mainframes with batch sharing). As telephones became less scarce, direct dial and home nodes resulted (PCs).

Users relied on telephones because they were pervasive in permanent places. This extended to mobile phones, initially by "move and reconfigure". In all these, messaging services were necessary, because the callee wasn't always available. Telephones were asynchronous, except during business hours.

Telephones evolved to true mobile phones and pagers. These are ubiquitous *vade mecums*, with a single, persistent user and number. Before, a phone number was a business or home. Now phone numbers are people. Hosts evolved from office to laptop addresses. The PN is the next step, allowing people to become nodes.

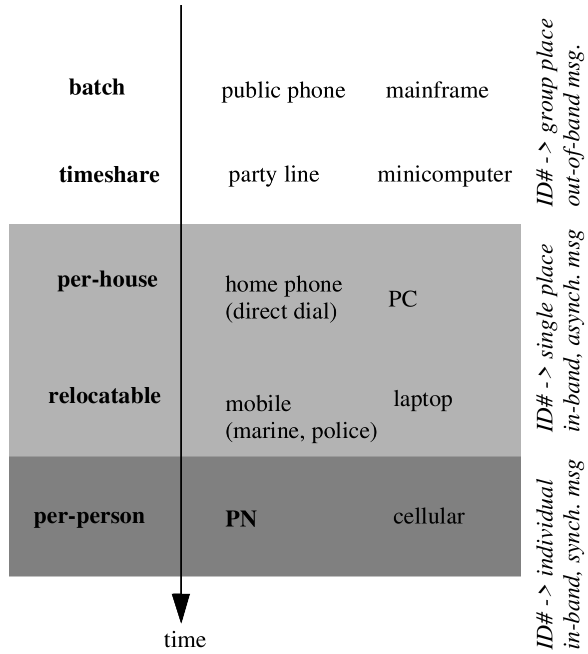

FIG. 2. Computer evolution emulates telephony

3.2: PN Application Domains

Behavior exhibits a phase change when accessibility is continuous, as seen in page or cell-phone use. The PN similarly is a catalyst enabling user interaction with SSs.

Presence Sensitive Applications

The field operative example shows an SS augmented by sensitivity to users. There are many other examples:

- Smart doors automatically unlock for users.
- A smart docent delivers user-specific tutorials based on the PN's data about the user's language and level of subject knowledge.
- Soldiers' PNs are asked for supply levels, which is aggregated for logistics support.
- A smart subway collects user destinations, to skip empty or unnecessary subway stops
- A PN is loaded with URLs on entering a smart business space. Current prices, private to the group, are provided to local PNs.
- Training scenarios gather the user status, to catalog participants and behaviors.

Smart Emergency Spaces and Services

A PN is a wireless point-of-contact for the user, with instrument and minimal processing assets. This combination enhances emergency services (ES):

- A PN can be loaded with site-specific ES information and software.
- A PN can authenticate ES messages.

- When local nets fail, a PN can use its wireless links for ad-hoc baseless networking.
- A PN can be addressed by location, finding a user or sending alarms to affected PNs

Autonomous Information Gathering

As a user roams, her PN will pass through SSs. Data can be cached by regional broadcast to passing PNs. Data can also be forwarded by the PN to the SS.

- PNs in vehicles or carried could indicate current level of supplies, which can be aggregated to logistics for disposition. Shortages can be addressed by redirection of the driver/user toward depots, while also debiting that depot.
- Delivery and repair services operate more efficiently. Resources are staged as needs move.
- A PN identifies its user, allowing businesses to use profiling to direct the user to specials.

4: Research Issues

PNs raise a number of research issues that concern protocols, naming and addressing, coordination and configuration, privacy, scale and user interface. Their existence enables new application areas that involve roaming, information capture and ad-hoc networking.

4.1: Protocol integration

The PN requires continuous communication as it spans different link technologies, and may require periodic hibernation to conserve power. State-oriented network protocols, notably TCP, do not react well to such idle periods and are not intended to support endpoint renaming. TCP is inefficient for simple request/response protocols. T/TCP is better, but requires further modification to support seamless transitioning [5].

The PN may also need to support proxy operation of other protocols. These might include delegated request/response, switchboarding, or remote control of a delegation point that coordinates or redirects multimedia streams among other SS devices.

Device-Control Protocols

Smart devices and PNs are network attached peripherals (NAPs). NAPs are uncommon today and most utilize media-specific transport protocols. Making smart devices themselves internet-accessible raises two issues:

- Standardization of device network APIs [9]
- Preservation of privacy and integrity [22]

Link agility

To maintain network presence the PN must monitor the ‘liveness’ of its links and reassociate with new ones as needed. Liveness monitoring and link association algorithms need to be developed. Low-power consumption is a requirement that must guide this work. There are a number of triggering events to consider:

- Failure of 802.11 low-power beaconing
- Hearing mobility agent from another subnet
- Distance from wireless hub
- Rate of damaged messages
- Heading and speed

Proxy protocols

The PN is not necessarily the best device to run request/response or stream protocols. Its limited bandwidth and power hinder it from first-class participation as a router in the SS. Instead, it may be appropriate to off-load some protocols to proxies at other SS devices.

Protocol trade-offs

There are a number of bandwidth vs. latency vs. power trade-offs in a PN that need to be considered:

- Asymmetric protocols to reduce transmission
- Periodic retransmission and server anticipation
- Split interfaces, i.e. IR out, 802.11 in

4.2: Naming and addressing

The PN challenges the traditional network notions of naming and addressing. The name of a PN should be intrinsically linked to its owner, not the device itself. GSM cell phones have this property; the encoding card identifies the telephone number, independent of phone. Other challenges are only beginning to be researched.

Geographic Addressing and Broadcasting

Providing each PN with knowledge of its location allows it to be addressed both by-interface and by-location. Various approaches to realizing geographic routing and broadcasting need to be examined.

Geographic routing and addressing in the Internet has been approached by creating a virtual network from geographically aware routers located within the Internet [15]. Earlier work pointed out that geographic addresses could be used directly by routers [8].

Geographic addressing could be grafted into IP as an option. However, IPv6 reserves 1/8th of its 128-bit address space for geographic addressing [19]. The possibility of providing hosts both interface-oriented and location-oriented addresses needs to be investigated.

SS Discovery

As a PN enters a SS it should become aware of that SS and vice versa. Mechanisms are needed for a PN to discover available smart devices in a SS, which ones it can access, and the application interfaces they support.

Generalizing Multicasting

Multicast groups are currently created and associated with a multicast address. A host explicitly joins a group to become its member and routers alter their routing tables to service group members. Once joined, a host remains a member until it explicitly leaves the group or the group is destroyed. Host mobility has no effect on membership in this type of group.

A multicast group could also be defined geographically, e.g., hosts within a geographic region, a room, a building. To within location precision, a host is inside or outside a group's region. Membership in a multicast group is then implicit, regardless of host mobility.

There are significant differences in how these two classes of multicast group are defined and in how membership is defined. Mobility makes ephemeral the membership criteria in geographically defined multicast groups. The set of such multicast groups that a mobile host is potentially a part of could change frequently.

4.3: Coordination and configuration

The determination of resources in a SS that a PN has entered and the run-time matching of those to application requirements is a producer/consumer problem that requires solution.

In conventional system architectures, both device controllers and devices are resident in the chassis. However, in a smart-space environment the set of devices that a PN may come into contact with as the user roams will be large and dynamic. It will be unrealistic to expect a PN to be preconfigured with all needed drivers. This immediately imposes requirements upon PNs:

- Need for Dynamic Reconfigurability
- Interface Matching
- Push/Pull Configuration Software

4.4: Scale

Both PNs and SSs increase the scale of networks in a variety of ways. The dynamic range of bandwidth increases, mostly due to a lower bandwidth required for WAN signals to the PN. The latency range increases, also because WAN signals are liable to use satellite paths. The number of devices in the network vastly increases because addresses are required both for SS components for PNs. While SSs might support address aggregation, the global roaming capability of PNs may inhibit such a simplification.

4.5: Security

The need for security is especially important for PNs because they are directly associated with individuals, and because they contain so much local state (GPS, microphone, etc.). Two levels of security are required for PNs. The data content itself must be secure (authenticated or encrypted), and the event of communication may also require privacy (source confidentiality) to prevent tracking or behavior monitoring.

There is an external aspect of security, that of device theft, which also requires consideration. The small size of a PN encourages its theft. A number of approaches deserve consideration:

- PIN at power-up and periodically
- Secure card for sensitive state like PCS phones
- Biometrics: voice, fingerprint

4.6: User interface

Size limitations prevent a PN from having a traditional keyboard or display. It is also unrealistic to expect individuals to use a conventional display and keyboard while roaming. It is our contention that when users are not roaming they will likely be able to use nearby conventional display/keyboards. Consequently, the user-interface for a PN must be nearly hands-free, depending primarily upon voice control with limited use of buttons.

Developing an effective nearly hands-free user interface for roaming will be a major research area. The need for speech recognition does imply that a PN needs access to significant computing resources.

5: Feasibility

The PN is currently feasible, even given our demanding combination of capability, portability, and continuous operation. It is possible to bootstrap its development with an off-the-shelf, rapid prototype, in parallel with the coordinated application of well-known low-power, integrated packaging design.

5.1: Rapid prototyping

The principal components needed to prototype a PN are readily available. Setting aside the size and packaging issues, much of the needed research and development could be done using a prototype built from off-the-shelf components. Existing PDAs and handheld PCs, together with wireless PCMCIA network interfaces can be used to emulate a PN.

Once that prototyping effort is finished, packaging, size and power consumption issues could be addressed separately. The industry has already developed suitable low-power processors, memories and interface circuits.

5.2: Power conservation

PDAs achieve their month-long recharge intervals by remaining normally off. They await an explicit activation by the user, perform a small amount of resulting computation, display the result and then turn off again.

On the other hand, PNs must maintain persistent network presence and so cannot be turned off. PNs must achieve a minimum recharge interval of 24 hours.

Variations on paging and polling techniques let a PN approach the normally-off power consumption characteristic of a PDA without sacrificing its network presence at the cost of increased latency. Each technique requires the cooperation of wireless hubs.

- Hubs page a low-power pager in the PN.
- PNs poll their hub (simpler, scales worse).
- Hubs poll the PNs (802.11 low-power mode).

Allowing a PN to remain mostly inactive will extend battery lifetime to a reasonable recharge interval.

5.3: Communication

The PN requires integration of multiple link technologies, from high-speed desktop to low-speed wide-area. Current variants of these include FIR (fast InfraRed) for the desktop, 802.11 wireless ethernet for the office, Metricom for the city, and text paging for the wide-area.

These different technologies have widely varying bandwidth, latency, and reliability. The application protocols need to adjust to available link capability, operating in loosely- or tightly-coupled modes as needed.

5.4: Packaging

Packaging issues include power conservation, thermal diffusion, ruggedness, and integration for miniaturization. Current sensor technology already supports component-level and chip-level versions of many of the devices proposed for the PN. Power consumption and heat buildup can be reduced by conventional techniques (power devices only when in use, or only periodically).

There appears to be a common *vade mecum* size, that of a cell phone or PDA, that is acceptable. A PN therefore needs to be at most wallet-sized and 1 lb.

6: Related work

The PN is a variant of PDA technology and wireless 'presence' devices. It also extends the networking efforts of recent wireless and mobile protocols.

6.1: Handheld PDAs

Recent PDAs and handheld PCs have integrated small displays, touchscreens, and sometimes keyboards to provide access to their limited local resources. Examples include the 3Com Pilot and a variety of WindowsCE palmtop PCs. The Philips Nino incorporates a microphone to support speech-based commands [17]. In addition handwriting or script recognition is provided. Compared to the PN, these lack environment sensors, have only limited wireless capability (usually only IR) and are used intermittently.

6.2: Wireless 'presence' devices

The ParcTab [23] was an early example of a wireless personal node. It had a single infra-red interface, provided persistent presence for in-building roaming and provided PDA-like services directly. In contrast, the PN extends wireless access beyond the building confines and focuses on catalyzing of other devices on its behalf.

The Lovegety is a simple wireless personal node that demonstrates mobile information capture [12]. It uses peer-to-peer beaconing, is small enough to fit on a keychain and runs for days to weeks on battery power. It can be considered a low-bandwidth variant of a PN, enabling singles to detect each other within a SS created by a multi-party ad-hoc baseless network.

6.3: Wireless and mobile protocols

Providing persistent internetwork presence while roaming is the subject of Mobile IP [18][13]. A mobile computing environment that uses multiple types of wireless networks is called a *wireless overlay*. Maintaining connectivity while running applications in this environment is extremely challenging [14][20] and is the subject of a number of research efforts, including BARWAN [2] and Odyssey [16]. Operating systems originally designed for workstations require extensive changes in a nomadic environment [3].

Imielisnski and Navas proposed embedding of geographic routing and addressing in the Internet by creating a virtual network from geographically aware routers [15]. Geographic addressing can also be directly used to route packets, support host mobility and provide regional broadcast [8].

7: Implications

The PN extends and challenges SSs and general network research. By including users as nodes, it extends the scope of the network, and the capability of applications. It also uses technology being developed for low-power, integrated sensors in a unique way to provide ad-hoc mobile smart sensor nets.

7.1: Smart spaces

The PN avoids the distinction between a user's on-line and off-line presence. The user is always on-line, accessible to signal for feedback, supporting immediate urgent-mode interaction. Because of its integrated, multi-level links it helps catalyze the aggregation of other network resources for the user's benefit.

7.2: Network research

Traditional networking considers users as temporary presences at permanent end-points known as hosts. The PN extends this notion, where people themselves become end-points on the network. People are more mobile, even than laptops, and so require hand-off without dead time, and a truly persistent identifier. Location of a user is a key network resource discovery issue.

The PN provides an opportunity to review more conventional host and gateway requirements, using a model that challenges their assumptions. Overall network architecture, naming, addressing, and resource discovery all may require re-examination.

In addition, transport protocols may require additional support for continuous relabeling of the end-points, as users move between SSs. The PN itself may provide bridging capabilities between adjacent PNs when necessary. Finally, the traditional request/response protocols may require redesign, to support a proxy-mode operation, to off-load capabilities to SS resources and conserve local power.

7.3: Application of related technology

There are a number of related technologies that are required for a PN to be developed. Small, low-power sensors already exist, but need to be integrated with a small amount of processing and storage into a handheld device. The PN focuses on placing as much I/O technology where the user is as possible, so there is virtually no limit to the challenge to integration technology here.

By placing the sensors where the user is, the PN provides a unique opportunity for ad-hoc deployment of sensor networks, in effect a mobile SS centered, and concentrated exactly where the users are. Deployment at the correct place is de-facto achieved.

There is also a challenge to integrate a number of wireless communication technologies into a single, low-power, configurable device. This includes bandwidths from 1-1Mbps, latencies from ms to 100's of ms, and ranges from feet to tens of miles, using IR, CDMA, GSM, and even simple analog paging technologies.

8: Summary

Wireless technology will soon be used to create and leverage SSs comprised of peripheral devices and sensors that communicate with one another and the network. As humans we can't directly perceive the wireless spectrum and so we aren't aware when we are in a SS and we won't know what's in it. Conversely, SSs won't be aware of our presence. As long as people do not have the capability of directly interacting with SSs as they roam, SSs will remain restricted in their scope of application and ease of use.

These issues are addressed by creating small personal wireless nodes (PNs) that are carried with individuals as they roam. The PN's goal is to integrate the human being into the Internet. The PN allows the user to become a persistent part of the network, by providing:

- - continuous communication with the user
- - user-centric telemetry and biometry sensors

By providing a minimal initial access, these capabilities can be used to bootstrap the user's access to more advanced services, and to support ad-hoc base-less networking when disconnected from the rest of the net.

The authors would like to thank Bill Manning, Gene Tsudik and Jon Postel for their helpful suggestions. An earlier, extended version of this paper appeared as an USC/ ISI Research Report, ISI-RR-98-461, July 28,1998.

[1] Barham, P., Hayter, M., McAuley, D., Pratt, I., "Devices on the Desk Area Network," IEEE JSAC, May 1995.

[2] BARWAN Project, http://www.cs.Berkeley.edu/~randy/Daedalus/BARWAN/BARWAN_over.html

[3] Bender, M., et al., "Unix for Nomads: Making Unix Support Mobile Computing," First USENIX Symposium on Location Dependent Computing, 1993.

[4] Braden, R (ed.), "Requirements for Internet Hosts - Communication Layers," RFC1122, Oct. 1989.

[5] Braden, R., "T/TCP -- TCP Extensions for Transactions, Functional Specification," RFC1644, Jul. 1994.

[6] Braden, R., Postel, J., "Requirements for Internet Gateways," RFC1009, Jun. 1987.

[7] DIGITAL Semiconductor SA-1100 Data Sheet, EC-R8XUA-TE, Digital Equipment Corp., Jan. 1998.

[8] Finn, G. G., "Routing and Addressing Problems in Large Metropolitan-scale Internetworks," Research Report ISI/RR-87-180, USC/ISI, Mar. 1987.

[9] Hotz, S., Van Meter, R., Finn, G. G., "Internet Protocols for Network-Attached Peripherals," Sixth NASA Goddard Conf. on Mass Storage Sys. and Tech., Mar.1998.

[10] Houh, H., et al., "The VuNet Desk Area Network...," IEEE JSAC, May 1995.

[11] Imielinski, T., Navas, J. C., "GPS-Based Addressing and Routing," Tech. Report (LCSR-TR-262), Rutgers Univ. Computer Science, Mar. 1996 (updated Aug. 9, 1996).

[12] Lovegety, http://www.freeyellow.com/members2/onmarketing

[13] Johnson, D. B., "Mobility Support in IPv6," (work in progress).

[14] Katz, R., Brewer, E., "The Case for Wireless Overlay Networks," Ch. 23 in *Mobile Computing*, Kluwer Academic Publishers, 1996.

[15] Navas, J. C., Imielinski, T., "GeoCast: Geographic Addressing and Routing," Third ACM/IEEE Int'l. Conf. on Mobile Computing and Networking (MobiCom'97), Budapest, Sep. 26-30 1997.

[16] Odyssey Project, http://www.cs.cmu.edu/afs/cs/project/coda/Web/docs-ody.html

[17] Nino PDA, http://www.nino.philips.com

[18] Perkins, C., Editor, "IP Mobility Support," RFC2002, Oct. 1996.

[19] Rekhter, Y., Li, T., Eds, "An Architecture for IPv6 Unicast Address Allocation," RFC1887, Dec. 1995.

[20] Satyanarayanan, M., "Fundamental Challenges in Mobile Computing," Fifteenth ACM Symposium on Principles of Distributed Computing, May 1996, Philadelphia, PA.

[21] Stewart, B., (chair), "Charter of the Special Host Requirements (shr) working group", Proc. 21st IETF, Jul. 1991.

[22] Van Meter, R., Hotz, S. Finn, G. G., "Derived Virtual Devices: A Secure Distributed File System Mechanism," Fifth NASA Goddard Conf. on Mass Storage Systems and Technologies, Sep. 1996.

[23] Want, R., Schilit, B.N., et al., "The ParcTab Ubiquitous Computing Experiment," Ch. 2 in *Mobile Computing,* Kluwer Academic Publishers, 1996.

[24] Wearable Computing FAQ, http://lcs.www.media.mit.edu/projects/wearables/FAQ/FAQ.txt