Wearable computing and communication

Making computing and communication more personal seems both natural and somewhat frightening. This talk will explore some issues in making our systems more personal (in many ways).

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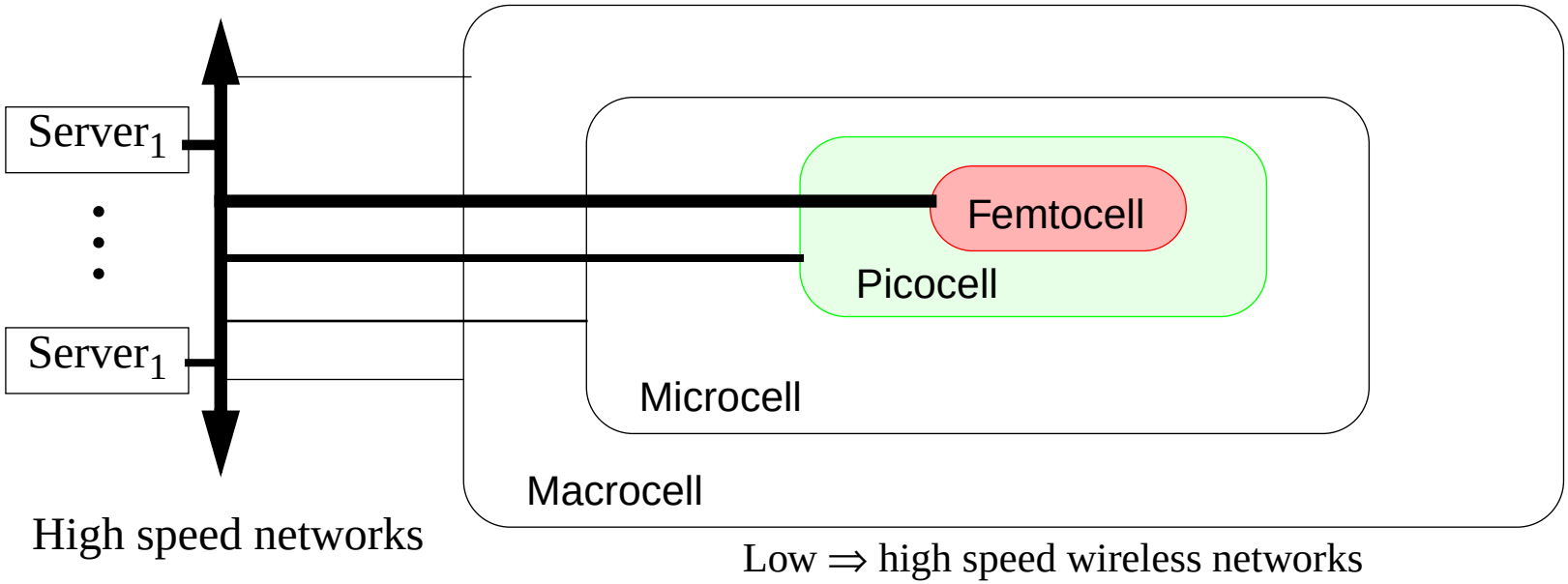
http://www.it.kth.se/~maguire

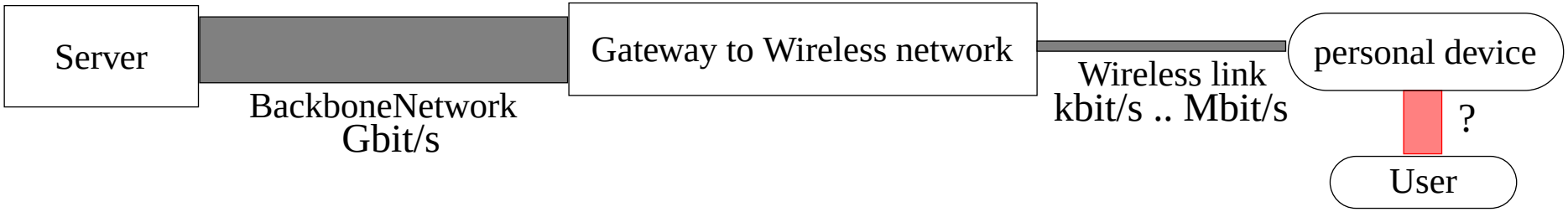
LARK, 29 November 1998, Kista, Sweden

Bottlenecks

- Server and Network Bandwidth and latency



- User Bandwidth and latency



- Power and Energy ⇒ need a computational theory of O(energy)
- Imagination!

Infinite Bandwidth on the backbone

Guilder's Law: network speeds will triple every year for the next 25 years.
This dwarfs Moore's law that predicts CPU processor speed will double every 18 months.

Some examples:

- MCI network backbone:
  - 1995 capable of moving 45 Mb/s
  - 1996 already 1.2 Gb/s
  - by 1999 at or above 40 Gb/s
  - by 2000 who knows?
- Telia installing a 60 Gbps transatlantic fiber
- Dense Wavelength Division Multiplexing is starting to be introduced

Mobile **internet multimedia computers**

It is not simply connecting PCs wirelessly!

Although networked multimedia PCs are the starting point for many applications and services - they will be supplanted by wirelessly networked appliances and other new devices.

Wearables

"… It will be possible to put a 100+ MIPS CPU and a 0.5 GFLOP DSP in a $200 Nintendo Game Boy within 2 years, for less than $25 bucks of Si cost. With this kind of cheap, available cycle time, how hard would it be to add a communications cartridge/dongle into a game slot? …"

-- John Novitsky
of MicroModule Systems,
and of Microprocessor Report[1]

Who are the competitors?

Ericsson, Lucent, Nokia, Siemens, … or Nintendo

1. From Wearables mailing list Wed, 17 Sep 1997 19:22:17 -0700.

Near Future systems

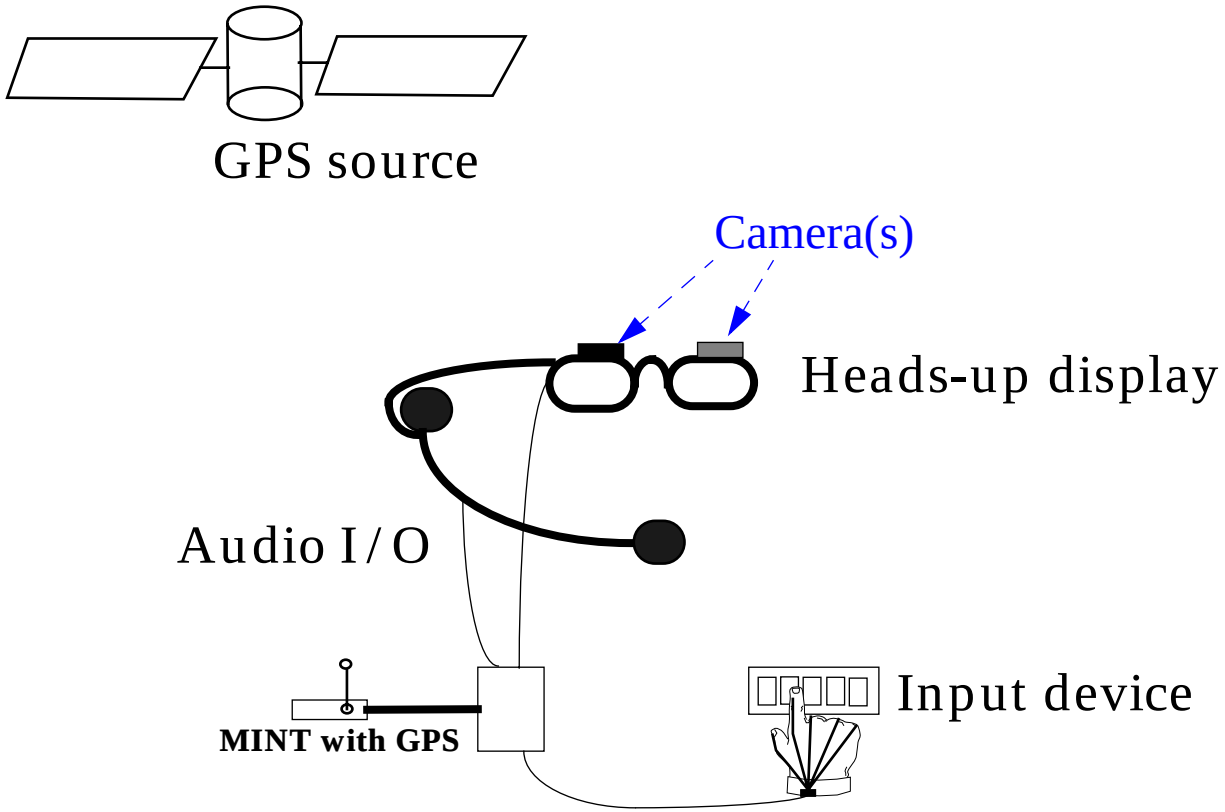


Figure 1: Vision-2, 2000 - high level of integration

Evolution of new varieties of networks

Already we have: WANs (Wide Area), MANs (Metropolitan Area), LANs (Local Area Networks)

VANs Vehicle Area Networks

Very local networks

DANs Desk Area Networks

The computer/printer/telephone/… will all be part of a very local area network on your desk.

- wireless links ⇒ No longer will you have to plug your printer into your computer (PDA/…) into your computer
- active badges⇒ No longer will you have to sign in/out of areas, write down peoples names at meetings, … the system can provide this data based on the active badges

Olivetti and Xerox are exploring "Teleporting" your windows environment to the workstation nearest you, on command, if there are multiple choices probe each one (currently a "beep" is emitted to tell the user which).

BANs Body Area Networks

Users will be carrying multiple devices which wish to communicate:

- thus there will be a need for a network between these devices which you carry around; and
- personal devices will wish to interact with fixed devices (such as Bankomat machines, vehicle control systems, diagnostic consoles (for a "mechanic" or repairman), …) and other peripherals.

Situational awareness and Adaptability

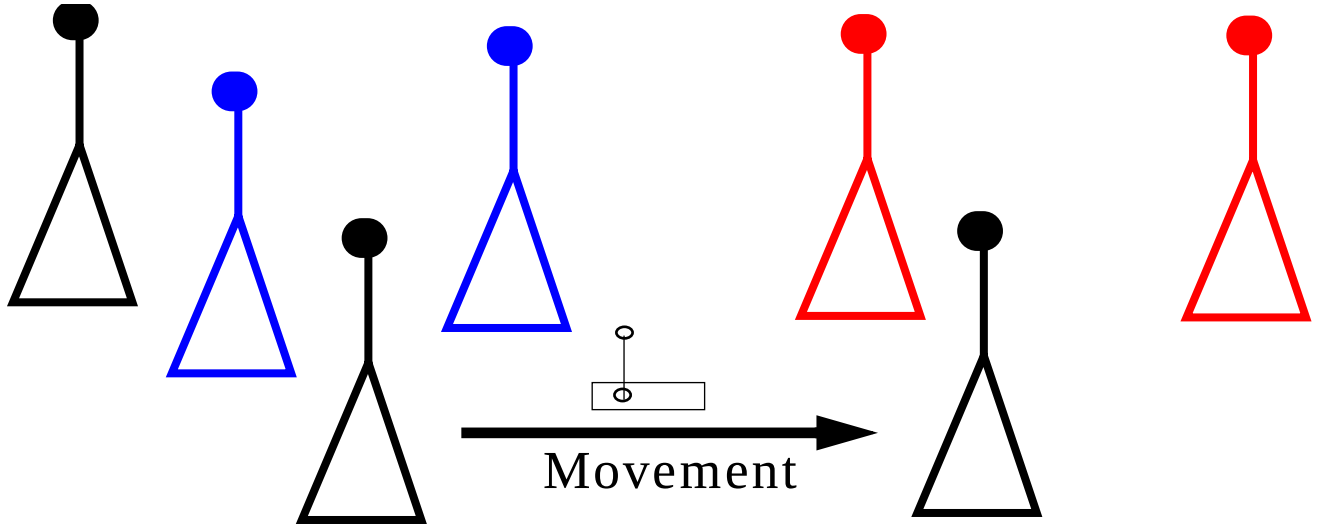


Figure 2: Where am I? What am I? Who am I?
Where am I going? When will I be there? What should I become? Who should I become?

- Location dependent services
- Predicting location to reduce latency, reduce power, hide position, …
- Adapting the radio to the available mode(s), purposely changing mode, …
- Reconfigure the electronics to adapt, for upgrades, for fault tolerance, …; Reconfiguration vs. powering up and down fixed modules (what are the “right” modules, what is the “right” means of interconnect, what is the “right” packaging/connectors/…, needed speed of adaptation)
- “right” level of independence; spectrum from Highly Independent ⇒ Very Dumb

Location Dependent service(s)

How do I know where I am?

- Outdoors: GPS or from the network operators knowledge [resolution: 100m to sub-centimeter]
- Indoor: IR and RF beacons, triangulation, knowing what you can **see** or **hear**

What can I do with this knowledge?

KTH students built a JAVA Applet which gets data from GPS unit and dynamically displays a list of the information available - as a function of where you are:

- if near bus, subway, train stop - you get transit information - potentially with real-time schedule - since the system knows current location of vehicles
- list of restaurants, shops, etc. where you are and in the direction you are headed
  - the scope is based on your velocity vector - so if you move quickly it reduces detail, but increases the scope
- map information with updated position

How do I know who I'm with or what I'm near?

- Olivetti, Xerox, and MIT - using IR emitters as "ID" tags
  - Olivetti put them on people, equipment, …
  - Xerox put them on electronic notepads, rooms, …
  - MIT Media Lab is putting them on people + lots of inanimate objects (clock, fish tank, …)

Human centered

- Computer - human interaction is currently focused on the computer (computer-centric)
  - Currently computers know little about their environment
    - Where are we?
    - Who is using me?
    - Is the user still there?
- Evolving Environment awareness
  - Give computers senses via sensors
    - Environment
    - User identity and presence
- Badge as a smart card replacement
    - biometric signature of the person currently using the badge
    - the badge ensures that only you can use it
- You wear your own personal user interface
  - interface can be consistent across all appliances
    - not because each appliance supports the interface, but because the user's own interface provides consistency
- Make the human the focus of the computer's interaction ($\Rightarrow$ human-centric)

Requirements

- Systems with which humans wish to interact:
  - ♦ traditional computers, desktop workspaces, domestic appliances, building and automotive systems, doors, elevators (lifts), environmental control, seats and mirrors, etc.
- Systems to provide sensor data:
    - ◆ location, orientation, light, heat, humidity, temperature, gas analysis, biomedical, …
- Systems to correlate the sensor information and provide it in a useful way to the computer systems:
  - ♦ Spatial and temporal sensor fusion,
  - ♦ 3D and 4D databases,
  - ♦ Machine Learning, and
  - ♦ Prediction (based on pattern extraction)
- Agents and actuators to provide intelligent control of the environment
- wireless/wired/mobile communications infrastructures to link it all together
  - ♦ must assure privacy and security

Dumb Badge, Smart Badge, and Intelligent Badge

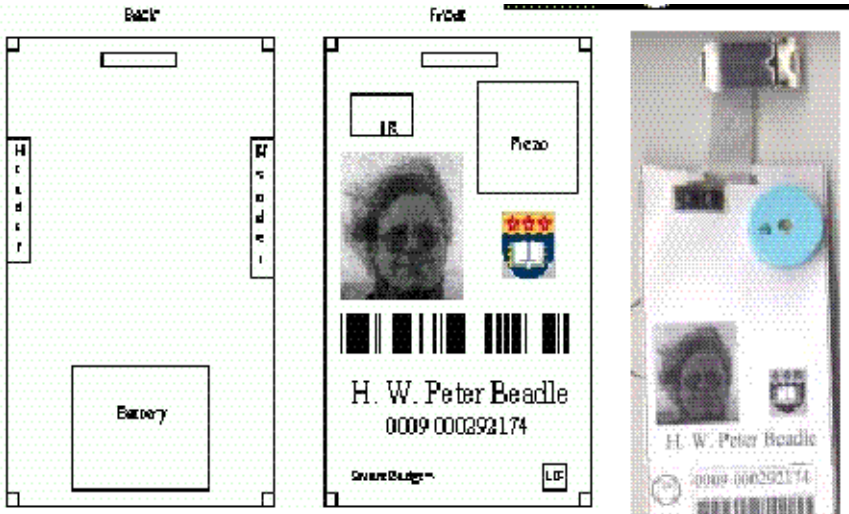
- Dumb Badge just emits its ID periodically
- Smart Badge - [an IP device] Location and Context Aware (i.e., a sensor platform)
- Intelligent Badge - add local processing for local interaction by the user

Acknowledgment:

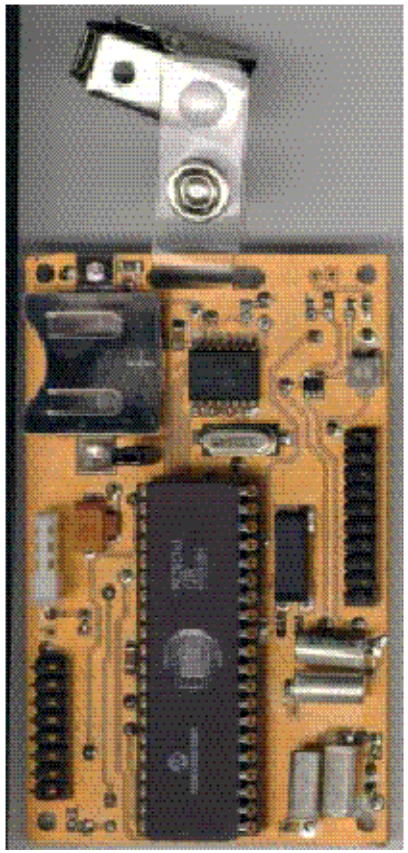
All of the badge work is done in cooperation with:

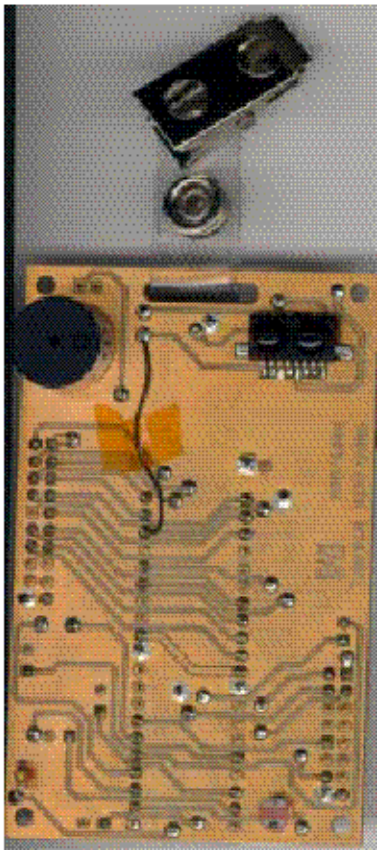
- Dr. Mark T. Smith - Hewlett-Packard Research Laboratories, Palo Alto, California, USA
- Dr. H. W. Peter Beadle
  - ♦ Formerly: University of Wollongong, Wollongong, Australia
  - ♦ Currently: Assistant Director, Motorola Australian Research Centre, Botany, NSW, Australia

Badge Prototype and Badge 1

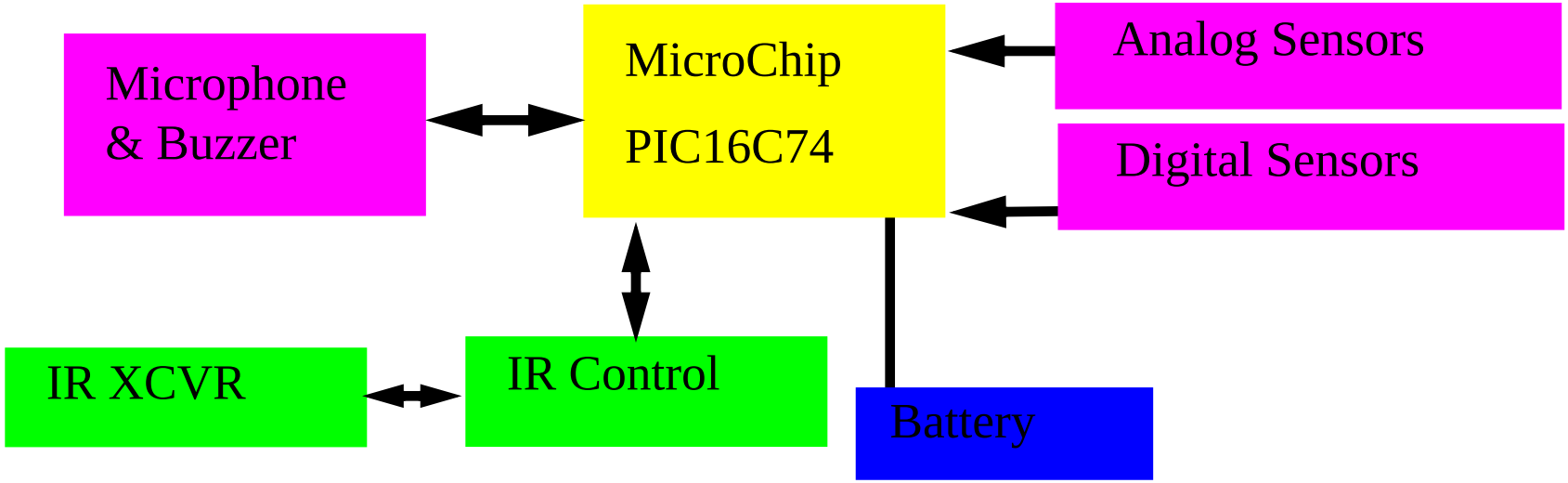


- Sound, Light, Temperature, Humidity, Orientation, Adjacency
- Beeps
- PIC 16C74A-jw based
- 5 MIPS
- 4m range
- 98mA average power





Smart Badge 1



Conceived in January 1997; Used in the “finger” course in May 1997

URL: http://www.it.kth.se/edu/gru/Fingerinfo/telesys.finger/Mobile.VT97/mobile.vt97.html

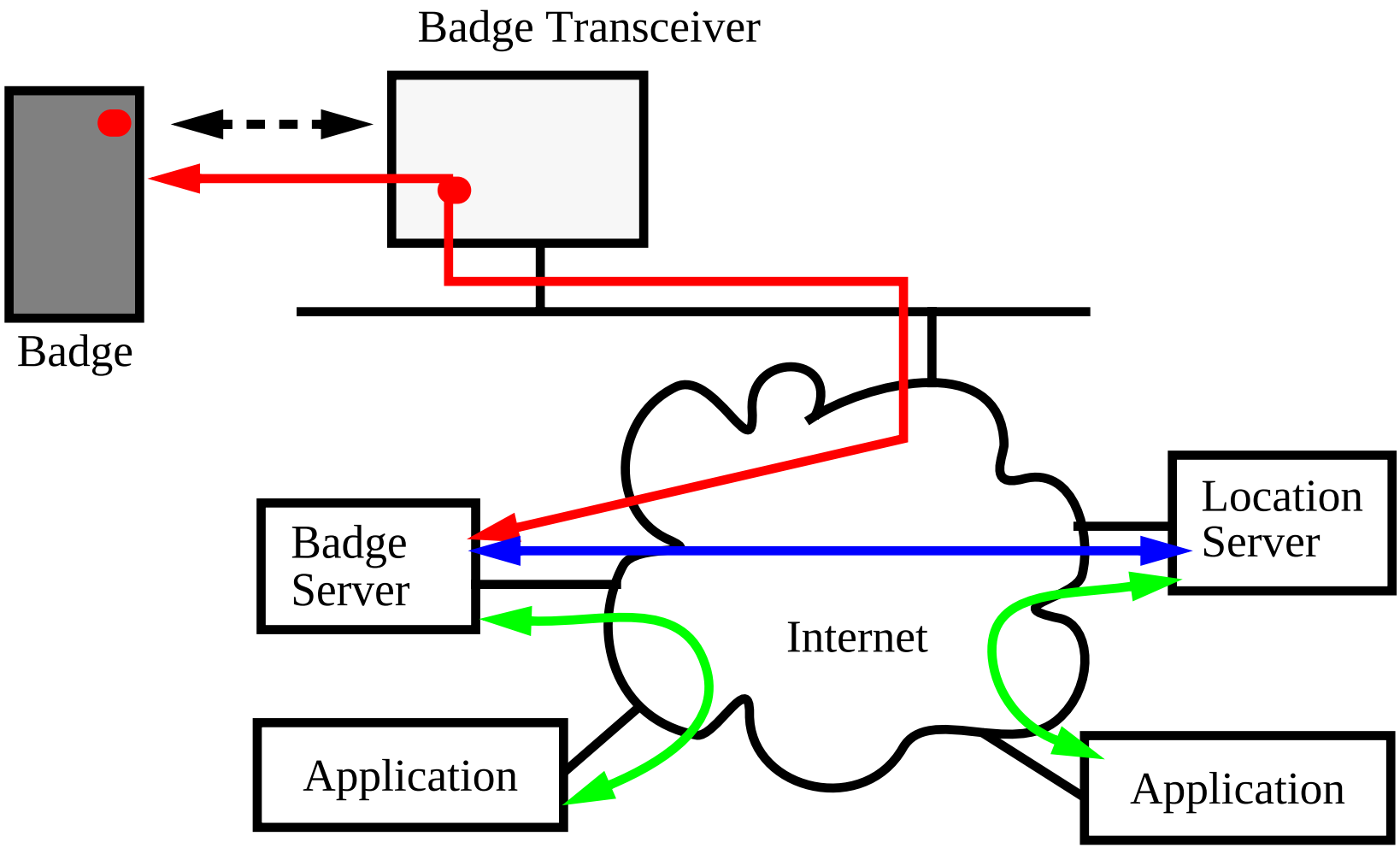
85x55mm $\Rightarrow$ 46.75 mm^2 - component cost ~US$30

24 systems made using milling machine and hand assembly

Subsequently used for course at Univ. of Wollongong and thesis projects at: KTH, Wollongong, Ellemtel, Ericsson Radio, …

Badge Communications Model

Badges are IP devices (or should be), they communicate via network attached access points.



Software for Badge1

Badge

In the badge was a small C program which:

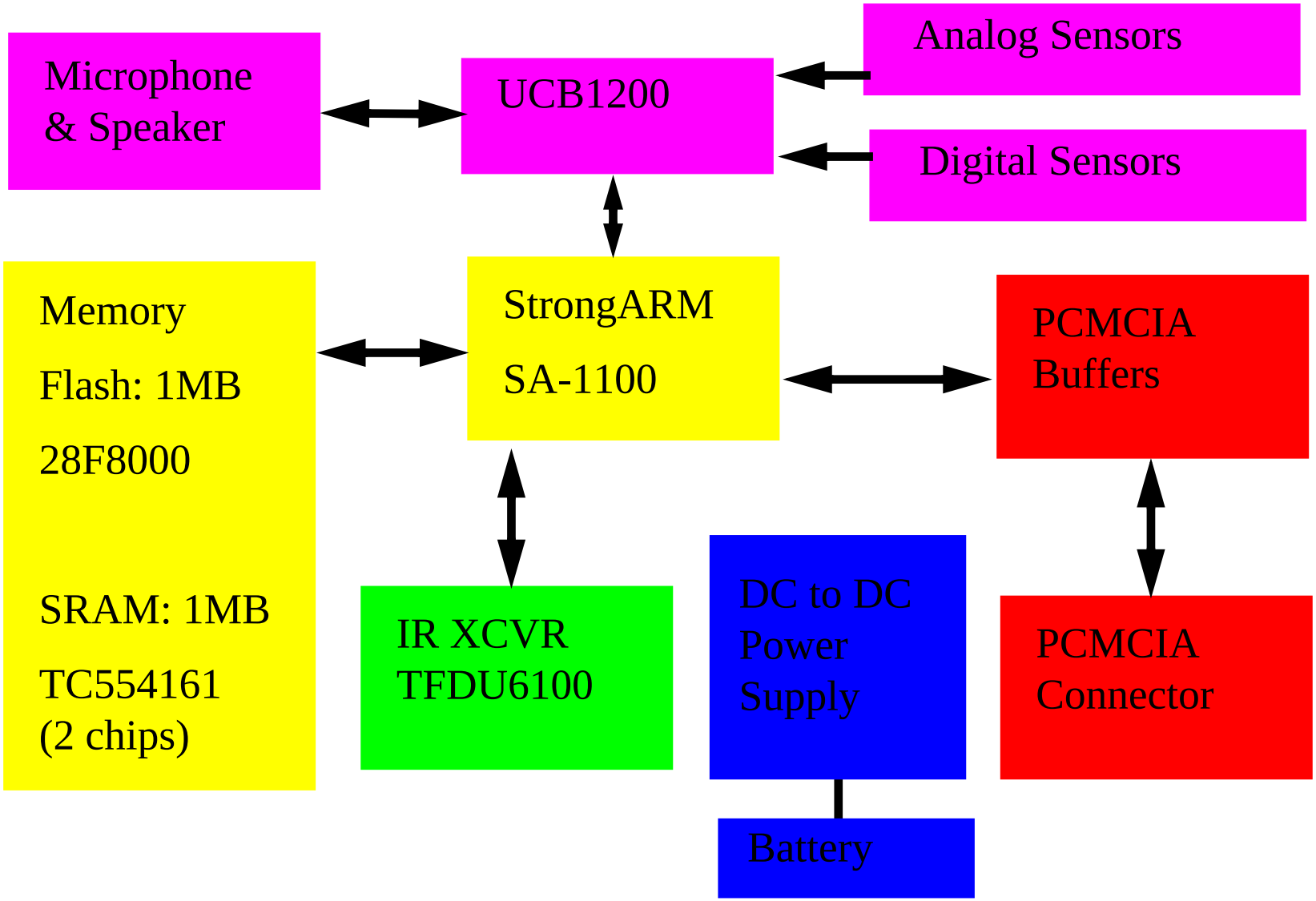
- got the sensor values and sent them to badge server
- listened for a response from an access point
- went to sleep

It was smart enough to sleep longer if it realized that it was horizontal and in the dark.

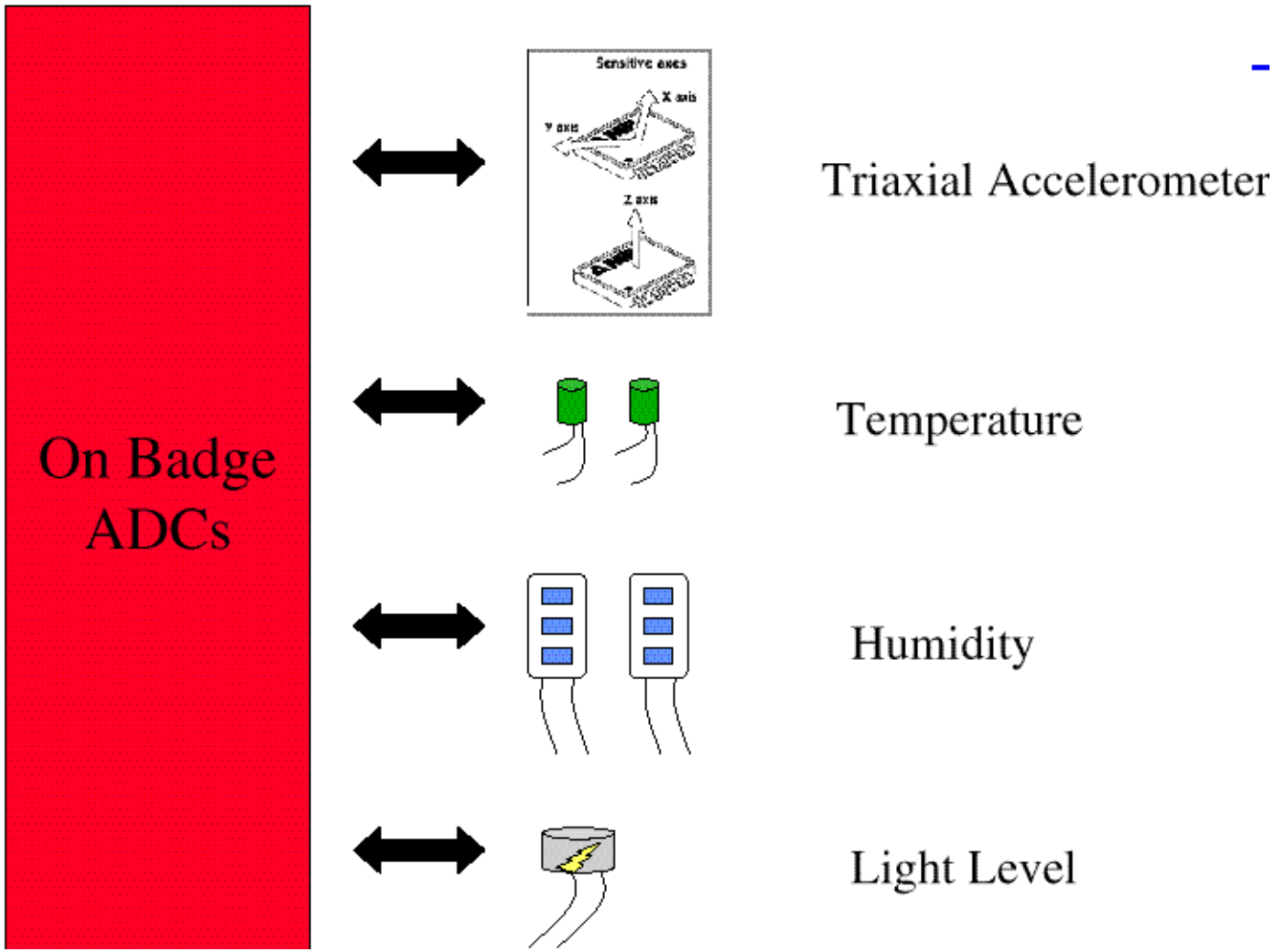
Badge Server

- Put badge sensor values and reports into a set of WWW pages
- Ran scripts which could be triggered by new badge “events”

Smart Badge 3

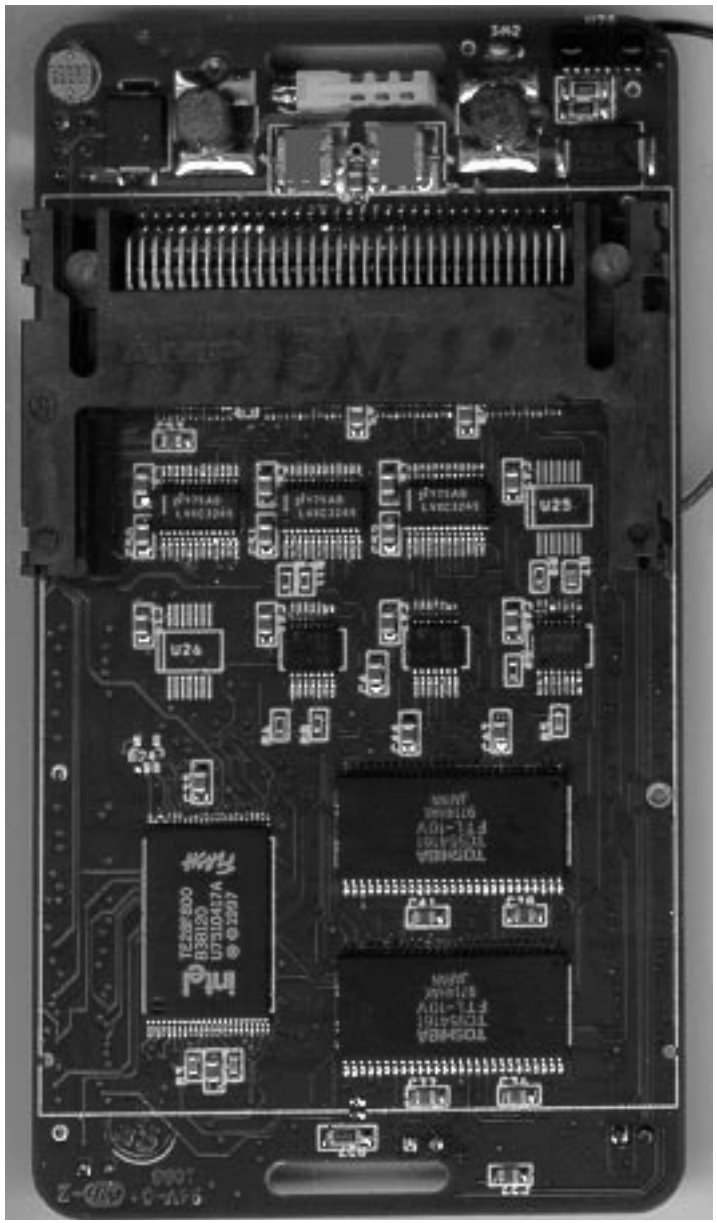


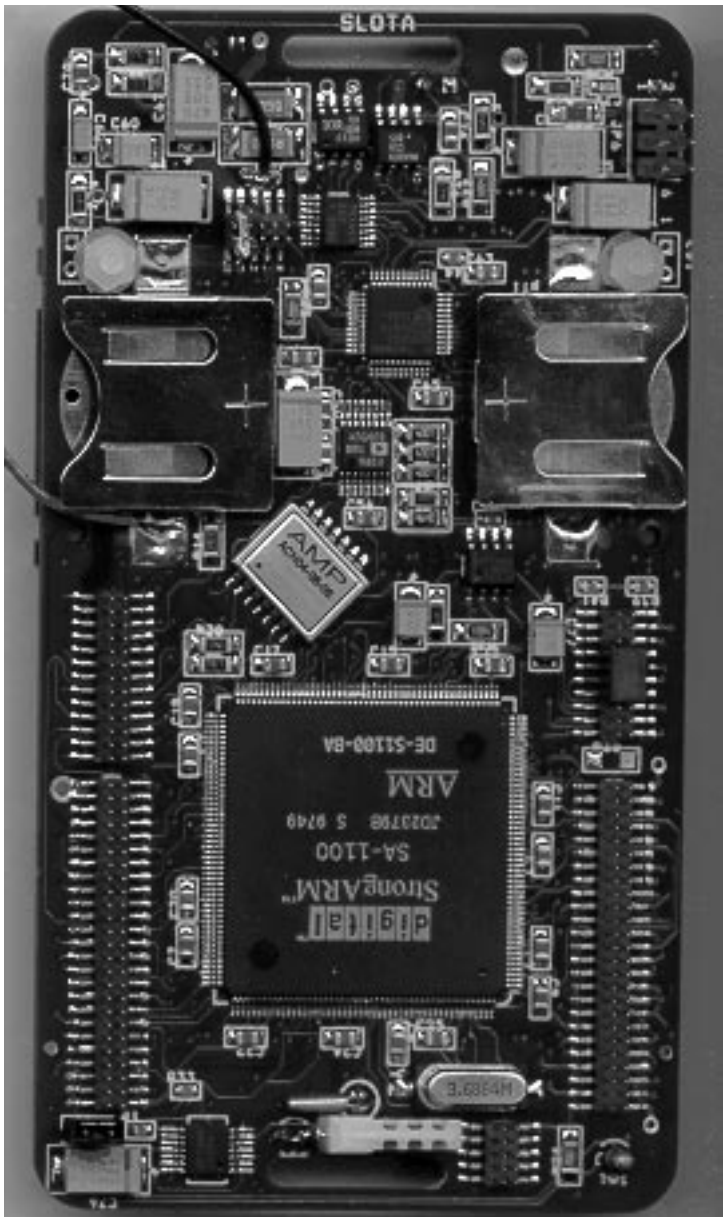
Smart Badge Sensors



Details of the 3rd version:
http://www.it.kth.se/edu/gru/Fingerinfo/telesys.finger/Mobile.VT98/badge3.html

Badge 3





Software for Badge3

Currently

- Small kernel based on ARM debugger (Angel)
- Extended to allow user installed device drivers
- Mostly small applications written in C, most of their time is spent doing interrupt drived processing and sleeping

Future

- Inferno
  - ✘ currently it is too large
  - ✔ provides a VM which makes supporting (and developing) applications easier [my not need much from an OS]
  - ✔ provides security and distributed computing - from the start
- Java
  - ✘ current much too large
  - ✘ does not really provide a based of distributed computing

IBM Visionpad

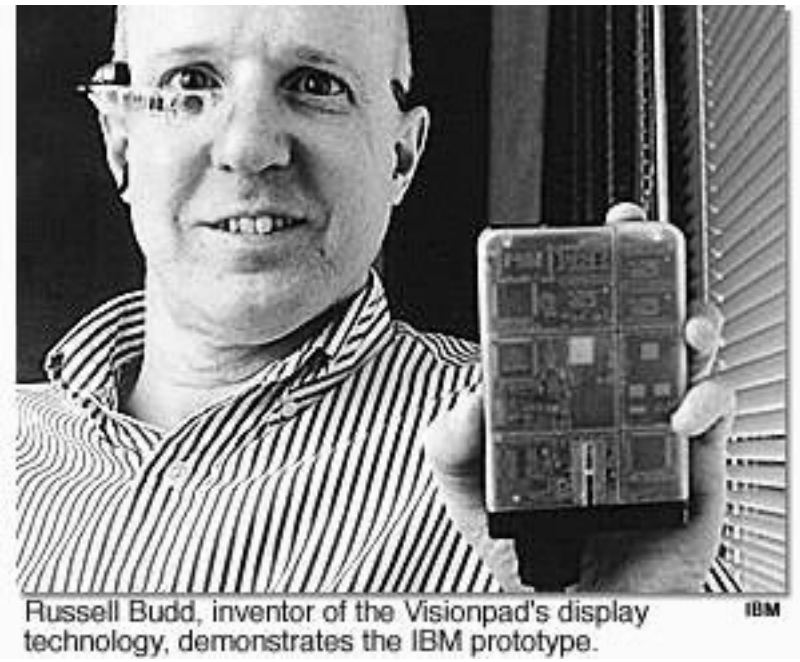


Figure 3: from http://www.zdnet.com/zdnn/stories/news/0,4586,2169690,00.html

Possible limited rollout of the Visionpad by the end of the 1999 at ~$3,000

IBM Embedded Systems in Japan: ThinkPad 560X (Prototype)

http://www.watch.impress.co.jp/pc/docs/article/980911/ibm.htm

CPU	Intel Pentium with MMX @ 233MHz
Memory	64MB(EDO)
Framebuffer	NeoMagic MagicGraph 128XD 2MB
Hard disk drive	IBM Microdrive 340MB
Display	320x240with 256 colors - to headsup display
	800x600 - external video
Serial interface	USB
Card Bus Controller	TI1251
	Intel NorthBridge + SouthBridge
Mouse	Trackpoint + 3 buttons on a cord
Audio interface	Crystal CS4237B + external headset+microphone
IR communications	IrDA 1.1
Audio - software	ViaVoice Gold
OS	Windows 95/98
Size	80 x 120 x 26mm
Weight	299g + 50g

IBM MicroDrive 340MB

http://www.storage.ibm.com/hardsoft/diskdrdl/prod/micro/170340/170spec.htm

Capacity	340MB / 170MB
Number of heads	2 / 1
Number of disks	1
Rotational rate	4,500RPM
Seek time (typical read) average	15ms
Voltage	3.3V
Dimensions	36.4x42.8x5.0mm
Weight	20g
Interface	CompactFlash Type II (CF Type II)

Displays

A summary of links is at:

http://lcs.www.media.mit.edu/projects/wearable/display.html

Basically the status is that for low power, small size, low resolution - Kopin's technology is still in the lead (used in the Microoptical eyeglasses display: http://www.microopticalcorp.com/).

The IBM micro-display probably uses techniques from laser printers - given the background and earlier patents by Russell Budd.

Other Wearables

Primarily built on PC (often PC/104) or smart phone base

Most PC based wearables have not taken **power** and **size** into enough consideration

Connectors are a major problem on wearables

- USB is not a small connector
- supporting dual voltage PC Card (aka PCMCIA) required physically large connectors

Xybernaut's MA IV - price $5,000 to $6,000

- 200MHz or 233MHz Pentium with MMX Technology processor
- accessed via keypad and belt-bound mouse, or by a headset microphone and IBM's ViaVoice.
- a 6.3-inch tablet **or** a head-mounted display capable of 640x480-resolution and 256 colors

ViA's ViA II - price $3,200 to $5,000

- Cyrix Corp.'s 180MHz MediaGX processor
- pen-based tablet or voice recognition for input -- partnered with Lernout & Hauspie Speech Products N.V. - to create a new voice recognition package

Software

- Most of these PC style devices are running Microsoft software (typically Windows CE)
- Some of these systems are using Virtual Machines (Java or Inferno)
- Some are running real-time kernels
- Some are running proprietary kernels: such as that proposed of Symbian (http://www.symbian.com/)

Wireless (Radios, IR)

IEEE 802.11

		Cost US$
Freq. Hopping	BayStack 660 Wireless LAN **PC Card**	$569
	BayStack 660 Wireless LAN Access Point	$1,799
Direct Sequence	BayStack 650 Wireless LAN **PC Card**	$499
	BayStack 650 Wireless LAN Access Point	$1,499

See for example: http://www.baynetworks.com/news/press/9808241.shtml

GSM - Ericsson GC25, Nokia PC Card Phone, …

- PCMCIA Type III card
- full GSM services

Ericsson Mobile Office DI 27

- clip on IR interface for 900 series phones

DECT (Digital Enhance Cordless Telephony) - as a wireless LAN technology

Latency

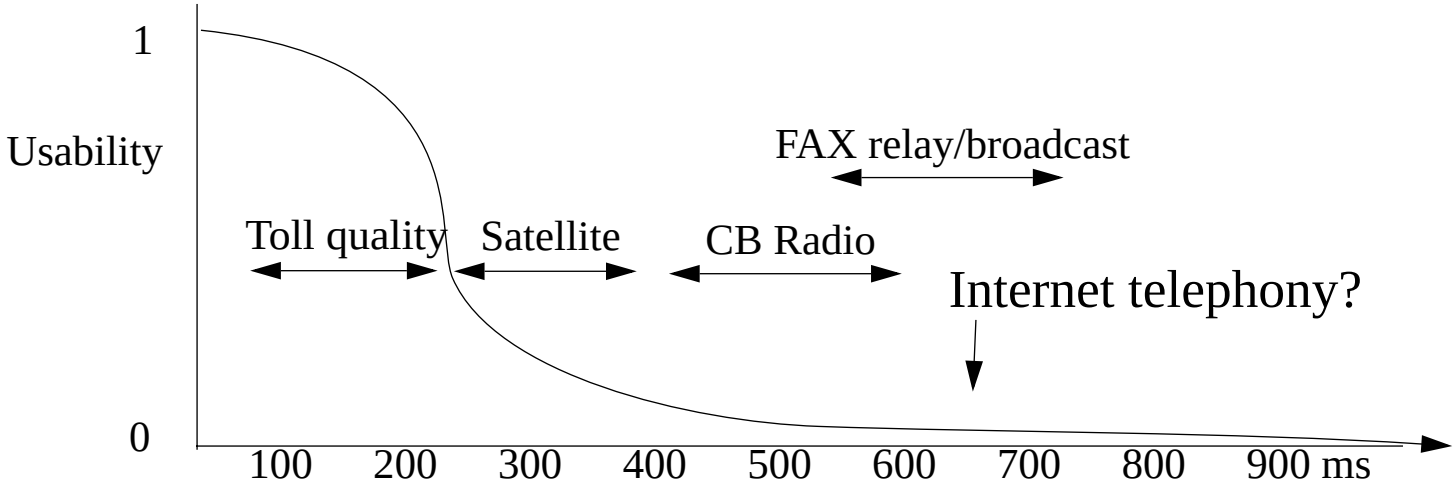


Figure 4: Usability of a voice circuit as a function of end-to-end delay (adapted from a drawing by Cisco)[a]

a. http://www.packeteer.com/solutions/voip/sld006.htm

However:

Round-trip	min (ms)	avg (ms)	max (ms)	hops
Local LAN	1	1	3	0
to northern Sweden (basil.cdt.luth.se)	21	25	41	8
to Austria (freebee.tu-graz.ac.at)	73	109	353	18
To server in US network	131	306	526	19
To my machine in the US (~30 ms is the ISDN link)	175	328	600	21
To KTH's subnet at Stanford University in the US (ssvl.stanford.edu)	166	170	217	20

Voice over IP (VOIP)

- PC to PC
- PC-to-Telephone calls
- Telephone-to-PC calls
- Telephone-to-Telephone calls via the Internet
- Premises to Premises
  - use IP to tunnel from one PBX/Exchange to another
- Premises to Network
  - use IP to tunnel from one PBX/Exchange to a gateway of an operator

Future Developments building on VOIP

- Fax broadcast
- Improved quality of service
- Multipoint audio bridging
- Text-to-speech conversion and Speech-to-Text conversion
- Voice response systems
- Replacing the wireless voice network's infrastructure with IP:
  U. C. Berkeley's ICEBERG: Internet-based core for CEllular networks BEyond the thiRd Generation

More audio on-line

Microsoft® Cordless Phone - http://www.microsoft.com/products/hardware/phone/overview/default.htm

- voice commands
- voice mail
- (only a serial connection to attached PC)

MP3 players - http://www.mp3.com/hardware/

- Diamond Multimedia's new Rio PMP300 Portable Music Player, ...

Mobile RealAudio - http://www.audible.com/audible/tour/real.html

Cameras

Adding cameras to eye-glasses

- Forward looking - so the camera sees what the person is looking at
- Backward looking - so the camera can see the person’s eye - for eye tracking, …

More Images on-line

- HP CapShare 910 - Handheld scanner - with automatic stitching - produces PDF
- Network attached “copiers” - really a scanner + printer
- CrossPad® - Personal Digital Notepad - from pen strokes to digital stroke info
- Web cameras - networked cameras, cameras notebooks, cameras on your eyeglasses

⇒ more and more source material

⇒ scanning and image capture allow parallelism in adding material to the web

Dr. Mark T. Smith of HP Labs asks the question:

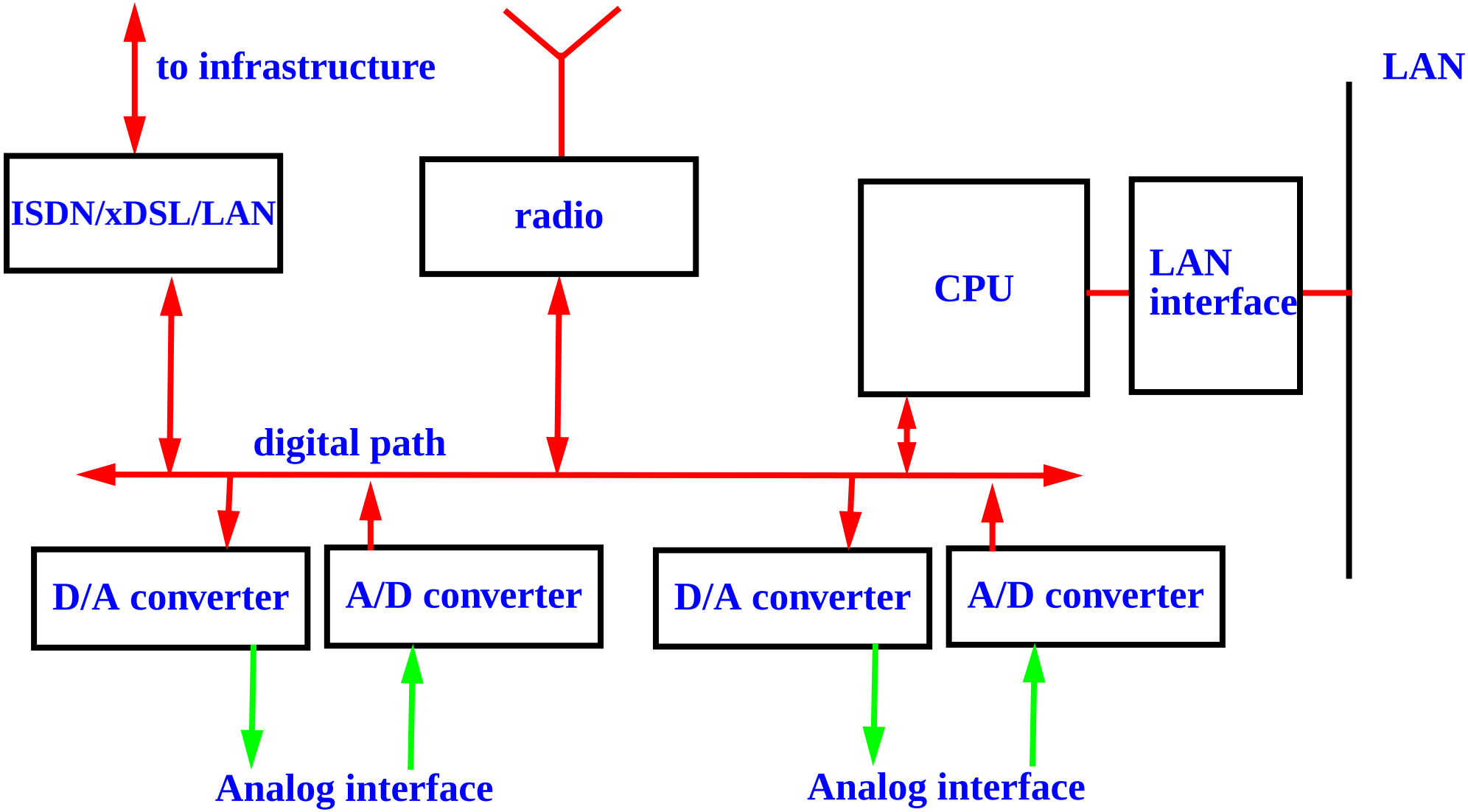
> “Given the large numbers of digital cameras, if they labelled their pictures with the location and orientation of the camera at the time of the picture, then how long would it be before you could do a virtual walkthrough of San Francisco?”

With network attached handheld scanners - how long before 90% of all books are scanned?

CapShare 910

Press photo from HP's web page: (see http://www.capshare.hp.com/press/images/zorro1.jpg)

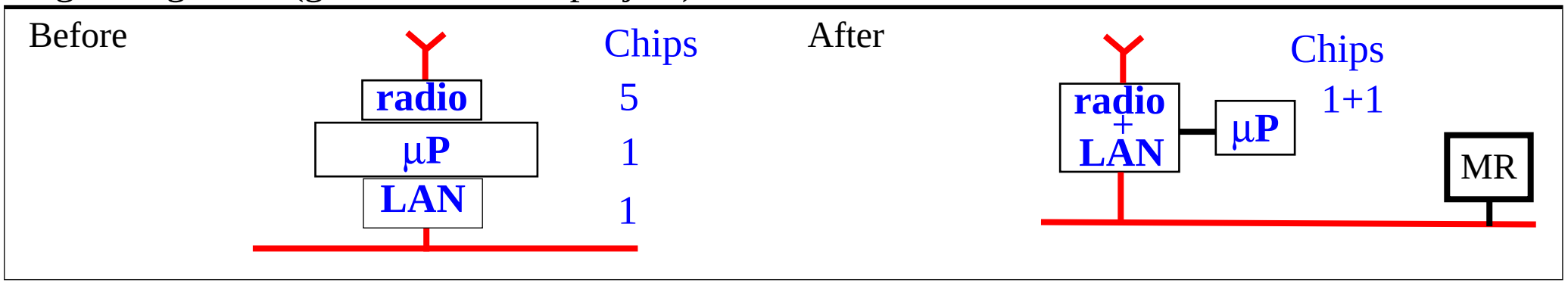
Local access point



All but the radio are current inside an Ascend Communications Pipeline 25 or 75.

MEDIA

High integration (goal of MEDIA project)



Partners:

- Kungl Tekniska Högskolan (KTH/ELE/ESDlab and KTH/IT/CCSlab)
- Tampere University of Technology (TUT)
- GMD FOKUS (GMD)
- Technische Universität Braunschweig (UBR)
- Interuniversity Microelectronics Centre (IMEC)
- Ericsson Radio Systems AB (ERA)

See http://www.ele.kth.se/ESD/MEDIA for more information

New objects in Web space: URLs or URNs on everything

Henrik Gustafsson'Matchbox Badge
http://www.pcs.ellemtel.net/pcc/TI98/Prototype/equipment.htm

I magine an International Article Numbering Association (EAN International) or Universal Product code (UPC)[1] subspace mapping to product web pages with safety, ingredients, recipes, etc.

as computed by:
http://www.milk.com/barcode/

http://051000029522.upc.org

or perhaps:

http://029522.051000.upc.org

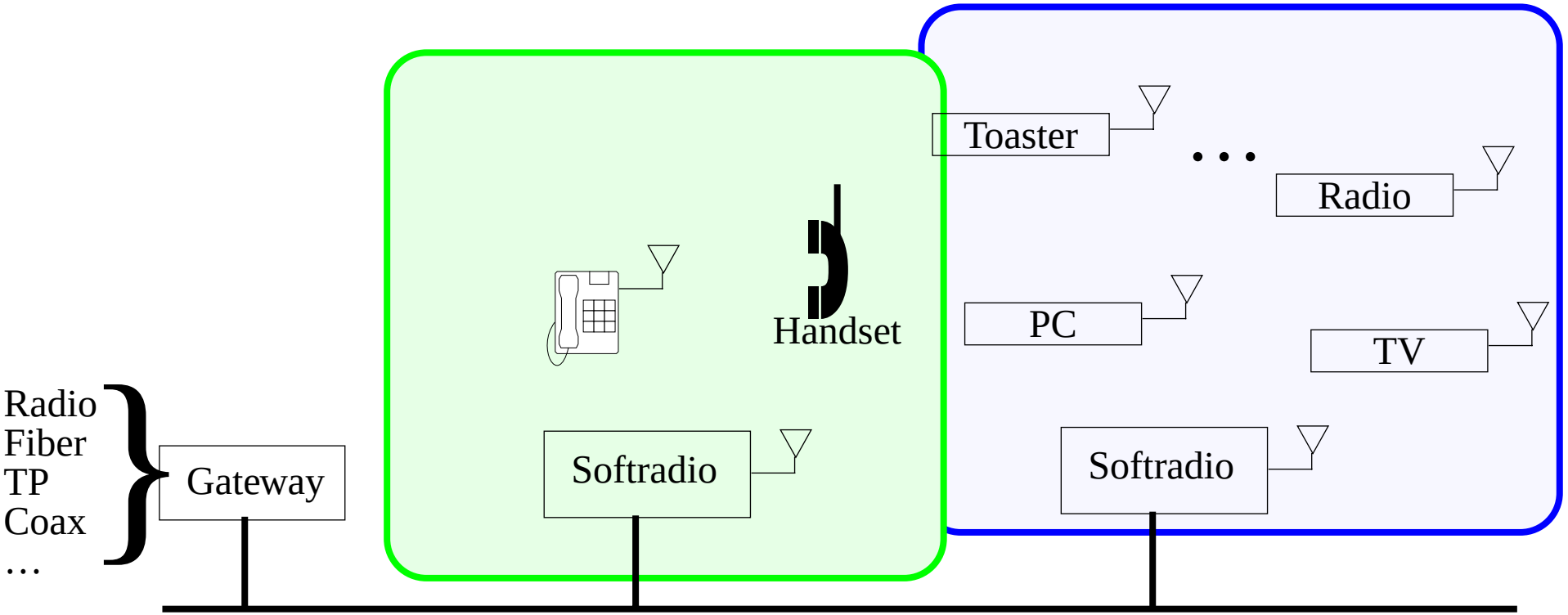
in item.manufacturer form more suitable for DNS use

For decodings see http://www.deBarcode.com/ for UPC or
http://www.upclink.com/ for mapping from ISBN to publisher's information about a book

http://www.icepick.com/ - internet connected trash bin via pen-type barcode scanner

1. Invented by George J. Laurer of IBM, in 1973

Future home/office/… network accesspoints



Disappearing objects[1]

list of products which will disappear (in the sense of having a separate identity)

Wired phones	garage door openers
Cordless phones	wireless car door/vehicle security transmitters
Mobile (cellular) phones	GPS units (as a separate single purpose device)
(pocket) radios [Also applies to vehicles]	calculators
stereo receivers	credit cards/checks/cash {the later will soon be outlawed in any case}
tape decks	clocks and watches
TVs	pagers
CD players	computers as PCs/Workstations/... {which we already can not always recognize!}
modems	File Cabinets[a]
answering machines	ATM machines
cable decoders	Maps
FAX machines	Thermometers
newspapers and other periodicals (in print form)	Business Cards
film based cameras (except for pure hobbyists)	Security Badges
VCRs and camcorders	Toll Booths

a. This item and the following 6 were contributed by prof. J.M. Smith, University of Pennsylvania.

1. This list was originally proposed by G.Q. Maguire Jr. in 1995

Problems

When should others be able to know your location and context?

Who should be able to know? When?

Can you be compelled to provide such data?

When should others be able to know the substance of your communications?

U. S. law: “Communications Assistance for Law Enforcement Act” (CALEA)

- http://www.fbi.gov/calea/calea1.htm
- seems to be leading towards E911 level of location information (within ~100m 66% of the time) as part of the **start** and **end** mobile call records
- access to call records don’t require a court order, only reasonable cause
- wire tapping being extended to those near the person for who there is a court order
- proposes wiretapping in Packet Networks

For some analysis of the privacy issues see http://www.cdt.org/digi_tele/status.html

Tapping of all US phones is feasible[1]

150M	number of phones in North America
1.20E+12	total bytes per second of all phones
3.78E+19	total bytes per year for all phones

Total	GSM compressed audio	8hours/day of GSM compressed audio	
37.8E+06	3.37E+06	1.12E+06	Terabytes/year
103.68	9.23	3.08	Terabytes/station/day
300	27	9	Drives/site
$75B	$6.75B	$2.25B	Capital cost
$189M	$16.9M	$5.62M	Cost per year

Assuming 64Kb/s single B channel data rate, the drives cost $250K each, media $5K/Terabyte, writing rate of 4 Megabytes/s/drive, with 1000 distributed stations for recording

Compare to expected number = 27,688; maximum expected = 37,348; and “historical evidence” = 18,532 from FBI’s Final Notice of Capacity, Appendix A - requirements by county.

1. Technically and economically; but not necessarily politically

Personal Computing and Communication (PCC)

Upper limit of bandwidth: saturate the senses: sight, sound, touch, smell, taste

$\Rightarrow$ ~1 Gbit/sec/user

Current workstations shipping with 1 Gbit/sec interfaces for LAN!

Telepresense for work is the long-term “killer” application

-- Gordon Bell and James N. Gray[1]

1. “The Revolution Yet to Happen” in Beyond Calculation: The Next Fifty Years of Computing, Eds. Denning and Metcalfe, Copernicus, 1997.

Looking forward

Turning a transistor on/off - number of electrons:

1997: 10^3 2010: 8-9 2020: < 1

We already have DNA based computing, the beginning of Quantum Computing, …

50 years: Auxiliary brain

- a single chip storing $2x10^{16}$ bits of data, ~storage capacity of 10^5 human brains.
- volume of 1 cubic centimeter, about the size of a sugar cube.
- with power of 500 million Pentium Pros
- able to record life's experiences and replay them

"We should not be shy about our predictions."

-- Joel Birnbaum, Senior VP R&D and Director of HP Labs[1]

1. from ACM'97:The Next 50 Years of Computing (http://www.acm.org/acm97/home.html) and http://www.research.microsoft.com/acm97/

Uploading ourselves to the net

In Bob Metcalf's speech at MIT: http://web.mit.edu/alum/president/speech.html

One of great insights of this talk is that the internet is the way to immortality[1]:

> Now, for the next 50 years, the web will drive electronic commerce into the information age, ubiquitous computers will disappear into the woodwork, and we'll start uploading ourselves into the Internet to become at last immortal.
>
> -- Robert M. Metcalfe
> June 26, 1997

1. Robert M. Metcalfe, "Internet Futures", MIT Enterprise Forum, June 26, 1997.

The Future is Now

The easiest way to predict the future is to make it.

- Alan Kay

Conclusions

- Low cost access points which exploit existing or easily installed infrastructure are key to creating a ubiquitous mobile infrastructure with effectively infinite bandwidth.
- Smart Badge is a vehicle for exploring our ideas:
  - Exploits hardware and software complexity by hiding it.
  - Explores allowing devices and services to use each other in an extemporaneous way.
  - Enables a large number of location and environment aware applications, most of which are service consuming.
  - Service is where the money is!
- Distributed research - means that the project never sleeps; global operations will be part of the key to success.
- Personal Communication and Computation in the early 21st century: "Just Wear IT!"
- Coming in 20-30 years: "Just implant IT!"