Personal Computing and Communication

It is more than just networking of mobile devices

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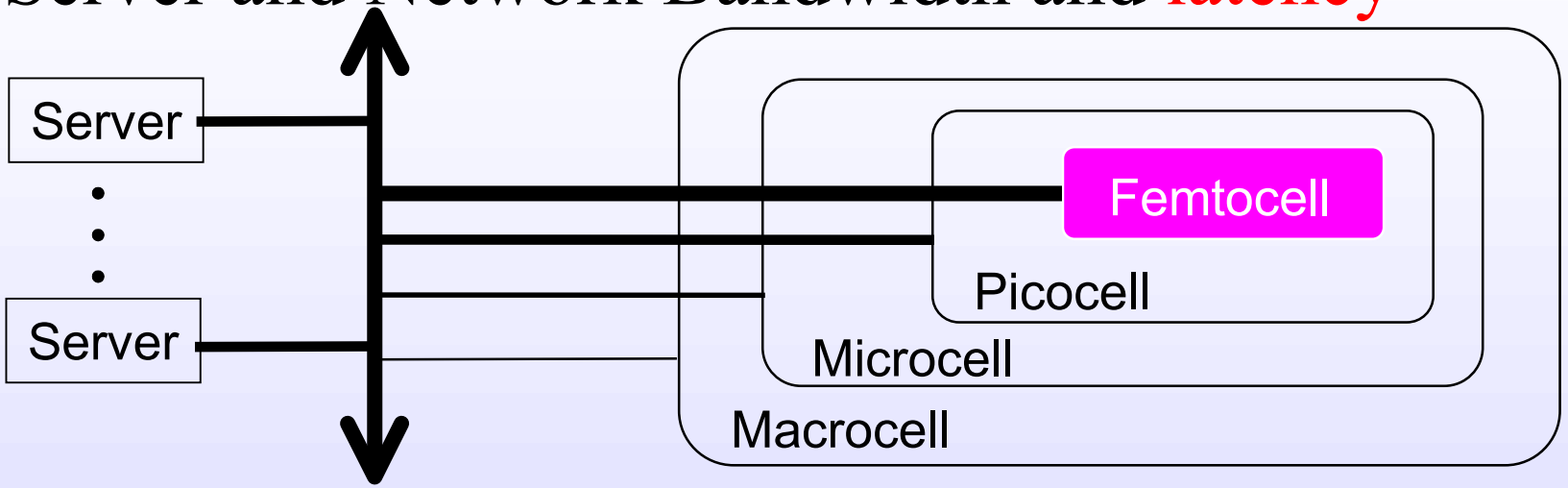
http://www.it.kth.se/~maguire

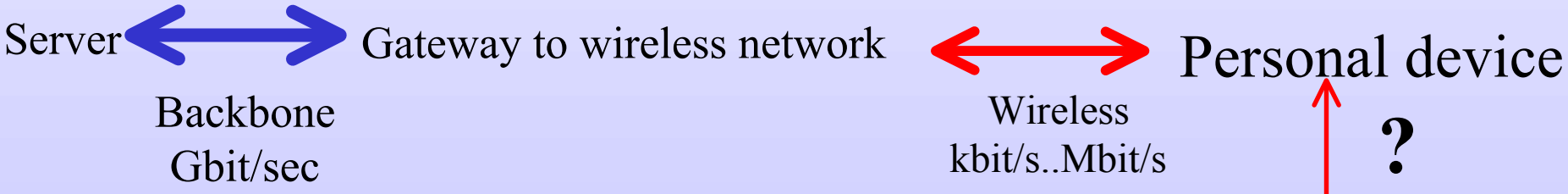
Networking 2002
23 May 2002, Pisa, Italy

Bottlenecks

- Server and Network Bandwidth and latency

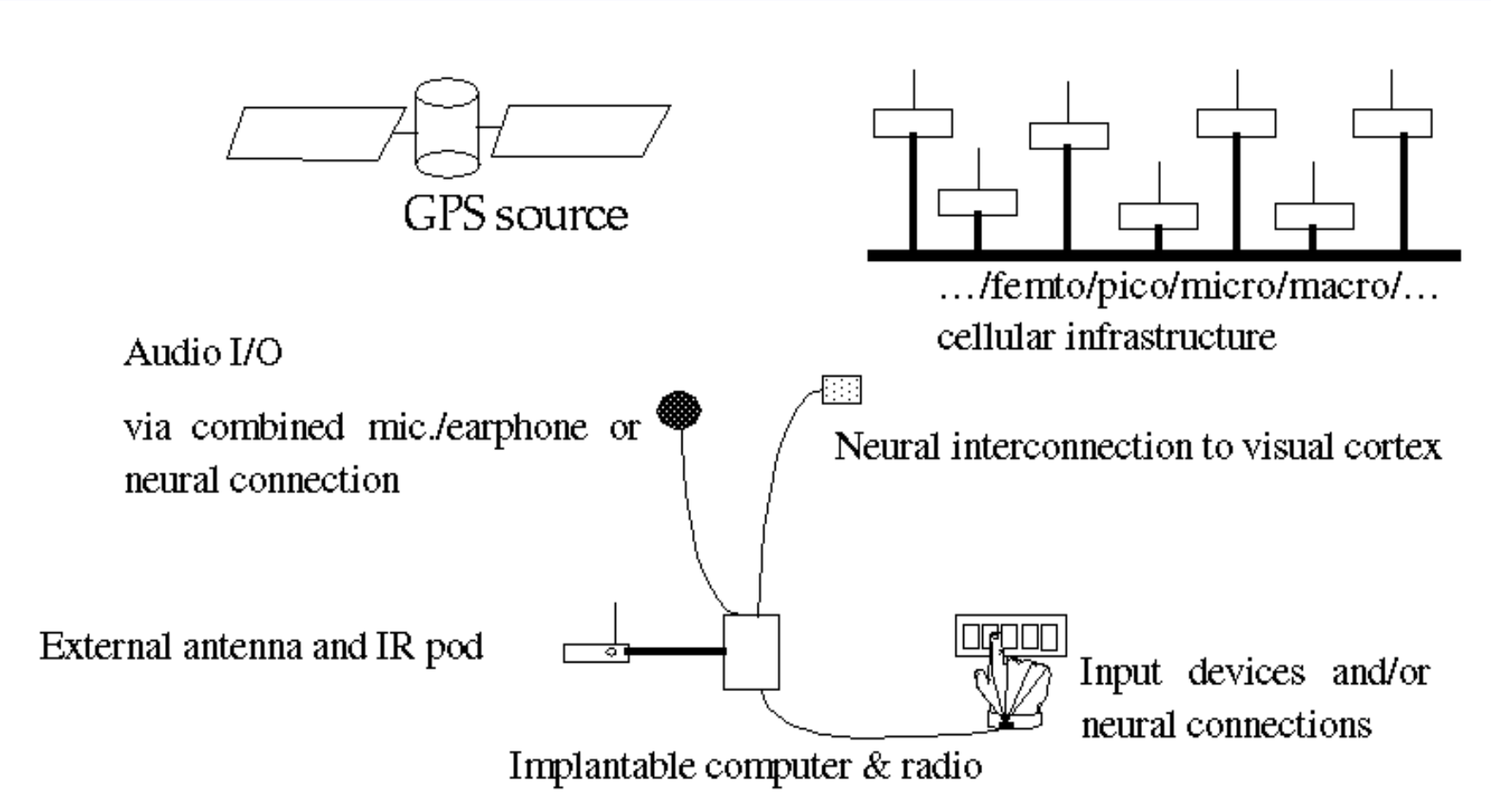


- User Bandwidth and latency



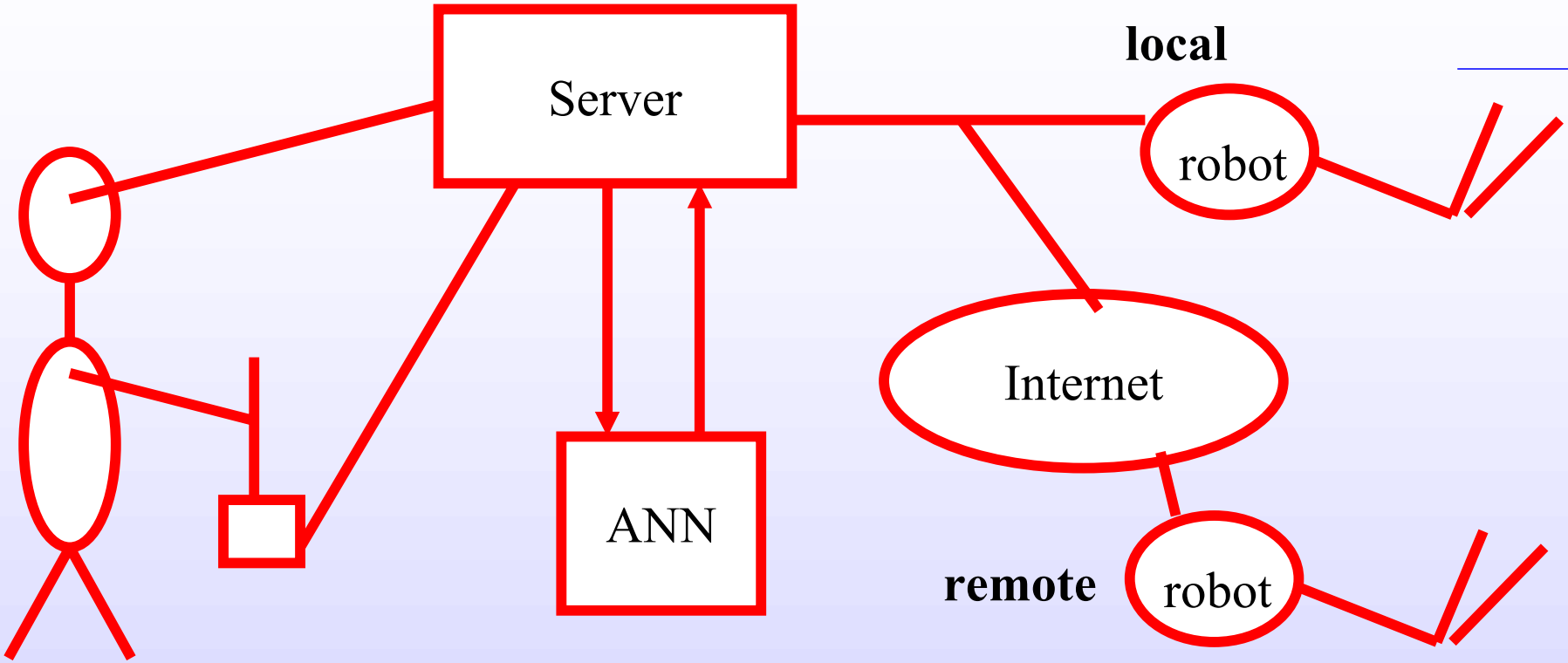
- Power and Energy → O(energy)
- Imagination!

Future Systems



2005-2015 - very high level of integration

Remote Hapatics, Remote Control, ...



"Real-time prediction of hand trajectory by ensembles of cortical neurons in primates" , J. Wessberg, C. R. Stambaugh, J. D. Kralik, P. D. Beck, M. Laubach, J. K. Chapin, J. Kim, S. J. Biggs, M. A. Srinivasan, and M. A. L. Nicolelis, NATURE, v408, 16 Nov. 2000 pp. 361-366.

Up to **96** 50-µm diameter microwires implanted in different cortical areas

see also **Tom Clarke, "Here come the Ratbots: Desire drives remote-controlled rodents",** Nature, 2 May 2002 and **S. K. Talwar, et al. "Rat navigation guided by remote control." ,** Nature, 417, 37 - 38, (2002).

1989 - Student Electronic Notebook Project (IBM Research and Columbia University)

Notebook computer with "paperlike" (stylus) input + DS-SS radio

D. Duchamp, S. Feiner, and G. Q. Maguire, Jr. Software Technology for Wireless Mobile Computing. IEEE Network. 5(6):12-18, November, 1991

talk "*Student Electronic Notebook*", Swedish Institute of Computer Science, Nässlingen, Sweden,17 August 1990.

Partial support from NSF Grant ECD-88-11111 to Center for Telecommunications Research, Columbia University.

Student Electronic Notebook (SEN) Project

~20 Notebook computers with “paperlike” (stylus) input + ARLAN 230kbps DS-SS radio (in 902-928MHz ISM band) + flex circuit interconnects. Built upon an IBM PS/2 model 55 motherboard + PS/2 to ISA bus interface (for radio and LCD controller); 50 minute battery life

Running diskless AIX (a UNIX variant), X11, Andrew Windowing system, NFS, … first version of Mobile*IP.

J. Ioannidis, G. Q. Maguire Jr., I. Ben-Shaul, M. Levedopoulos, and M. Liu. Porting AIX onto the Student Electronic Notebook. 1991 ACM Conference on Personal and Small Computers, pages 76-82. Association for Computing Machinery, June, 1991.

NC State Univ. also had the same notebooks, but chose to use serial interface and make custom applications rather than use UNIX + X11. In the same amount of time they had **3 applications**, we had **all of the Andrew tools, UNIX applications, and several books** -- all working via a popup keyboard!

Student Electronic Notebook: Traffic

Researchers at IBM Research wanted "**traffic models**" from the group at Columbia University

- Initial models were **based on desktop applications**

These initial models were wrong!

- Mobile users switch tasks more often
- Mobile users have many more tasks running in parallel
- Very high correlation across users - due to social correlations
  (for example, course start times, professor saying "As you can see in figure XXX" and everyone wants figure XXX, …
  limited battery life ⇒

(a) Multicast wireless booting of 1Mbyte OS + 1 Mbyte of initial file system.

J. Ioannidis and G. Q. Maguire Jr. ***The Coherent File Distribution Protocol***, **RFC 1235, Network Working Group, June, 1991.**

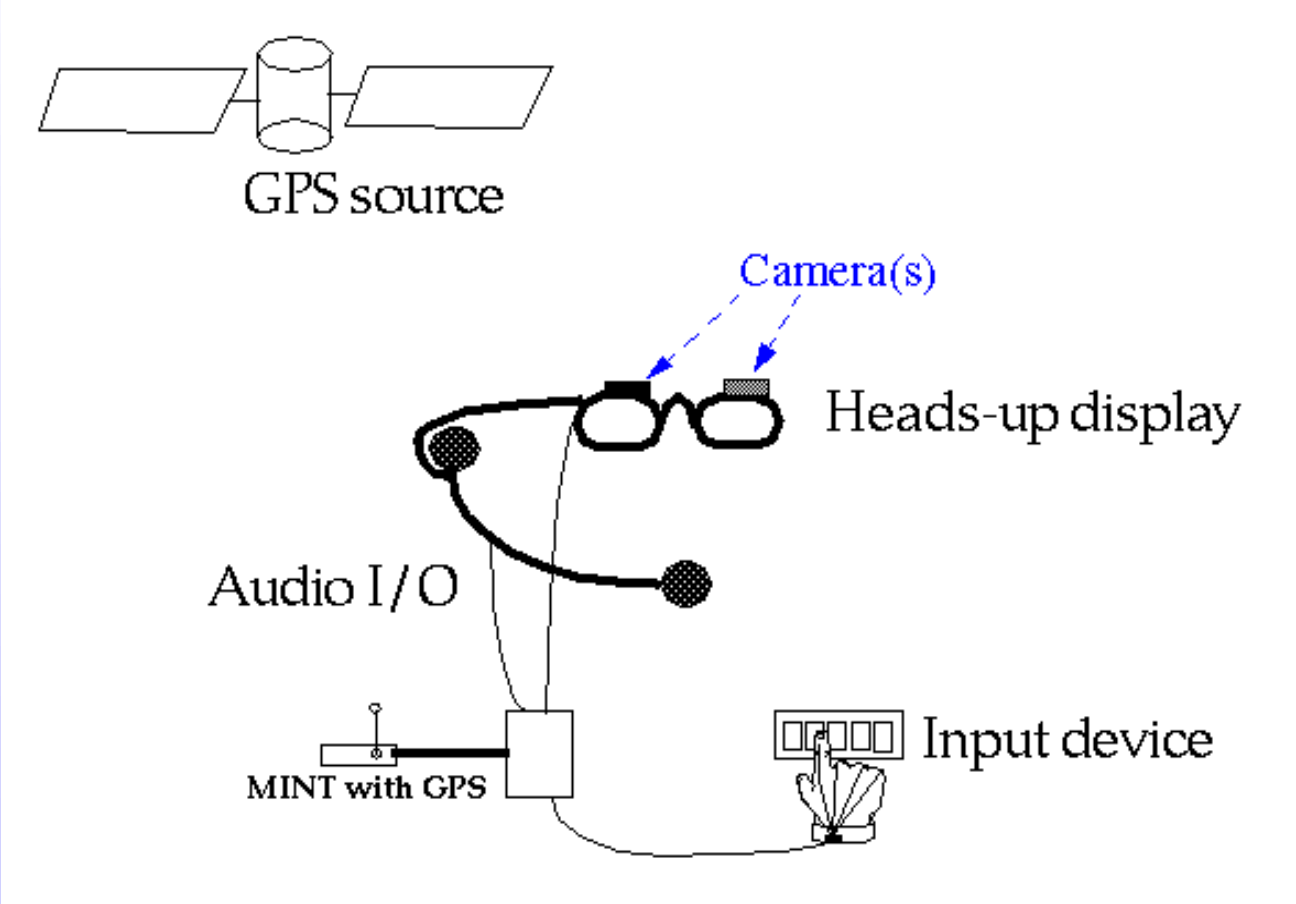
(b) Discussion of "anticipatory" file system

Carl Tait, Hui Lei, Swamp Acharya, Henry Chang ***Intelligent File hoarding for Mobile Computers*****, MOBICOM 1995**

Correlation (Lots of open problems)

- **Very high correlation across users - due to social correlations**
  (e.g., course start times, professor saying "As you can see in figure XXX" and everyone wants figure XXX, … , limited battery life
- **Multicasting induces correlation across streams (as observed by Don Towsley, University of Massachusetts, Amherst**
  - **" Network Tomography through End-to-End Multicast Measurements",** BU/NSF Workshop on Internet Measurement, Instrumentation and Characterization, Boston University, Boston, Massachusetts, August 30, 1999)
  - note that he **exploits** this in his MINC (Multicast Inference of Network Characteristics) technique: http://www-net.cs.umass.edu/minc/

Wearable(s)



June, 1995

WLAN in 2002

- IEEE 801.11b @ 11Mbps going to 23 Mbps ⇒ 802.11g
- IEEE 801.11a @ 54 Mbps ⇒ IEEE 802.11h

- Single mode 802.11b radio chips at < US$10
  - 802.11b built-in to: laptops, PDAs, MP3 players, ...

Ultrawideband (UWB)

- US FCC gave regulatory approval 14 February 2002
- Intel recently demo'd transmitter and receiver at **100Mbps**
- Intel expects to be able to get **500Mbps** at a few meters dropping to 10Mbps at 10m.

Martin Cooper's Law

Wireless bandwidth has effectively doubled every 2.5 years since Guglielmo Marconi received his first wireless telegraphy patent in 1896 (>100 years ago). This same pace of innovation will continue for the next 100 years.

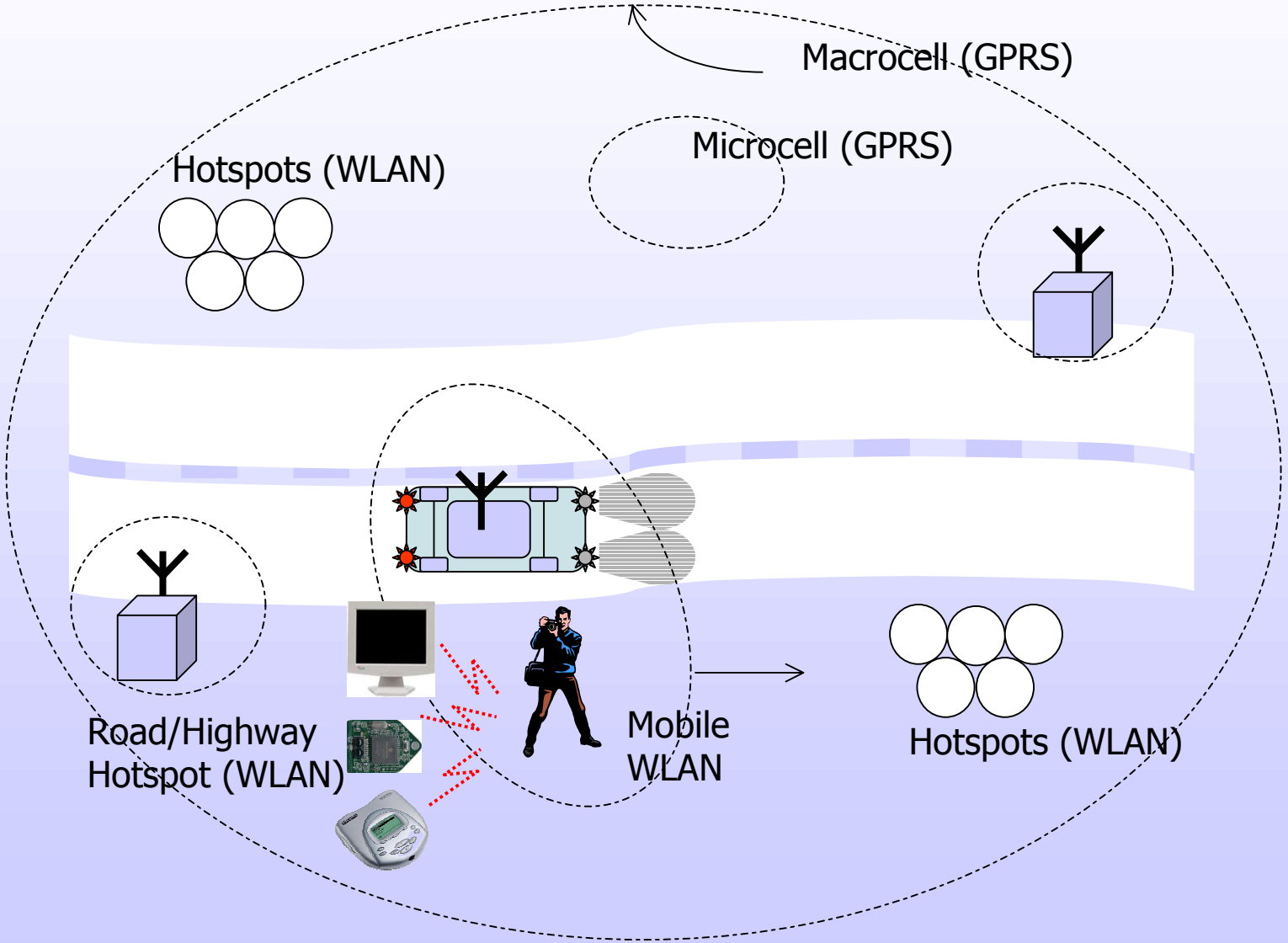
⇒	**2009**	**> 100 Mbps**	**10^8 bps**
	2016	**> 1 Gbps**	**10^9 bps**
	2041	**> 1 Tbps**	**10^{12} bps**
	2066	**> 1 Pbps**	**10^{15} bps**
	2091	**> 1 Ebps**	**10^{18} bps**

Beyond single radios

- Multiple radios
  - multiple bands GSM 900/1800/1900
  - multiple radio standards
    - W-CDMA + GSM
    - WLAN +GSM/GPRS
    - Multiple receivers - for enhanced handoff

  $\Rightarrow$ Theo Kanter's **πG** ($\pi \notin \mathbf{N} \wedge \mathbf{3} < \pi < \mathbf{4}$)
- Software defined radios - one radio which is just right (now)
- Cognitive radios
  - planning and negotiating to determine what it should be
  - Joe Mitola III's dissertation (http://www.it.kth.se/~jmitola)

Heterogeneous Wireless Packet Networks



Adampted from

T. Kanter

Doesn't Mobile IP provide the answer?

- First mobile version of IP protocol developed by John Ionannidis in 1989; one of two approaches at SIGCOMM'91
- Mobile IP defined by RFCs 2002 .. RFC 2006 (Fall 1996)

Mobile IP: Design Principles and Practices
Charles Perkins (January 15, 1998)

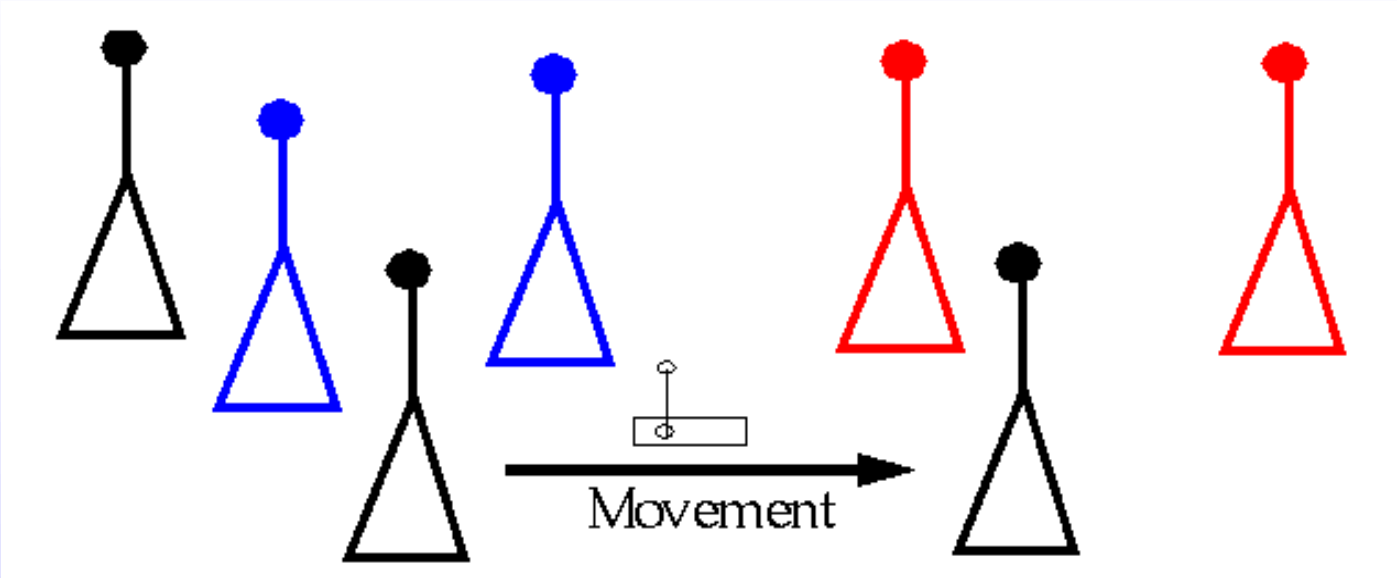
Mobile IP: The Internet Unplugged
James D. Solomon (January 15, 1998)

Objectives of Mobile-IP

- Provide mobility support across changes in IP subnet
- Support change in node location without changing IP address
- Communication should be possible while moving
- TCP/IP connections & Active TCP/UDP port bindings should survive the movement

problems: Mobile IP **hides** location & mobility!

Situational awareness and Adaptability



Where am I? What am I? Who am I?
Where am I going? When will I be there?

What should I become?
<u>Who</u> should I become?

Mobile keeps asking: Are we there yet?

Being able to listen for the next access point or new infrastructure is very powerful:

- can reduce handover times
- can reduce power usage (since you can use a low power link just as soon as it is available)
- dynamically assigned channels - useful for bursting data to a device (these could be orthogonal to the resources used in the cell) - consider for example use of a shorted (or longer) spreading code in a CDMA system

⇒ **Multiple receivers (more open problems)**

Toward human-centric systems

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?

But there is evolving environment/context awareness

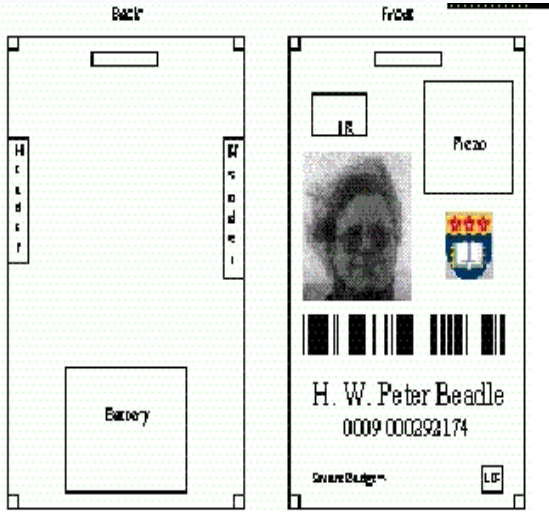
- **Give computers senses via sensors**
  - Environment/context
  - User identity and presence

You will wear your own personal user interface

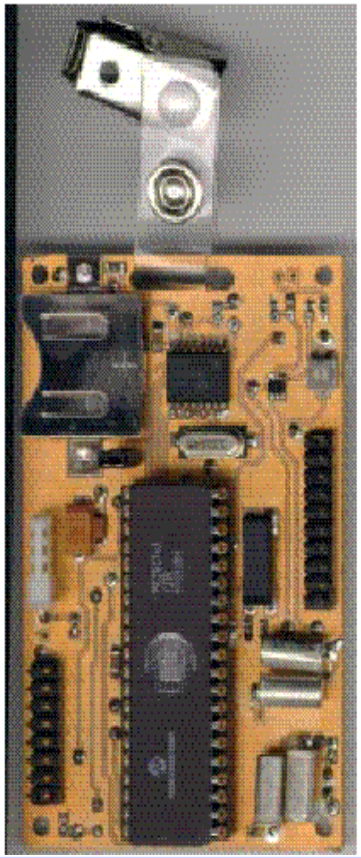
- **interface can be consistent across all appliances**
  - **not because each appliance supports the interface, but because the user's own interface provides consistency**

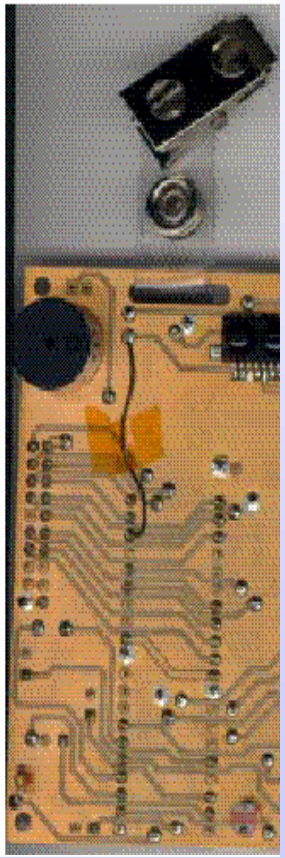
- **Make the human the focus of the computer's interaction**

Badge Prototype and Badge 1 (Spring 1997)



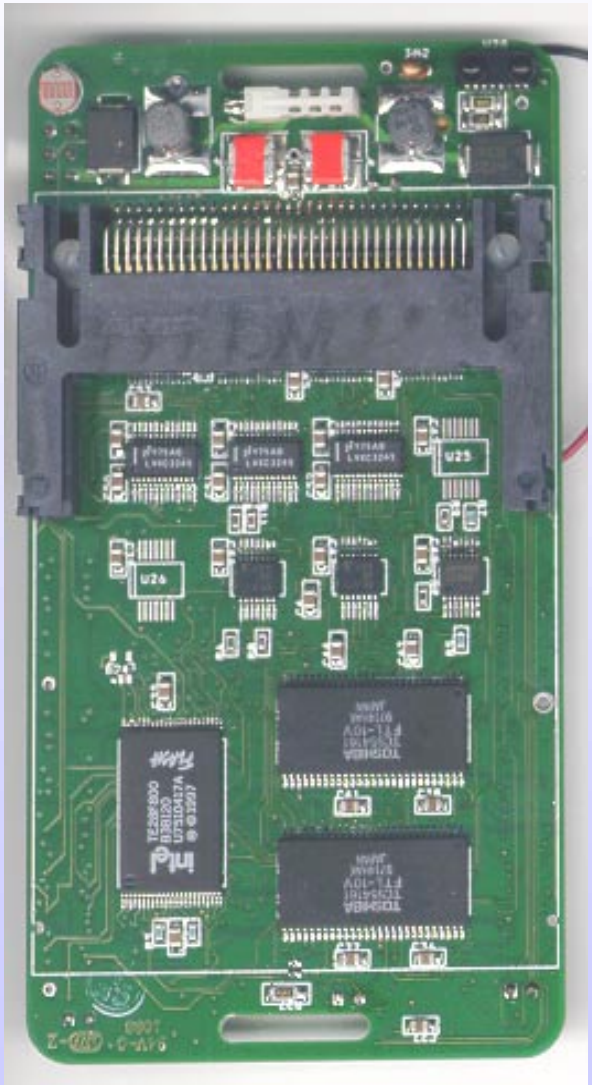
- Sound, Light, Temperature, Humidity, Orientation, Adjacency
- Beeps
- PIC 16C74A-jw based
- 5 MIPS
- 4m range
- 98mA average power

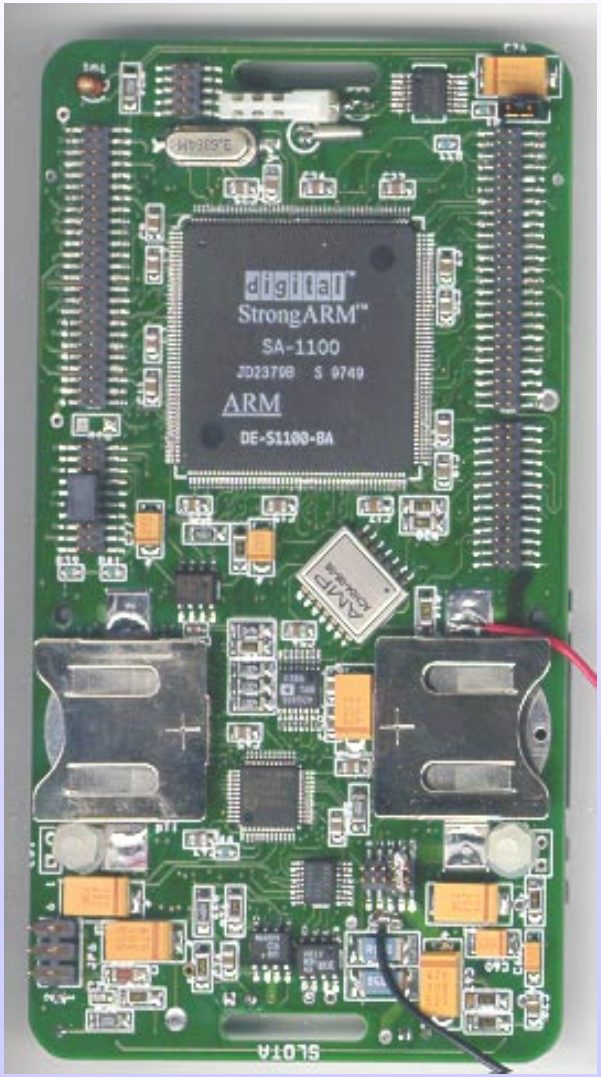




Badge3 (1998) - front and back

- 206MHz StrongARM
- Audio in/out
- LCD driver
- 2 x temperature
- 2 x humidity
- light level
- 3-axis Accelerometer
- PC Card slot
- IrDA
- 2 serial
- JTAG
- 1MB FLASH
- 1 MB SRAM
- full processor/memory interface on headers



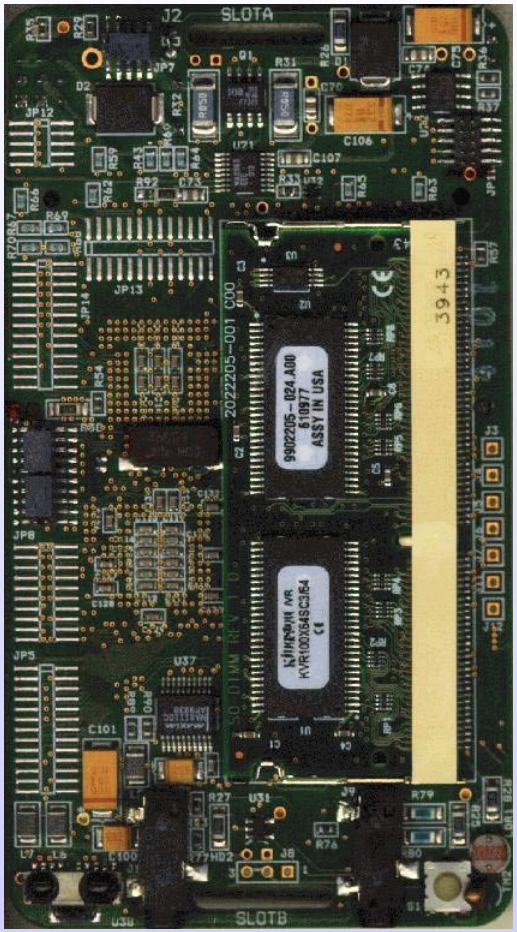


Badge4 (2001) - front and back

- 206MHz Intel SA1110 processor and SA1111 coprocessor
- CD qualityAudio in/out
- LCD driver
- 2 x temperature
- 2 x humidity
- light level
- 3-axis Accelerometer
- PC Card slot
- IrDA
- 2 serial
- USB (master)
- JTAG
- 4MB FLASH
- 2MB SRAM
- SO-DIMM slot

(PC100 SDRAM 64MB shown)

- Compact FLASH interface on header



HP + Swatch = webwatch

"The watch is an ideal way to stay connected to the Net because everyone has one and wears it willingly."

"You put it on in the morning and go about your business with no concerns."

"Because these devices are so smart and personalized, they're easy to use.

"No pointing, clicking, dragging, dropping, connecting or configuring. It just works." – Mark T. Smith, 15 Jan. 1999

Current Design (2002)

- Display System - supports multi-media
- 32 bit processor
- memory file system
- wireless network
- audio: speaker, microphone
- Multithreaded OS
- Peer web connectivity
  - XML/HTTP/TCP/IP
  - MPEG-2 to MPEG-4 transcoding (in transform domain)

In Future

More sensors

- Motion, biometric…

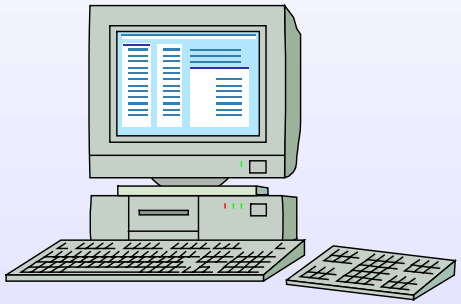
Security

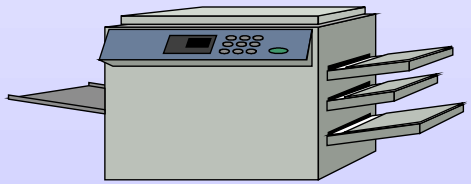
- encryption
- wrist band
- secure co-processor
- smart/SIM card

From Secure Ids ⇒ Device personalization

Authenticate the user

Personalize the device automatically





Consider a hotel without a check-in/out desk!

Camera/Scanner + Connectivity

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

User agent can get details at http://051000029522.upc.org or http://029522.051000.upc.org {hypothetical domains}

Returning "item.manufacturer" for further lookups: dietary information, recipies, check with the fridge, …

For example: www.airclic.com returns:

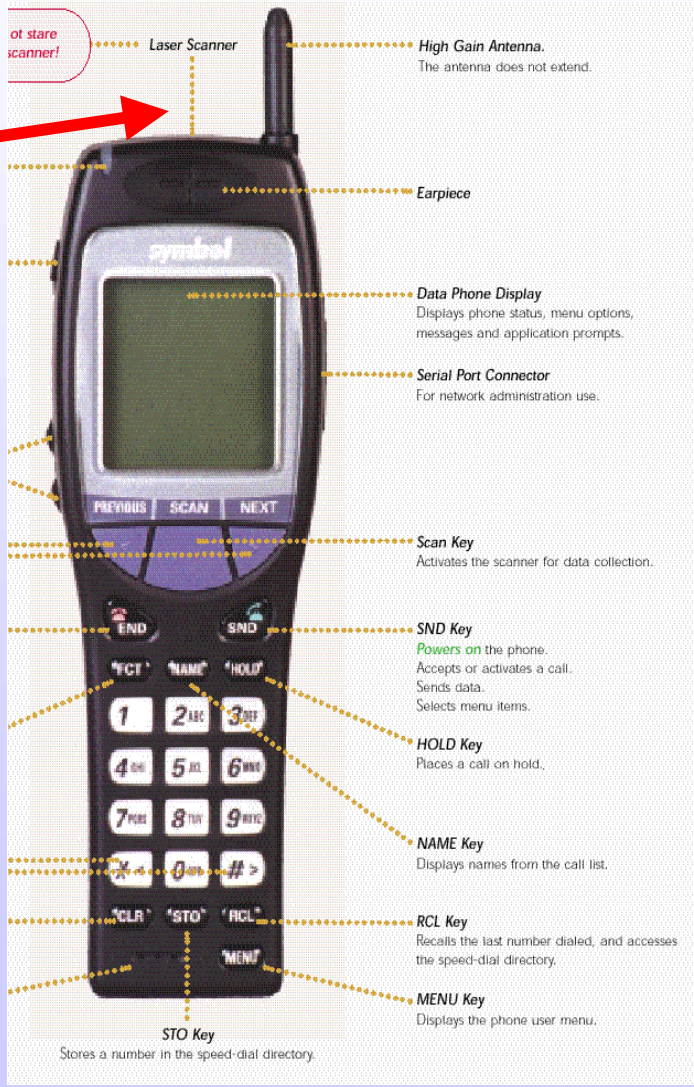
"You have entered, Campbells Pork And Beans in Tomato Sauce 16 oz Can …"

Intranet Telephone System:
Symbol Technologies' NetVision® Data Phone

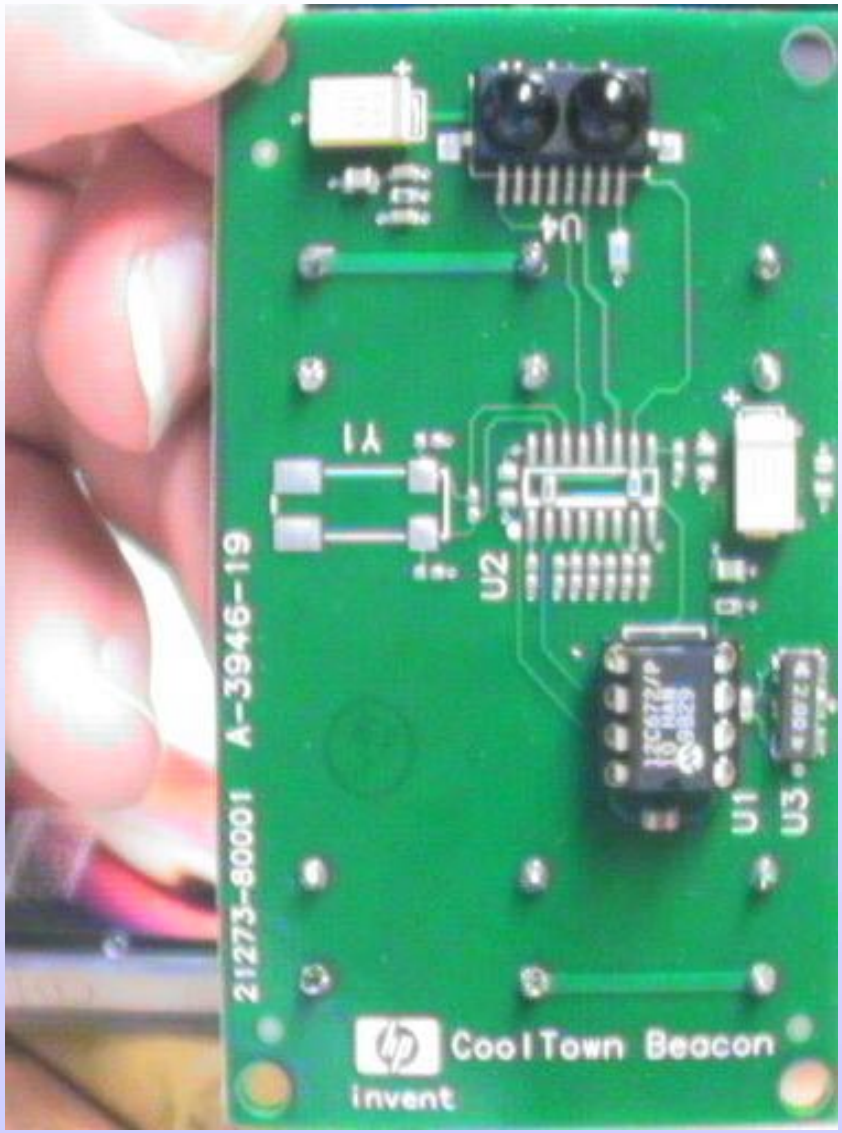
- WLAN
- HTML browser
- VOIP "phone"
- bar code reader

⇒ Telia's HomeRun

⇒ basis for subscription broadband wireless voice and data



Direct URLs



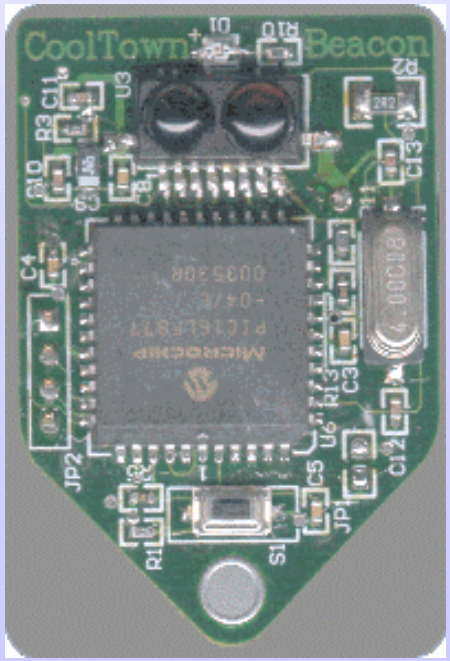
HP's CoolTown Beacon

Directly **emit** a **URL**

- direct to a page
- indirectly via a redirector (ala SIP) - allowing per user, time dependant, … mappings

V1

V2



f(User, context {location, URL, … }) ⇒ new URL

Use SIP like redirectors to remap based on user, location, context, … ⇒ highly personalized and adaptive information

T. Kanter's Open System Architecture + explicit Mobile Service Knowledge ⇒ *Adaptive Personal Mobile Communication* (http://www.it.kth.se/~theo)

HP's Websign

sensors (location + orientation) **+**
wireless communication (e.g., WLAN) **+**
algorithms
⇒ enable an augmented reality device

Example

a PDA can automatically acquire **new services** using virtual CoolTown beacons relative to the user's position

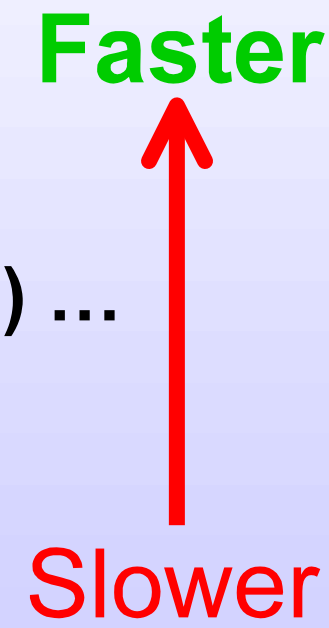
Personal Entertainment/Info/…
the declining importance of synchrony

Personalised data: text, picture, audio, ads, ... play lists

burst download in hotspots (WLAN) …

faster than "real-time" (DAB/DSS/… + GPRS) …

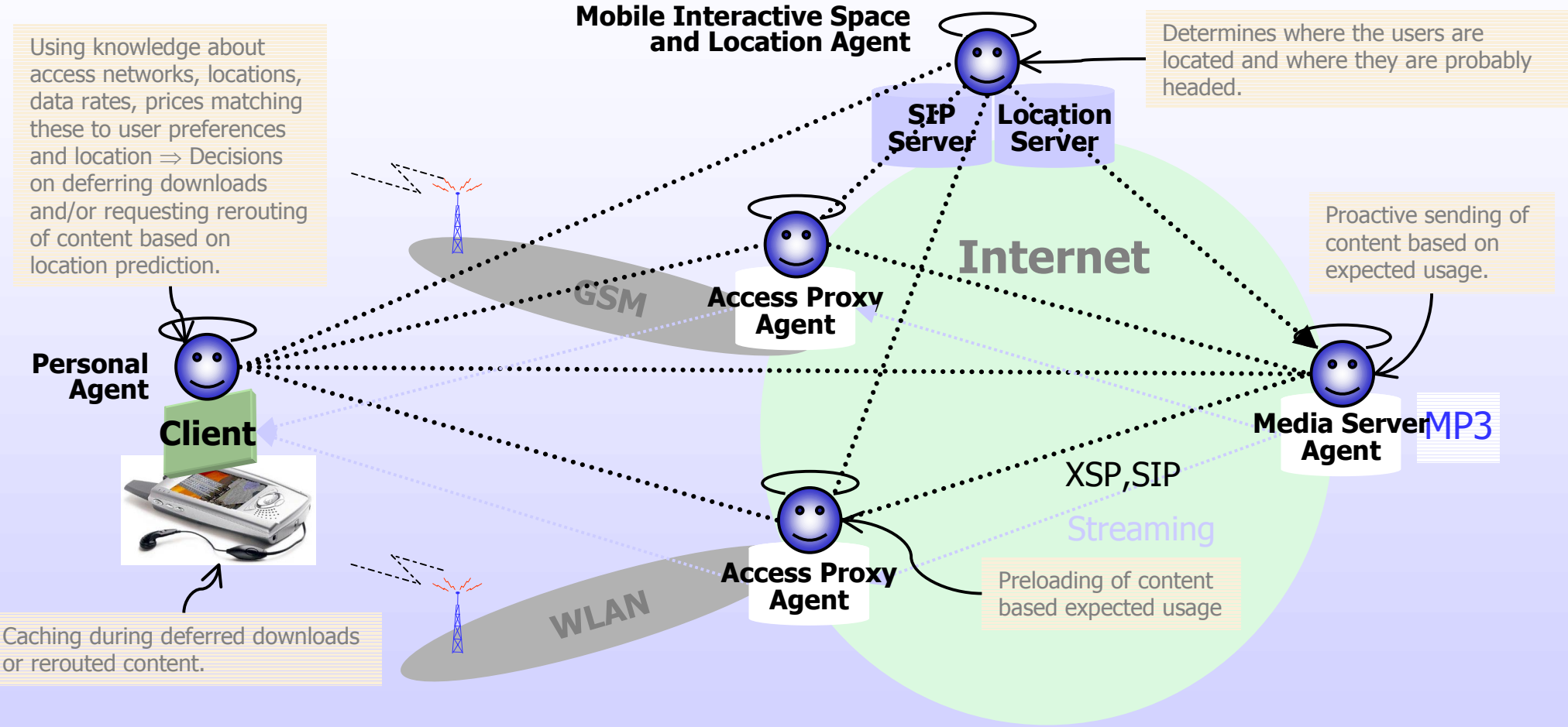
download in the background (GPRS)



Theo Kanter, Per Lindtorp, Christian Olrog, and Gerald Q. Maguire Jr.,
"Smart Delivery of Multimedia Content for Wireless Applications",
MWCN'2000, Paris, May 2000

See also http://www.slimdevices.com/products/slimp3/
an ethernet attached MP3 player which gets **bursts** of content to play

Smart Downloading of Multimedia



Conclusions: enables use of heterogeneous infrastructures which boosts the capacity of macrocells by offloading their traffic onto the hot spots **and** utilizing the caching of the devices to decouple the device from the currently available bandwidth.

Adapted from T. Kanter

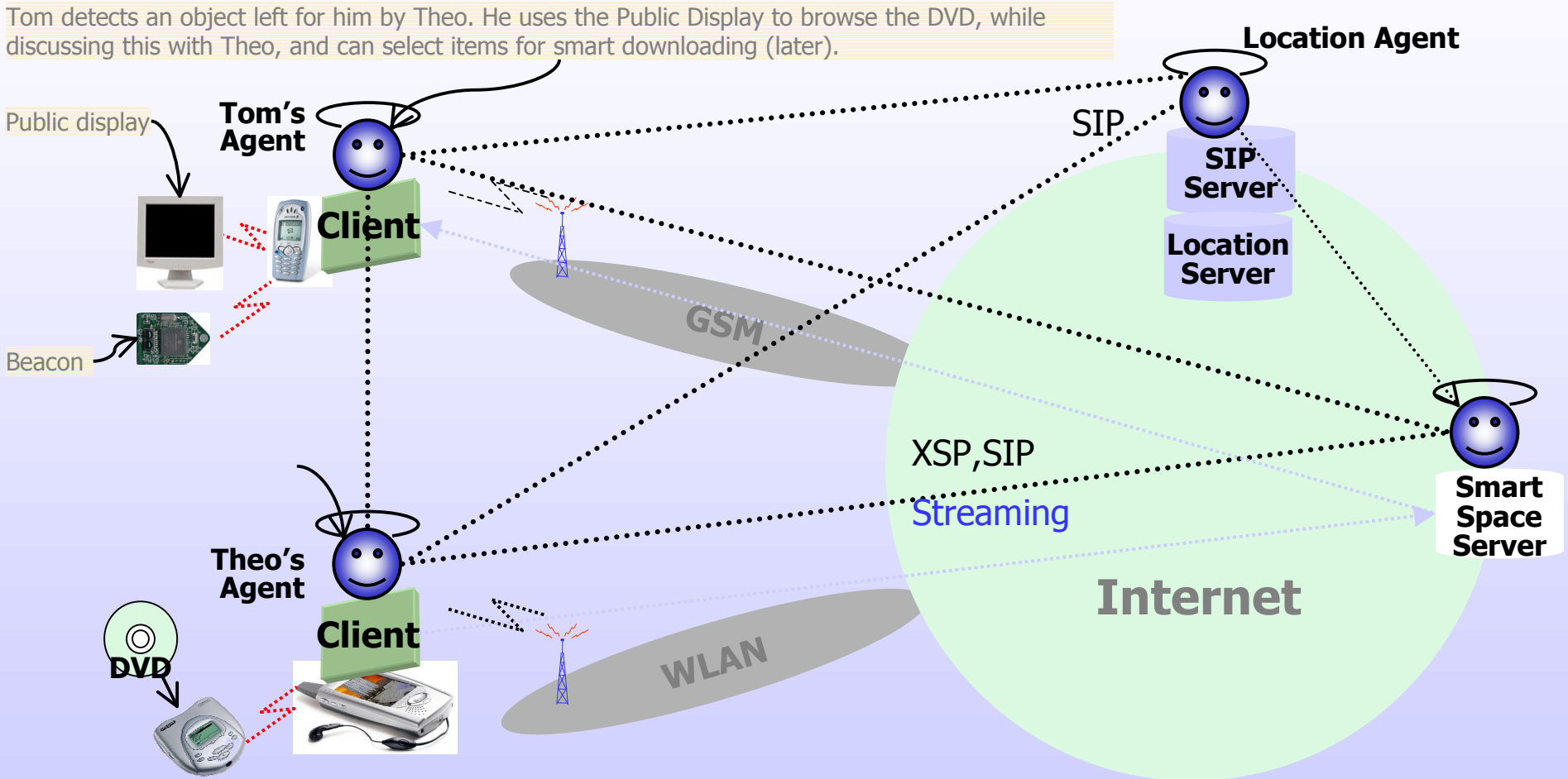
Digital amplifiers and SIP speakers

- **Digital amplifiers now very efficient and low cost - with 100W or more power per channel (with 5, 7, … more channels).**
- **Each channel has full power**
- **SIP + IP + digital amp + speaker = full dynamic home theater which can follow you as you move about**

⇒ Multi-Device & Multi-Session Communication

increasingly important for "Smart Spaces"

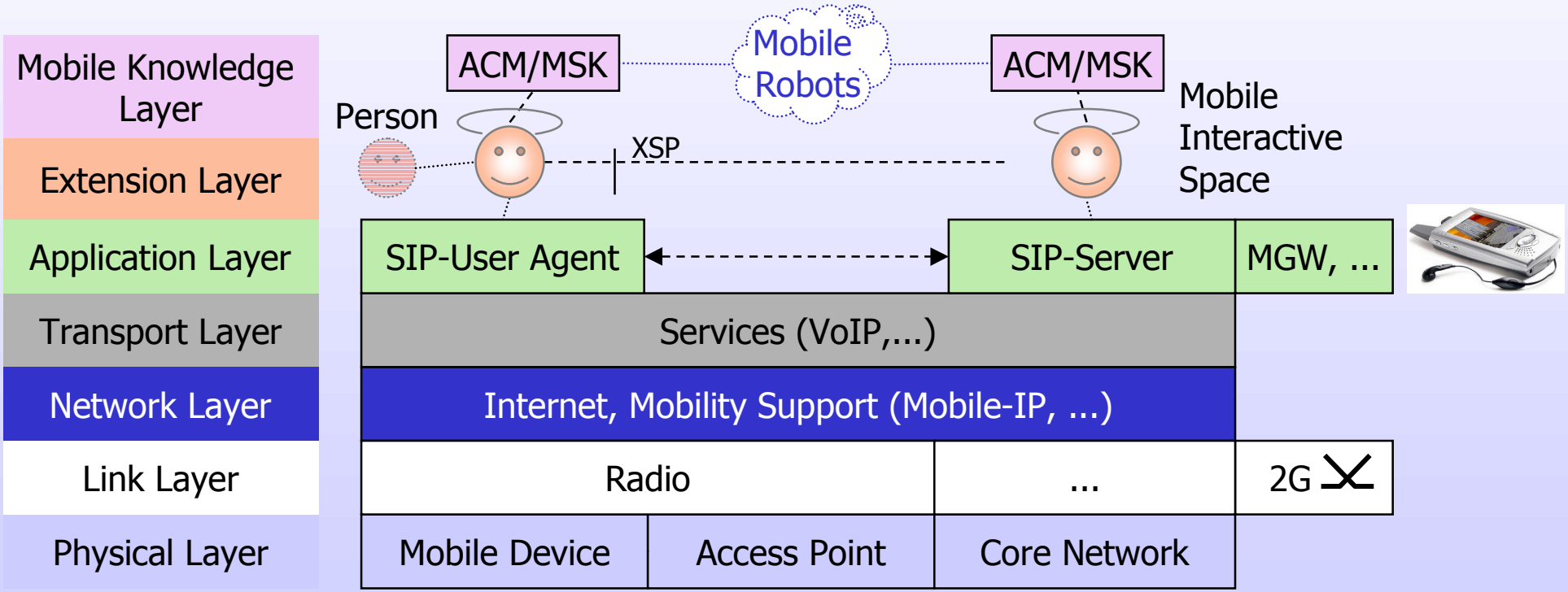
Multi-Device & Multi-Session Communication



Conclusions: XSP & MSK enable the end-points/users to negotiate and coordinate multi-session, multi-device communication which is not possible to arrange with either Jini or UPnP.

Adapted from T. Kanter

Open Service Architecture



But first you have to discover what is *where*!

You may need to learn what are the frequencies, modulation, coding, etc. of the access points and other devices in your environment.

If searching - Make them easy to find

- Solve the equations of LPD, LPI, LPE in the reverse!
  - LPD - Low Probability of *Detection*
  - LPE - Low Probability of *Exploitation*
  - LPI - Low Probability of *Intercept*

Personal information space

Where are my { friends, employees, pets, socks } ?

What is the state of my { . . . }

⇒Connected Application Spaces - more than just a Smart Space

Some initial projects:

- *Adaptive Personal Mobile Communication* and *Hottown* - Theo Kanter
- *Cooltown* and *Social Media* - HP Labs, Palo Alto California

From one handset suits all to ???

- Roll your own - from what you carry
  - Synthesizing the system you want from many appliances/accessories you carry/wear
- later: the walls really do have ears
  - Synthesizing the system you want from the many appliances/accessories/sensors/actuators around you (perhaps even using Smart Dust)

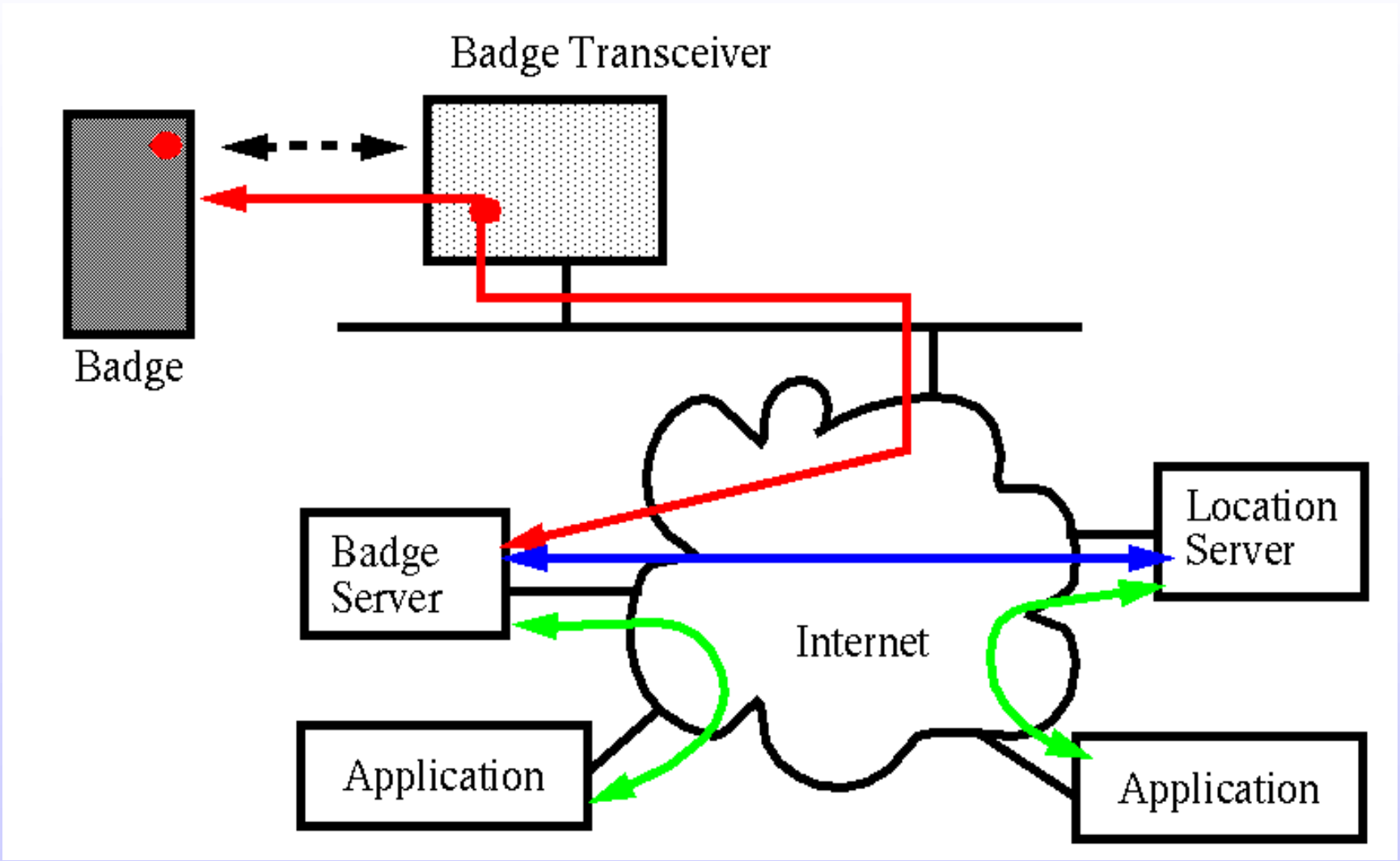
Communications and Privacy

- Encryption essential - Onetime pads feasible
- Identity hiding
  - Authentication when you mutually want to
  - Anonymous network access
- Location hiding
  - Alberto Escudero-Pascual, www.it.kth.se/~aep

"*Anonymous and Untraceable Communications - Location privacy in mobile internetworking*", Licentiate Thesis, KTH/IMIT, June 2001

- Unlinkability between the location of wireless users and their activities
- extension to Zero Knowledge Systems's pseudonymous IPv4 network.
- supports modification to the graph of anonymizers, thus supports mobility
- Location mis-direction ⇒ End of Sovereignty
- Traffic pattern hiding
- Traffic hiding

Badge Communications Model



Encryption as the norm

- Since all the speech and other media content will be in digital form, it will be trivial to provide encryption and authentication of all communication
- “public telephony” will be viewed as less secure than VPNs

Applications

- Location Aware
- Context Aware
- Adaptive Personalization
- Extending the individual
  - extending the user's senses and knowledge (mixed reality)
  - Hive/cooperative applications (games/entertainment/news/...)

Even more sensors

Temperature

Humidity

Barometric pressure

Light level

Solar radiation

Weight

Acceleration

...

- Distributed Weather data collection
- Environmental monitoring
- Energy and building management (HVAC)
- Intelligent appliances
- Automated customer care
- Augmented Reality
- ...

Scaling up

- Large sites have hundreds of access points and
- thousands of mobiles

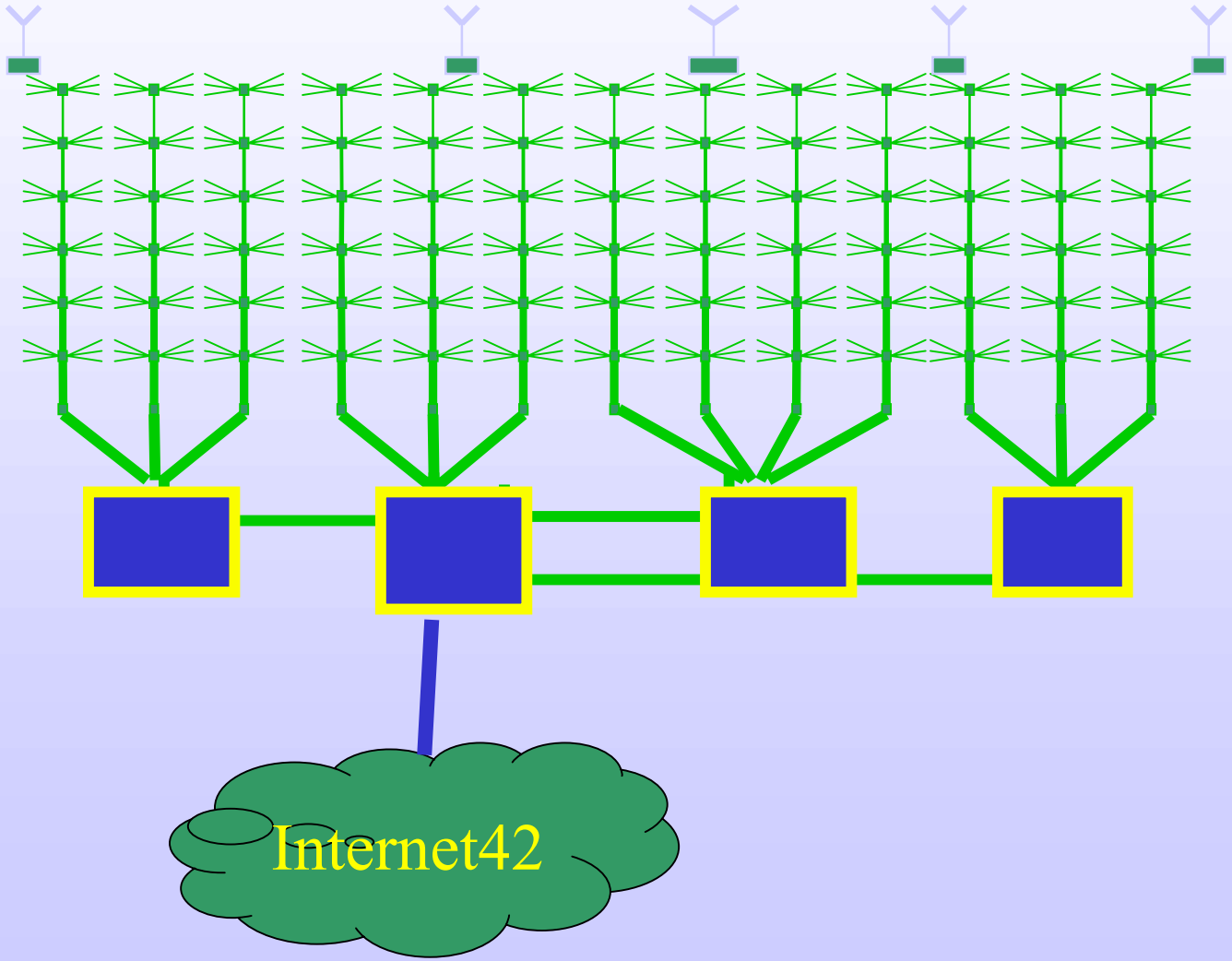
But this is only a start!

Emergence of Wireless Internet Service Providers (WISPs)

- Formal operators
  - Telia's HomeRun, PersonalTelco, or Seattle Wireless, …
- Informal associations
  - Electrosmog - http://www.elektrosmog.nu/
  - Global Access Wireless Database (GAWD) - http://www.shmoo.com/gawd

Emergence of Brokers providing settlement services between WISPs.

Internet42 extended with WLAN



11 Mbps 802.11b

100 Mbps Switched Ethernet

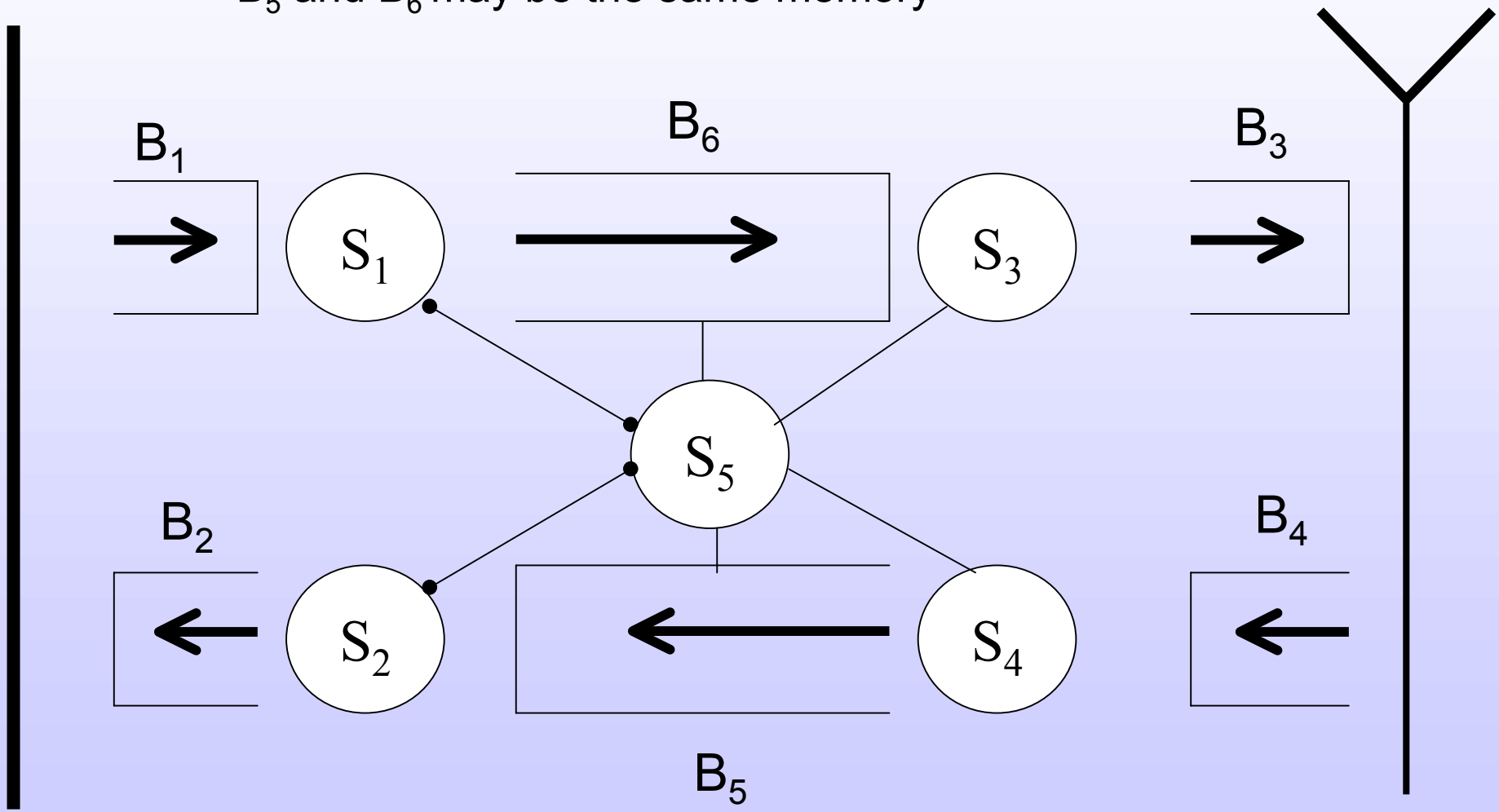
1Gbps Ethernet

New Viewpoint

- **Forget spectrum availability as** the **problem**
- **Forget limited bandwidth as** the **problem**
- **Forget error rate as** the **problem**
- **Problem:** Finding the **trade off** between available high quality bandwidth and the cost of the infrastructure, i.e., if cells shrink (thus increasing capacity, available bandwidth, decreasing error rate, …), then infrastructure cost increases, or is there another way?

Current WLAN Access Points

- B_1 and B_2 may be the same memory
- B_3 and B_4 may be the same memory
- B_5 and B_6 may be the same memory



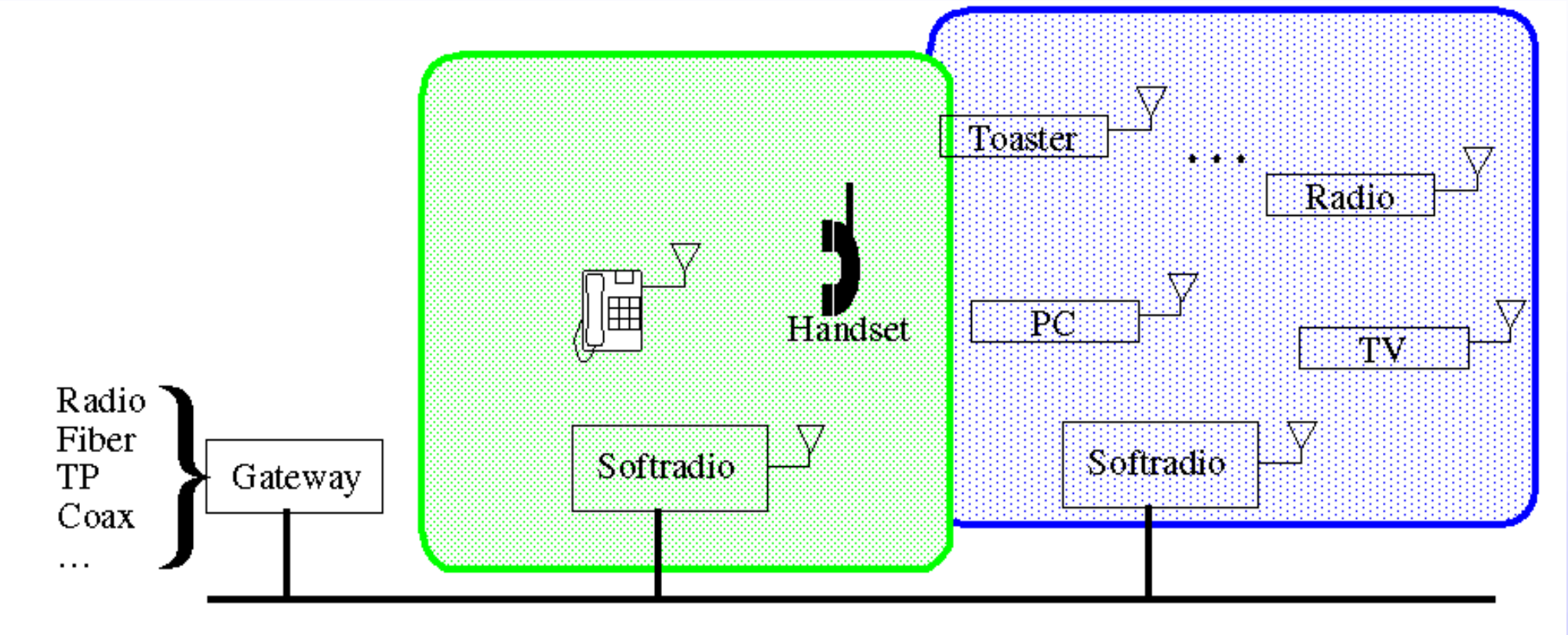
Unfortunately S1, S2, S3, S4, and S5 are often a single µP.

1996-1999 MEDIA - very low cost basestations

Ericsson Radio Systems AB, Tampere University of Technology (TUT), GMD FOKUS (GMD), Technische Universität Braunschweig (UBR), Interuniversity Microelectronics Centre (IMEC), and KTH.

- **SDL implementation of 802.11**
- **Partitioning out much of the MAC's functionality (i.e., the <u>access point only needs to have the per packet processing -- all else can be done remotely</u> -- including some buffering!)**
- **perhaps the access point does not even need a processor!**

Future home/office/… network accesspoints



Who is going to install these network access points

Getting home gateways into place may occur for the following reasons:

1. **Energy management** -- as California and other places become third world countries - saving power will be very important
2. **Insurance** - detecting leaks, … can save your insurance company lots of money - so they may pay for the installation
3. Serving as my **home agent**, repository for my mobile agents, being virtually located (probably at some tax advantaged location!), ...

What are the connectivity expectations?

- Ubiquity is wrong
- Model for communication vs. transactions (the transactor model)

  or Why TCP isn't so important!
- Role of re-intermediation (Delegation)
  - introduction of proxies to do service enhancements
  - Delegating things to agents

Example: PDA to IP Phone

Avaya 4606 IP Telephony

http://www1.avaya.com/enterprise/photo_library/photos/plipc88_lo.jpg

PDA via IP Phone to server ⇒ (1) IP phones as access points

http://www1.avaya.com/enterprise/photo_library/photos/plipc88_lo.jpg

(2) Changing from providing a remote Console to providing Service(s)

Goal is **to deliver a service to the user:**

- **change from simply remoting the buttons/knobs/…**
- **to delivering a service to the user**

If I'm listening to audio content and walk from one room to another, the goal is not to give me a remote control that lets me find and control a radio in this new room - but **rather the audio should be delivered by the appropriate means to where I am.**

Former trends

- **Lots of asymmetric network links** such as ADSL and cable modems
- **increasing use of firewalls** - others have open networks which I can down load from, but my network is one-way
- **use of dynamic IP address** - my machines only need an address when I want to download something
- **use of Network Address Translation (NAT)** - you can't see inside my network and I only need addresses when I'm downloading
- **user's system is only a "client"**

Increasingly Peer-to-Peer

- My computers each **need addresses all of the time**
- **others** get **content from me**
- **others can not only put data on my machines**, but in many cases **I don't even know (or care) what the data is** {in fact, I'd just as soon not know} - data sharing Napster/Gnutella/ICQ/Morpheus, KazAa, …
- **don't need a firewall - I want others to use my machines - since they also let me use their machines** (does this lead to the Metcalf law for peers?, value is proportional to the peers^2)
- user systems are clients and servers
  - (more general) **Resource sharing** - for example CPU sharing (SETI@HOME -- ~25 Teraflops of computing)
  - **Service Sharing** - rather than raw cycle or disk blocks, the servers now make higher level services available - a user does not have to know where the service is - it simply **is and hence is available**

IPv6

- Important transition
- facilitate peer-to-peer
- reduce costs and efforts for configuration of user's machines (plug and serve)
- importance of ANYCAST addressing

But it is not arriving fast enough!

New network interface functions

To exploit correlation

- Need: anticipatory network interface (with caching)

To avoid problems with handover between devices (see Mattias Ronquist, “Wireless Transport Layer Performance”, M.Sc. Thesis, KTH, 1999)

- Need an API to tell the interface to **forget sending packets already enqueued in the device’s output queue**
- Need an API to tell the network layer to **immediately resend unacknowledged packets** via the **new** interface

Summary

- Personalized, adaptive, … everything
- Ubiquity is wrong aim - NOT “anywhere & anytime”, but rather what I expect - where I expect it
- Increasingly heterogeneous, but open architectures exploiting IP over every link
- Decreasing need for synchrony
- Exploiting bursts + dribble
- Increasingly Transactions vs. Communication
- Role of re-intermediation (Delegation)
- Multimode radios (perhaps even SDR) coming onto the market at low cost
- Increasing correlation in traffic

⇒ Lots of new research problems

Don’t waste!
Help stamp out analog phones.

Use each jack as a place to put a base station.

With lots of picocells, everything can and <u>will</u> be on the net.

¿Questions?