

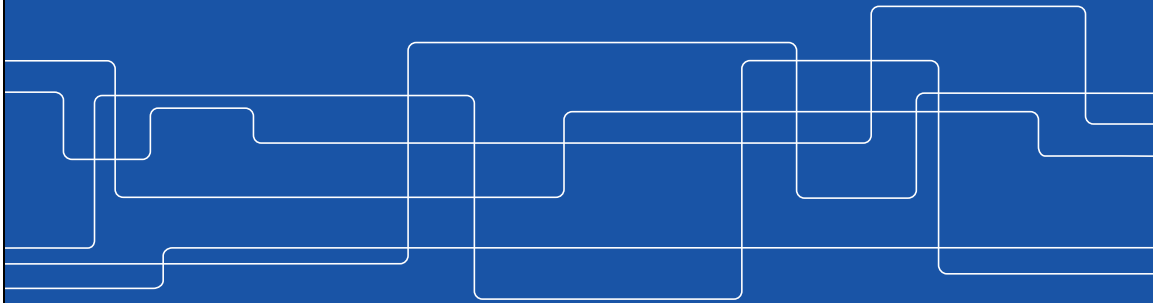
Slide 1



IK1550 & IK1552 Internetworking/Internetteknik

prof. Gerald Q. Maguire Jr. <http://people.kth.se/~maguire/>

School of Information and Communication Technology (ICT), KTH Royal Institute of Technology
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Slide 2



Module 14: Future and Summary

Lecture notes of G. Q. Maguire Jr.

Slide 3



Outline

- n^{th} generation of networking
- Growth & trends
- A glimpse into the future.

Slide 4



Generations of technology versus generative technology

Today there are lots of discussion of future communication systems, such as the cellular variants Theo Kanter calls π G systems[†], next generation internet, ...

There is even discussion of **if** there will be a 4th **generation** of cellular systems or **if** we will see the end of *generational* architectures and systems.

For some additional insights on the future of networking, see Patrik Fältström's "Future of the Internet"[Fältström 2008] and Jonathan Zittrain's *The Future of the Internet -- And How to Stop It* [Zittrain 2008] (see <http://futureoftheinternet.org/>).

Note that Jonathan Zittrain's book focuses on the fact that upto this point the Internet can be seen as a **generative system/technology** (i.e., provides high **leverage**, is highly **adaptable**, is **easy to master**, the technology and tools are readily **accessible**, and there is high **transferability** {developments can easily be transferred to another user}) - see [Zittrain 2008], page 70-73.

[†] Because $3 < \pi < 4$ and π is an irrational number.

Patrik Fältström, "Future of the Internet", Lecture slides, 27 March 2008,

<http://stupid.domain.name/stuff/future-internet.pdf>

Jonathan Zittrain, *The Future of the Internet -- And How to Stop it*, New Haven: Yale University Press, 342 pages, 2008. ISBN 978-0-300-12487-3, Web site of the book and blog: <http://futureoftheinternet.org/>; the author's web site: <http://www.jz.org/>

Slide 5



Third generation of networking

Van Jacobson describes the three generations as:

- "Generation 1: the phone system - focus on the wires.
- Generation 2: the Internet - focus on the machines connected to the wires.
- Generation 3? dissemination - focus on the data flowing between the machines connected to the wires."

-- slide 2: "A Brief History of Networking" of Van Jacobson, "If a Clean Slate is the solution what was the problem?",

Stanford Clean Slate Seminar,
February 27, 2006

<http://cleanslate.stanford.edu/seminars/jacobson.pdf>

Slide 6



Dissemination not conversation

On slide 17 of the same talk, Van Jacobson states:

- "The raison d'être of today's networking, both circuit switched and TCP/IP, is to allow two entities to have a conversation.
- The overwhelming use (>99% according to most measurements) of today's networks is for an entity to acquire or distribute named chunks of data (like web pages or email messages).


Acquiring named chunks of data is not a conversation, its a *dissemination* (the computer equivalent of "Does anybody have the time?")"

- slide 17 of Van Jacobson, "If a Clean Slate is the solution what was the problem?",

Stanford Clean Slate Seminar, February 27, 2006

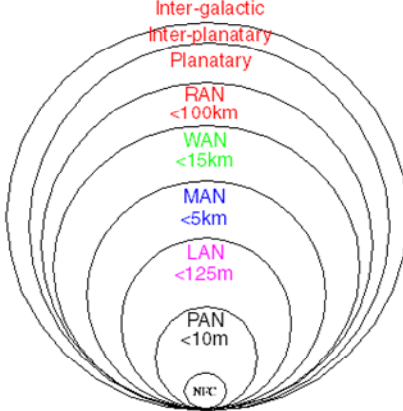
<http://cleanslate.stanford.edu/seminars/jacobson.pdf>

Slide 7



From PANs to RANs and beyond

The communication range of users - range from $\sim 10^{-3}$ m to $\gg 10^6$ m:



Inter-galactic

Inter-planetary

Planetary

RAN
<100km

WAN
<15km

MAN
<5km

LAN
<125m

PAN
<10m

NAN
<10m

Standards?

IEEE 802.22
18-24 Mbps

IEEE 802.20, GSM, GPRS, 2.5G, 3G
10kbps-2.4 Mbps

IEEE 802.16a/d/e - 70 Mbps
LMDS - 28 Mbps

IEEE 802.11a/b/g/h - 11-54 Mbps
IEEE 802.11n - 100 Mbps

IEEE 802.15.1 (Bluetooth) - 1 Mbps
IEEE 802.15.3 > 20 Mbps
IEEE 802.15.3a (UWB) <480 Mbps
IEEE 802.15.4 (Zigbee) < 250 kbps

From Personal Area Networks (PANs) to Regional Area Networks (RANs) inspired by slide 5 of [Cordeiro 2006]

⇒ This implies that solutions will involve **heterogeneous** networks.

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Carlos Cordeiro, Report on IEEE 802.22, IEEE J-SAC, and IEEE DySPAN
2007 tutorials, TCCN meeting at Globecom on November 27, 2006

http://www.eecs.ucf.edu/tccn/meetings/Report_06.ppt

See also Figure 1.3 on page 5 of Carlos de Morais Cordeiro and Dharma Prakash Agrawal,
Ad Hoc and Sensor Networks : Theory and Applications, 2nd ed. Singapore: World
Scientific Publishing Company, 2011.

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Are interplanetary and intergalactic networks relevant to you?

- 1 Some customers: NASA, ESA, ... ; but also scientists/astronomers who want to look back in time
- 2 Future space explorers & tourists?
- 3 => **delay tolerant networks** (DTNs) - since the one-way delays are very high - perhaps this offers insights into other DTNs
 - For example, content distribution by the physical movement of “carriers” near to someone who wants the content or someone who will pass it on (and on and on and on!)
- 4 The communication is going to have to remain **uncorrupted for a very long period of time** (<http://www.digitalpreservationeurope.eu/>)
 - Note the Austrian goal of preserving digital documents for 200 years; this is much harder than just copying the bits from one media to another, but also includes issues such as the validity period for a digital signature (for authentication) or encryption (for privacy) and how these properties can be extended for much longer periods of time
 - Who is going to provide this storage/archiving/ ... ?
 - Who is going to transfer the “documents” to and from the storage repository (repositories)?



Delay Tolerant Networks (DTNs)

Traditional applications generally assumed that to some degree there was:
(1) end-to-end connectivity, (2) low round trip time, and
(3) access to naming/caching/searching/... infrastructures.

Delay Tolerant Networks do not require these assumptions, thus nodes can communicate using an **opportunistic exchange of messages** (think of the messages as a propagating virus - moving from host to host) \Rightarrow **epidemic routing** protocols[Vahdat and David Becker 2000].

Key issues include [Crowcroft 2008]:

- What application layer data units are bundled into the DTN-layer protocol bundles for transport?
- Actual mobility patterns (social networks, commuting patterns, ...)

Metrics include [Crowcroft 2008]: Delivery ratio, Delivery Delay, and Delivery Cost

Amin Vahdat and David Becker, "Epidemic Routing for Partially-Connected Ad Hoc Networks", Technical Report CS-2000-06, Duke University, July 2000.

<http://issq.cs.duke.edu/epidemic/epidemic.pdf>

Jon Crowcroft, Eiko Yoneki, Pan Hui, and Tristan Henderson, Promoting Tolerance for Delay Tolerant Network Research, Editorial Note, Computer Communication Review, Volume 38, number 5, October 2008, pp. 63-68. <http://ccr.sigcomm.org/online/files/p63-crowcroft.pdf>

Slide 10



Trends: Shifting from traditional telecommunications to data communications

This is often referred to as the shift to "All-IP" networking.

This embodies:

- A shift from **circuit-switched** to **packet-switched**
 - such as: from Intelligent network (IN) to IP Multimedia Core Network Subsystem (IMS)
- Introduction of new technologies:
 - Voice over IP (VoIP)
 - Number portability
 - Context-awareness (including location-awareness) in services
- From services being what the **telecommunication operator** offers *to you* to what **anyone** offers to you. This is accompanied by a major shift in:
 - How services are created
 - Where services are provisioned
 - Where data is stored and who stores it
- Desperate efforts to retain **control, market share, high profits, access to dial numbers, and call contents**, ... - the genie is reluctant to go back into the bottle!

Trends: Shifting from traditional telecommunications to data communications

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Growth rates

n = number of users

Sarnoff's Law: value of a **broadcast** network $\propto (n)$

purely linear growth in the number of "viewers"

Metcalf's Law: value of a **communication** network $\propto (n - 1) \times (n) \approx n^2$

represents the possibility of each user to choose who they want to communicate with

Briscoe, Odlyzko, and Tilly propose [Briscoe 2006]: value of a network $\propto n \log(n)$

- they claim this is a better guide for investors and developers
- less than quadratic, but it is still far greater growth than linear!


Reed's Law: value of a network $\propto 2^n$

in networks that enable **groups** to form, the value goes up with the number of groups which can form {This is why **social networks** can be very important to networking.}

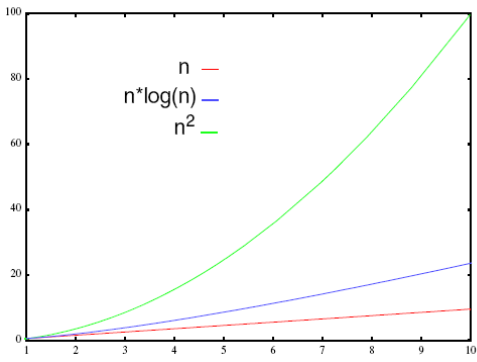
So if Briscoe, Odlyzko, and Tilly are correct that "Metcalf's Law is wrong"[Briscoe 2006] - then **what is the growth law which is relevant to you?**

Bob Briscoe, Andrew Odlyzko, and Benjamin Tilly, Metcalfe's Law is Wrong, IEEE Spectrum, 43(7):34-39, July 2006, DOI: 10.1109/MSPEC.2006.1653003
<http://www.spectrum.ieee.org/jul06/4109>

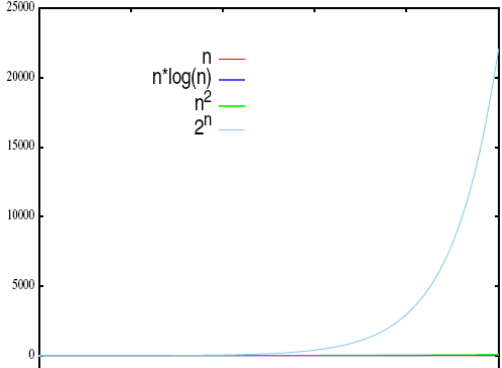
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Visualizing these laws



n	n	n*log(n)	n^2
1	1	0	1
2	2	2	4
3	3	4.75	9
4	4	7.39	16
5	5	10.13	25
6	6	13.01	36
7	7	16.03	49
8	8	19.22	64
9	9	22.59	81
10	10	26.13	100



n	n	n*log(n)	n^2	2^n
1	1	0	1	2
2	2	2	4	4
3	3	4.75	9	8
4	4	7.39	16	16
5	5	10.13	25	32
6	6	13.01	36	64
7	7	16.03	49	128
8	8	19.22	64	256
9	9	22.59	81	512
10	10	26.13	100	1024

linear, $n \log n$, n^2 , and 2^n

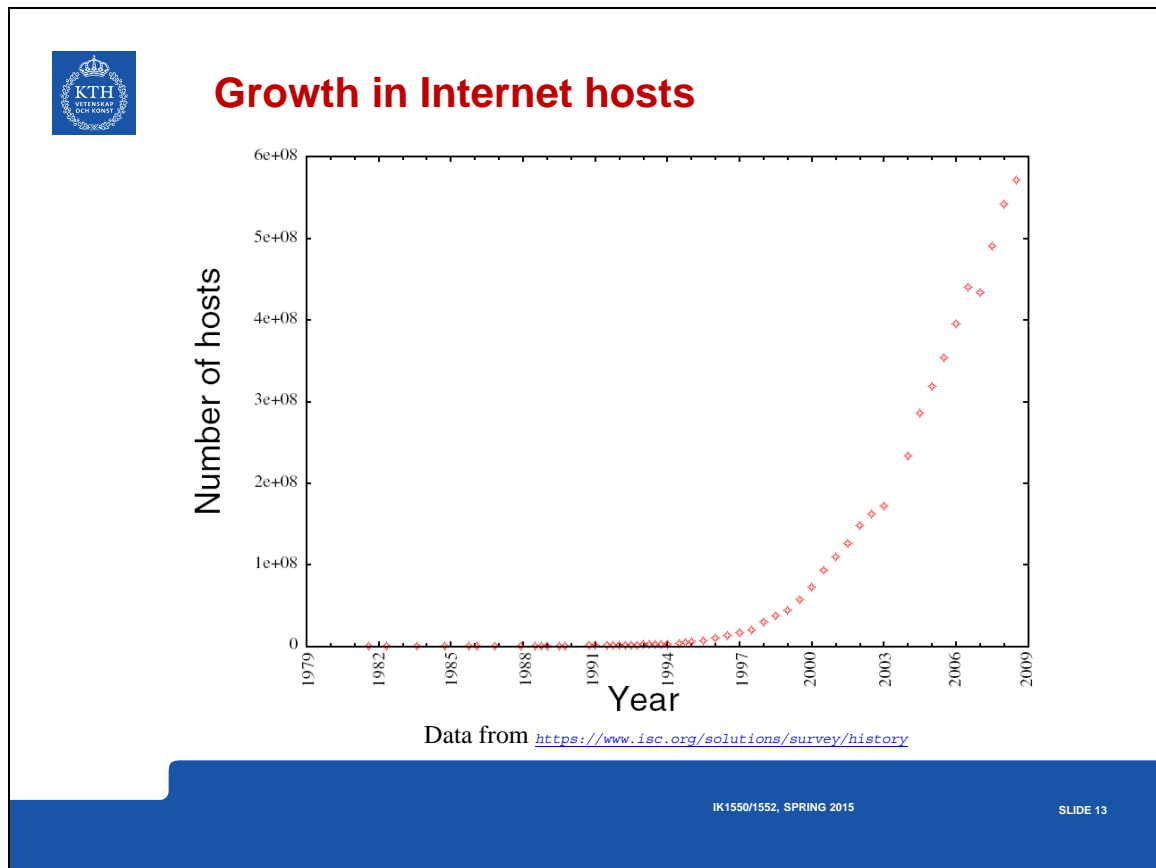
It is important to not simply think and act **linearly** (The Lewis model of Cultural types [Lewis 2000]: linear active vs. multi-active vs. reactive). Note that Lewis has extended this model to include **context**[Lewis 2005].

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Richard D. Lewis, *When Cultures Collide: Managing Successfully Across Cultures*, Nicholas Brealey Publishing, 2000, 462 pages, ISBN 1857880870, 9781857880878

Richard D. Lewis, *When Cultures Collide: Leading Across Cultures*, Nicholas Brealey Publishing, 2005, ISBN 1904838022, 9781904838029

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Slide 14



Exponential growth

As Ray Kurzweil points out in Chapter 1 of his book, *The Singularity Is Near* [Kurzweil 2005], the law of accelerating returns implies that the rate of change is increasing[†].

Up close exponential change is not much different from linear change, but step back slightly and we see there is a very big difference (see our earlier plot on the right in Figure 2). For information technologies he states that the growth rate is exponential, and that is the exponent is increasing and not simply a constant.

He predicts that the 5th Epoch involves the merger of technology and human intelligence and that by the end of the 2020s a computer will pass the Turing test. If this is the case, then shortly computers will combine the strengths of both human and machine intelligence -- What does this imply about services?


With Google being on a trajectory to having all information available on-line and offering on-line services with nearly unlimited storage for ~\$2/year. What is next?

[†]Irving Wladawsky-Berger makes this same point regarding the commoditization of computing in the cloud [Siegele 2008].


Ray Kurzweil, *The Singularity Is Near: When Humans Transcend Biology*, Viking, 2005

Ludwig Siegele, *Let it Rise: A special report on corporate IT*, *The Economist*, October 25th 2008 http://www.economist.com/specialreports/displayStory.cfm?story_id=12411882

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Long tail



Long tail distribution

Book stores stock books that they expect to sell at least one of per year, but Amazon.com has near zero cost of "shelf space" - so they sell well into the tail!

Chris Anderson's *The Long Tail: Why the Future of Business Is Selling Less of More* [Anderson 2008] and his earlier article in Wired Magazine discussed the power law relationship between the volume of sales ($r^{-\beta}$) and a product's rank (r); with a β of 1.214, the sales hits are ~20% of 100 offerings, but 80% of the sales; but as the number of unique items increases the market share shifts from the head of the distribution to the tail (i.e., there is more money in the [sum of the sales from the tail](http://www.thelongtail.com/) than from the head)[†], see <http://www.thelongtail.com/>

[†]See <http://demonstrations.wolfram.com/TheLongTail/> for an interactive demo

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Chris Anderson, *The Long Tail: Why the Future of Business Is Selling Less of More*, Hyperion, New York, 2006. ISBN 1-4013-0237-8 or Revised and Updated edition, July 8, 2008: ISBN-10: 1401309666, <http://www.thelongtail.com/>

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Is this only true for books?

Chris Anderson's blog of 2 October 2009 "The long Tail of Travel"[†], presents research done by Maren Jinnett using data compiled by the UK's Civil Aviation Authority - travel to top 50 flat, but growth in the tail.

You can find Maren Jinnett's spreadsheet at:

<http://www.longtail.com/long%20tail%20of%20travel.xls>

Chris Anderson's hypothesizes:

- ``* Lowered flight costs = more travel, more risk-taking
- * Lower "search costs" = broader vistas, more willingness to go off the beaten path
- * Better word-of-mouth tools = "bottoms-up hits"
- * Peer ratings, reviews reinforce authentic success, punish "manufactured experience"

[†]<http://www.thelongtail.com/>

Slide 17



Free

Chris Anderson's *Free: The Future of a Radical Price* [Anderson 2009] discusses how businesses can make money in an age when lots of things are free (i.e., a price of \$0.00)

A key insight is that in the **digital** economy, when the "margin cost" is near zero, **then round down to zero**.

⇒ Feeconomics

⇒ Freemium (a free version and a matching premium version)

He gives interesting example of how air travel can be free (pg. 19), how a DVR can be free (pg. 21), how everything in a store can be free (pg.60), how a car can be free (pg.81), healthcare (pg. 104), trading stocks (pg. 113), webmail (pg. 115), an exclusive conference (pg. 117), directory assistance (pg. 122), silverware (pg. 141), music CDs (pg. 155), textbooks (pg. 160), university education (pg. 185), and second hand goods (pg. 188).

Chris Anderson, *Free: The Future of a Radical Price*, Hyperion, July 7, 2009, 288 pages, ISBN-10: 1401322905, ISBN-13: 978-1401322908 or paper back ISBN 978-1-9052-1148-7

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Too cheap to meter

"It is not too much to expect that our children will enjoy in their homes **electricity too cheap to meter**, -- will know of great periodic regional famines in the world only as matters of history, -- will travel effortlessly over the seas and under them and through the air with a minimum of danger at great speeds, -- and will experience a lifespan far longer than ours as disease yields and man comes to understand what causes him to age."

-- Lewis L. Strauss, Chairman of the U.S. Atomic Energy Commission In
an address to the National Association of Science Writers
16 Sept. 1954

Today three other technologies are approaching the too cheap to measure point:

- computing power
- digital storage
- communication bandwidth

⇒ faster, better, cheaper -- a "triple play" for on-line services

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Working for free

Once you have food, shelter, ... (Maslow's subsistence needs[†]) people move on to social needs, esteem needs, and "self-actualization" - using their **cognitive surplus** (the energy and knowledge that isn't used for your "job")- page 189 of [Anderson 2009]

Hence the importance of:

- community
- visibility
- because I like to do it ("fun")

These are driving forces behind open source software/hardware, web pages, social networks, Wikipedia,

See Andrew Lih, *The Wikipedia Revolution: How a Bunch of Nobodies Created the World's Greatest Encyclopedia* [Lih 2009]

[†] "Hierarchy of Needs": physiological, safety, social, esteem, self-actualization; see Abraham H. Maslow, *Motivation and Personality*, Harper 1954

Chris Anderson, *Free: The Future of a Radical Price*, Hyperion, July 7, 2009, 288 pages, ISBN-10: 1401322905, ISBN-13: 978-1401322908 or paper back ISBN 978-1-9052-1148-7

Andrew Lih, *The Wikipedia Revolution: How a Bunch of Nobodies Created the World's Greatest Encyclopedia*, Hyperion 2009, 272 pages, ISBN-10: 1401303714 and ISBN-13: 978-1401303716 http://wikipediarevolution.com/The_Book.html

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What Would Google Do?

Jeff Jarvis' *What Would Google Do?* (WWGD) [Jarvis 2009] explores re-thinking how you do business by [finding a new world view](#) and [seeing things differently](#)

The book is not about what would Google as a business do, but rather what seeing the world as Google sees it - then [thinking differently](#) about solving problems could do[†].

Rather than thinking about "Will it make money?", start with:

- Will users think it is cool?
- Will it scale to support 100 million users?
- Is there a positive feedback cycle as it grows?

See [Buzzmachine.com](http://buzzmachine.com) for more about the book

For a counterpoint see:

Ken Auletta, *Googled: The End of the World as We Know It* [Auletta 2009] (and the review [Waters 2009])

[†] I refer to it as "enlightened self-interest"

Jeff Jarvis, *What Would Google Do?*, Collins Business, 2009, ISBN 978-0-06-170971-5.

Ken Auletta, *Googled: The End of the World as We Know It*, Penguin Press HC, (November 3, 2009), 400 pages, ISBN-10: 1594202354, ISBN-13: 978-1594202353 - also in paperback from Virgin Books

Richard Waters, Three brilliant idealists awaiting wisdom, Book review of *Googled: The End of the World as We Know It*, by Ken Auletta, Financial Times, November 11 2009 20:17, <http://www.ft.com/cms/s/0/35a36ada-cef6-11de-8a4b-00144feabdc0.html>



Quality of Service (QoS)

QoS refers to statistical performance guarantees that a network can make regarding packet loss, delay, throughput, and jitter.

Best effort delivery means **no** QoS guarantee.

QoS is thought to be more and more important these days. Many proposals, implementations and studies.

Does Internet need QoS? How can IP network provide it?

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Service Differentiation

Integrated Services (InteServ):

- RSVP: connection request
- All nodes IntServ-capable
- Scalability
- Complicated network management

Differentiated Service (DiffServ): end of one-size-fits-all

- Classes of Service
- QoS based Routing
- Classes of Service at Gigabit rates
- New Pricing and Billing Policies
- New Resource Allocation Methods

See: [Kilikki 1999]

Kalevi Kilikki, Differentiated Services for the Internet, Macmillan Technical Publishing, 384 pages, June 1999, ISBN: 1578701325.



Constraint-based Routing

QoS routing: selects network routes with sufficient resources for the requested QoS parameters

- to satisfy the QoS requirements for every admitted connection;
- to achieve network efficiency in resource utilization.

Policy-based Routing: e.g. Virtual Private Networks (VPN)

How can we combine this with IP mobility?

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Mobile *ad hoc* Networks (MANETs)

Ad hoc networks exploit the links which are possible with their neighbors

Mobile *ad hoc* networks (MANETs) exploit the fact that as nodes move the set of neighbors may change.

There may exist gateways between a MANET and fixed infrastructures - see for example the combination of Mobile IP and MANETs (MIPMANET) [Jönsson 2000]

Ulf Jönsson, Fredrik Alriksson, Tony Larsson, Per Johansson, and Gerald Q. Maguire Jr, MIPMANET - Mobile IP for Mobile Ad Hoc Networks, First Annual Workshop on Mobile Ad Hoc Networking & Computing, IEEE/ACM, August 11, 2000, Boston, Massachusetts. <http://doi.acm.org/10.1145/514151.514163>

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Performance

Routers:

1/2 to 1 Million packets per second (pps) for every gigabit per second of aggregate bandwidth
more than 250,000 routes

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PC interfaces

Standard I/O ports of PCs:

- Accelerated Graphics Port (AGP) \Rightarrow PCIe
- PCI \Rightarrow PCIe
- Universal Serial Bus (USB)
 - USB: 12Mbps - with plug and play, USB 2.0 [USB.org 2005], USB 3.0 (5 Gbit/s), USB 3.1 (10 Gbit/s)
- Apple Computers' Firewire™ \Rightarrow IEEE 1394
- Displays and other devices via Thunderbolt, HDMI, ...
- 10/100/1000 Ethernet
- Wi-Fi (with every increasing data rates)

PCI-SIG, PCI-X 2.0: High Performance, Backward Compatible PCI for the Future, May 19, 2005 http://www.pcisig.com/specifications/pcix_20

USB.org, Universal Serial Bus Revision 2.0 specification, May 19, 2005
http://www.usb.org/developers/docs/usb_20_02212005.zip

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Fibre Channel

From the X2T11 standards activity

Topologies: Point-to-Point, Fabric, and Arbitrated loop

Addresses: Loops, LANs, and worldwide addresses Fibre Channel

Profiles

Fibre Channel products

- Disk drives
- Network interfaces

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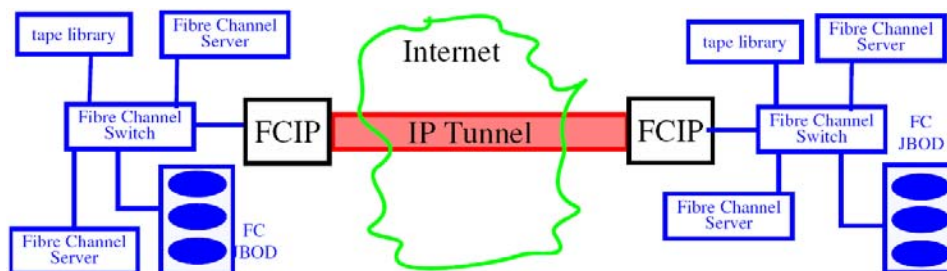


IP Storage Area Networks (SANs)

Using IP in conjunction with storage:

- Fibre Channel Over IP (FCIP)

JBOD == Just a Bunch of Disks



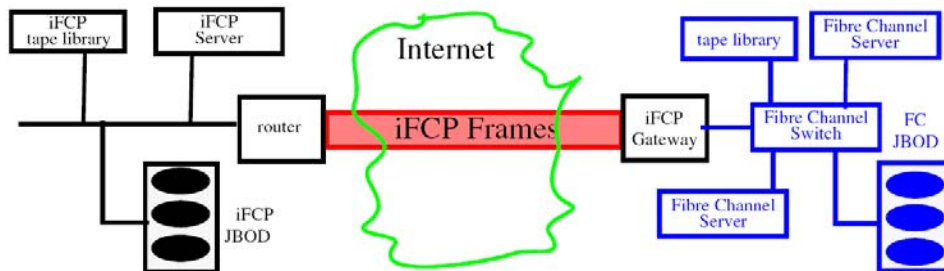
Note that this approach simply interconnects the two Fibre Channel switches. The connection between the two switches is TCP and it simply encapsulates a FCIP header and a Fibre Channel Frame.

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- Internet Fibre Channel Protocol (iFCP)

JBOD == Just a Bunch of Disks

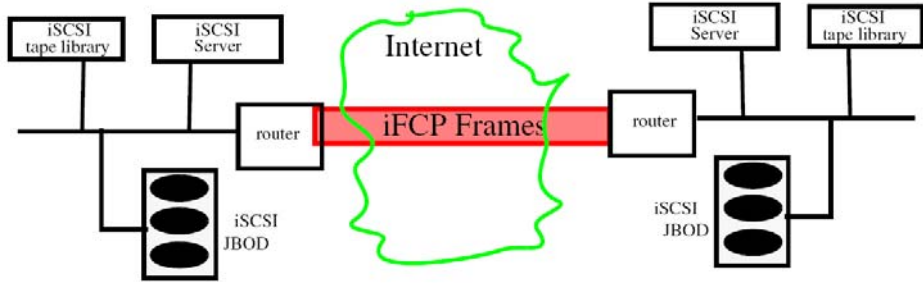


Note that this approach interconnects Fibre Channel devices. The connection between the two switches is TCP and it encapsulates a iFCP header and a Fibre Channel Frame; note that iFCP devices can simply be attached to the internet or an intranet. This means that there has to be a mapping between Fibre Channel addresses an IP addresses.

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- Internet SCSI (iSCSI)
JBOD == Just a Bunch of Disks



One a SCSI initiator has logged-in to a SCSI target, it can simply issue SCSI commands, just as if the device were on a local SCSI chain!

For more information see [Clark 2002]

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Tom Clark, IP SANS: A Guide to iSCSI, iFCP, and TCIP Protocols for Storage Area Networks, Addison-Wesley, 288 pages, 2002, ISBN: 0-201-75277-8

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Clustering

Myricom, Inc. <http://www.myri.com/>

Started by

- Prof. Charles L. Seitz - Caltech, President and CEO
- Dr. Robert Felderman - Director of Software Development
- Mr. Glenn Brown - Engineer and programmer

Clusters used to form high performance servers, using commodity networks and hosts.

In 2013 they were bought by CSP and today make 10-Gigabit Ethernet adapters.

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“Beowulf-class” machines

Using large numbers of commodity machines to make high performance computational systems by interconnecting them with a network.

- LANL's Loki <http://loki-www.lanl.gov>
- LANL's Avalon <http://loki-www.lanl.gov/papers/sc98/>
- JPL's Hyglac <http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/8076/1/02-0019.pdf>
- INRIA's PopC (Pile of PCs)
- ...

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Very high-speed Backbone Network Service (vBNS)

vBNS project created to provide a backbone for the US high-performance computing users and their SuperComputer Centers.

- mostly OC12C, but later added OC48C links (2.4Gbps)
- connections to all NAPs
- provide for multimedia services (provides multicast)
- participate in developing advanced routing technologies
- supports IPv4 and IPv6

vBNS backbone network \Rightarrow vBNS+ \Rightarrow a service of Verizon Business

See also http://www.nsf.gov/od/lpa/nsf50/nsfoutreach/htm/n50_z2/pages_z3/47_pg.htm

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Internet2

<http://www.internet2.org/>

- World class **research**
Driven by computational physics, biology, chemistry, ... and scientific visualization, virtual “experiments”, and remote control of real experiments.
- Networking R&D - focused on exploiting the capabilities of broadband networks media integration, interactivity, real time collaboration, ...
- Improve **production** Internet services and applications for **all** members of the academic community, both nationally and internationally.

Purpose: support national research objectives, distance education, lifelong learning, and related efforts.

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Gigapops

Who will be operating them? Where will they be?

How many will there be?

What is the aggregate throughput that they will require? What is the maximum per port throughput?

How many ports will they need to support?

Will they support "mixing"? (mixing is used to defeat traffic analysis)

Whose hardware and software will they use? What is the required functionality?

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Speed through Silicon

FPGAs used in many routers - for flexibility and to allow near hardware speed implementations of protocols.

ASICs: Vertex Networks, Inc. (merged with Mitel Networks Corporation) , MMC Networks, Inc. (acquired by Applied Micro Circuits Corp.), Galileo Technology (merged into Marvell® Technology Group Ltd.), Texas Instruments (TI), ...

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Future networks

Terabit per second == 10^{12}

Readily achievable via combining multiple Gigabit per second streams using Wavelength Division Multiplexing (WDM).

Petabit per second == 10^{15}

Differentiated Services: Classes of Service, Multimedia

Constraint-based Routing (QoS Routing)

Ad Hoc Networking

Auto-configuration (Plug and Play Internet)

Active Networking

Smart Networking

Knowledge-based

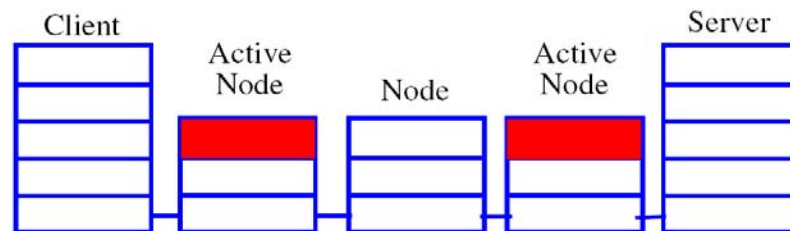
Networking

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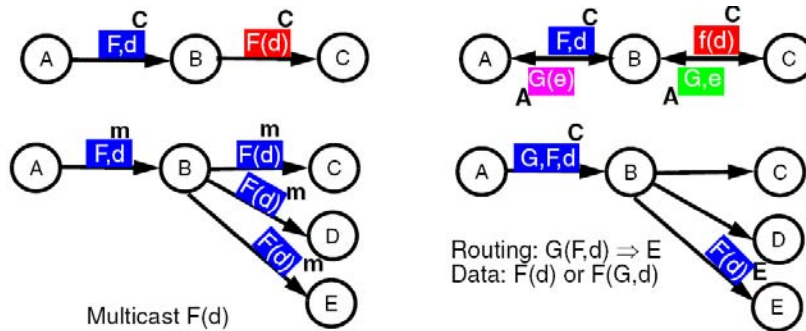
Active Networks

- Network nodes can perform customized computations on the messages flowing through them.
- Can change, modify the contents of the messages.
- Potentially Mobility Enabling Routing using active network concept





Active networks



B acts as an intermediary between A and x:

- (1) **operates** on the **data** as it passes through using the “program” F and/or
- (2) **routes** based on the computed **address** using a “program” G

Packets carry the **program** that each node on the path is to execute.
{Even the program(s) can be transformed as the packet propagates.}

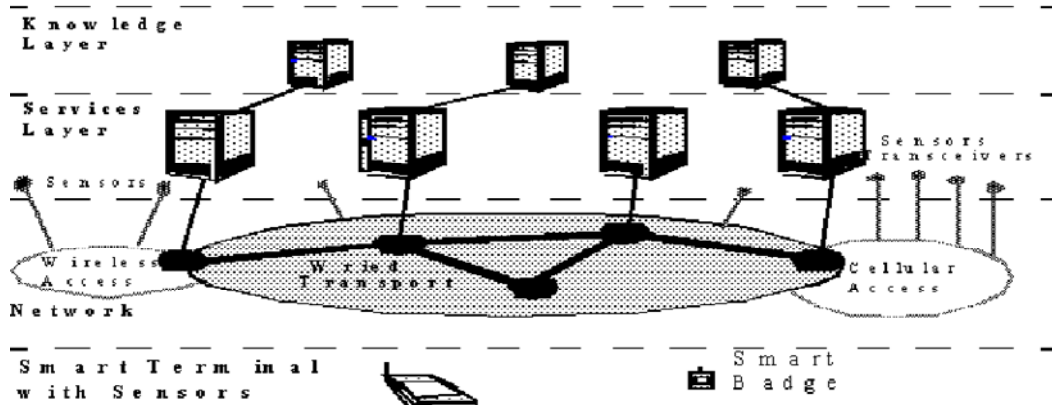
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Smart Networks with Sensors

(Ren and Maguire, KTH)

- Context/situation-aware Systems
- Smart services: active + user-awareness networking
- Knowledge-based Networking



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Internetworking as the future?

Now that internetworking technology is well on its way to wiping out the traditional industries, such as:

- Voice telephony operators
- Newspaper & magazine publishers
- Scientific journal publishers
- Record Companies, Movie distributors, ...
- ...

What comes next?

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Future of the Internet

An important part of the success of the current internet is the engineering design decision to make the network “**stupid**” - thus the intelligence is in the endpoints and not in the core network (the exact opposite of traditional telephony networks).

⇒ end-to-end principle

This end-to-end principle has driven both innovation and policy (see for example [Lessig 2001] and current arguments regarding “*network neutrality*”).

See the EU’s Future of the Internet [EU 2008] efforts at <http://www.future-internet.eu>

Lawrence Lessig, *The Future of Ideas: The Fate of the Commons in a Connected World*, New York: Random House, 352 pages, 2001.

The Future of the Internet: A Compendium of European Projects on ICT Research Supported by the EU 7th Framework Programme for RTD, Brochure by the European Commission, Information Society and Media DG, May 2008, ISBN 978-92-79-08008-1 ftp://ftp.cordis.europa.eu/pub/fp7/ict/docs/ch1-g848-280-future-internet_en.pdf

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Counter currents

However, there are forces working against innovation and openness:

- Major efforts to avoid **network neutrality** (<http://opennet.net/>)
- **Walled gardens & tethered devices**
- Built-in **kill switches** or remote reconfiguration - **not** under the control of the user
- **Legal action** or threats thereof (see <http://www.chillingeffects.org/>)
- **Filtering** (including national filtering) [Deibert 2008]
- ...

Jonathan Zittrain's recent book: *The Future of the Internet -- And How to Stop it* offers a technical, legal, policy, and social view of the future of the Internet and why "tethered appliances" ends the tradition of a generative system (which have the ability to "produce **unanticipated change** through unfiltered contributions from broad varied audiences" [Zittrain 2008]) potentially leading to ending the cycle of innovation which has driven the success of the Internet.

Jonathan Zittrain, *The Future of the Internet -- And How to Stop it*, New Haven: Yale University Press, 342 pages, 2008. ISBN 978-0-300-12487-3, Web site of the book and blog: <http://futureoftheinternet.org/>; the author's web site: <http://www.jz.org/>
Ronald Deibert, John Palfrey, Rafal Rohozinski, and Jonathan Zittrain, eds., *Access Denied: The Practice and Policy of Global Internet Filtering*, (Cambridge: MIT Press) 2008. <http://opennet.net/accessdenied>

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Clean slate re-design of the Internet

Many have questioned one or more of the basic concepts and currently several groups are attempting to do a clean slate re-design of the Internet.

Consider for example the two research questions that researchers at Stanford University are asking as part of their Clean Slate program:

- "With what we know today if we were to start again with a clean slate, how would we design a global communications infrastructure?", and
- "How should the Internet look in 15 years?"

-- Quoted from
<http://cleanslate.stanford.edu/>

See also: http://cleanslate.stanford.edu/about_cleanslate.php

This is only one of many such projects, see also:

- U. S. National Science Foundation GENI: <http://geni.net>
- European Union Future Internet Research and Experimentation (FIRE):
<http://cordis.europa.eu/fp7/ict/fire/>

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Implicit vs. Explicit Information

Van Jacobson expresses this as:

- "The nice properties of packet switching result from moving source & destination information *implicit* in a circuit switch's time slot assignments into *explicit* addresses in the packet header.
(But its easy to do this wrong, e.g., ATM.)
- The nice properties of dissemination result from making the time & sequence information *implicit* in a conversation be *explicit* in a fully qualified name."

-- slide 26: "Digression on Implicit vs. Explicit Information" of
Van Jacobson, "If a Clean Slate is the solution what was the problem?",
Stanford Clean Slate Seminar, February 27, 2006

<http://cleanslate.stanford.edu/seminars/jacobson.pdf>

The emphasis (in *italic red characters*) in the above quotation were added by Maguire.

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Is an hourglass the right model?

Rui L. Aguiar argues that perhaps it is **two** hourglasses - one for data and one for control. His argument is based upon **per flow** or aggregate processing *versus* **per packet** processing - for details see [Aguiar 2008].

Rui L. Aguiar, "Somme Commented on Hourglasses", Editorial Note, Computer Communication Review, Volume 38, number 5, October 2008, pp. 69-72.
<http://ccr.sigcomm.org/online/files/p69-aguiar.pdf>

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Peer to peer networking

Lots of the ideas that were covered also apply to other settings, for example - consider peer-to-peer networks for distributing entertainment multimedia content. These can use the caching of user's machines to provide the storage and can [exploit the bandwidth within the distribution network](#) to reduce the ISPs costs for peering!

See these Masters theses:

Cao Wei Qiu, *A new Content Distribution Network architecture – PlentyCast* [Qiu 2004]

Ayodele Damola, *Peer to peer networking in Ethernet broadband access networks* [Damola 2005]

Athanasios Makris and Andreas Strikos, *Daedalus: A media agnostic peer-to-peer architecture for IPTV distribution* [Makris and Strikos 2008]

Cao Wei Qiu, A new Content Distribution Network architecture - PlentyCast, Masters thesis, KTH, IMIT, IMIT/LCN 2004-05, April 2004

<http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-99127>

Ayodele Damola, Peer to peer networking in Ethernet broadband access networks, Masters thesis, KTH, IMIT, IMIT/LCN 2005-10, May 2005

<http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-92290>

Athanasios Makris and Andreas Strikos, Daedalus: A media agnostic peer-to-peer architecture for IPTV distribution, Masters thesis, Royal Institute of Technology (KTH), School of Information and Communication Technology, Stockholm, Sweden, COS/CCS 2008-11, June 2008 <http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-91855>

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Wikinomics

Don Tapscott and Anthony D. Williams in their book *Wikinomics: How mass Collaboration Changes Everything* [Tapscott and Williams 2008] point to cooperation in the form of “peer production” - where massive collaboration drives innovation.

Examples:

- open source software: linux, gcc, ...
- wikis: Wikipedia
- blogs: blogosphere
- prosumers: “cocreating goods and services rather than simply consuming the end product” (see [Tapscott and Williams 2008, p. 1])
- gaming: Second Life, ...
- peer-to-peer services: Skype, BitTorrent, ...
- Web 2.0 + social networking: Flickr, YouTube, Facebook, MySpace, ...
- e-science: Human Genome, the Goldcorp Challenge[†], ...

[†]<http://www.goldcorpchallenge.com/> - a gold mining company that put its proprietary data on-line and made it accessible to the public with a total of US\$575,000 in prizes ⇒ 6 million ounces of gold Red Lake Mine in Ontario, Canada as a result!

Don Tapscott and Anthony D. Williams, *Wikinomics: How mass Collaboration Changes Everything*, Portfolio, 2008, ISBN-13: 978-1591841937
<http://www.wikinomics.com/book/>

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Resource pooling

Damon Wischik, Mark Handley, and Marcelo Bagnulo Braun in their article “The Resource Pooling Principle” [Wischik 2008] define **resource pooling** as:

“Resource pooling means making a collection of networked resources behave as though they make up a single pooled resource. The general method of resource pooling is to build mechanisms for shifting load between various parts of the network.”

They go on to make two observations:

- 1 “Resource pooling is often the only practical way to achieve **resilience** at acceptable cost.”
- 2 “Resource pooling is also a **cost-effective** way to achieve flexibility and high utilization.”

Damon Wischik, Mark Handley, and Marcelo Bagnulo Braun, “The Resource Pooling Principle”, ACM/SIGCOMM Computer Communication Review, Volume 38, Number 5, October 2008, pp. 47-52 <http://ccr.sigcomm.org/online/files/p47-handleyA4.pdf>

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Resource pooling examples

Resource pooling can be used for:

- sharing lines/links/sites
- sharing storage
- computing power

This leads to [grid computing](#), [computing clouds](#), ...

Consider the proposal for Green IT by Bill St. Arnaud of Canada's CANARIE: <http://green-broadband.blogspot.com/> - put server farms in places with local renewable energy supplies - then move the bits to/from the user

⇒ moving [Gigabits/second](#) vs. [Gigawatts](#)

This implies the use of [dense wavelength division multiplexing](#) (DWDM) over optical fibers from these (often remote) sites to where the users are.

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Context of the module

Communication systems have been both increasing their number of users and increasing the variety of communication systems. Additionally, increasingly communicating entities are **not** people, but rather things.

	numbers	sources
Micro controllers	6 x 10 ⁹ per year	http://doi.ieeecomputersociety.org/10.1109/MM.2002.10015
People	7 x 10 ⁹	http://en.wikipedia.org/wiki/World_population
Mobile subscribers	> 5 x 10 ⁹	as of end of 2010 http://www.itu.int/ITU-D/ict/newslog/Mobile+Broadband+Subscriptions+To+Hit+One+Billion+In+2011.aspx
PCs	> 1 x 10 ⁹	as of June 23, 2008 http://www.gartner.com/it/page.jsp?id=703807
Automobiles	59.87 x 10 ⁶	http://oica.net/category/production-statistics/
Commercial vehicles	20 x 10 ⁶	

Ericsson's CEO (Hans Vestberg) predicts the future (~2020) Internet will have 50 billion interconnected devices, while Intel predicts 15 billion connected devices by 2015 [Higginbotham 2010]. Increasing numbers of these devices are connected via a wireless link.

Stacey Higginbotham, Ericsson CEO Predicts 50 Billion Internet Connected Devices by 2020, GigaOM , Apr. 14, 2010, 10:08am PT, <http://gigaom.com/2010/04/14/ericsson-sees-the-internet-of-things-by-2020/>

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What kinds of things might be interesting?

- **Personal monitoring:** for health, for sports, for law enforcement, to replace prisons, ...
- **Vehicles:** Vehicle Area Networks (VANs), Vehicular *ad hoc* networks (VANETs), ...
- **Packages:** logistics (tracking, routing, ...), monitoring of package - for temperature, pressure, acceleration/deacceleration, ..., transport security (has the package been tampered with), customs/law enforcement/...
- **Buildings:** Heating, Ventilation, and Air Conditioning (HVAC), minimizing energy waste while maximizing productivity, facilitating human & device location, avoiding theft/loss/floods/leaks/..., ...
- **Appliances:** Is the refrigerator working? Did I leave the stove on? Warm up the sauna/hot-tub/... I'm on my way home! ...
- **Infrastructure:** Is their ice on the bridge? Did the earthquake damage the bridge? ...
- **Environment:** air, water, oceans, land, ...

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Personal monitoring

Darwin Valderas Núñez's Master's thesis "Integration of sensor nodes with IMS" showed the ability for a coach to monitor a runner remotely via IMS [Núñez 2008].

However, the **delays** of IMS are so high as to make this approach impractical, but he could have simply used SIP + RTP (or SRTP) to stream the sensor data to the coach's PC and had very low delay.

Look at today's personal training monitors, smart watches, etc.

Darwin Valderas Núñez, "Integration of sensor nodes with IMS", Master's thesis, KTH Royal Institute of Technology, School of Information and Communication Technology, Stockholm, Sweden, , COS/CCS 2008-22, October 2008

<http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-91678>

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Vehicle Area Networks (VANs)

Controller Area Network (CAN) bus within vehicle to interconnect sensors, actuators, and controllers ⇒ **improved performance with a decrease in vehicle weight**. Truck to trailer communication - extending the vehicular network to the trailer (or trailers) [Gunnarsson 2001]

In vehicle entertainment - audio/video/gaming/... for passenger and audio for the driver.

Hands free voice telephony - as handheld cellular is banned in most countries

- Does the driver plug in their iPod/phone/... and use the facilities of the vehicle?
- Does the vehicle incorporate the driver/passengers by extending/adapting itself for them?
- Does the vehicle adapt the output audio/video/... to the vehicles context (for example, the phone will not permit calls at high speed when there are lots of other cars within minimum breaking distance)?

Mikael Gunnarsson, Truck-Trailer Wireless Connections, Masters Thesis, School of Microelectronics and Information Technology, Royal Institute of Technology (KTH), December 2001 <http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-93271>

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Vehicular ad hoc networks (VANETs)

VANETs are thought to facilitate a wide variety of applications (adapted from Table 1 of [Schoch 2008]):

Active safety

- Warning about dangerous road features: curves, height restrictions, upcoming intersections/bridges/tunnels/rail crossings/...
- Warnings about traffic and road conditions: ice/water/... on road, potholes, work-zone, school-zone, ... congestion
- Danger of collision: due to lane change, braking of vehicles in front of you, ...
- Pre-sensing crash
- Assistance following a crash

Public service

- Facilitating movement of emergency vehicles and public transport
- Support for authorities: tolls, fines, vehicle inspection, driver's license, ...

Improved driving

- Improving driving via various forms of assistance, heads up forward IR and rear views, heads up signage, ...
- Traffic efficiency: updating traffic control centers with local conditions \Rightarrow advising driver of alternative routes, maps and navigation aids, guidance to available parking/gas station/restaurant/...

Business and entertainment

Elmar Schoch, Frank Kargl, Michael Weber, and Tim Leinmüller, "Communication Patterns in VANETs", IEEE Communications Magazine, Volume 46, number 11, November 2008, pp. 119-125.

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- Vehicle maintenance: diagnostics, software updates, recalls, ...
- Mobile communication services: internet access, messaging, ...
- Enterprise solutions: fleet management, vehicle tracking (for rental vehicles and hazardous/valuable cargos), ...
- E-payment: tolls, parking, ...

Note that IEEE Communications Magazine, Volume 46, Number 11, November 2008 issue has several article on VANETs - including an excellent article discussing the requirements for **security** and **privacy** for VANETs [Papadimitratos 2008].

Panagiotis Papadimitratos, Levente Buttyan, Tamás Holczer, Elmar Schoch, Julien Freudiger, Maxim Raya, Zhendong Ma, Frank Kargl, Antonio Kung, and Jean-Pierre Hubaux, Secure Vehicular Communication Systems: Design and Architecture, IEEE Communications Magazine, Volume 46, number 11, November 2008, pp. 100-109.
<http://infoscience.epfl.ch/getfile.py?docid=21529&name=sevecom1&format=pdf&version=1>

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Packages

Logistics (tracking, routing, ...), monitoring of package - for temperature, pressure, acceleration/deacceleration, ... , transport security (has the package been tampered with), customs/law enforcement/...

Note that Qualcomm's first enterprise wireless service was a satellite-based mobile communications system for the transportation and logistics markets called OmniTRACS®.

Today the U.S. Homeland Security Department opens & inspects ~6 percent of the 11 million cargo containers that enter U.S. [Government Technology Magazine 2007] - a new approach is to do inspection at port of origin, then ensure (electronically) that the container is not tampered with on the way.

Note: For many people the "Internet of Things" primarily concerns things with RFIDs attached - we will not limit our thoughts in this way.

WiFi Wireless Secures New Patents for Cargo Tracking and Monitor Systems, News Report, Government Technology Magazine, Folsom, CA, USA, April 11, 2007, <http://www.govtech.com/gt/articles/104903>

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Buildings

Heating, Ventilation, and Air Conditioning (HVAC), minimizing energy waste while maximizing productivity, facilitating human & device location, avoiding theft/loss/floods/leaks/..., ...

- Half the cost of a HVAC system is the wiring from the sensors and actuators to the HVAC control system!
- Just how much electrical power/water/... am I using now?
- How much power am I **selling** to the grid?
- One of the greatest sources of losses for Swedish insurance companies is water leaks due to pipes bursting in cold weather - as the leak is not discovered in time to prevent a major loss. What is the value vs. cost of a simple leak detector?

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Appliances

- Is the refrigerator working?
- Did I leave the stove on?
- Warm up the sauna/hot-tub/... I'm on my way home! ...
-

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Infrastructure

Is their ice on the bridge?
Did the earthquake damage the bridge? ...

Wind and Structural Health Monitoring Systems (WASHMS), for example the New Svinesund Bridge in Sweden instrumentation consists of ([Koljushev 2005] p. 5):

- 16 vibrating-wire strain gauges, 4 at arch base and 4 just below the bridge deck (on both Norwegian and Swedish sides)
- 8 resistance strain gauges (2 at arch base, 2 in a segment just below bridge deck, and 4 at the crown)
- 4 linear servo accelerometers, installed pair-wise as each new arch segments is construction; on completion 2 accelerometers moved to the arch mid point and 2 to the arch's Swedish quarter point
- 28 temperature gauges (in the same locations as the strain gauges)
- 1 outside air temperature gauge, and
- 1 3-directional ultrasonic anemometer for measuring wind speed and direction at deck level close to the first support on the Swedish side.

See <http://www.byv.kth.se/svinesund/index.htm>

The Rion-Antirion Bridge in Greece is monitored by Advitam in France - using 372 measurement channels via the internet[Basile 2007].

I. Koljushev, P. Toivola, and A. Vesterinen, Combining the Construction Period and Service Life Structural Monitoring Requirements to Enable Delivery of a Single, Cost Effective Solution, Fifth International Conference on Bridge Management, 11-13 April 2005.

<http://www.futurtec.fi/downloads/BM5%2520April%25202005%2520reprint.pdf>

Bernard Basile, "Monitoring the Structural Health of the Rion-Antirion Bridge Using LabVIEW Real-Time", National Instruments Corporation, 4 August 2007.

<http://sine.ni.com/cs/app/doc/p/id/cs-68>

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Environment

Monitoring air and water quality, food, ...

Monitoring for natural disasters: earthquakes, tsunamis, ...

Monitoring for man made disasters: fires, pollution, ...

Coupling monitoring with prediction - both micro-weather prediction (for crops/forest/...) and macro-weather prediction with lots of local measurements as input.

See for example Alexandros Zografos' Master's thesis:
"Wireless Sensor-based Agricultural Monitoring System"

Alexandros Zografos, Wireless Sensor-based Agricultural Monitoring System, Master's thesis, KTH Royal Institute of Technology, School of Information and Communication Technology, Stockholm, Sweden, TRITA-ICT-EX-2014:25, March 2014
<http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-143633>

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Is saying “Internet of xxx” misleading?

Dirk Trossen, Chief Researcher, BT Research in a recent talk at the Internet of Things 2008 conference says that think of the various xxx’s impairs our thinking and results in embedded concerns into the architecture, thus he proposed “Tussle networking” [Trossen 2008].

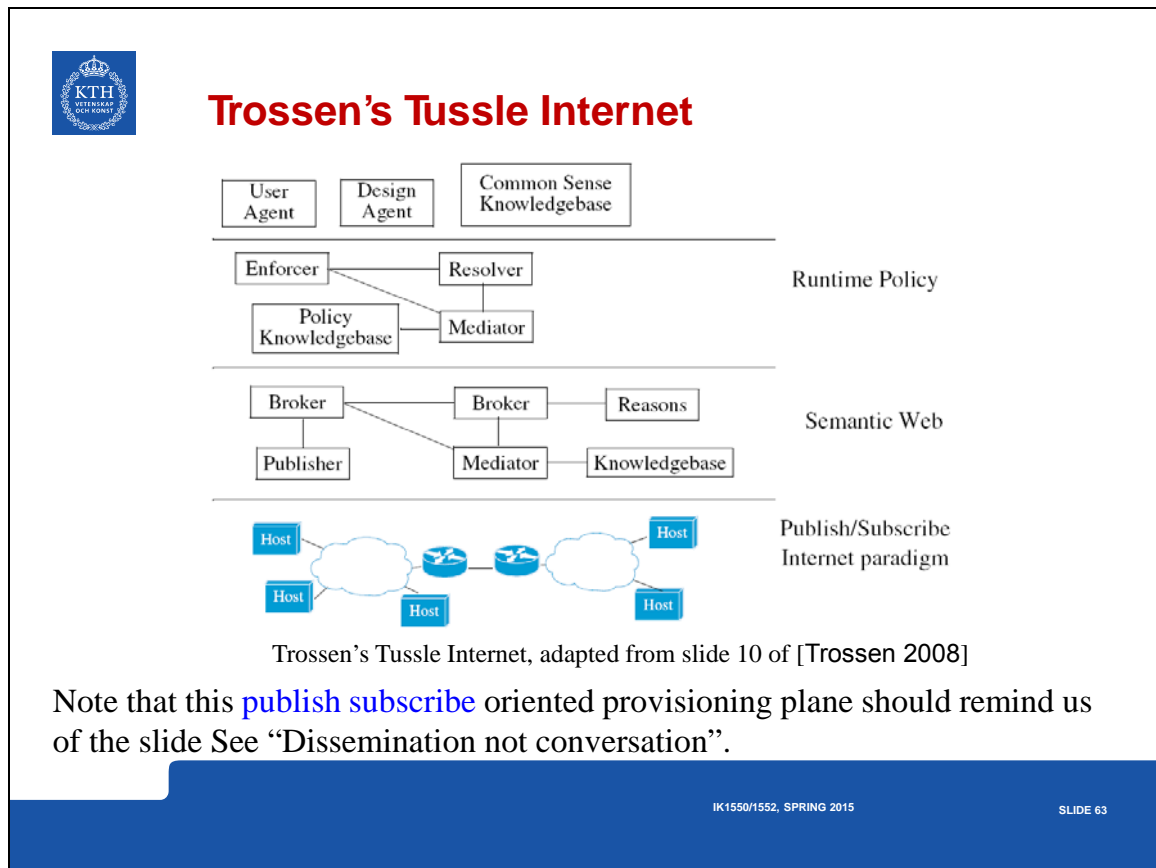
This is because communication is delimited by questions such as [Trossen 2008]:

- **Who** to share **what** with?
- **Where** to deliver/produce/consume/...
- **What** to receive in return?
- **How** to receive what I need?
- **What** is it used for?

He goes on to say that the concerns of “individuals, organizations, communities, and societies could lead to conflicts (tussles)” ⇒ explicitly representing concerns as **constraints**. These are resolved at run time via “policy mediation, negotiation, and enforcement”.

Dirk Trossen, “From The Internet of ??? To The Future Internet”, Internet of Things 2008 conference, Zurich <http://www.the-internet-of-things.org/prg/slides/trossen.pdf>

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Dirk Trossen, "From The Internet of ??? To The Future Internet", Internet of Things 2008 conference, Zurich <http://www.the-internet-of-things.org/prg/slides/trossen.pdf>

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Trossen's observations

Adapted from slide 4 of Dirk Trossen, *Information-centric Internetworking: A Few Insights*, University of Cambridge, Computer Laboratory, 14 November 2010 <http://www.cl.cam.ac.uk/teaching/1011/R02/slides/psirp.pptx>

Fundamentals of the Internet	Reality of the Internet today
<p>Collaboration collaborative forwarding and routing</p> <p>Cooperation trust among participants</p> <p>Endpoint-centric services (e-mail, FTP, WWW, VoIP, ...) end-to-end principle</p> <p>⇒ IP with end-to-end reachability</p>	<p>Commercial services provided by ISPs</p> <p>Trust has eroded due to phishing, spam, worm, viruses, ...</p> <ul style="list-style-type: none"> • current technology favors senders • receivers pay the costs of unwanted traffic <p>Do endpoints really matter?</p> <ul style="list-style-type: none"> • Often the content is more important than where you get it from (if you can trust that it really is the original content) • Many endpoint services moving toward information retrieval via CDNs <p>⇒ Ossification of IP-based network architecture</p>

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Trossen's Design principles to Architecture Invariants

Adapted from slides 7 & 8 of Dirk Trossen, Information-centric Internetworking: A Few Insights, University of Cambridge, Computer Laboratory, 14 November 2010

<http://www.cl.cam.ac.uk/teaching/1011/R02/slides/psirp.pptx>

Main design principles	Resulting Architecture Invariants
Everything is information (as connected graphs)	Flat-label space to identify information items
Information is scoped	Scoping groups information, functions, and even scopes
Functionality is scoped functions that disseminate information utilize a scoped strategy	Use a Publish/Subscribe model for delivery
Scoped information neutrality Within each scope data is forwarded based upon a scoped identifier	Separation of functions: each scope provides functions for: <ul style="list-style-type: none"> • rendezvous (finding/lookup) • constructing a topology • delivering (based on forwarding)
Ensure balance of power Entities only receive data if they have ask for it	Each scope has a dissemination strategy this is inherited by sub-scopes

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Publish-Subscribe Internet Routing Paradigm (PSIRP) project

An information-centric internetworking architecture - based on publish-subscribe paradigm - see <http://www.psirp.org/home>

Note that in this model multicast and caching are the norm - since the goal is to make **content** available - rather than establishing a *conversation*.

This lead to the FP7 PURSUIT project (<http://www.fp7-pursuit.eu>)

The resulting architecture implements the following components:

- In the application nodes: publish & subscribe functions, fragmentation of content, and some caching
- In the network: rendezvous points (in a rendezvous network), explicit inter-domain topology formation, caching, error control, etc. + one or more forwarding networks containing forwarding nodes and topology management nodes

See also Zhang Yuanhui's Master's thesis: *Evaluating a publish/subscribe proxy for HTTP*

Zhang Yuanhui, Evaluating a publish/subscribe proxy for HTTP, Master's thesis, KTH Royal Institute of Technology, School of Information and Communication Technology, Stockholm, Sweden, TRITA-ICT-EX-2013:68, April 2013

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Bottlenecks

- Server and Network Bandwidth and **latency**

High speed networks

Low \Rightarrow high speed wireless networks

- User Bandwidth and **latency**

Server

BackboneNetwork
Gbit/s

Gateway to Wireless network

Wireless link
kbit/s .. Mbit/s

personal device

User

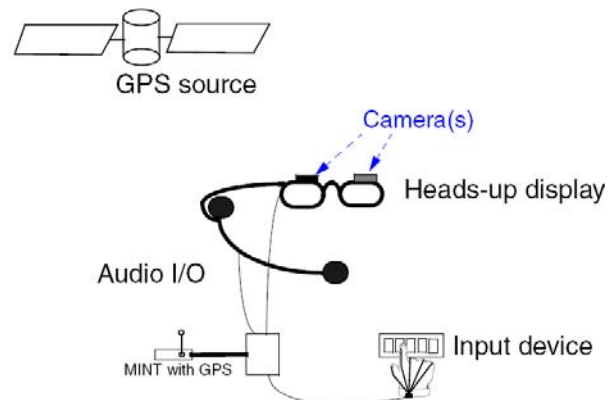
- Power and Energy \Rightarrow need a computational theory of $O(\text{energy})$
- **Imagination!**

IK1550/1552, SPRING 2015 SLIDE 67

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Near Future systems: Personal Portal



Vision-2, 2000 - high level of integration

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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).

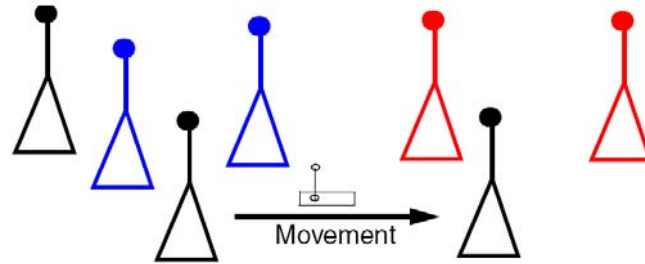
BANs Body Area Networks

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



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 \Rightarrow Very Dumb

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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, ...)

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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)

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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

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MEDIA

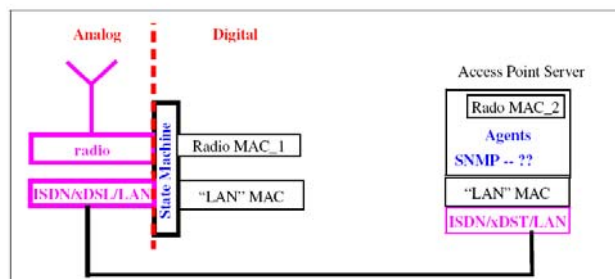
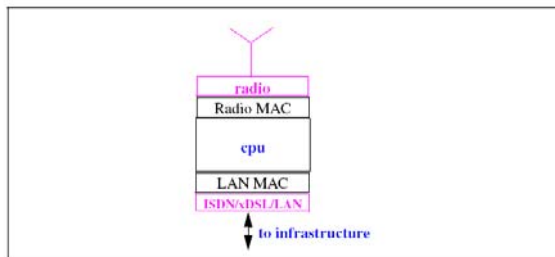
High integration (goal of MEDIA project – Sept. 1996 to Aug. 1999)

**Partners:**

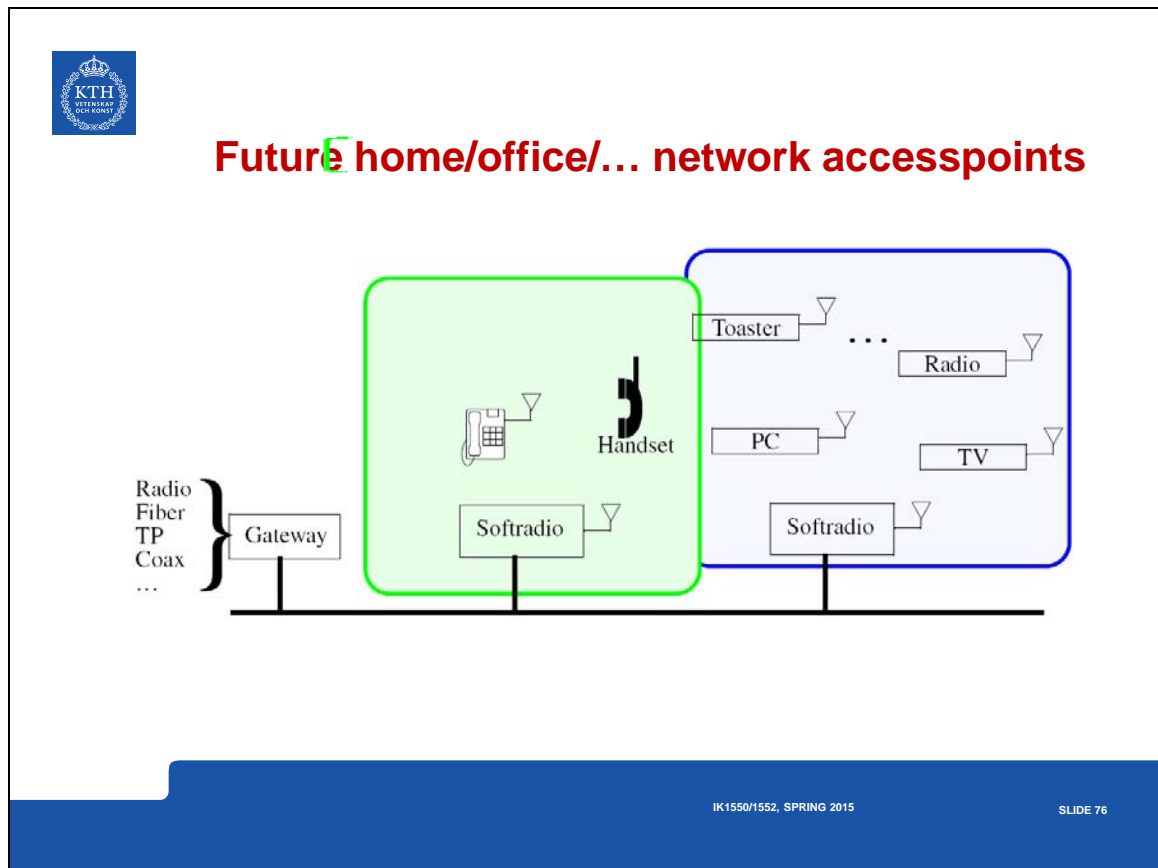
- Kungl Tekniska Högskolan (KTH/ELE/ESDlab and KTH/IT/CCSlab)
- Tampere University of Technology (TUT)
- GMD FOKUS (GMD)
- Technische Universität Braunschweig (UBR)
- Interuniversity Microelectronics Centre (IMEC)
- Ericsson Radio Systems AB (ERA)



Split the functions between access point and access point server



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Internet of Things (IoT)

More and more “things” will be connected to the network. Open questions are what protocols and what data representations (e.g., W3C Semantic Sensor Networks (SSN) ontology - <http://www.w3.org/2005/Incubator/ssn/ssnx/ssn>)

See for example:

J. Soldatos, et al., ‘OpenIoT: Open Source Internet-of-Things in the Cloud’, in *Interoperability and Open-Source Solutions for the Internet of Things*, vol. 9001, Springer International Publishing, 2015, pp. 13–25. Available: http://dx.doi.org/10.1007/978-3-319-16546-2_3

J. Soldatos, N. Kefalakis, M. Hauswirth, M. Serrano, J.-P. Calbimonte, M. Riahi, K. Aberer, P. Jayaraman, A. Zaslavsky, I. Žarko, L. Skorin-Kapov, and R. Herzog, ‘OpenIoT: Open Source Internet-of-Things in the Cloud’, in *Interoperability and Open-Source Solutions for the Internet of Things*, vol. 9001, I. Podnar Žarko, K. Pripužić, and M. Serrano, Eds. Springer International Publishing, 2015, pp. 13–25. Available: http://dx.doi.org/10.1007/978-3-319-16546-2_3

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Personal Computing and Communication (PCC)

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

⇒ ~1 Gbit/sec/user

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

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

-- Gordon Bell and James N. Gray[†]

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

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Uploading ourselves to the net

In Bob Metcalfe'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**[†]:

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.

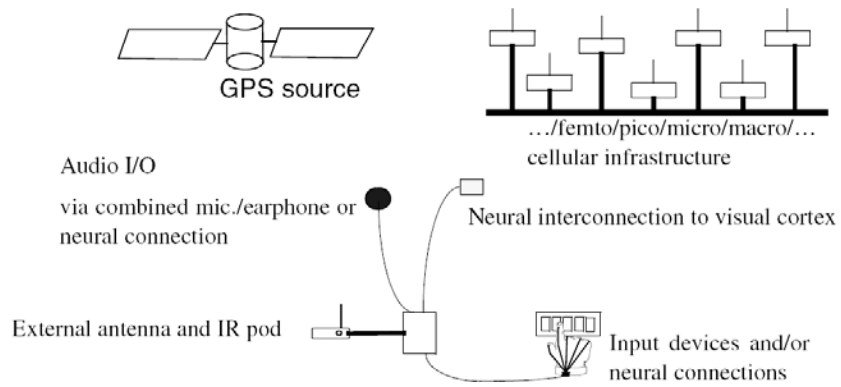
-- Robert M. Metcalfe June 26, 1997

[†] Robert M. Metcalfe, "Internet Futures", MIT Enterprise Forum, June 26, 1997.

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Future Systems



Vision-3, 2005-2015 - very high level of integration

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Bionic Technologies, Inc.[†]'s Intracortical Electrode Array – aka “Utah array”

Acute microelectrode assembly (10x10 array, 100 active electrodes)

10 x 10 silicon electrode array (each electrode: 1.5mm long, 0.08mm wide at base, 0.001mm tip), Built at the Univ. of Utah, by Richard A. Normann, et al.; from Scientific American, March 1994, pg. 108.

See <http://www.blackrockmicro.com/content.aspx?id=78> and <https://www.youtube.com/watch?v=EbOkBbtw74>

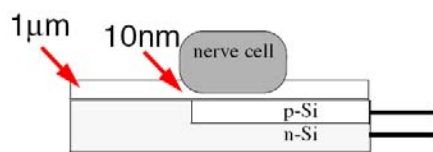
[†]Now: Blackrock Microsystems LLC.



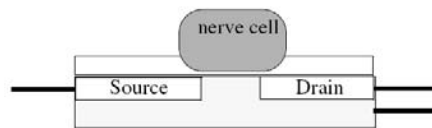
Non-metallic bi-directional neural interfaces

Neurochip: Neuron silicon circuits <http://www.biochem.mpg.de/en/eg/fromherz>

(a) Silicon-Neuron Junction (input to the nerve)



(b) Neuron transistor (output from the nerve)



(a) Capacitive coupling of data into nerve and

(b) using the charge in the nerve to control a transistor's gate for getting data out of the nerve

(a) Peter Fromherz and Alfred Stett, "[Silicon-Neuron Junction: Capacitive Stimulation of an Individual Neuron on a Silicon Chip](#)" Phys.Rev.Lett. 75 (1995) 1670-1673

(b) P.Fromherz, A.Offenhäusser, T.Vetter, and J.Weis, "A Neuron-Silicon Junction: A Retzius-Cell of the Leech on an Insulated-Gate Field-Effect Transistor" Science 252 (1991) 1290-1293.

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What is **your** time line?

- What is going to be your planning horizon?
- What will be the depreciation time for your equipment/software/infrastructure/... ?
- How fast:
 - ◆ can you change?
 - ◆ should you change?
 - ◆ will you change?

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Spotting trends at 1%

Mark J. Penn with E. Kinney Zalesne book:

Microtrends: The small forces behind tomorrow's big changes
[Penn with E. Kinney Zalesne 2007]

⇒ trend spotting

The goal is to spot trends early enough to exploit them, while you competitors do not even realize there is an opportunity!

⇒ Innovation

Mark J. Penn with E. Kinney Zalesne, *Microtrends: The small forces behind tomorrow's big changes*, Twelve (The Hachette Book Group), NY, NY, 2007, ISBN 978-0-446-69976-1

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Summary

- Telecom operators are **reinventing themselves and their infrastructures**
- Things to watch IPv6, IPsec, Mobile-IP, DHCP, the new domain name registries, appliances, ...
- 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 was 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.
 - Keep you eyes open for the increasing numbers of sensors which will be on the network.
 - Service is where the money is!
- Personal Communication and Computation in the early 21st century: **“Just Wear IT!”**
- Coming in 20-30 years: **“Just implant IT!”**
- Remember: The internet will be what **you** make it.

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¿Questions?