

# A Tubeless internet

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# Agenda

Metaphors matter

Communications systems go through **phase transitions**

Internet melted wired communications

Beyond tubes

Engineering liquidity

The relativity principle

New patterns

# An internet of tubes

- “the Internet is not something you just *dump* something on. It's not a truck. It's a *series of tubes...*”
- “the core unit of congestion control is the *flow*”
- “*what you want is a virtual circuit*”

# A view from 1976

- ARPANET demonstrated packet nets
- PCs on LANs emerging at PARC, Cambridge, MIT, CMU
- “Interoperability” of heterogeneous networks
- The phone company model vs. the message switch model

# The end-to-end argument

- Implement functions at the end points or edges, if at all possible
- Add function in the network only if it's the only possible way to do it.
- (corollary: "Stupid Network")

But why?

# Uncertainty and the value of options

- Option: the *right* but not the *obligation* to invest money, effort, ... on a future opportunity
- The *value* of an option *increases* with uncertainty
- Putting functions at the edges creates value in the form of options
- Note: *late binding*

# Today: Pervasive Computing

- Thousands of computers in the home and corporate campus
- Functions distributed in multiple devices
- Many users per device, many devices per user
- So, Network Planner: What will be the killer apps?

# How to fail at pervasive computing

- Universal Plug and Play
- Bluetooth

The problem: embedding application functionality in the networking metaphor – presumes that the network designers know what apps matter, what users need

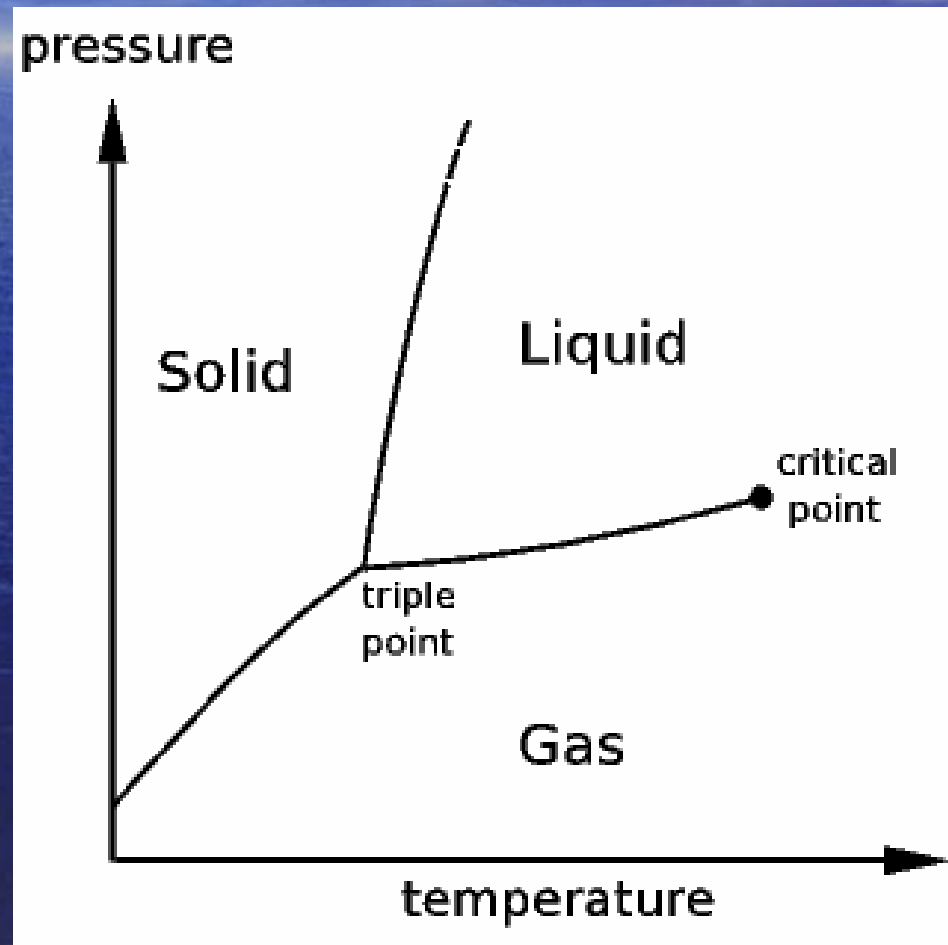
# Solution: An “hourglass model”

- A simple and general interconnection model that is application neutral
- Intelligence “in the network” assumes little about applications function or behavior *other than what it observes*
- Examples
  - IPv4, Ipv6 datagram transport
  - Ethernet
  - 802.11b

# Phase

From Wikipedia, the free encyclopedia.

In the physical sciences, a **phase** is a set of states of a macroscopic physical system that have relatively uniform ... physical properties.



# Phases occur outside physics

In economics, barter economies change into market economies via the creation of *liquidity*, creating a Law of One Price.

Traffic patterns – rural and suburban traffic (gas), rush hour (liquid), traffic jam (solid), NY City (semiconductor)

In living systems, colonial organisms become multicellular individuals through differentiation.

In social systems, class and family structured societies have very different “social capital” from agrarian societies and merchant cities.

# Phase change

From Wikipedia, the free encyclopedia.

Phases are emergent phenomena produced by the self-organization of a macroscopic number of particles.

In systems that are too small, the distinction between phases disappears.

Gas-Liquid: compressibility

Liquid-Solid: rigidity

Phases are **real** but you can't see a phase change by looking more closely at the elements!

# Communications Engineering – Solid phase

AT&T Bell System architecture

Hierarchical, optimized, planned for 30 years

At every level, specs, parts, interfaces, standards  
“fit”

Claim: attaching a phone not made by AT&T risked  
major dysfunction in the network's capabilities

# Communications: from Solid to Liquid

Through 1992, the Internet was an loose, optional feature of some computer installations layered on highly structured and purpose-built telecom networks.

1995-2000, a new phase began to emerge – the WWW, email, file servers, streaming media, and common file formats and standards transcended telecom's rigid substrate

By 2004, the infrastructure melts - Internet support becomes uniform and pervasive throughout the world – a computer would not make sense off the Internet, and most products and services had presence on the Internet

No hierarchy, but remarkable resiliency, adaptability, strength ***DO WE NEED A HIERARCHY???***

# Emergent properties of the liquid communications phase

Adaptable to conditions – absorbs new technologies and applications

Low energy to reshape – reducing the cost of innovation in culture and business

Boundaryless – globalization, no bottlenecks or middlemen

Solvent – absorbs and diffuses new innovations

Turbulence – local emergent structures: blog networks, discussion groups, etc.

# Engineering the liquid phase

No hierarchy, planned structure, command and control

We couldn't reboot the Internet and come up with the same thing (but a solid mechanism could be built)

It's something that grows

Learn from the biological "Engineer", not mechanical engineer

# Non-hierarchical, collective behaviors can do work reliably

We trust ships to float, farms to produce food, financial markets to promote and manage investments in the future

CDDDB – now Gracenote

Wikipedia

“Viral marketing”

Science

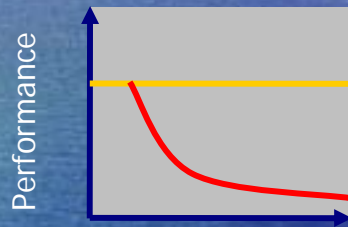
# The Sky is Not the Limit

There is no known physical principle that prevents scaling the RF communications capacity in a physical space proportional to the number of antennas in that space.

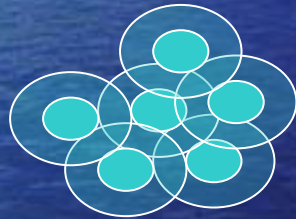
But today's hierarchical, centrally designed architectures can't do it.

# Viral Radio

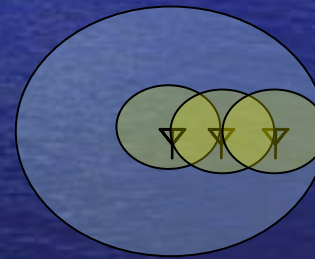
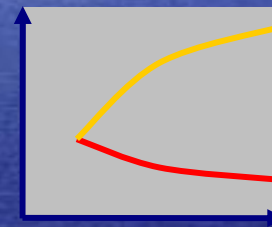
Frequency/Space  
subdivision



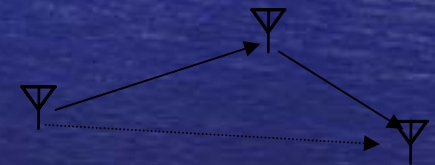
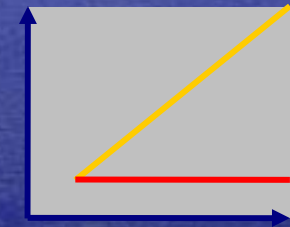
Node density



Packet multihop



Cooperative diversity



Increasing cooperation



# Viral Radio Networks

networks, not radios

transceivers, not transmitters and receivers

Liquidity principles (constructing liquid phase):

- receivers and transmitters equal

- don't optimize –becomes brittle and solid

- trust in numbers and statistical fluidity, which get better with scale

# The Relativity principle

- *The endpoint is the center of its network*
- What matters is personal, not fixed
- Relationships drive connectivity, not vice versa
- Users evolve the sharing and connectivity

# Integrating a community of people and devices

- Make networks that support mobile community members with stable and persistent relationships
- Multiconnected users, devices
- Applications span heterogeneous technology
- Most applications are *configurations*

# Attributes of Network

- Mobility: ends move (frequently, not always rapidly)
- Awareness: ends sense, and adapt
- Accomodating: environment accomodates new ends easily
- Transport independent: minimize dependency on specialized transport network functions

# Concerns to ensure

- Heterogeneous in function
- Heterogeneous in implementation
- Evolvable/futureproof
- Composable devices/functions/...
- Safe and respectful (rather than secure)
- Sharing/multiplexing is controllable

# Ends, not boxes

- Ends exist in boxes but are not boxes
- Multiplexing ends in boxes
- Ends virtualize boxes
- Ends virtualize people, too: personas are ends

# Focus on persistent groups

- Applications are persistent groups of ends
- Maintain group independent of connection - virtualize
- Facilitate group evolution (add drop ends)

# Focus on coordination

- Many events are of interest to a variety of devices, based on context
- Network exists to distribute event notifications
- Internetworked publish subscribe protocols:  
event = {producer, topic, consumer, timestamp, message} [where producer, topic, consumer are unique Ids or names]

# A new hourglass

- Above the neck:
  - Define groups and semantic meaning
  - Define policies and negotiate control
  - Respond to events and adapt to context
- Below the neck:
  - Signaling events to interested ends
  - Group routing and coordination
  - Sensing ends, sensing end context
  - Limiting scope and damping effect

# Enhanced WLANs

- No “association delay”
- Standardized position sensing and presence sensing
- Beyond “service discovery” to *context awareness and context sensitivity*

# Enhanced “mobile data networks”

- Can build on MVNO concept
- Home Location Registry and AAA/AN services move to edge, extensible
- New protocol abstractions that scale awareness, multiconnected devices, transport independence, event distribution
- Span space and time of the community

# Enhanced Identity and Authorization

- Put user in control of negotiated authorization to access community resources
  - Principle of least privilege
  - Principle of
- Support multiple identities, temporary identities, agency relationships
- Relativity principle applies