



# Liquid Protocols

David P. Reed

MIT Media Laboratory

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# Agenda

Communications systems go through **phase transitions**

Internet melted wired communications from solid (designed, optimized based on rigid structure) to liquid (adaptive, flexible)

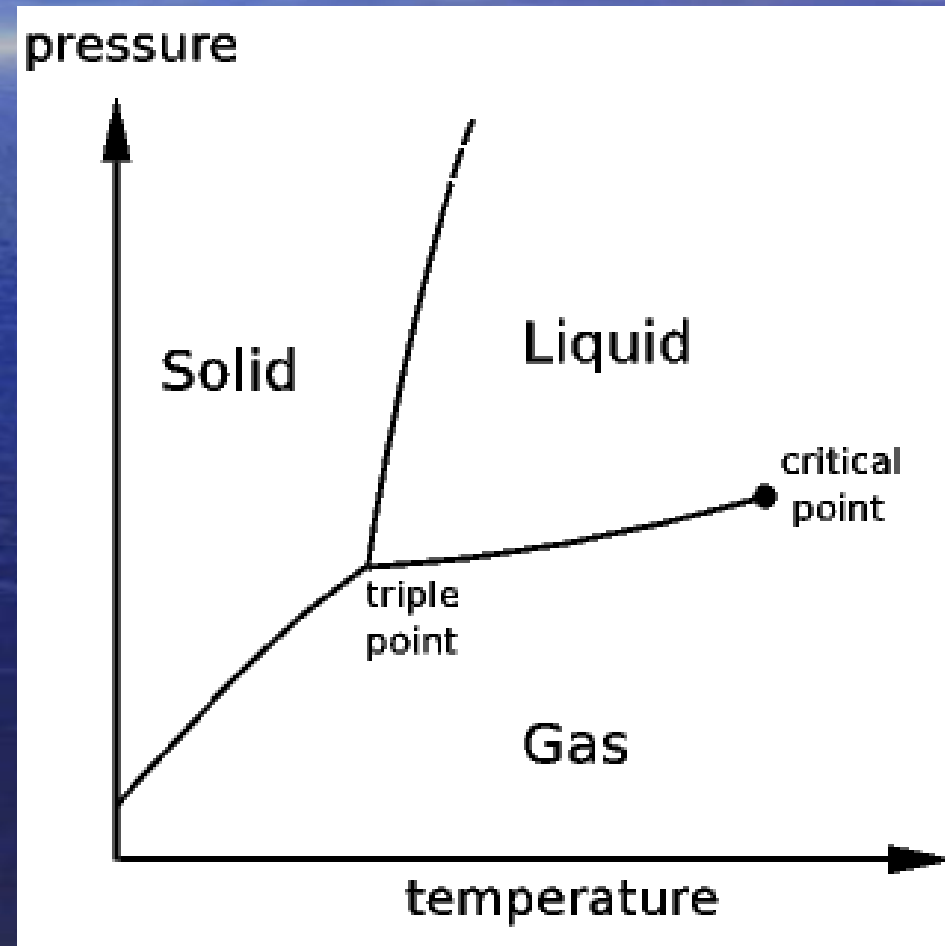
Understanding the liquid phase

Extending the liquid phase to wireless

# 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!

Phase arises from scaling properties among elements



# Communications – Solid phase

AT&T, North American Numbering Plan

Hierarchical, optimized, planned for 30 years

At every level, specs, parts, interfaces, standards

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

Because of rigidity – might have been true!

# 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



# Understanding 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 biology, not mechanical engineering





Collective behaviors can do work  
reliably

We trust ships to float!

CDDDB – now Gracenote

Wikipedia

BitTorrent

# BitTorrent – an emergent liquid-phase invention

A cooperative file distribution protocol

Everybody interested in getting a file required to help others get that file – self organizing

Protocol designed to reward cooperation, punish free-riders.

The same effect explains how Internet congestion control works – shared incentives to manage congestion without central control, “negotiation” of fair states via packet drops and mutuality



# Extending the liquid phase to wireless

Wireless

Mobile

Person-centered

- are goals

Yet radio systems remain in the "solid phase"

Why? Regulation founded on a presumption of scarcity of spectrum

# The Sky is Not the Limit

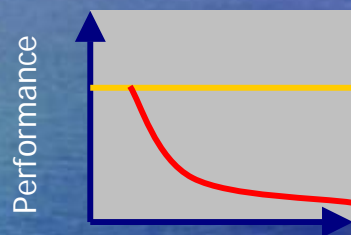
There is no known physical principle that prevents scaling the RF communications capacity in a physical space proportional to the number of antennas in that space.

But today's hierarchical, centrally designed architectures don't achieve that



# Viral Radio

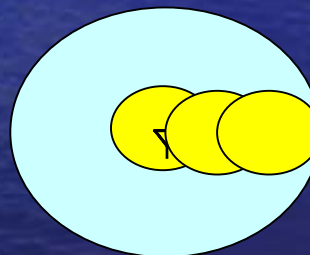
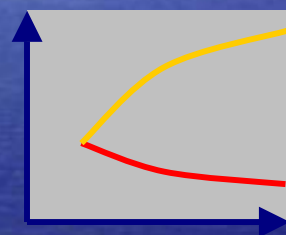
Frequency/Space  
subdivision



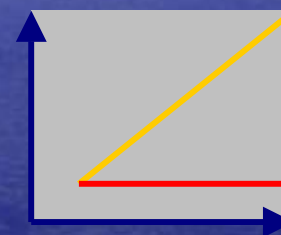
Node density



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

Viral structure – structure adapts to demand dynamically

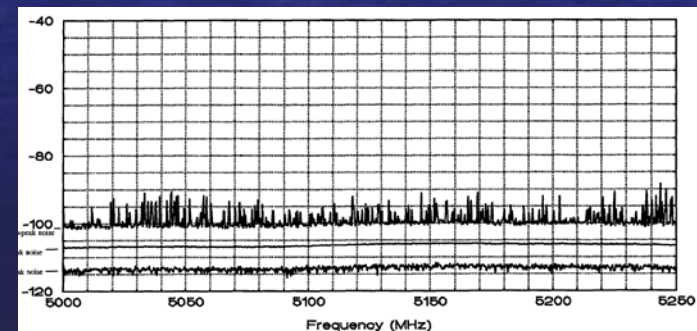
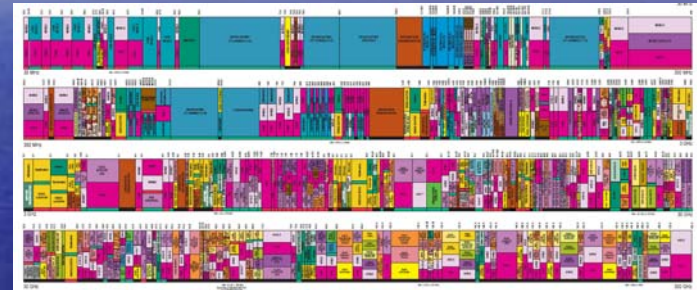


# Radio regulation creates the very scarcity it assumes

The spectrum is full (law)

Vs.

The spectrum is essentially empty (physics)



# Learn from Bit-torrent

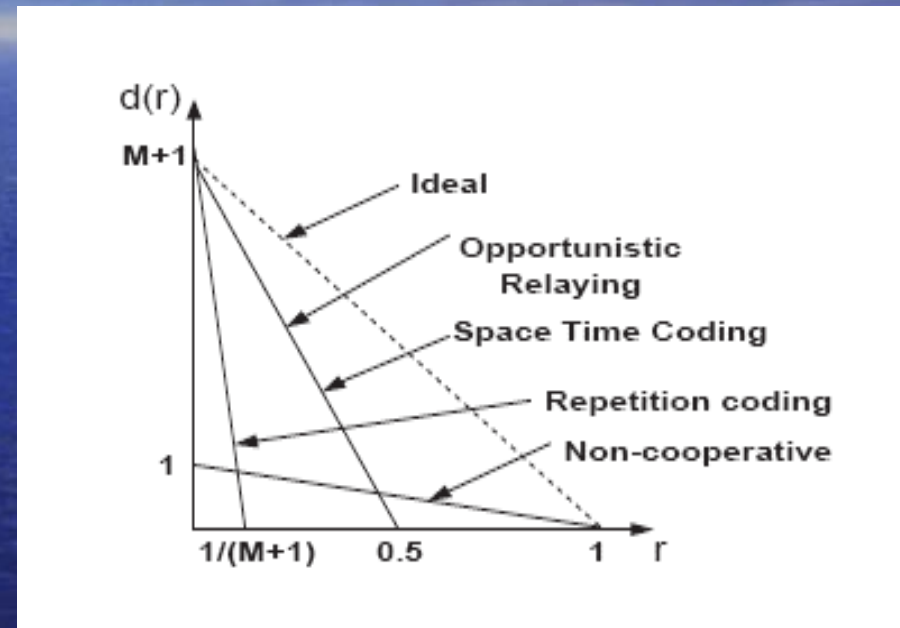
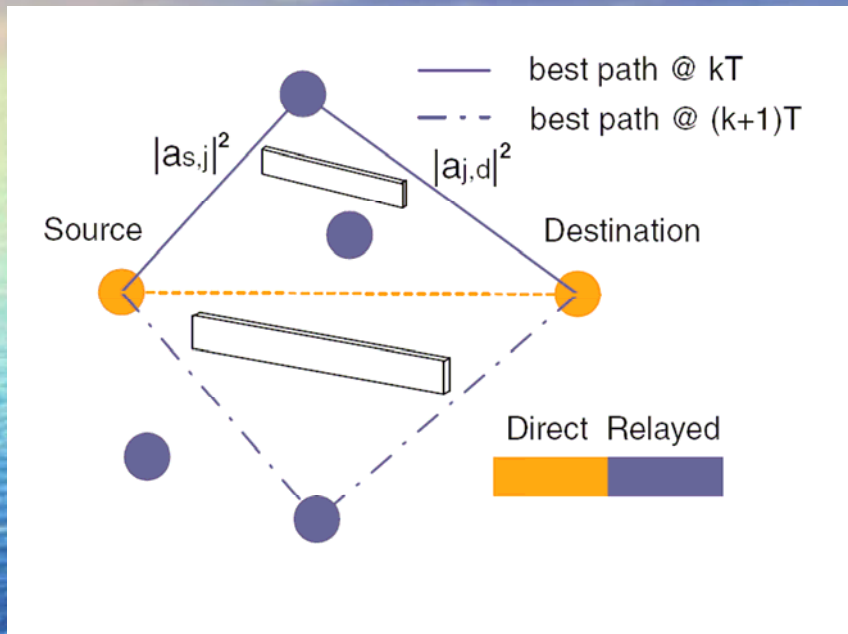
Cooperate by relaying where that helps

Sense the environment and adapt to conditions and demand dynamically

Use what you need; create incentives for cooperation, punishments for defection



# A simple example of adaptation and liquidity – opportunistic relay



Liquidity: the more relay choices, the more adaptation improves capacity

# Observations

Added nodes help (more degrees of freedom avoid brittle failure)

“Voluntary” cooperation pays forward

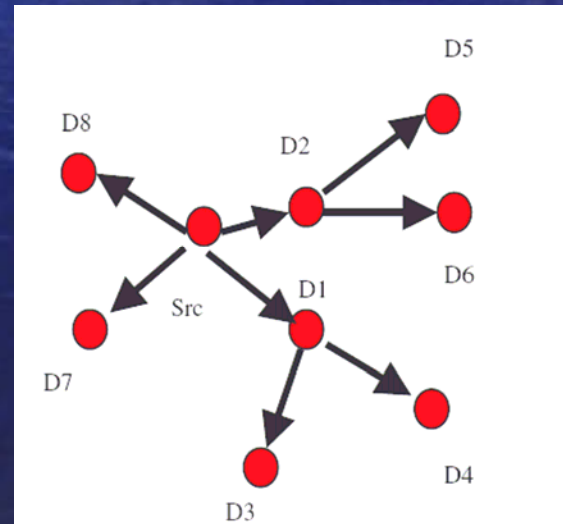
Idle nodes have incentive to cooperate

Based on the observation that capacity can increase with the number of nodes, because of more degrees of freedom, so scaling takes care of resource.



# Fulu Li

Cooperative relay boosts multicast, too  
Recipients receive both original and  
forwarded data



# Liquid Multicast Technique

Adaptive relay already depends on  
"multicast" of propagation information  
during periodic RTS/CTS

Can piggyback routing decision on that



# Liquid local cooperation decision

Piggyback propagation testing on periodic routing decision

Announce all in-flight data

Announce "route options"

Allow each relay to "volunteer" what it can forward

Transmit using relays

# Essence of “liquid” vs. “solid” protocols

Liquidity constantly tests the local environment, matching conditions to demand

Avoid operating near the optimum, which is brittle

“go for scalability”



# 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.