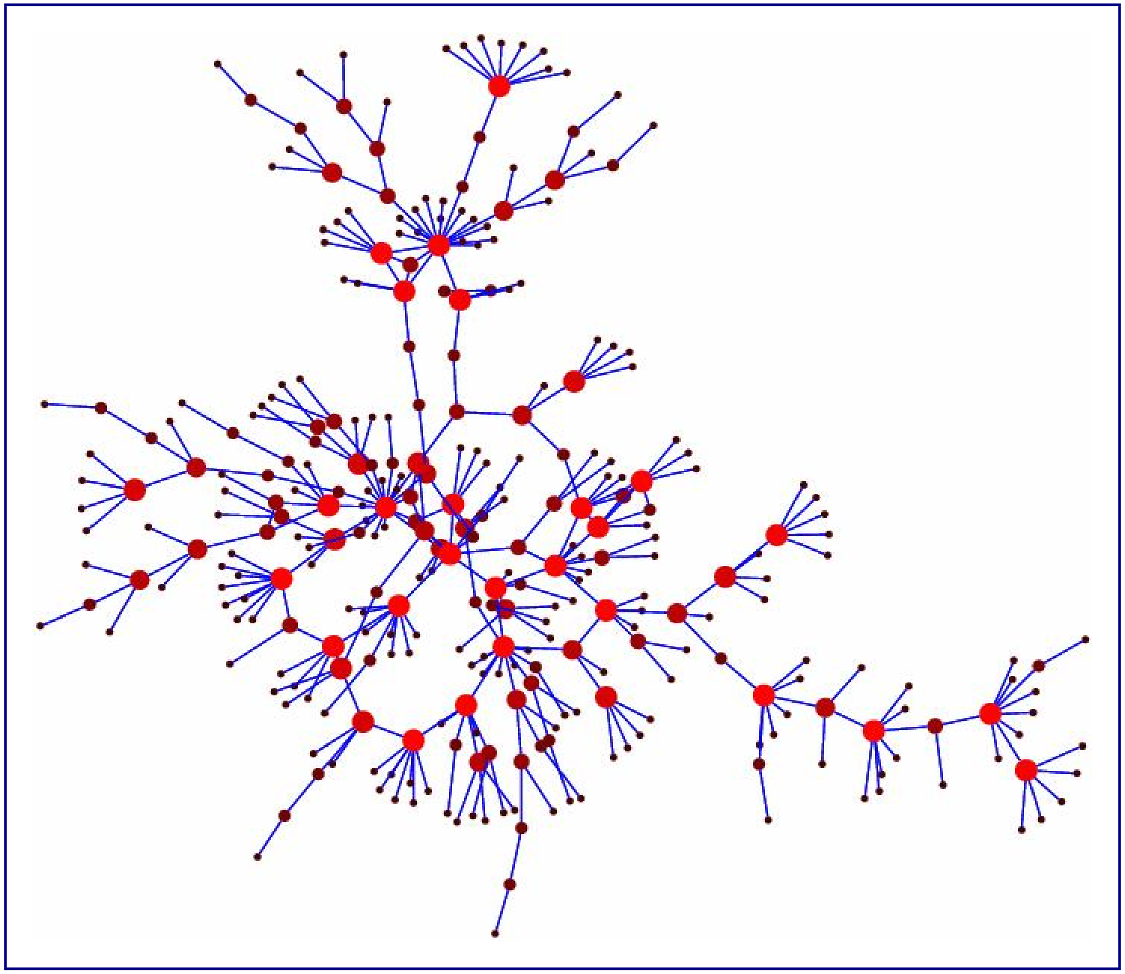
MAE 298, Lecture 11

Feb 20, 2008



"Flow on real-world networks"

Topics

- Optimal allocation of facilities and transport networks:
  – Michael Gastner (SFI) and Mark Newman (U Mich)

- Network flows on road networks
  – I. User vs System Optimal
  – II. Braess' Paradox
  – Michael Zhang (UC Davis)

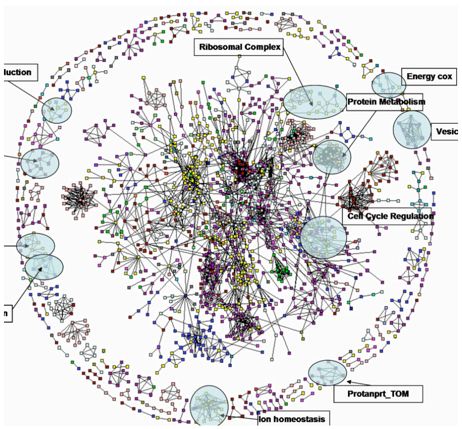
- Scale invariance in road networks:
  – Kalapala, Sanwalani, Clauset, Moore (UNM/SFI)

- Layered interacting networks:
  – Kurant and Thiran (EPFL)

“Interacting complex networks
Multiple Length and Time Scales”

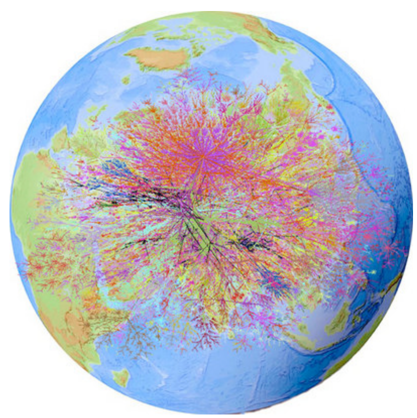
Networks:

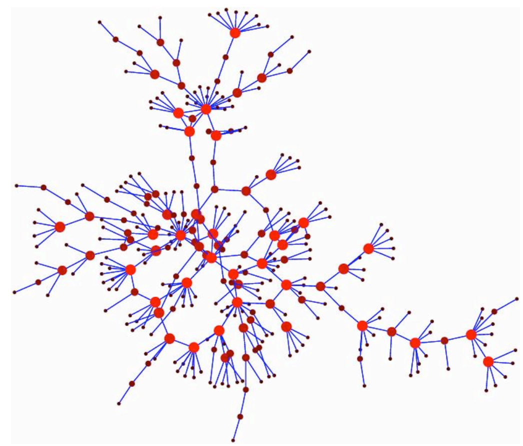
Transportation Networks/ Power grid
(distribution/ collection networks)



Biological networks
- protein interaction
- genetic regulation
- drug design

Computer networks





Social networks
- Immunology
- Information
- Commerce

Our modern infrastructure

Layered, interacting networks

ELECTRICITY

Banking and Finance

Government

Emergency Response

Transportation

Oil and natural gas

Water

TELECOM

Optimal design of spatial distribution systems:

(Download: Gastner.pdf)

Flow on transportation networks:

(Download: Zhang.ppt)

“Layered complex networks”

[M. Kurant and P. Thiran, “Layered Complex Networks”, Phys Rev Lett. 89, 2006.]

- Offer a simple formalism to think about two coexisting network topologies.
- The physical topology.
- And the virtual (application) topology.

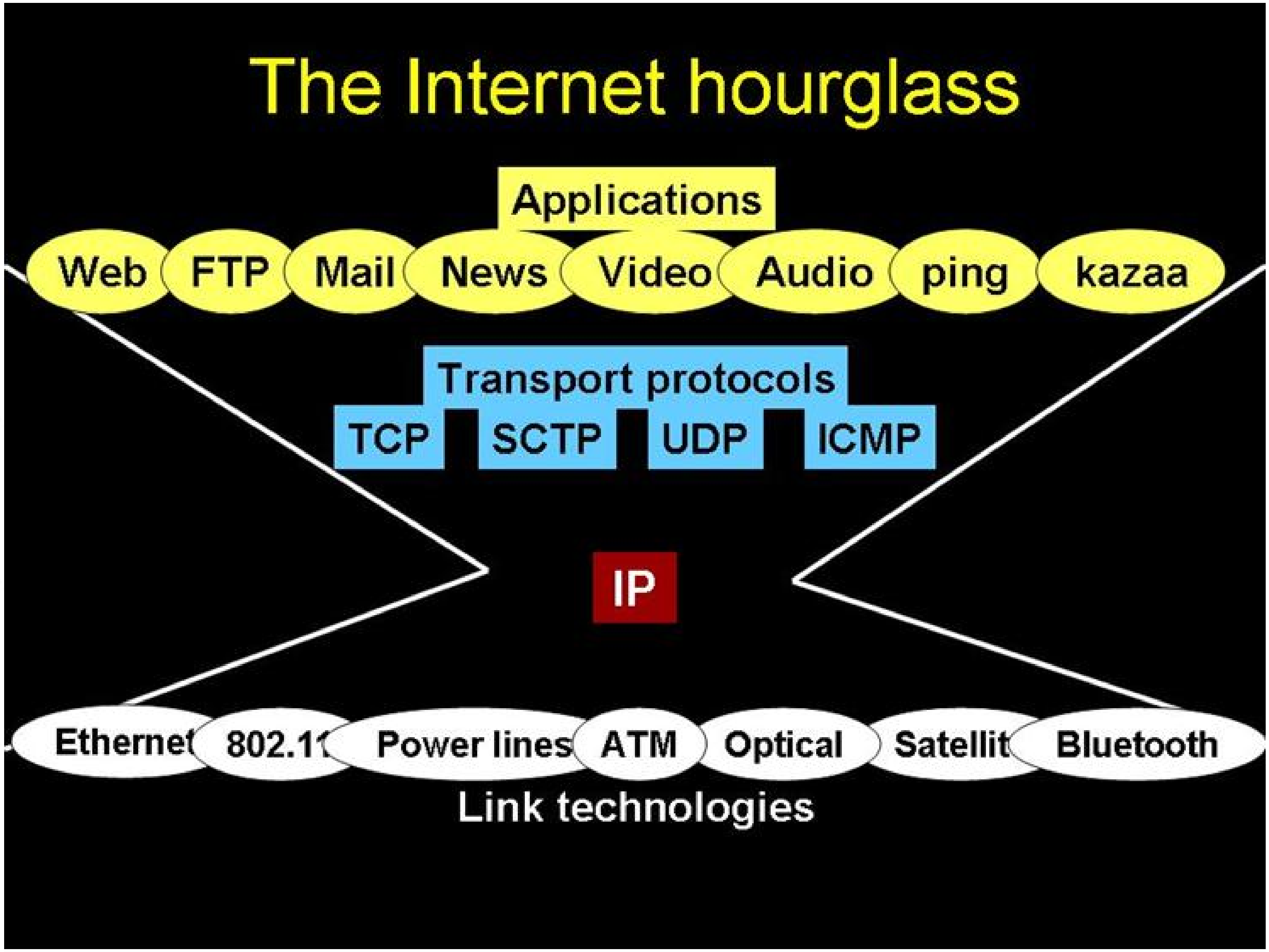
Example 1:
WWW and IP layer views of the Internet

- Each WWW link virtually connects two IP addresses.
- Those two IP nodes are typically far apart in the underlying IP topology, so the virtual connection is realized as a multihop path along IP routers.
- (Of course the IP network is then mapped onto the physical layer of optical cables and routers.)

AS
(BGP routes)

TraceRoute

Router level



(picture from David Alderson)

Example 2: Transportation networks

Up until now separate studies of:

1. Physical topology (of roads)

2. Real-life traffic patterns

Want a comprehensive view analyzing them both together.

The formalism

Consider two different networks:

- $G^{\phi} = (V^{\phi}, E^{\phi})$; the physical graph.
- $G^{\lambda} = (V^{\lambda}, E^{\lambda})$; the logical/application-layer graph.

Assume both sets of nodes identical, $V^{\phi} = V^{\lambda}$.

The load on a node

- Load on node i, $l(i)$, is the sum of the weights of all logical edges whose paths traverse i.

- E.g., in a transportation network $l(i)$ is the total amount of traffic that flows through node i.

Application

Study three transportation systems:

1. Mass transit system of Warsaw Poland.

2. Rail network of Switzerland.

3. Rail network of major trains in the EU.

Load

They can estimate the real load from the timetables (some assumptions; decompose into units (one train, one bus, etc), independent of number of people).

Two load estimators:

1. The node degree of the physical network.

2. Betweenness of the physical network.

(Note, these estimators are the ones currently in use in almost all cases: 1) Resilience of networks to edge removal, 2) Modeling cascading failures, etc.....)

Findings

[M. Kurant and P. Thiran, “Layered Complex Networks”, Phys Rev Lett. 89, 2006.]

- All three estimators 1) real load, 2) degree, 3) betweenness differ from one-another.
- Using the two-layer view can see the logical graphs may have radically different properties than the physical graphs.
- May lead to reexamination of network robustness (previous studies on Internet, power grid, etc, based on physical layer).

Additional References

Follow up

- M. Kurant, P. Thiran and P. Hagmann "Error and Attack Tolerance of Layered Complex Networks", Phys. Rev. E, Vol. 76, 2007.
- M. Kurant and P. Thiran "Extraction and analysis of traffic and topologies of transportation networks", Phys. Rev. E, Vol. 74, 2006.

David Aldous

- Flows through random networks
- "Spatial Transportation Networks with Transfer Costs: Asymptotic Optimality of Hub and Spoke Models"