The influence of realism on congestion in network simulations

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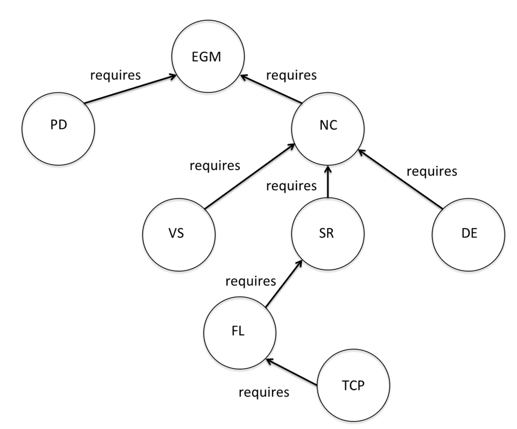
Introduction

No one seems to know what level of realism should be required in network models that study congestion. This raises questions about ten years of extant studies [e.g.,1-6]. How do various realism elements influence congestion spread? Are some elements essential? Can some be ignored?

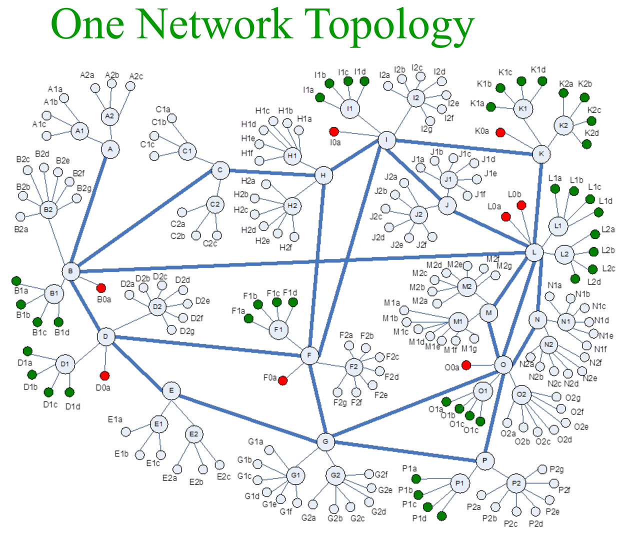
Seven Network Realism Elements and Dependencies

Factor	Enabled	Disabled
PD	Queue size = 250 x router speed	Queue size = infinity
NC	Three-tier 218-node topology as in Fig. 6 with routers labeled by class: backbone, point of presence, or access	Flat 218-node topology as in Fig. 6 but with routers unlabeled by class
VS	Router speeds differentiated by class, as shown in Table 2 and when sources and receivers are enabled half are fast (2 p/ts) and half are not fast (0.2 p/ts)	Router speeds identical at 9 p/ts and when sources and receivers are enabled all operate at 9 p/ts
DE	Backbone links in topology assume propagation delays consistent with geography and physics	Backbone links in topology have no propagation delay
SR	Sources and receivers are deployed below access routers using the parameters in Table 3	No sources and receivers are deployed below any routers
FL	Transfers occur as related streams of packets, with number of packets chosen randomly from Pareto distribution (mean 350, shape 1.5) and flows are set up with connection establishment procedures taken from TCP	Transfers involve individual packets
TCP	Packet transmission regulated with TCP congestion control procedures including slow-start (initial *cwnd* = 2; *fsst* = 100; *ssst* = $2^{30}/2$) and congestion avoidance	Packet transmission not regulated by any congestion control procedures



Method (network simulations)

One Network Topology



Four Responses

$\chi = |G_\chi|/|G_N|$ congestion spread

$\alpha = |G_\alpha|/|G_N|$ connectivity breakdown

$\pi = 1 - \rho - x$ packets delivered

$\delta = (\Delta - \Delta_{MIN})/(\Delta_{MAX} - \Delta_{MIN})$ packet latency

34 Configurations

Seq#	Config	TCP	FL	SR	DE	VS	NC	PD
1	C0	0	0	0	0	0	0	0
2	C1	0	0	0	0	0	0	1
3	C2	0	0	0	0	0	1	0
4	C3	0	0	0	0	0	1	1
5	C6	0	0	0	0	1	1	0
6	C7	0	0	0	0	1	1	1
7	C10	0	0	0	1	0	1	0
8	C11	0	0	0	1	0	1	1
9	C14	0	0	0	1	1	1	0
10	C15	0	0	0	1	1	1	1
11	C18	0	0	1	0	0	1	0
12	C19	0	0	1	0	0	1	1
13	C22	0	0	1	0	1	1	0
14	C23	0	0	1	0	1	1	1
15	C26	0	0	1	1	0	1	0
16	C27	0	0	1	1	0	1	1
17	C30	0	0	1	1	1	1	0
18	C31	0	0	1	1	1	1	1
19	C50	0	1	1	0	0	1	0
20	C51	0	1	1	0	0	1	1
21	C54	0	1	1	0	1	1	0
22	C55	0	1	1	0	1	1	1
23	C58	0	1	1	1	0	1	0
24	C59	0	1	1	1	0	1	1
25	C62	0	1	1	1	1	1	0
26	C63	0	1	1	1	1	1	1
27	C114	1	1	1	0	0	1	0
28	C115	1	1	1	0	0	1	1
29	C118	1	1	1	0	1	1	0
30	C119	1	1	1	0	1	1	1
31	C122	1	1	1	1	0	1	0
32	C123	1	1	1	1	0	1	1
33	C126	1	1	1	1	1	1	0
34	C127	1	1	1	1	1	1	1

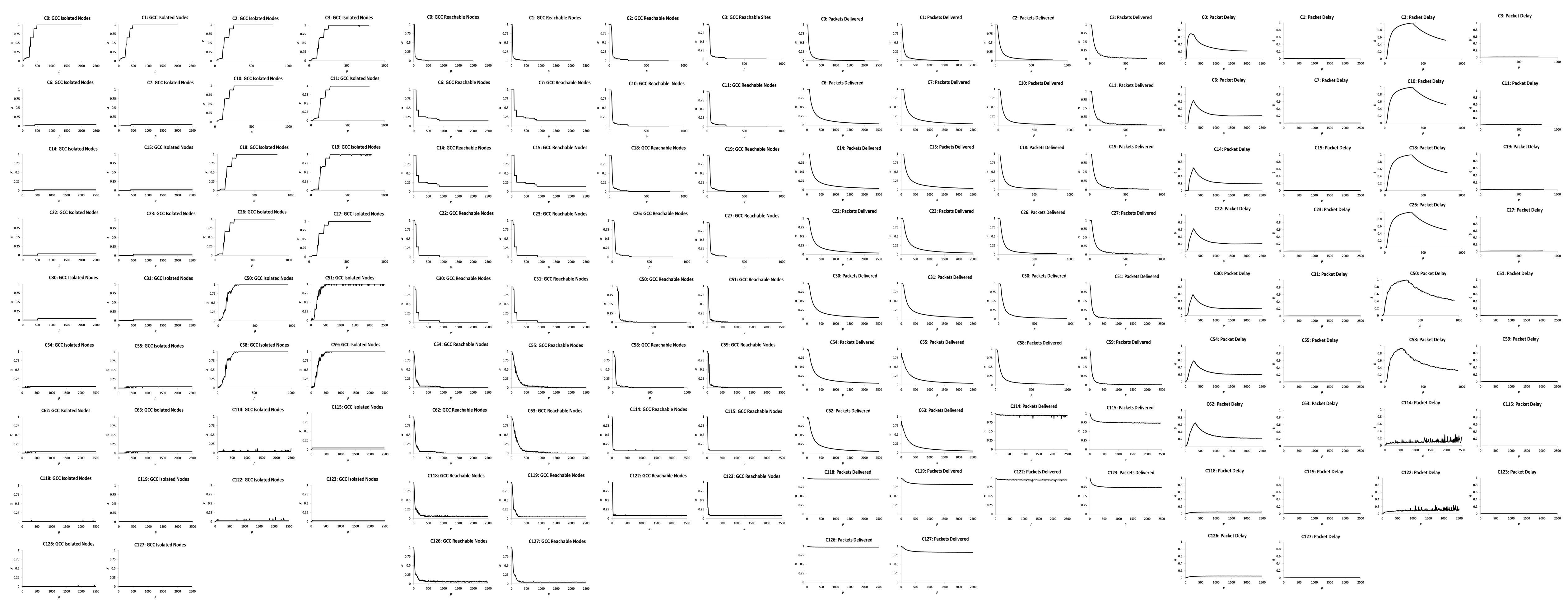
250 Load Levels

p = 1 to 2500 by 10

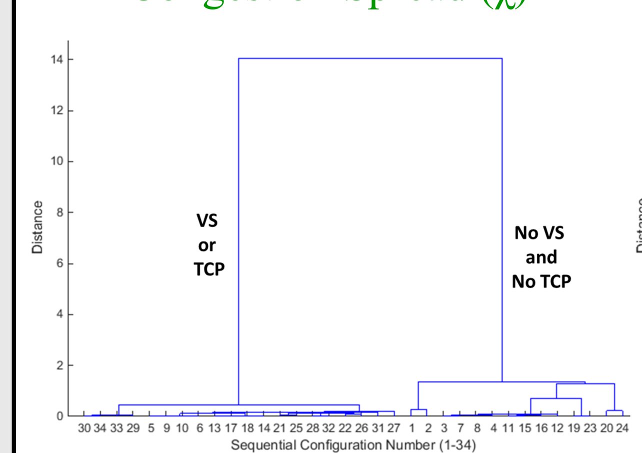
Results

We simulated 34 configurations at increasing packet injection rates, p = 1 to 2500, plotted on the x axes against four responses, χ, α, π and δ, plotted on the y axes. We used hierarchical clustering to identify configurations with similar congestion behavior, and used those clusters to identify realism elements with largest influence on each response. We also compared responses for the most abstract (C0) [6] and realistic (C127) [7] configurations.

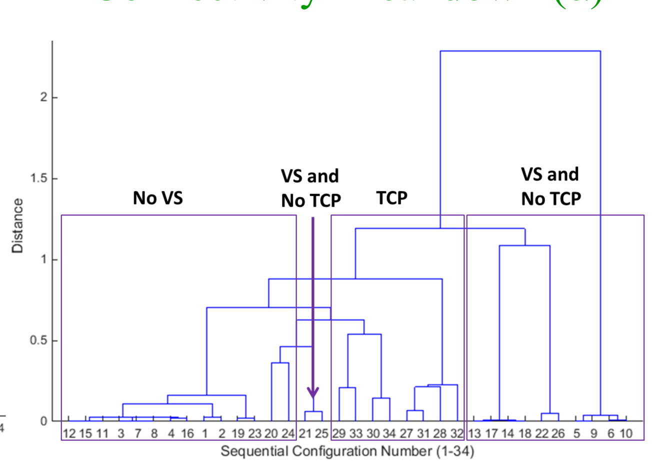
Congestion Spread (χ) | Connectivity Breakdown (α) | Packets Delivered (π) | Packet Latency (δ)



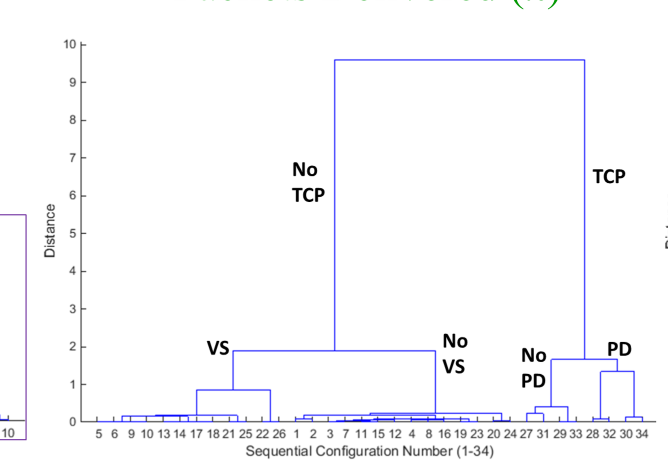
VS & TCP Influence
Congestion Spread (χ)



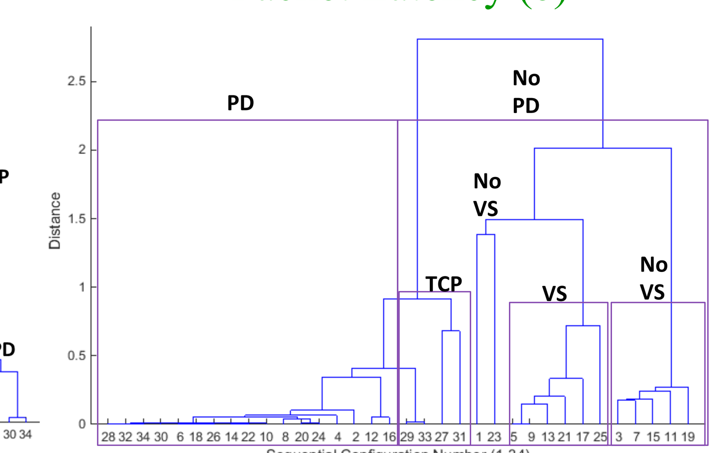
VS & TCP Influence
Connectivity Breakdown (α)



TCP & VS & PD Influence
Packets Delivered (π)

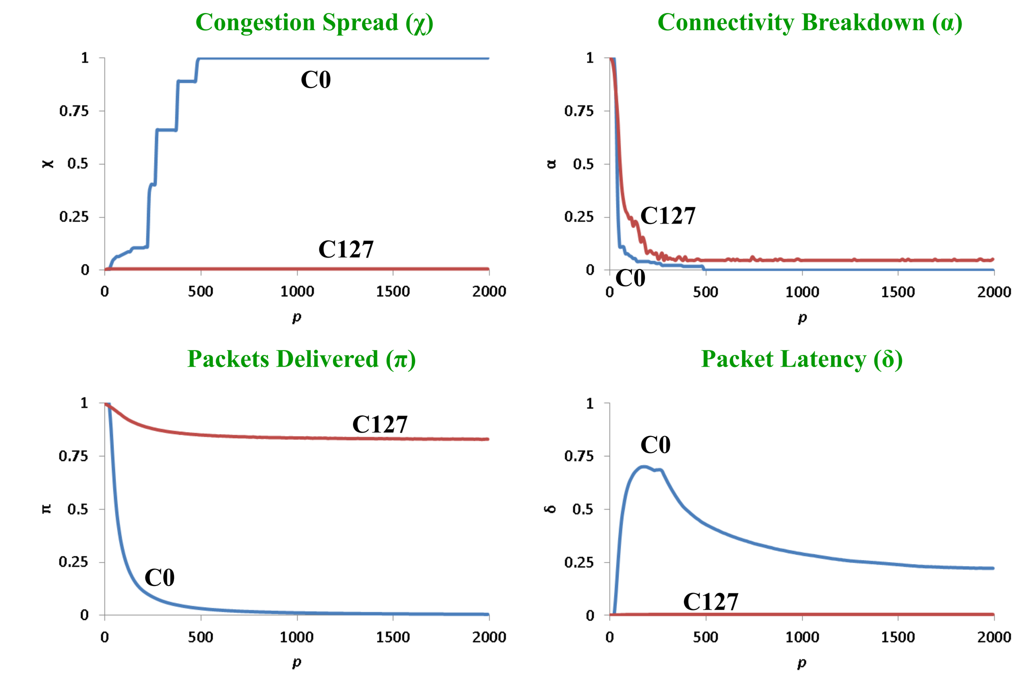


PD & VS & TCP Influence
Packet Latency (δ)



Conclusions

Abstract (C0) and realistic (C127) network models exhibit very different congestion behaviors.



Variable speeds (**VS**) among router tiers, engineered to ensure adequate throughput, are *very important to model*. And modeling **VS** requires node classification (**NC**), which restricts packet injection to nodes on the network edge.

The transmission control protocol (**TCP**), which detects *congestion* and adapts packet injection rate accordingly, is *very important to model*. In addition, modeling TCP requires modeling sources and receivers (**SR**) and flows (**FL**).

Packet dropping (**PD**) due to finite FIFO buffers is *important to model* for accurate measures of packet latency.

Propagation delay (**DE**) is not important to model in networks spanning the US, but could be important in global networks or networks with satellite hops, and would be very important to model in inter-planetary networks.

A decade of studies [e.g., 1-6 and many more] used models too abstract to simulate realistic congestion behavior in communication networks based on Internet technology. The validity of findings from such studies appears suspect.

Literature cited

[1] Solé and Valverde, Information transfer and phase transitions in a model of internet traffic. 2001. *Physica A* 289:595-605.
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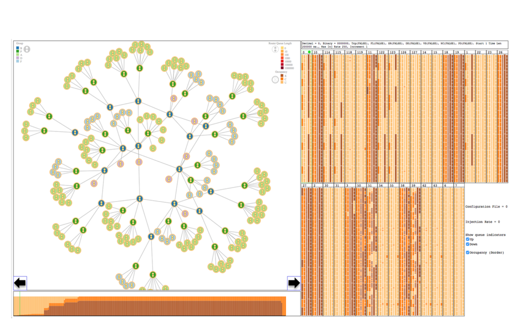
[7] Mills et al., How to model a TCP/IP network using only 20 parameters. 2010. *Winter Simulation Conference* 849-860.

Acknowledgments

Thanks to Philip Gough of CSIRO for creating a dynamic visualization that allowed us to investigate details of congestion spread in our topology.



Further information

For information about related research into complex systems behavioral modeling and analysis with emphasis on communication networks and clouds, see http://www.nist.gov/itl/antd/emergent_behavior.cfm or contact kmills@nist.gov.