Bank of Finland Simulation Seminar and Workshop

23 August 2006

Network topology and payment system resilience - first results

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Research problem and approach

- How does the topology of the payment network affect its resilience?

- Devise a simple model to test the impact of topology:

    1. stochastic instruction arrival process
    2. “prototypical” topologies of interbank relationships
    3. simple reflexive bank behavior, and
    4. single disrupted bank

1. Stochastic instruction arrival process

- Each bank has a given level of customer deposits (D_i)
- Each unit of deposits has the same probability of been transformed into a payment instruction

$$\langle I_i(t) \rangle = \lambda_i \cdot \frac{D_i(t)}{D_i(0)}$$

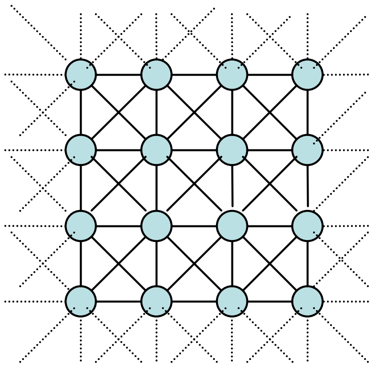
- where λ_i is the initial rate

- When a bank receives a payment its deposits increase
  -> the instructions arrival increases
- When a bank sends a payment its deposits decrease
  -> the instructions arrival decreases

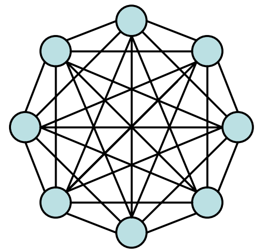
2. “Prototypical” topologies of interbank relationships

Homogeneous deposit distribution

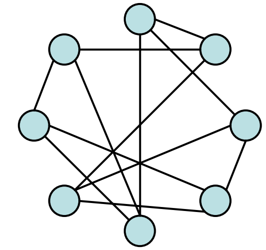
400 banks, 8*400 links



lattice

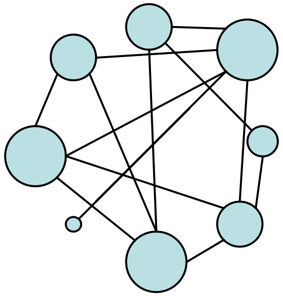


complete

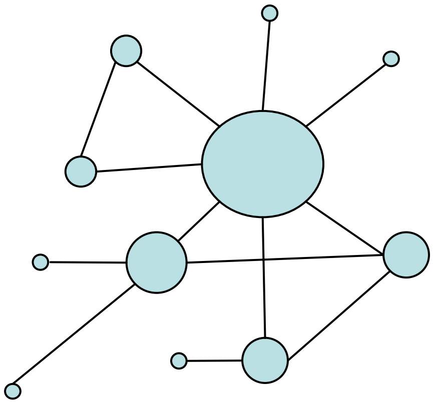


random

Heterogeneous deposit distribution

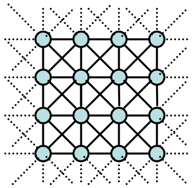
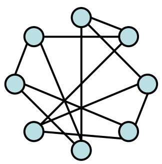
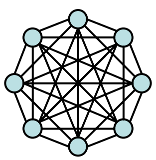
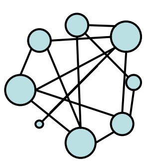
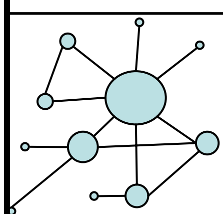


random

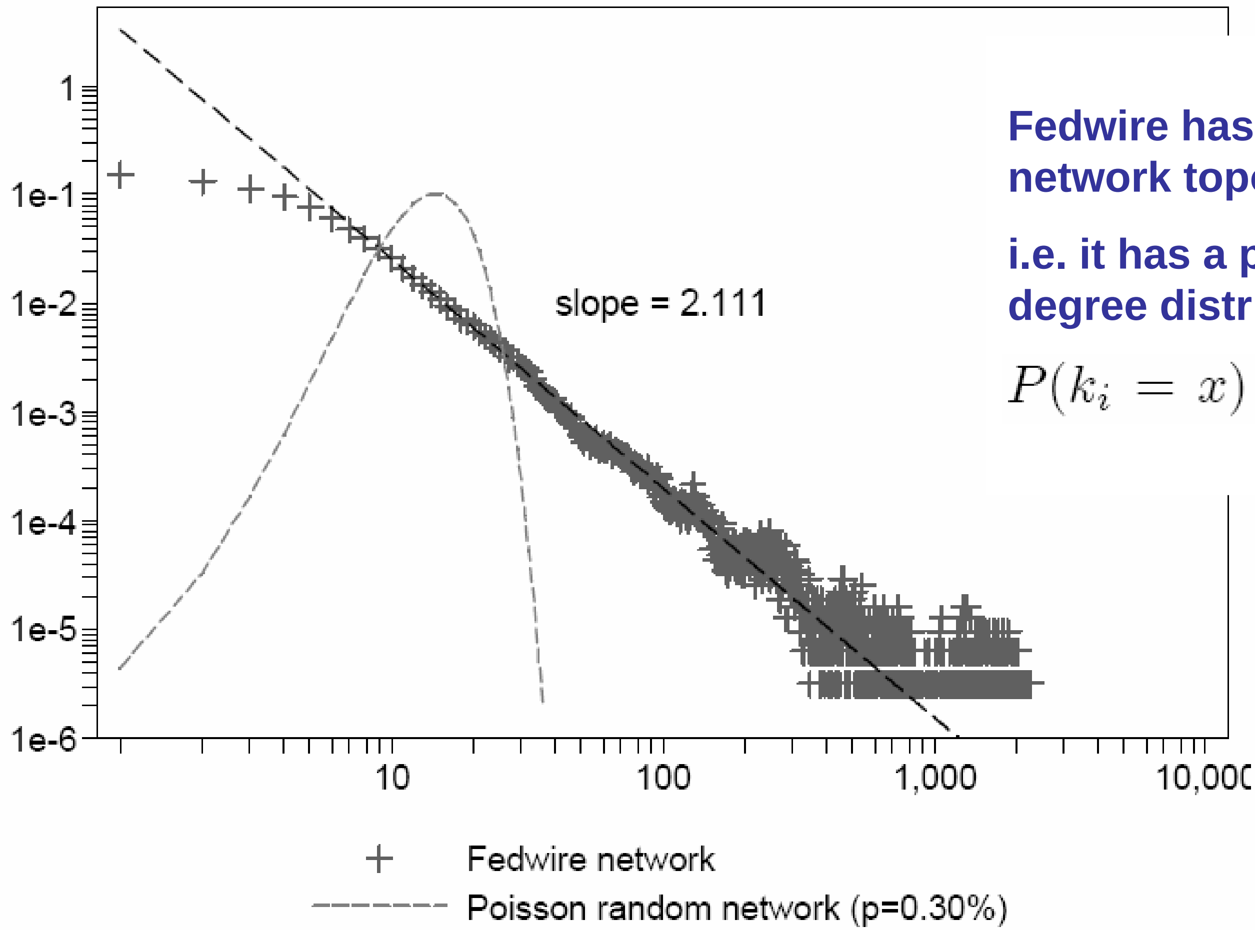


scale-free

2.1 Network statistics

	average degree	Degree range	average path length
 lattice	8	8	6.7
 random – homogeneous	8	8	3.1
 complete	399	399	1
 random – heterogeneous	8	1 – 19	3.1
 scale-free	8	1 – 225	2.6

2.2 Real networks…



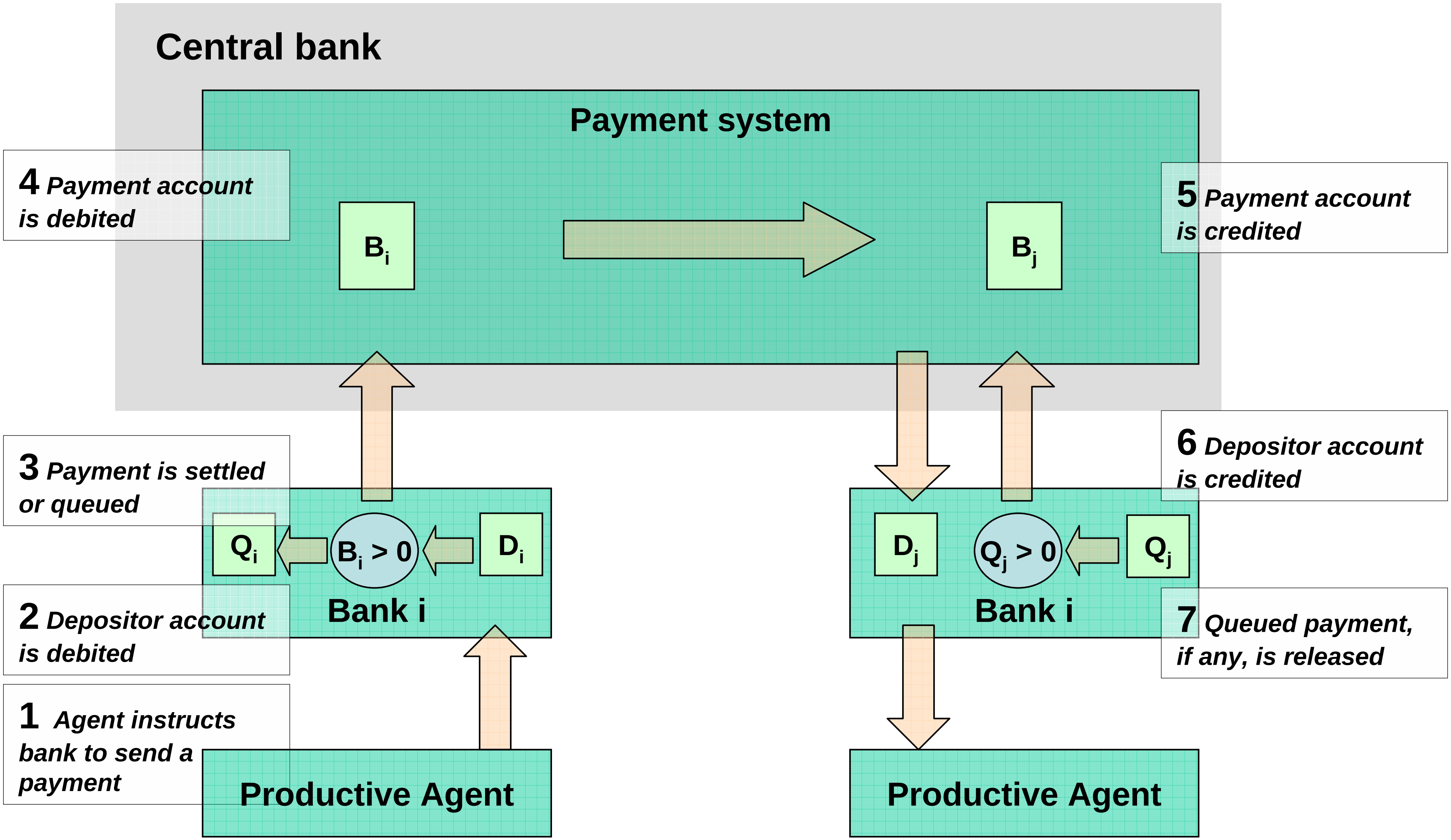
Fedwire has a scale-free network topology

i.e. it has a power law degree distribution, where

$$P(k_i = x) \backsim k_i^{-\gamma}$$

Source: The Topology of Interbank Payment Flows
http://www.newyorkfed.org/research/staff_reports/sr243.pdf

3. Simple reflexive bank behavior

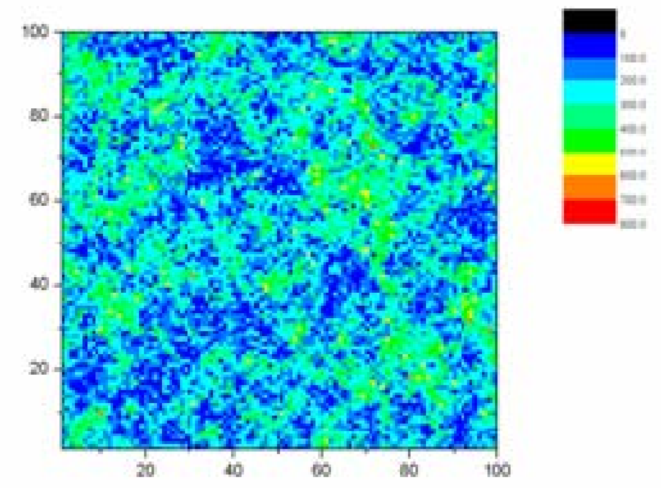


4. Single disrupted bank

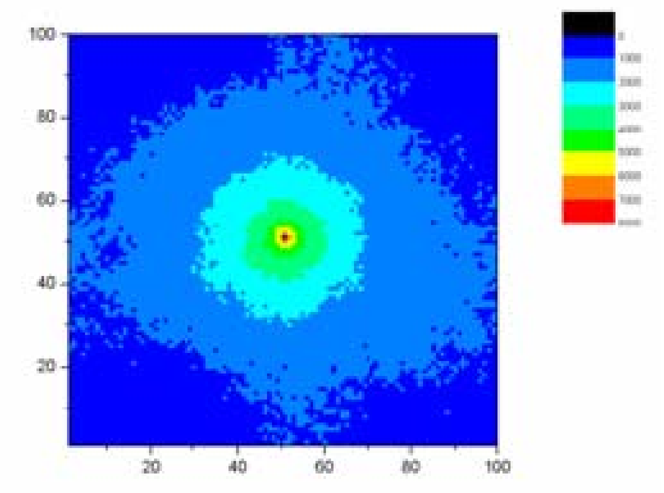
- An “operational incident”
- Other banks are not aware: the bank can receive, but cannot send payments
- The single bank acts as a liquidity sink. Eventually all liquidity is at the failing bank and no payments can be settled
- We examine the liquidity absorption rate and system throughput in the time period until all liquidity is at the failing bank

Example: queues in a lattice network, 10,000 nodes, low liquidity

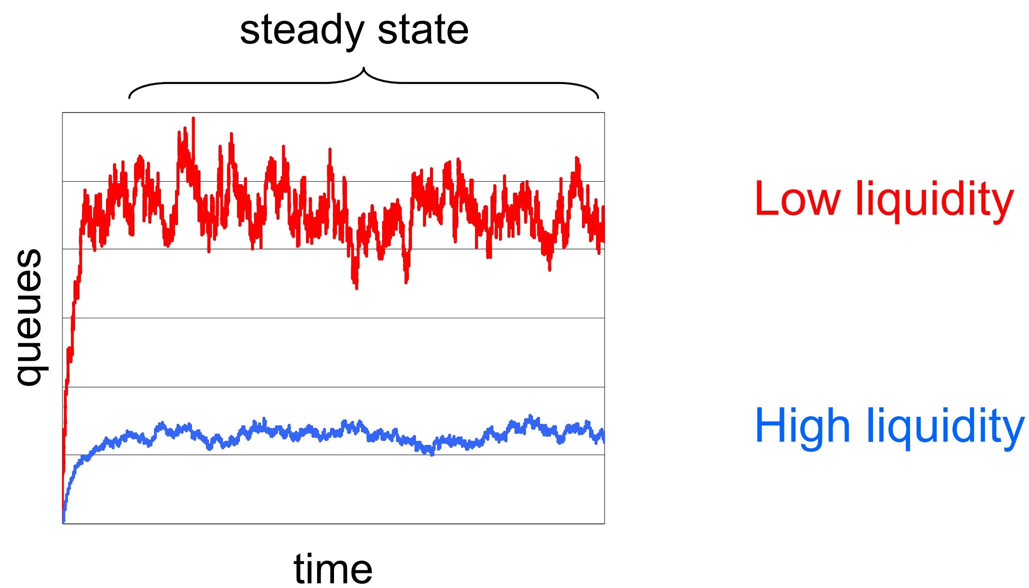
before:



after:



Steady state performance



Steady state performance is varies
under the alternative network topologies

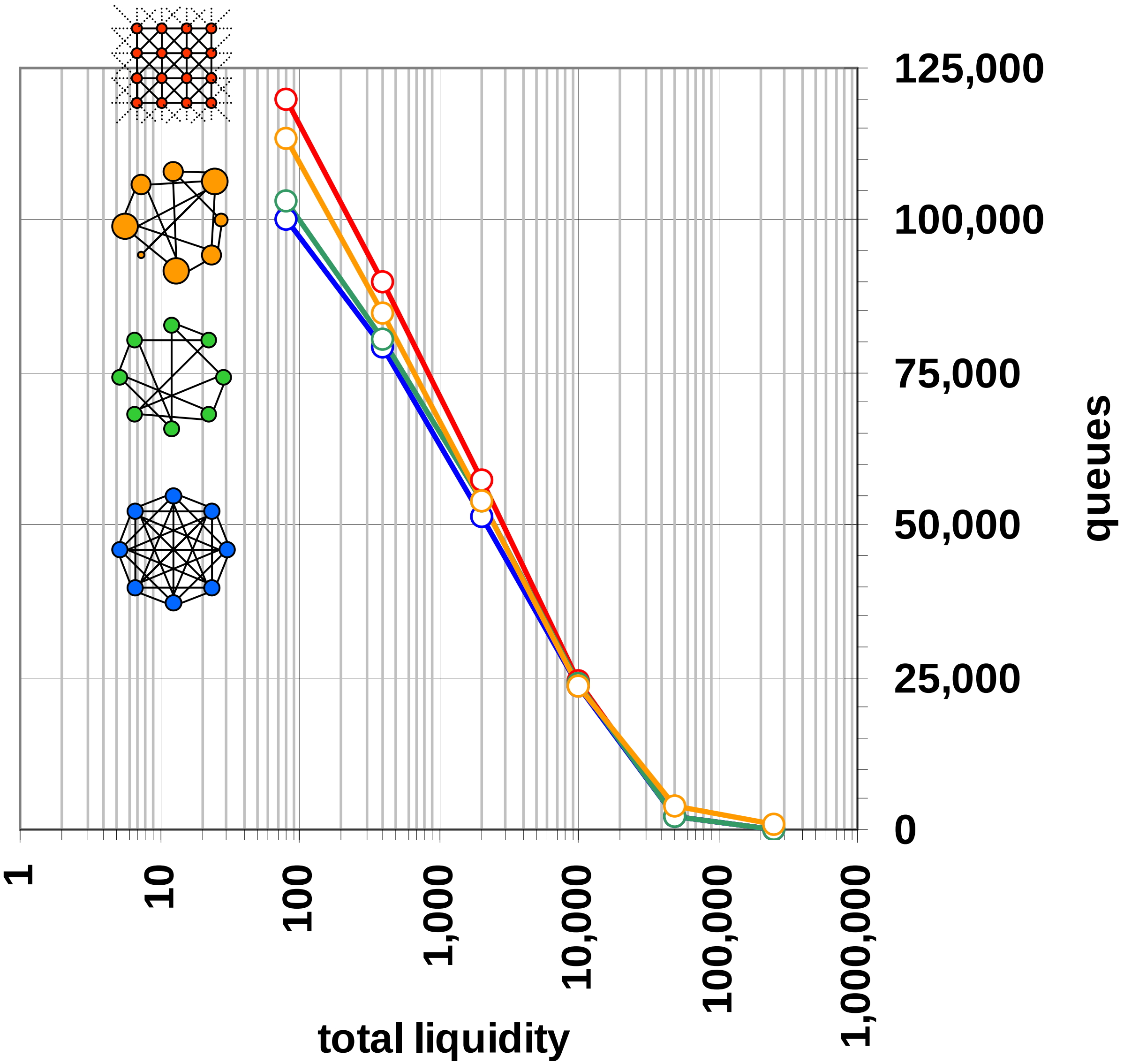
Queues in steady state

High average path length, uniform degree distribution

Shorter average path length, higher degree heterogeneity

Shorter average path length

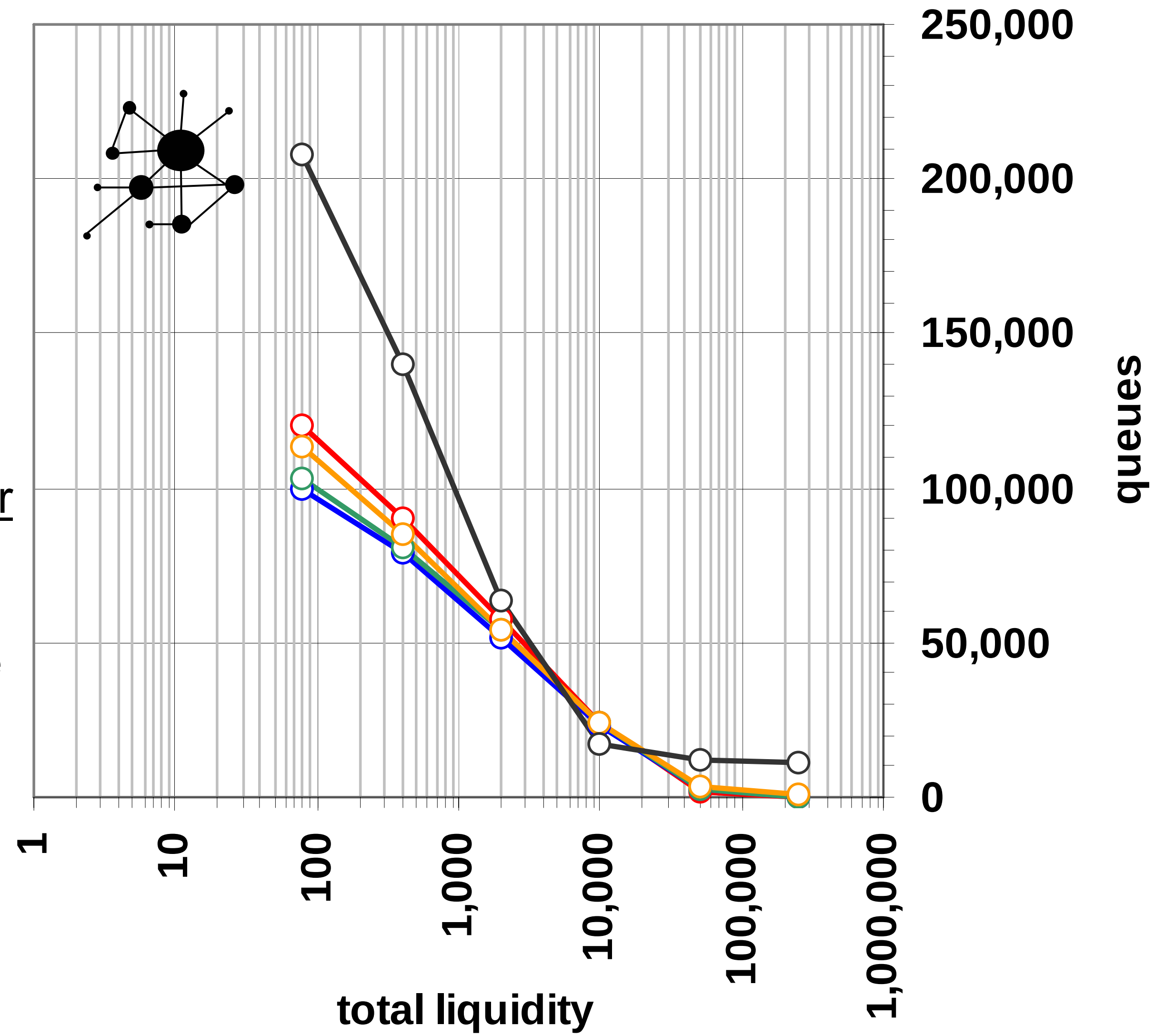
Shortest average path length



Queues in steady state: scale free network

Highest degree heterogeneity

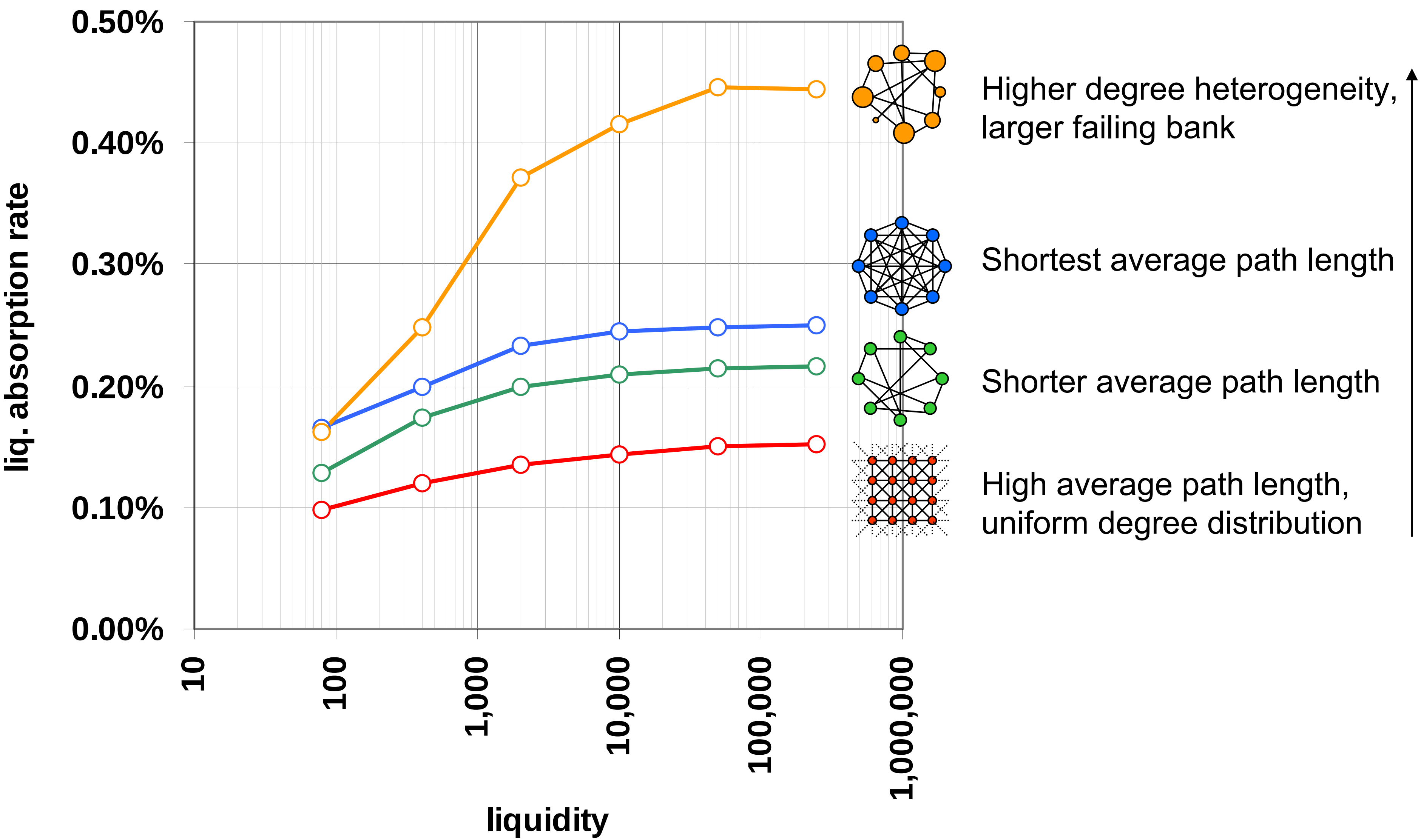
-> higher degree heterogeneity and a longer average path length increase the level of queues in the steady state



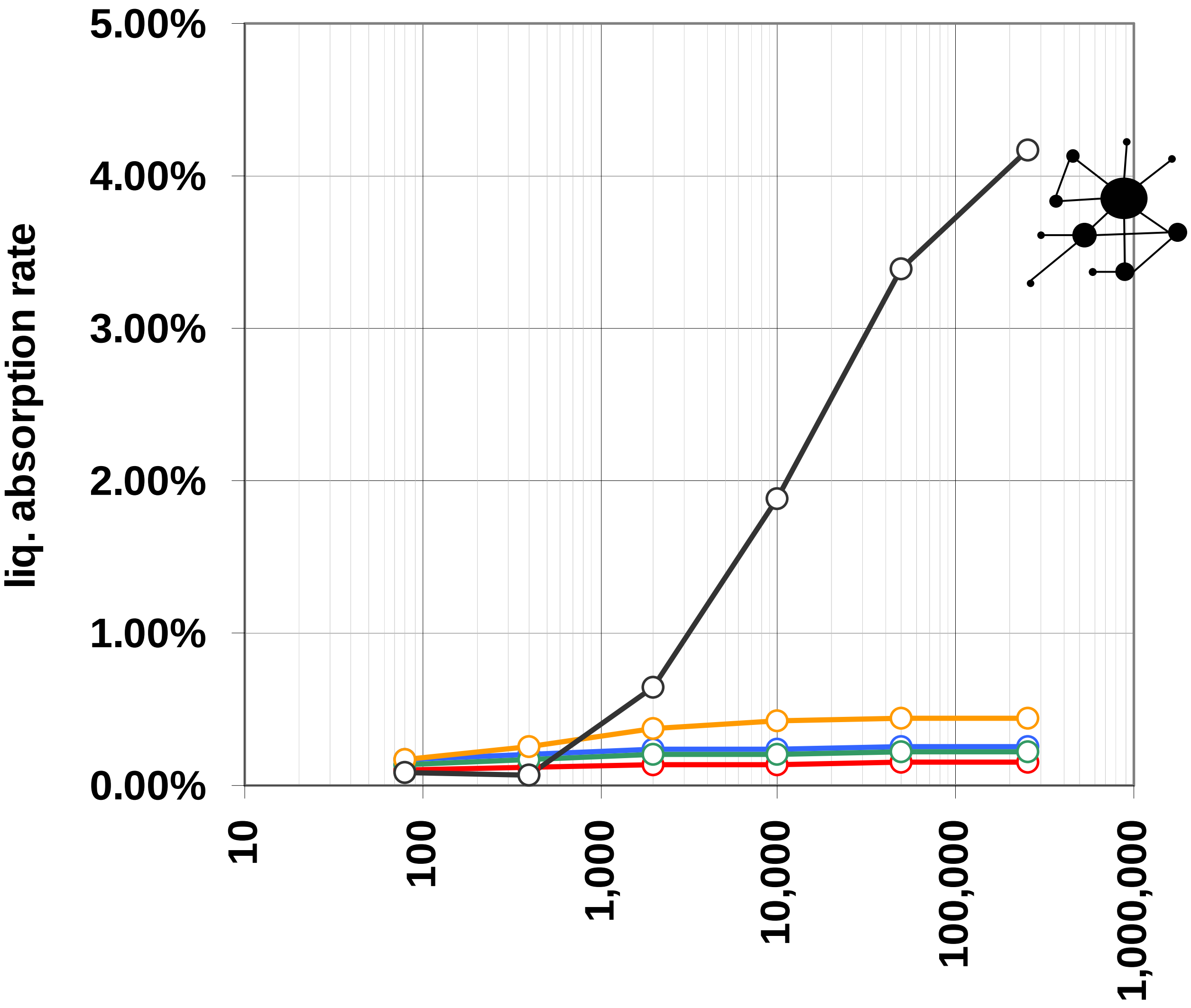
Liquidity absorption rate

The amount of liquidity absorbed
by the failing bank
by each instruction arriving to the system

Liquidity absorption rate



Liquidity absorption rate: scale free network



Highest degree heterogeneity, largest failing bank

Higher degree heterogeneity/ larger failing bank and a shorter average path length increase the speed of liquidity absorption

Throughput

The fraction of arriving instructions
that the bank can settle
in a given time interval
(the remaining being queued)

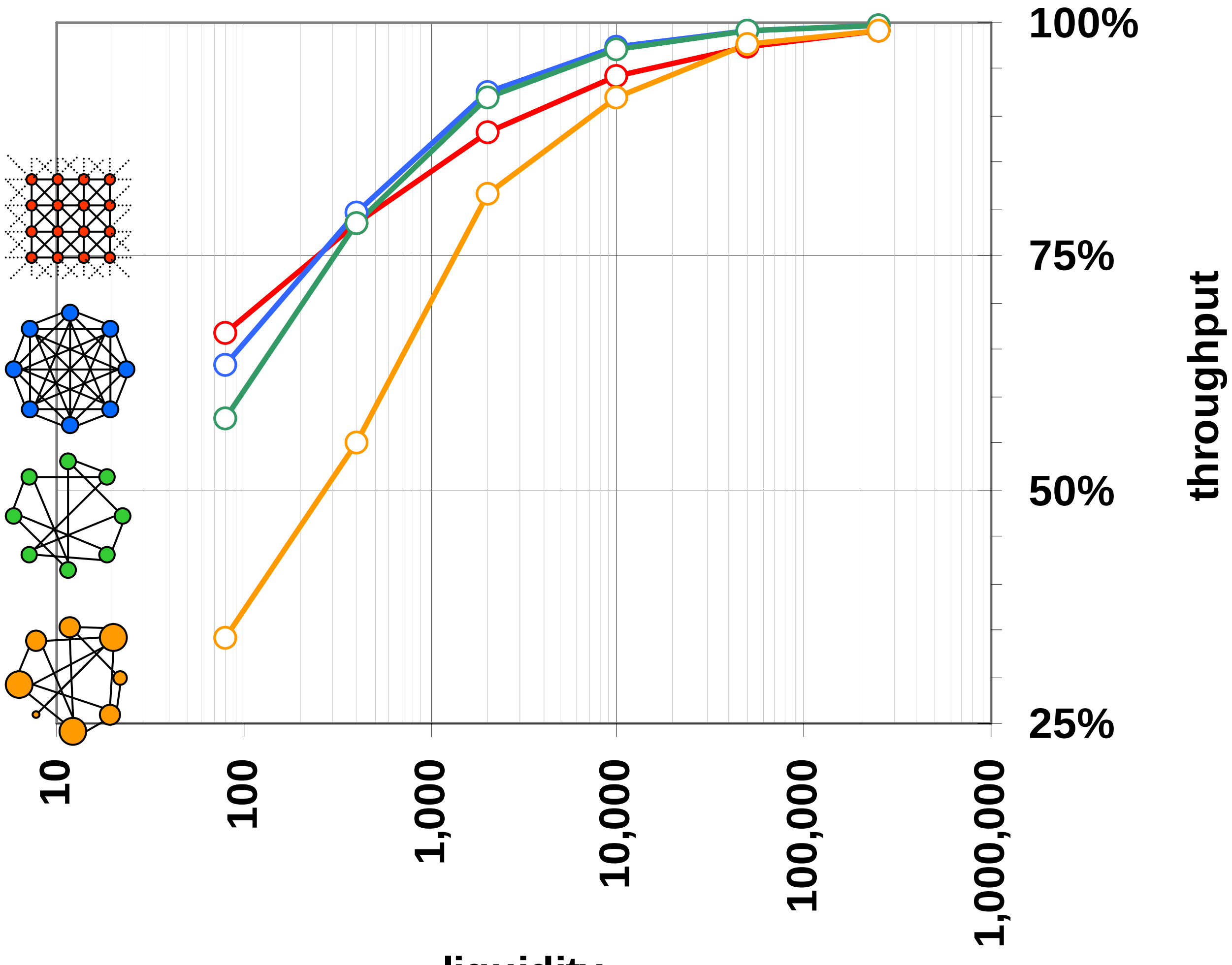
Throughput

High average path length, uniform degree distribution

Shortest average path length

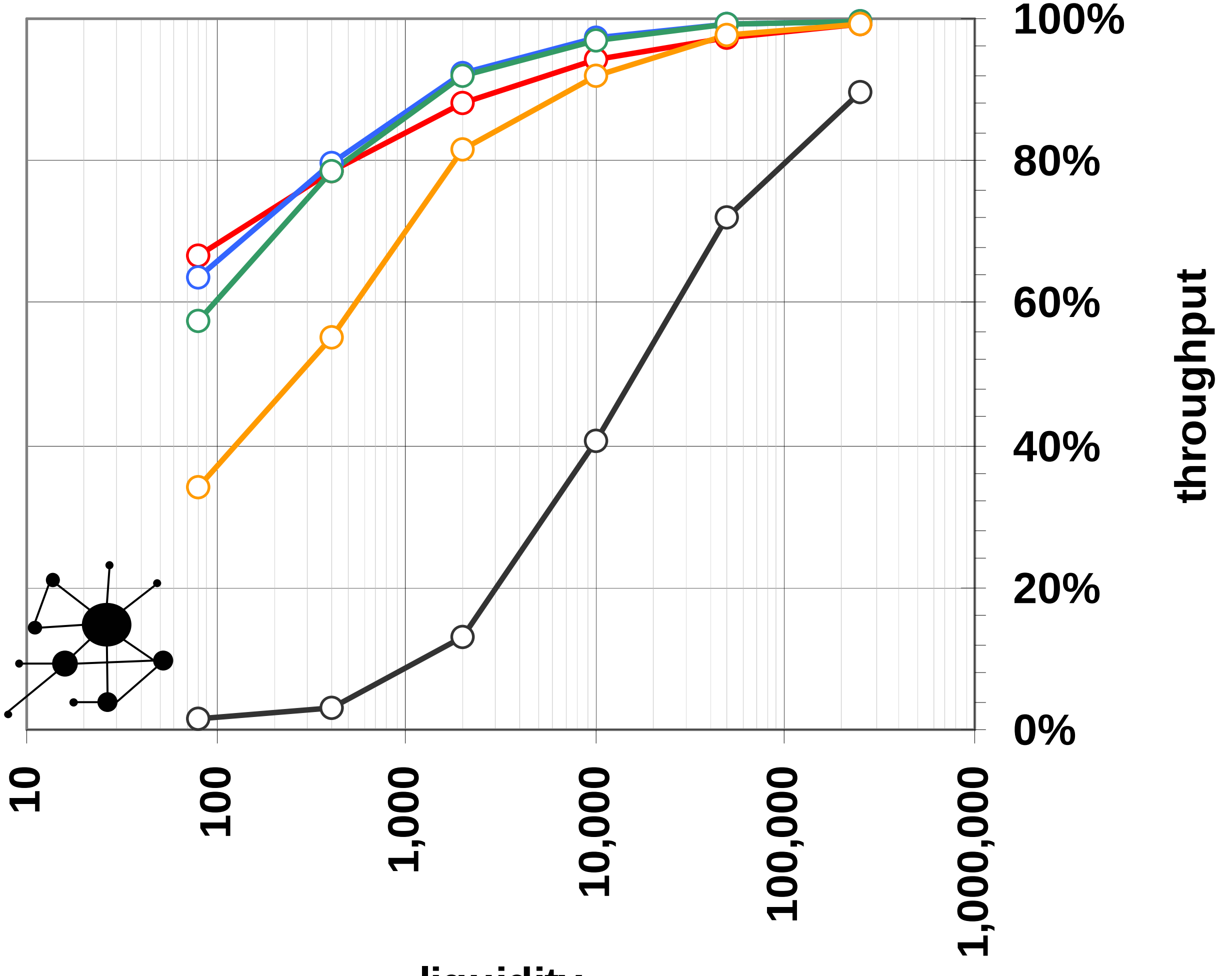
Shorter average path length

Higher degree heterogeneity, larger failing bank



Throughput: scale-free network

Throughput decreases with increased degree heterogeneity and the removal of larger banks



Highest degree heterogeneity, largest failing bank

Summary

- First investigation into the impact of topology in “payment system” type of network dynamics

- Topology matters
  - both for normal performance and
  - for performance under stress
  - efficient topologies are not necessarily less resilient

- Next steps
  - Investigate alternative times for other banks’ knowledge of failure and failure resumption times
  - Impact of the existence of a market?
  - Perturbations in market?
  - Build behavior for banks