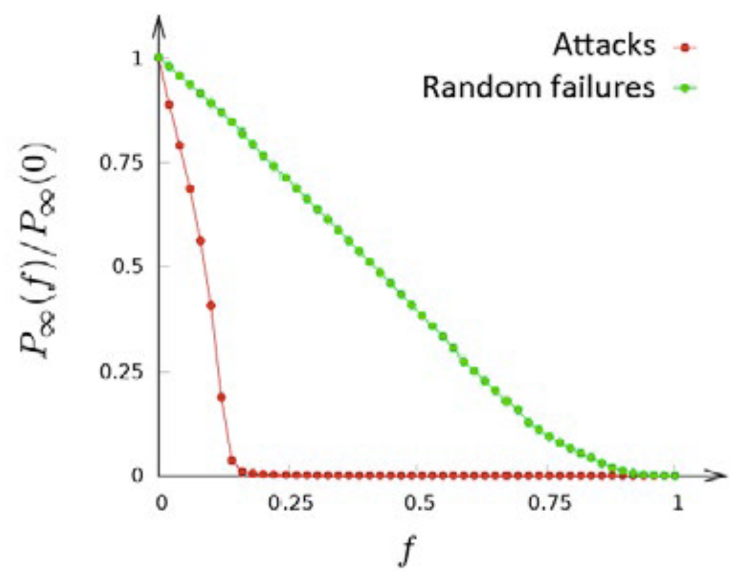
Complex Networks: Network Robustness

Ana Paula Couto

Computer Science Department

Universidade Federal de Minas Gerais



Network Robustness

- Errors and failures can corrupt all human designs:
  – The failure of a single component in your car's engine may force you to call for a tow truck
  – wiring error in your computer chip can make your computer useless

- Many natural and social systems, however, have a unique ability to sustain their basic functions even when several of their components fail.

Network Robustness

Biological, social and technological systems share a common feature: their functionality and robustness is guaranteed by densely interlinked networks

Network Robustness

Understanding the structure of the underlying network is essential if we want to quantify a system's ability to survive random failures or deliberate attacks

Network robustness

- Understand the impact of node or link removal on the integrity of a network
- The removal of a single node typically has only limited impact on a network's integrity
- The removal of multiple nodes can break a network into isolate, non-comunicating subgraphs

Network robustness

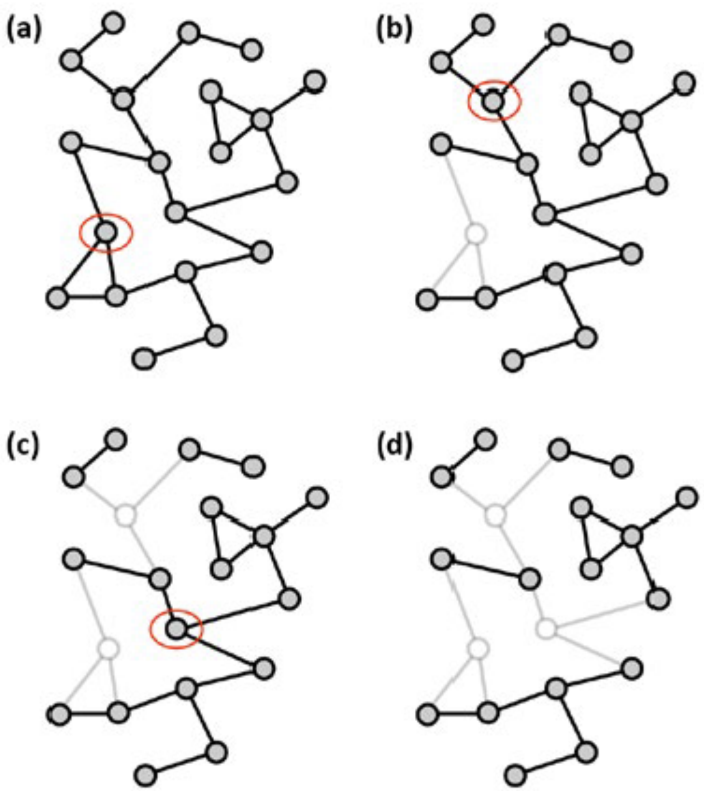


Figure 8.3
The impact of node removal

The gradual fragmentation of a small network following the breakdown of several nodes. In each panel we remove a new node (highlighted), together with its links. As the sequence of images indicates, while the removal of the first node has only limited impact on the network's integrity, the removal of the second node isolates two small clusters from the rest of the network and the removal of the third node fragments the network, breaking it into five non-communicating clusters of sizes s = 2, 2, 2, 5, 6.

Network robustness

- The more nodes we remove, the higher are the chances that we damage a network
- How many nodes do we have to delete to fragment a network into isolated components?
  - What fraction of Internet routers must break down so that the Internet turns into isolated clusters of computers that are unable to communicate with each other?

Network robustness

- How to measure network robustness?
  - Local Metrics
    - Evaluating the impact on few nodes
      - How many link has to be broken to disconnect a particular node?
  - Global Metrics
    - Evaluating the impact on the network structure
      - How failures and attacks impacts on the size of giant component?

Network robustness

Figure 8.1
Achilles' Heel of Complex Networks

The cover of the 27 July, 2000 issue of *Nature*, highlighting the paper entitled *Attack and error tolerance of complex networks* that sparked the interest in network robustness [1].

Network robustness

- Focus on global metrics
  - Network diameter
  - Changes on the network topology
    - Giant component size
    - Mean component size (all, except giant component)

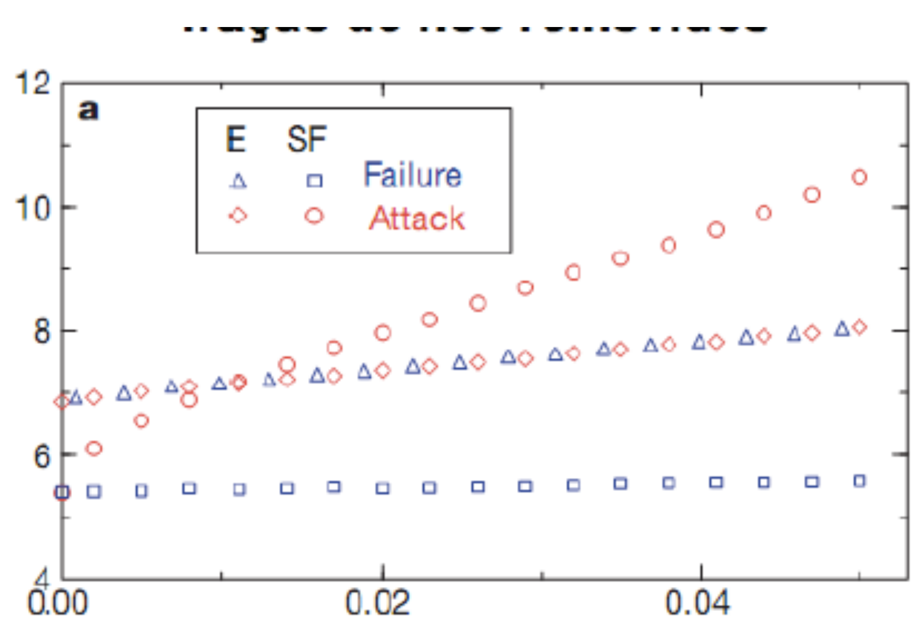
Failure types

- Random Failure (error)
  – Router went down
- Deterministic Failure (attack)
  – Router hacked

Failures - G(n,p) model

- Failures increase (slightly) the mean distance between nodes
- Both errors and attacks have the same impact on the network topology

Mean distance versus % of removed nodes

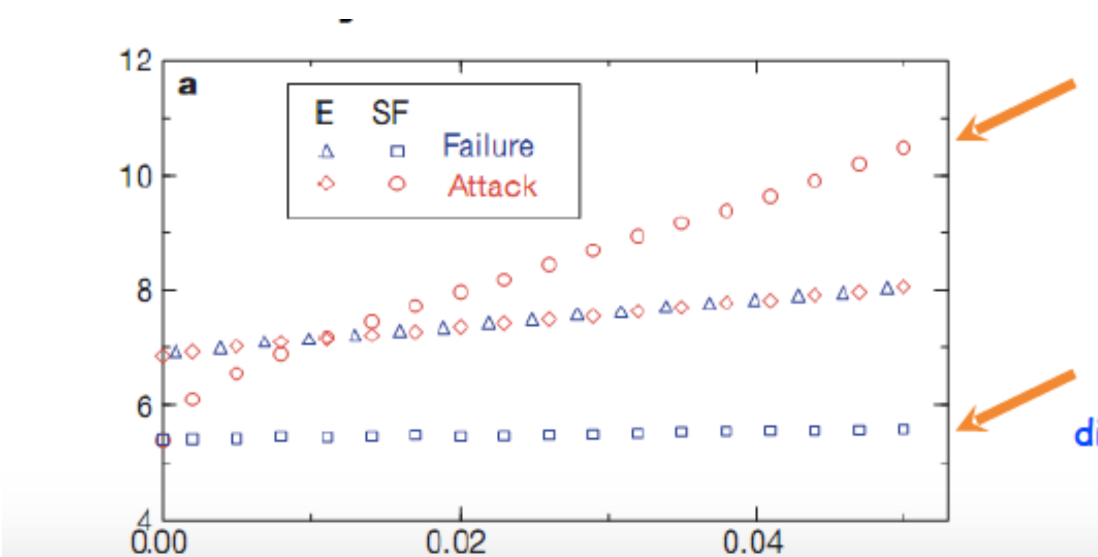


G(n,p): similar impact for both random and deterministic failures

Failures - BA model

- Random failures and deterministic failures provide different impacts on the topology network
- Random failures (errors): small impact
- Deterministic failures (attacks): huge impact

Mean distance versus % of removed nodes



Attacks: 5% of removed nodes: mean distance doubled

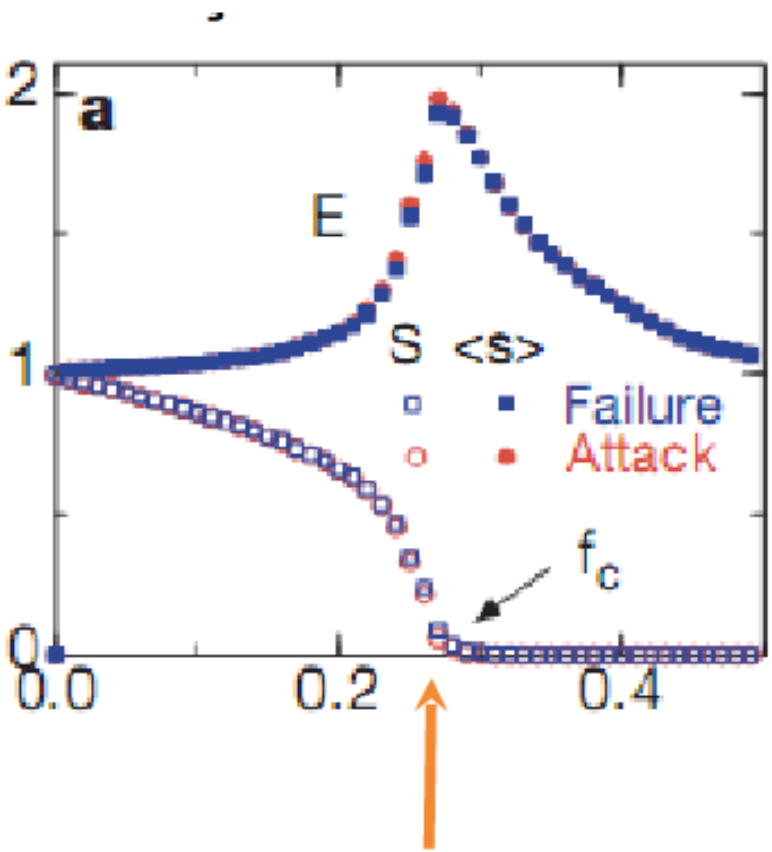
Errors: 5% of removed nodes: mean distance remains almost the same

Giant component analysis

- Giant component size (GC)
  - Fraction of nodes in GC
  - Represented by **S**
- Mean size of the remain components
  - Represented by **<s>**

G(n,p) model

S and <s> sizes in function of % of removed nodes

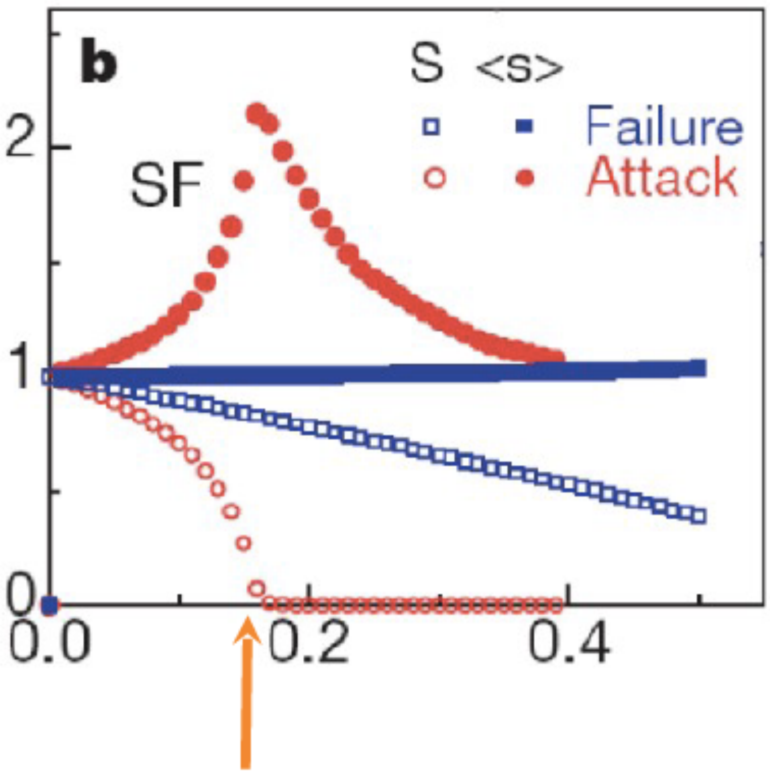


Network is fragmented

- Errors and attacks similarly decrease the GC size
- Reduction on the GC size increases the mean size of the other components
- As soon as the GC is fragmented, all other components fragmented as well

BA model

S and <s> sizes in function of % of removed nodes



Network is fragmented

- Errors : linear decreasing of GC size and slightly increase of the mean size of other components
- Attacks: GC is broken faster than in G(n,p) case and other components fragmented as well

BA model

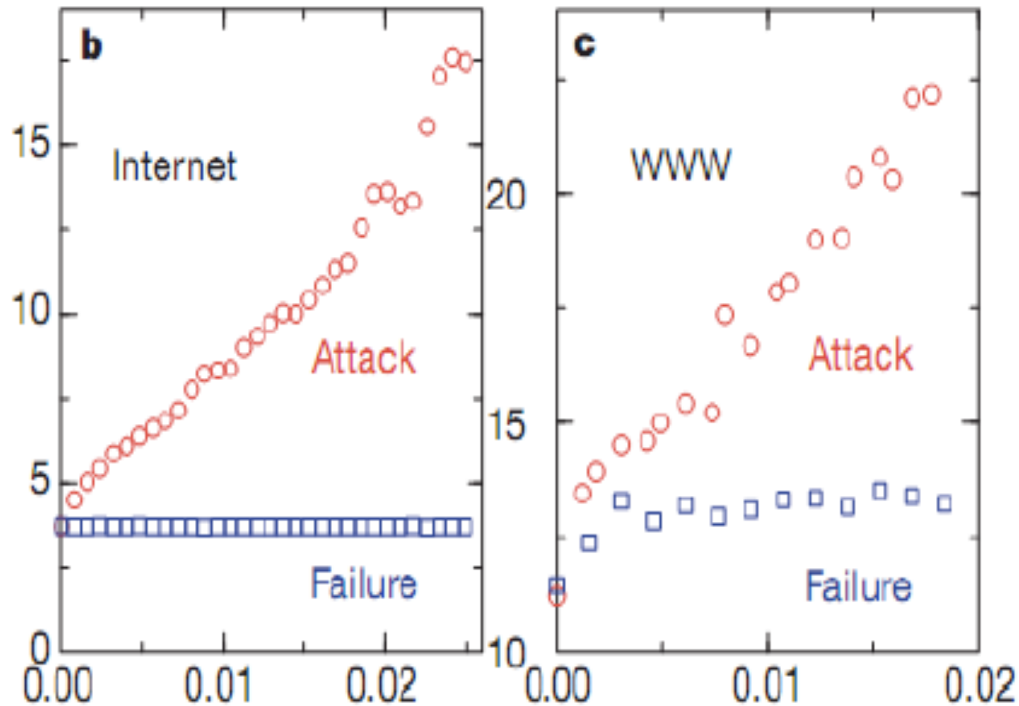
- Many nodes have small degree
- They do not have important role on the network robustness
- Error tolerant

- Few nodes with high degree
- They are very important for network connectedness
- Vulnerable to attacks

Internet AS and WWW

<s> size in function of % of removed nodes

- Power law networks
- BA model similar behavior
- Error tolerant, but vulnerable to attacks



NATURE | VOL 406 | 27 JULY 2000 | www.nature.com