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# Analysis of the Collaboration Structure in Router-level Topologies

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- Research Background
- Purpose and approach
- Numerical evaluation
- Confirmation
- Conclusion and future work



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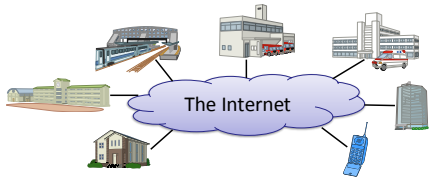
## Research Background

- The Internet becomes one of social infrastructures
- Reliability to survive against failures of network



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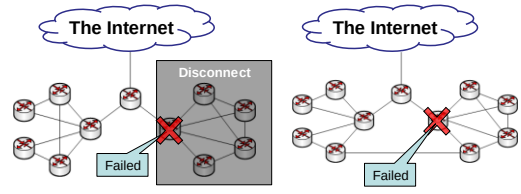
## Reliability and Physical connection

- Physical connection of network is essential
- Investigation of relationships between characteristics and structures in networks



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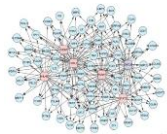
## Purpose and approach

Research physical structures
for high reliable router-level topology

- Approach
  1. Using knowledge in biology
     - Focus attention on "transcriptional regulatory networks (TRNs)"
  2. Comparing between router-level topologies and TRNs
  3. Evaluation of a structure relating to reliability
     - Collaboration structure



Transcriptional regulatory network [1]

[1] M. Carro, et. al., "The transcriptional network for mesenchymal transformation of brain tumours," Nature, Jan. 2010.



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## Networks in living organisms

- The networks with long evolutionary history
  - Many environmental changes
- Even if some components in the networks are broken, networks did not collapse
  - The organism keeps alive

high robustness and adaptability

- Focus attention on transcriptional regulatory networks
  - Deeply studied in the field of biology

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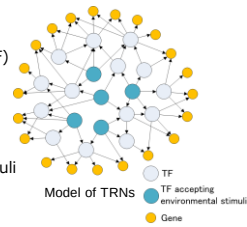
## Transcriptional regulatory networks (TRNs)

- TRNs are in a cell of organism
- Components
  - Node : Transcription factors (TF)
    - TF : protein
  - Link : Transmission of signal
- Function
  - To regulate proper genes in response to environmental stimuli



Model of TRNs

- Similarities to router-level topologies
  - Information flow
  - Hierarchical structure

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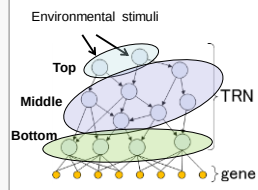
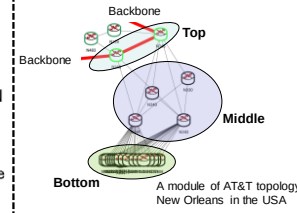
## Analogy : Downward information flow

**TRNs**




- Flow of regulation signal for expression

**Router-level topologies**



A module of AT&T topology New Orleans in the USA

- Flow of traffic from backbone to access networks

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## Analogy : Hierarchical structure

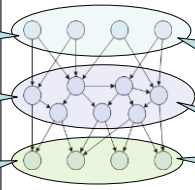
- Dividing the topologies into modules[2] in router-level topologies
  - Module is a set of nodes in each region

**TRNs**

**Top level :** zero in-degree

**Middle level :** in-degree and out-degree

**Bottom level :** zero out-degree



**Router-level topologies**

**Top level :** Nodes having links that connect with the other modules

**Middle level :** in-degree and out-degree

**Bottom level :** zero out-degree

[2] R. Guimera and L. A. N. Amaral, "Functional cartography of complex metabolic networks," *Nature*, vol. 433, p. 895, 2005.

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## Evaluation of reliability

- Which is more reliable, router-level topologies or TRNs?
  - Investigating with a ratio of nodes which can receive signal from top-level nodes when there are failure nodes
- Index for investigating reliability
  - Failure nodes :
    - A ratio of failure nodes
  - Reachable node ratio :
    - A ratio of nodes which can receive signal from top-level nodes

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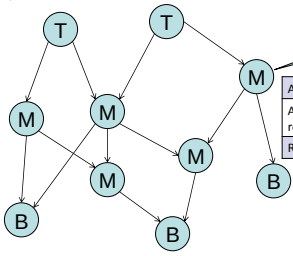
## Evaluation of reliability

- Measure of reliability of both networks
  - Calculate the number of nodes which can receive signal from top-level nodes



Randomly Failed

| | |
|---|---|
| Amount of failure nodes | 0 |
| Amount of nodes reachable from top-level | 10 |
| Reliability | 10/10 |

| | |
|---|---|
| T : Top | |
| M : Middle | |
| B : Bottom | |

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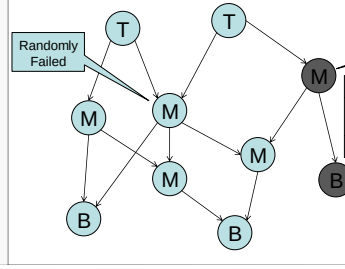
## Evaluation of reliability

- Measure of reliability of both networks
  - Calculate the number of nodes which can receive signal from top-level nodes



Randomly Failed

| | |
|---|---|
| Amount of failure nodes | 2 |
| Amount of nodes reachable from top-level | 8 |
| Reliability | 8/10 |

| | |
|---|---|
| T : Top | |
| M : Middle | |
| B : Bottom | |

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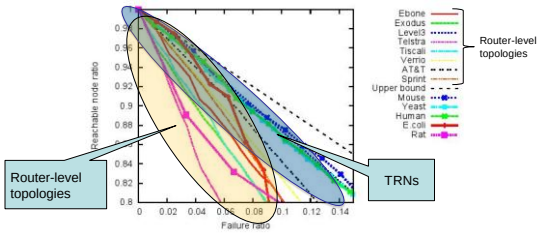
## Result of evaluation for reliability

- Most TRNs are more reliable than ISP router-level topologies



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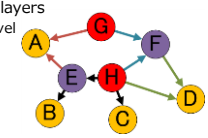
## Collaboration structure [3]

- A structure where multiple nodes connect with one node
  - Leading multi paths → Contributing reliability
- Hierarchical structure
  - Categorizing the topology into three layers
    - top level, middle level and bottom level
  - A key to identify the collaboration structure
    - Where and how many collaboration structures are?




(B , D), (B, E) and (E, F) contribute collaboration structure respectively.

[3] N. Bhardwaj, K.-K. Yan, and M. B. Gerstein, "Analysis of diverse regulatory networks in a hierarchical context shows consistent tendencies for collaboration in the middle levels," *PNAS*, vol. 107, pp. 6841–6846, Mar. 2010.



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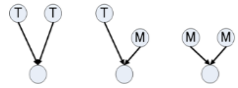
## Definition of collaboration

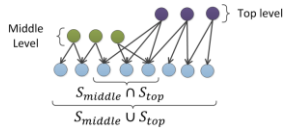
- Three types of collaboration structure
  - Classify collaboration structure




- Degree of collaboration $D_{collab}^{L_1,L_2}$
  - Amount of collaboration structure of $L_1$ level and $L_2$ level
  - Example :

$$D_{collab}^{middle,top} = \frac{S_{middle} \cap S_{top}}{S_{middle} \cup S_{top}}$$

$S_{middle}$ : A set of nodes regulated by nodes in middle level



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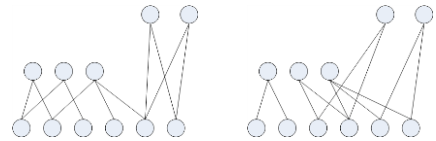
## Degree of collaboration

- Example : Degree of collaboration $D_{collab}$



$D_{collab}^{top,middle} = \frac{1}{6}$ $D_{collab}^{top,middle} = \frac{4}{6}$

- Degree of collaboration reflects amount of collaboration structures in networks



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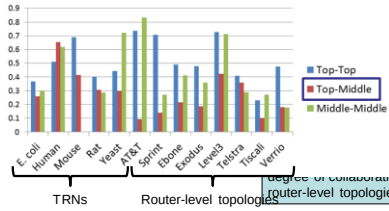
## Calculation result of degree of collaboration

- Degree of collaboration of top-level node and middle-level node is low in router-level topologies
- Expectation : Collaboration structure of top level and middle level contributes reliability



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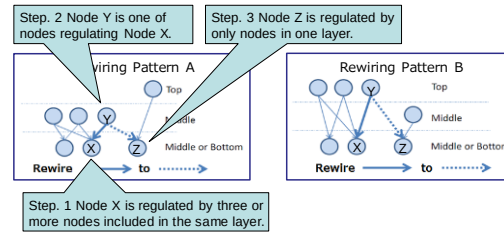
## Degree of collaboration and reliability

- Confirmation of correlation between collaboration structure and reliability by means of rewiring operation
  - To increase degree of collaboration of top-level and middle-level in router-level topologies



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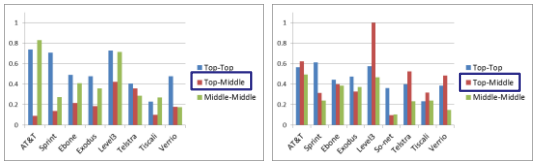
## Degree of collaboration after rewiring

- Calculating degree of collaboration after rewiring
  - Degree of collaboration of top-level and middle-level increased in router-level topologies




Before rewiring




After rewiring



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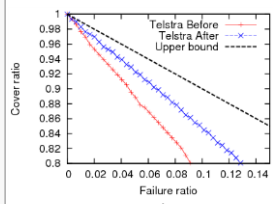
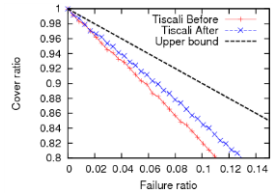
## Change of reliability in router-level topologies

- Reliability of router-level topologies before and after rewiring
- Reliability was improved in all topologies
  - AT&T, Ebone, Exodus, Level3, Sprint, Telstra, Tiscali, Verrio




Telstra

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## Conclusion and future work

- Conclusion
  - Degree of collaboration of top-level node and middle-level node in router-level topologies is lower than TRNs
  - Collaboration structures of top-level and middle-level contribute reliability
- Future work
  - Investigating why there is difference of improvement of reliability depending on router-level topologies after rewiring