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Exact computation of network's scale-wise unreliability

How likely do severe infrastructure failures occur?

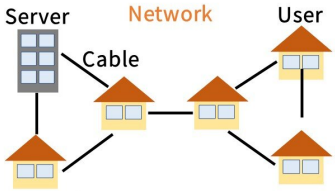
Abstract

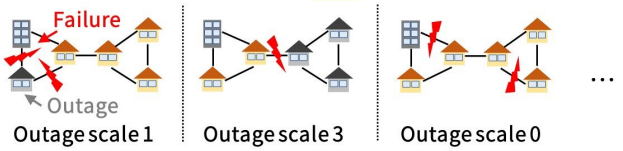
For network infrastructures such as telecommunication and power, to avoid severe outages, a high-reliability design where the probability of occurrence of large-scale outages is significantly low is in demand. We propose an algorithm that precisely computes the probability of occurrence of outages for every outage scale when network components fail occasionally. To improve efficiency, we use data structures called decision diagrams, enabling us to avoid repetitively performing equivalent computations. As a result, the proposed method successfully computes the probability of occurrence of every outage scale precisely for real-world network topologies with around 100 nodes. The proposed method contributes to checking whether a designed network meets a severe reliability requirement needed for modern network infrastructures. In the future, we want to automatically design network infrastructures such that large-scale outages are less likely to occur by extending the proposed method.

Evaluating Scale-Wise Unreliability

Components of network infrastructures such as cables fail occasionally. **Scale-wise unreliability** is **the probability of occurrence for outage events across various outage scales.**

Infrastructure's outage scale
= The number of users disconnected from servers





Requirement for infrastructures

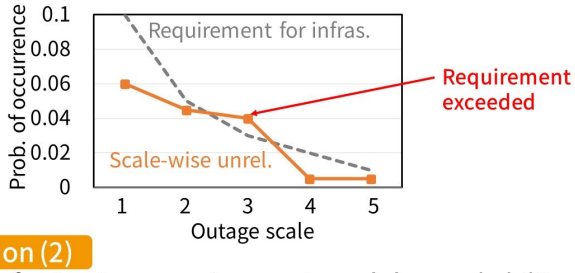
Severe outages of infrastructures should be avoided, e.g.,

- ✓ Telecommunication outage affecting many users
- ✓ Power outage over broad area

Motivation (1)

A high-reliability design that suppresses **the probability of occurrence for outage events of every outage scale** (=**scale-wise unreliability**) is in demand.

➡It should be computed to check the requirements.



Motivation (2)

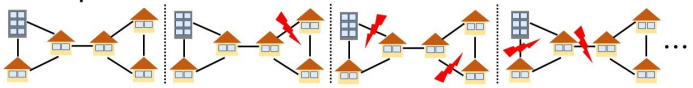
Modern infrastructures require an **extremely low** probability of occurrence of large-scale failures (**e.g., 0.00001%**).

➡**Precise evaluation** of scale-wise unreliability is needed.

Difficulty of evaluation

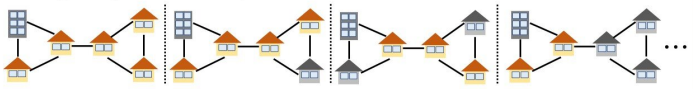
Difficulty (1)

We should inspect **all patterns of component failures** up to $2^{\#(\text{links})}$ **patterns** with a naïve solution.



Difficulty (2)

Even with methods for computing outage probability, we should compute the probability of **all patterns of user outages** up to $2^{\#(\text{users})}$ **patterns.**



Existing methods cost prohibitively large amount of time.

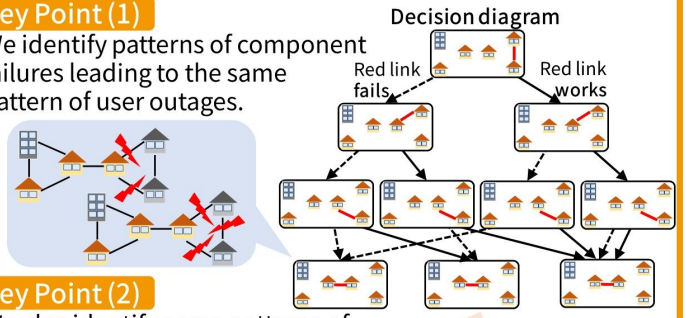
Solution with Decision Diagrams

We use **decision diagrams** to identify equivalent patterns of component failures, enabling us to avoid repetitively performing equivalent computations.

➡We can compute precise scale-wise unreliability of networks with ~**100 users** by yielding ≥**x100,000 speed-up.**

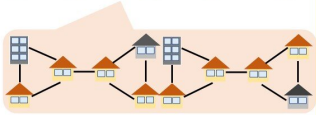
Key Point (1)

We identify patterns of component failures leading to the same pattern of user outages.



Key Point (2)

We also identify some patterns of user outages by focusing on the number of users disconnected from servers to equate more patterns of component failures.



References

[1] K. Nakamura, T. Inoue, M. Nishino, N. Yasuda, S. Minato, "Exact and efficient network reliability evaluation per outage scale," in *Proc. The 2023 IEEE International Conference on Communications (ICC)*, 2023.

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