Traffic Engineering with **Forward Fault Correction (FFC)**

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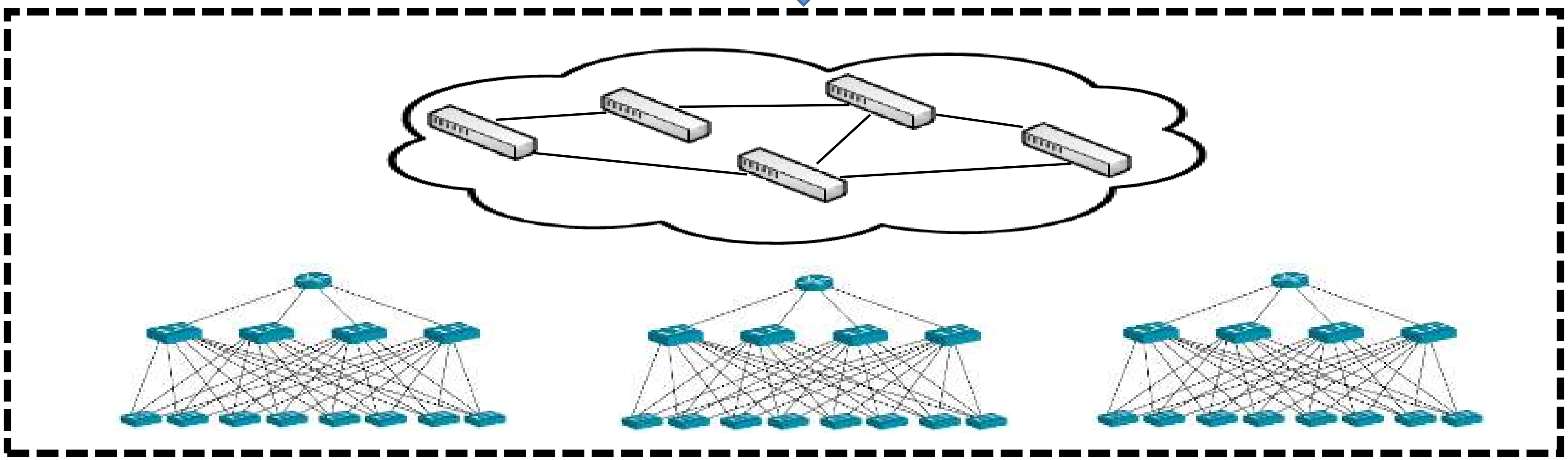
Cloud services require large network capacity

Cloud Services

Growing traffic

Cloud Networks

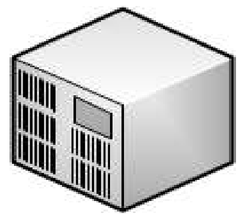


Expensive

(e.g. cost of WAN: $100M/year)

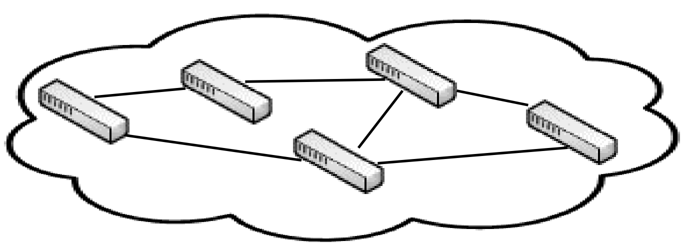
TE is critical to effectively utilizing networks

Traffic Engineering

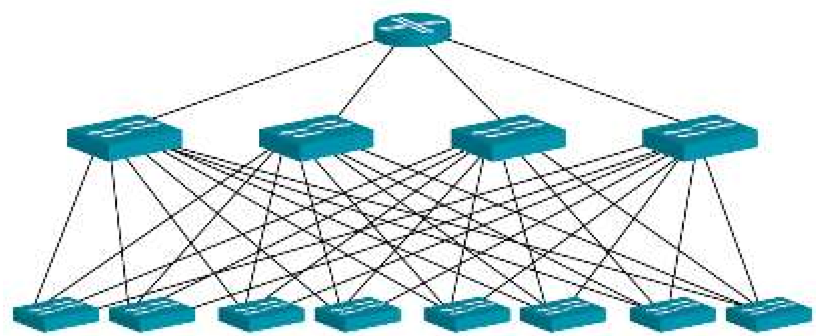


- Microsoft SWAN
- Google B4
- ……

- Devoflow
- MicroTE
- ……

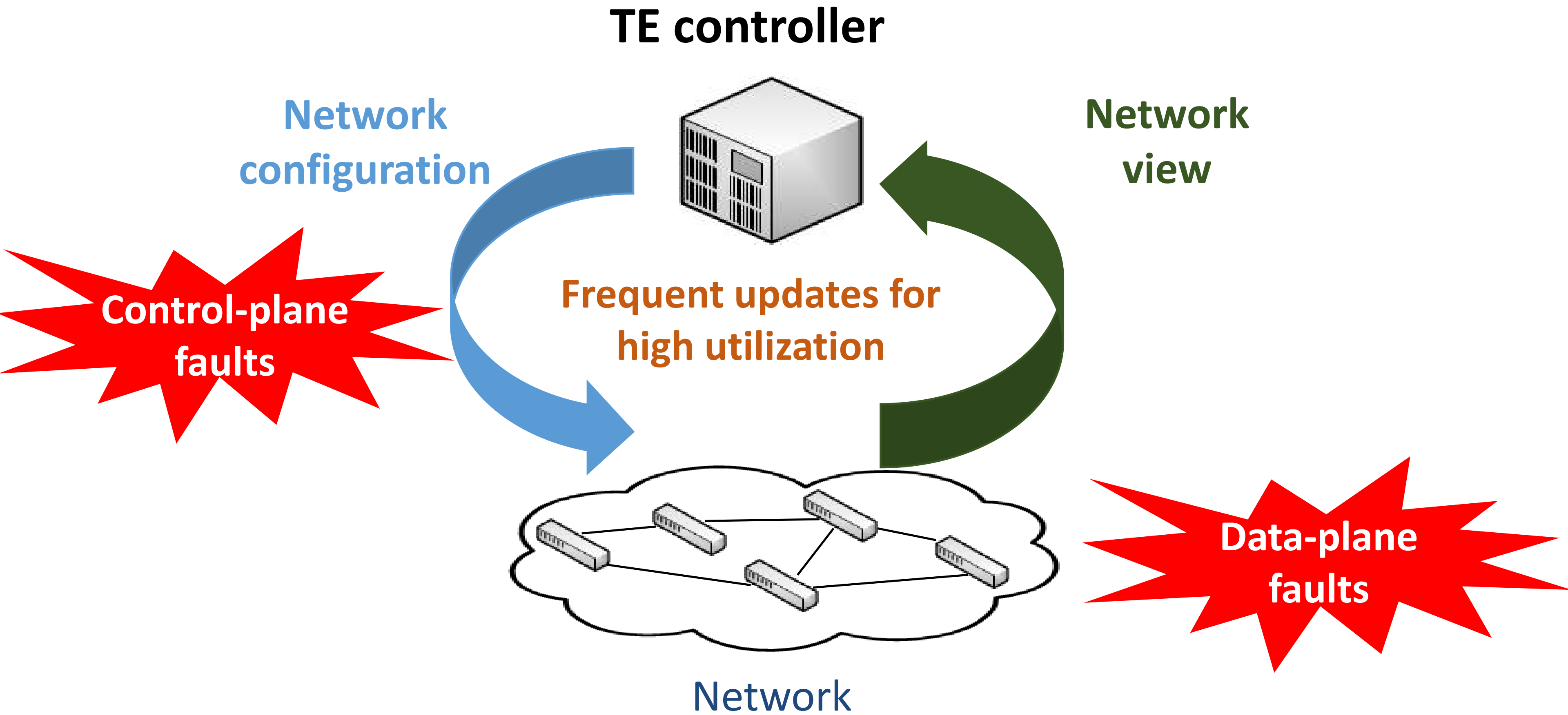


WAN Network



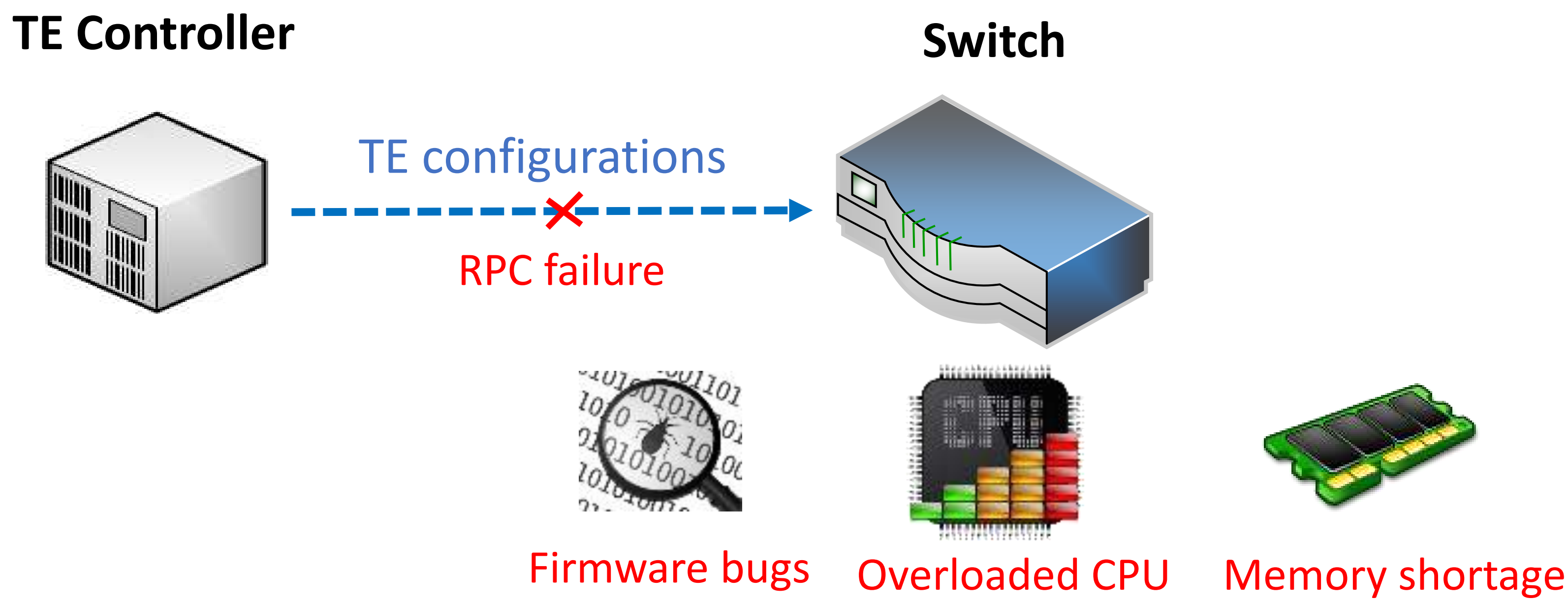
Datacenter Network

But, TE is also vulnerable to faults

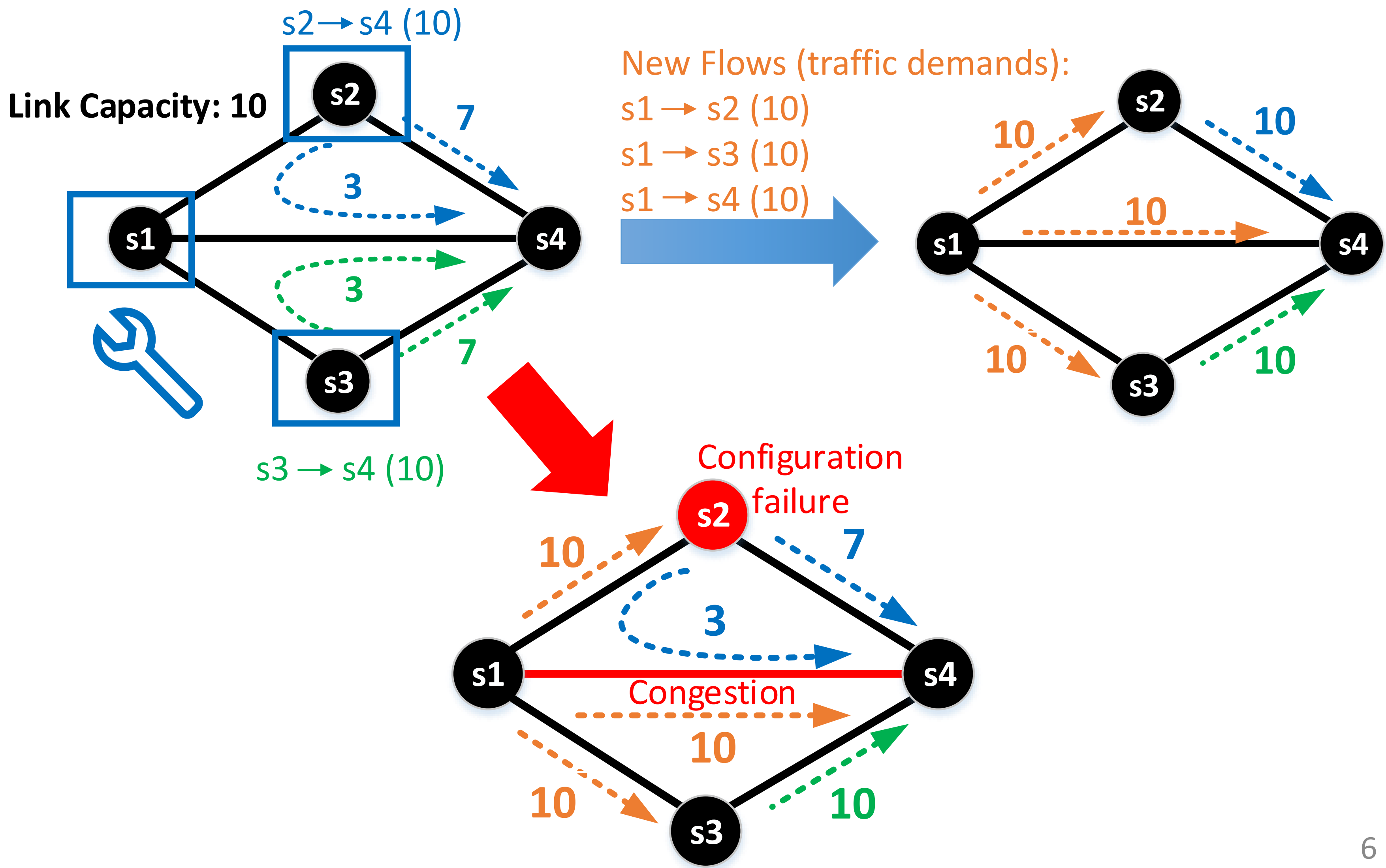


Control plan faults

Failures or long delays to configure a network device

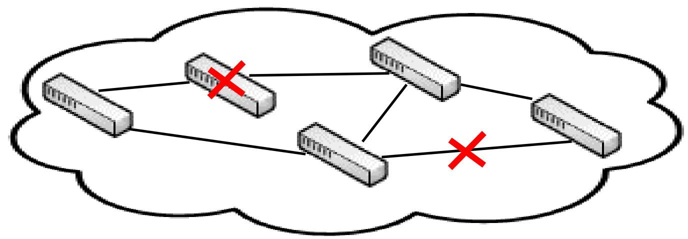


Congestion due to control plane faults

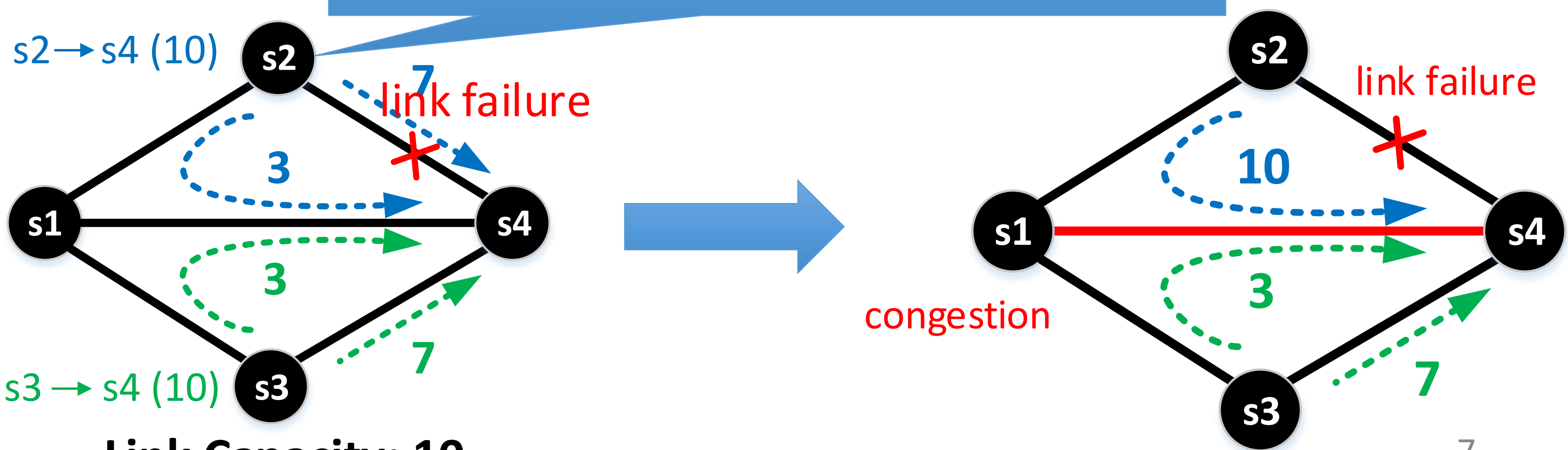


Data plane faults

Link and switch failures



Rescaling: Sending traffic proportionally to residual paths



Link Capacity: 10

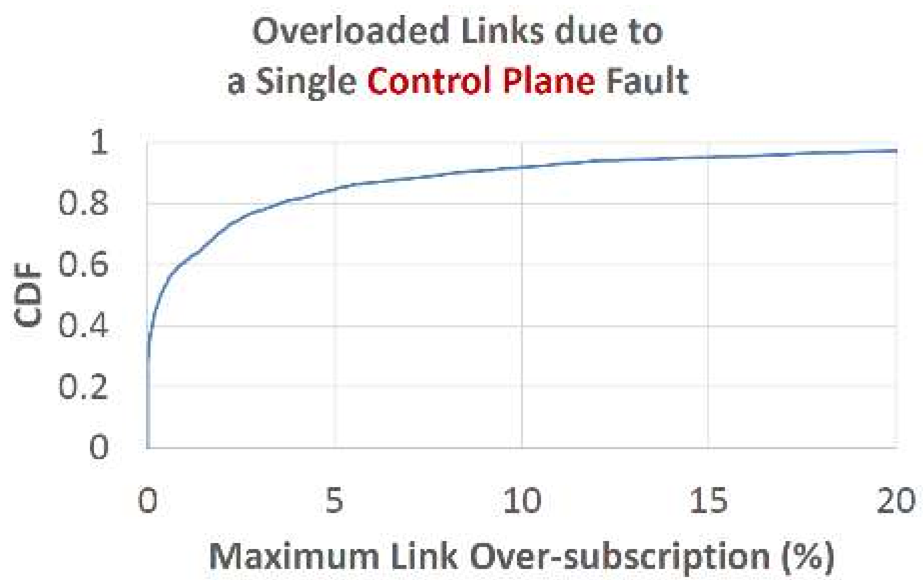
Control and data plane faults in practice

In production networks:

- Faults are common.
- Faults cause severe congestion.

Control plane:
fault rate = **0.1% -- 1%** per TE update.

Data plane:
fault rate = **25%** per 5 minutes.



State of the art for handling faults

- Heavy over-provisioning

Big loss in throughput

- Reactive handling of faults
  - Control plane faults: retry
  - Data plane faults: re-compute TE and update networks

Cannot prevent congestion

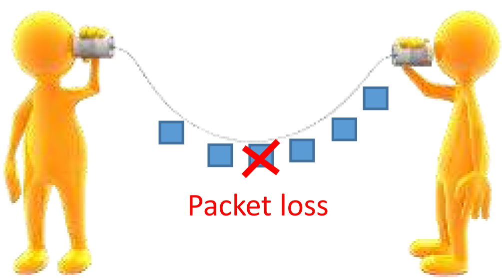
Slow (seconds -- minutes)

Blocked by control plane faults

How about handling congestion proactively?

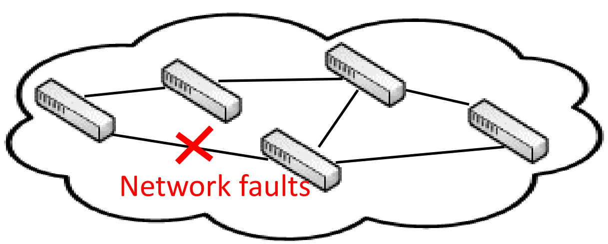
Forward fault correction (FFC) in TE

- [Bad News] Individual faults are **unpredictable**.
- [Good News] Simultaneous #faults is **small**.



FEC guarantees no information loss under up to k arbitrary packet drops.

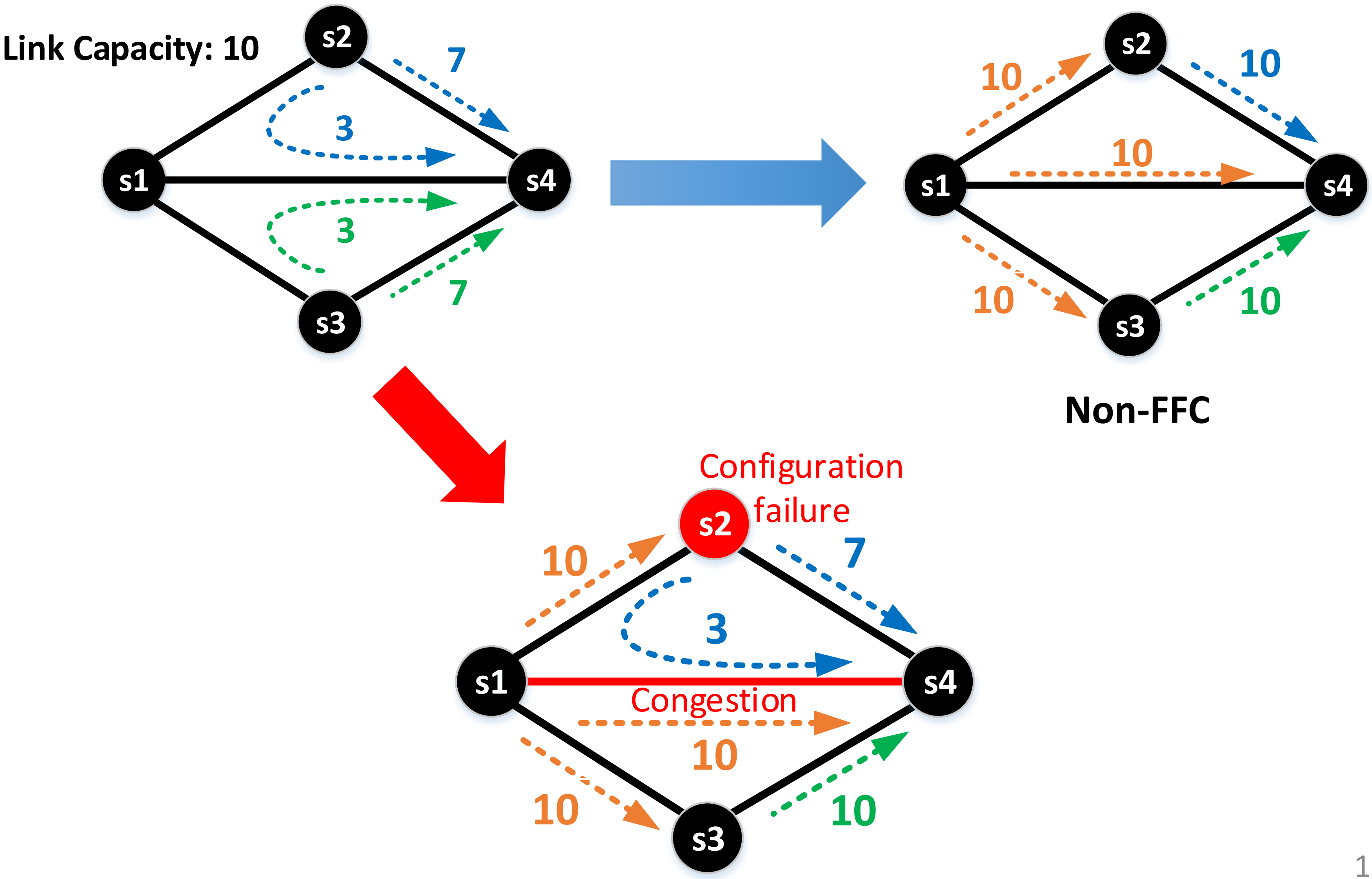
with careful **data encoding**



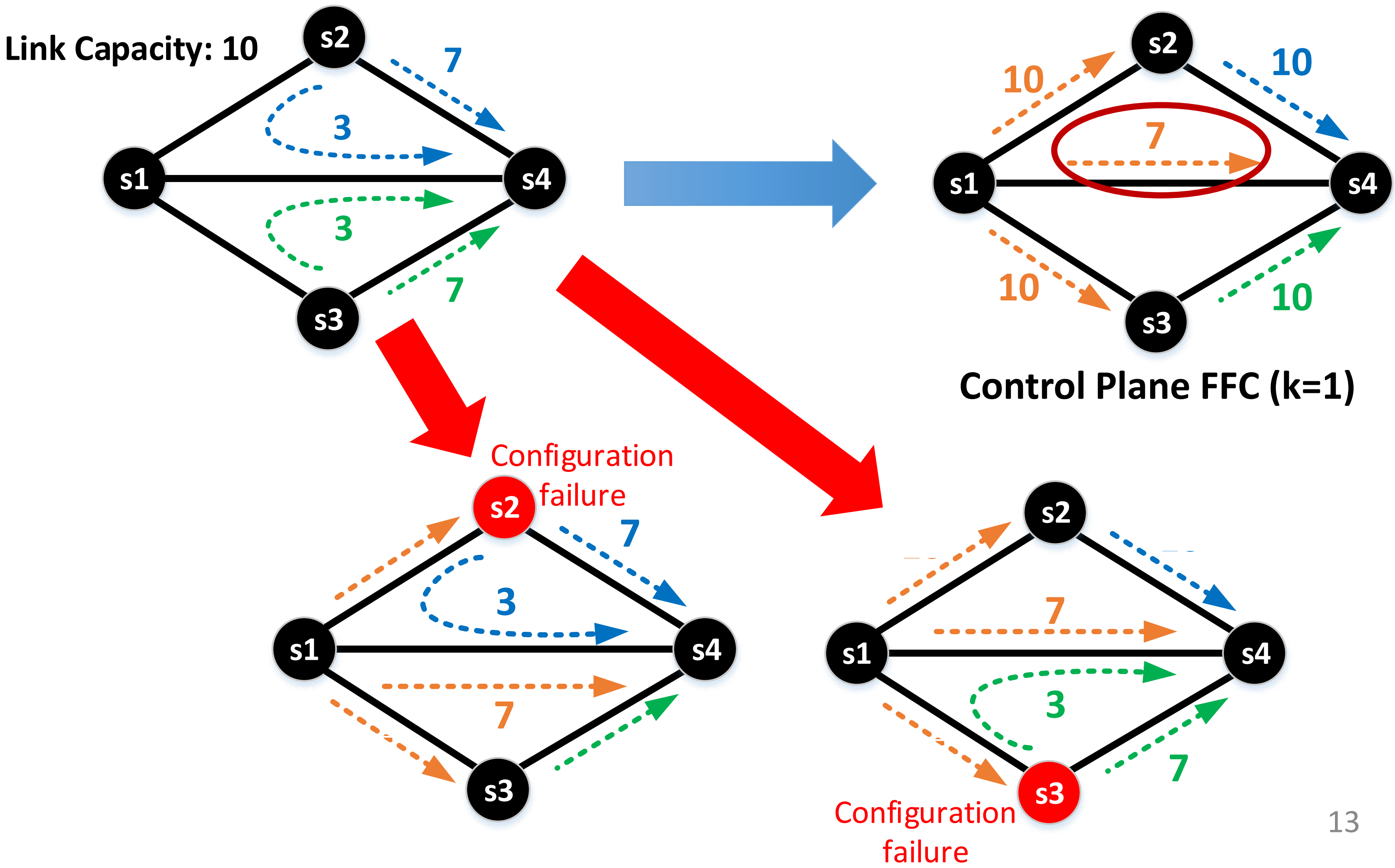
FFC guarantees no congestion under up to *k* arbitrary faults.

with careful **traffic distribution**

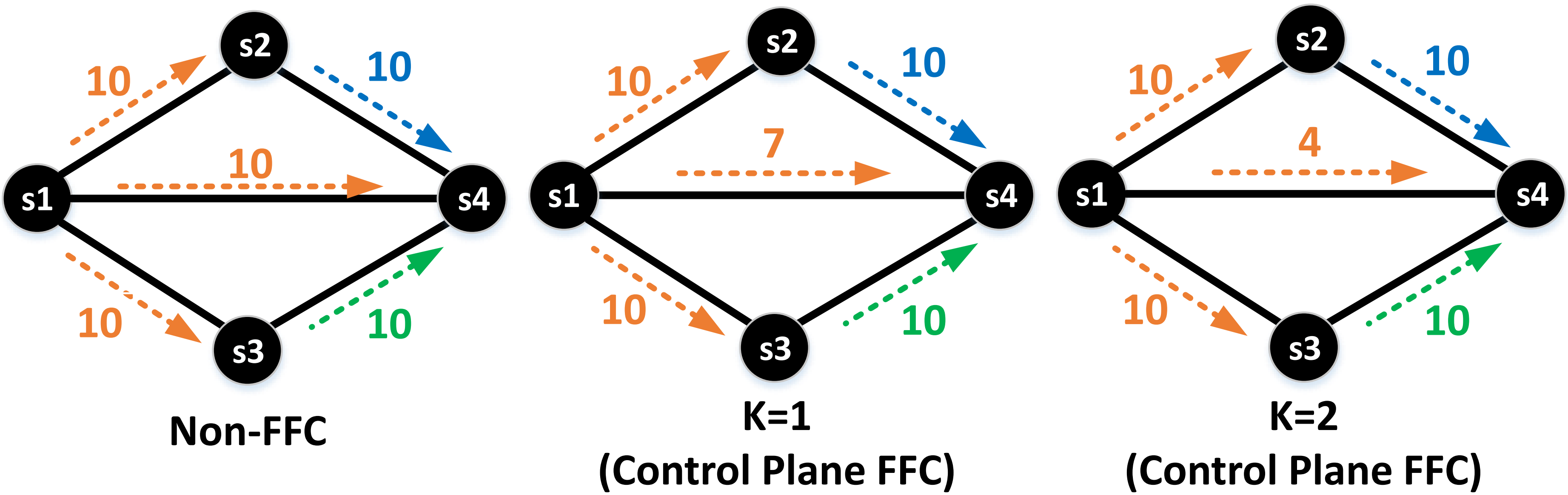
Example: FFC for control plane faults



Example: FFC for control plane faults



Trade-off: network utilization vs. robustness



Throughput: 50 ***Throughput: 47*** ***Throughput: 44***

Systematically realizing FFC in TE

Formulation:
How to merge FFC into existing TE framework?

Computation:
How to find FFC-TE efficiently?

Basic TE linear programming formulations

LP formulations

TE decisions:
- Sizes of flows — b_f
- Traffic on paths — $l_{f,t}$

TE objective: Maximizing throughput — max. $\sum_{\forall f} b_f$

Basic TE constraints:
- Deliver all granted flows — s.t. $\forall f$: $\sum_{\forall t} l_{f,t} \geq b_f$
- No overloaded link — $\forall e$: $\sum_{\forall f} \sum_{\forall t \ni e} l_{f,t} \leq c_e$
- … — …

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FFC constraints:

No overloaded link up to
- k_c control plane faults
- k_e link failures
- k_v switch failures

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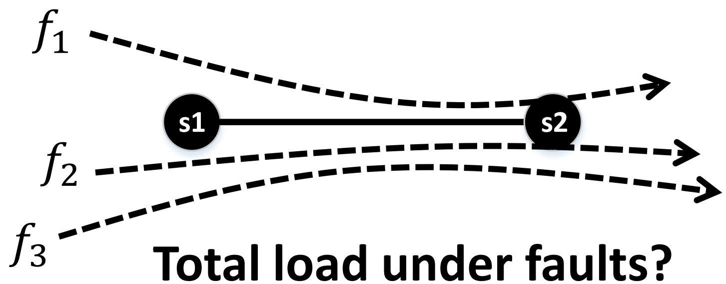
Formulating control plane FFC



Total load under faults?

f_1's load in old TE

f_2's load in new TE

$$\left.\begin{array}{ll}\text{Fault on } f_1: & l_1^{old} + l_2^{new} + l_3^{new} \le \text{link cap} \\ \text{Fault on } f_2: & l_1^{new} + l_2^{old} + l_3^{new} \le \text{link cap} \\ \text{Fault on } f_3: & l_1^{new} + l_2^{new} + l_3^{old} \le \text{link cap}\end{array}\right\} \binom{3}{1}$$

Challenge: too many constraints

With ***n*** flows and FFC protection ***k***:

#constraints = $\binom{n}{1} + \ldots + \binom{n}{k}$ for each link.

An efficient and precise solution to FFC

Our approach:

A **lossless** compression from O($\binom{n}{k}$) constraints to O(kn) constraints.

Total load under faults ≤ link capacity ⟷ Total additional load due to faults ≤ link spare capacity

x_i: additional load due to **fault-*i***

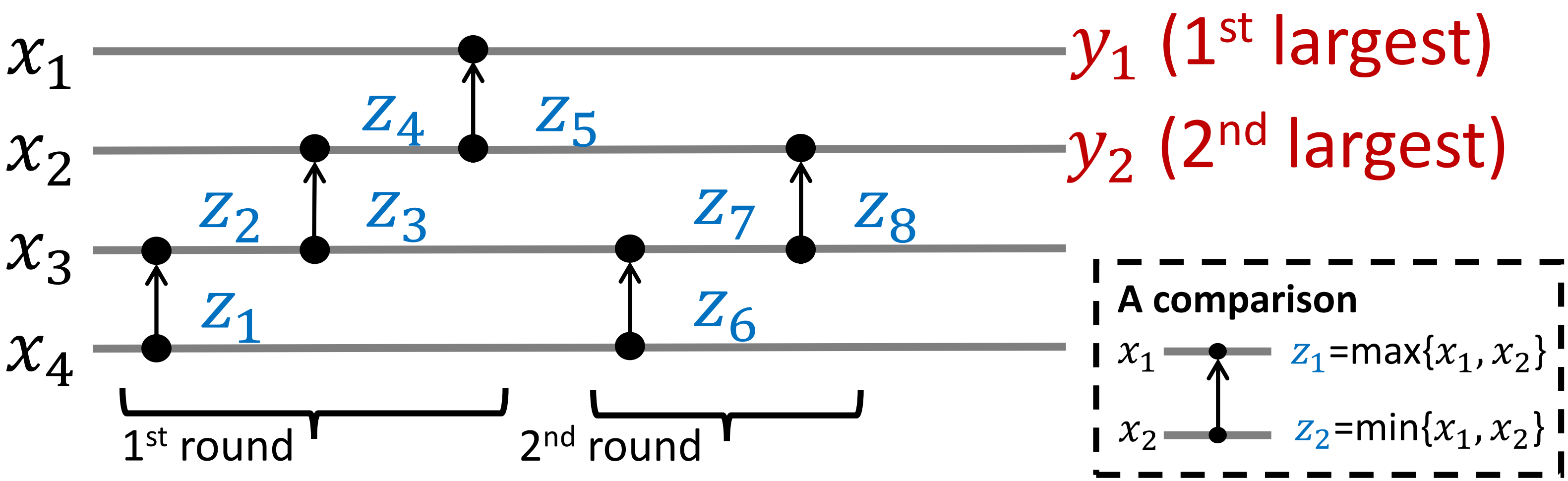
Given $X = \{x_1, x_2, \ldots, x_n\}$, FFC requires that **the sum** of ***arbitrary k*** elements in X is ≤ link spare capacity — O($\binom{n}{k}$)

⇕

Define y_m as the ***m***th ***largest*** element in X:
$\sum_{m=1}^{k} y_m$ ≤ link spare capacity — O(1)

Expressing y_m with X?

Sorting network



$y_1 + y_2 \leq$ link spare capacity

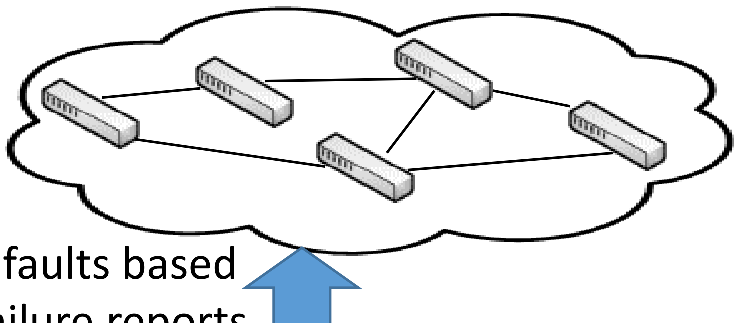
- **Complexity:** O(kn) additional variables and constraints.
- **Throughput:** optimal in control-plane and data plane if paths are disjoint.

FFC extensions

- Differential protection for different traffic priorities
- Minimizing congestion risks without rate limiters
- Control plane faults on rate limiters
- Uncertainty in current TE
- Different TE objectives (e.g. max-min fairness)
- …

Evaluation overview

- Testbed experiment
  - FFC can be implemented in commodity switches
  - FFC has no data loss due to congestion under faults
- Large-scale simulation



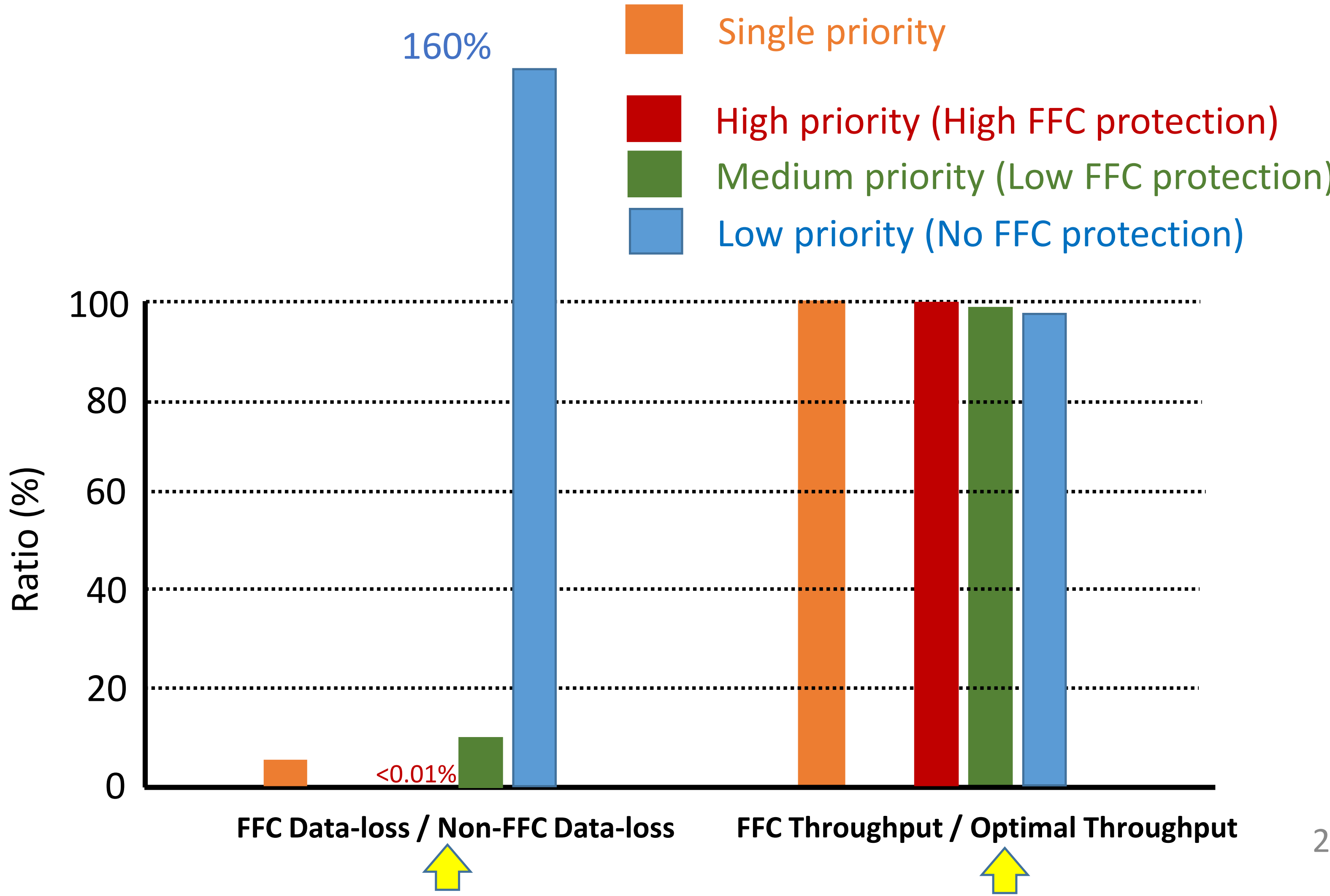
A WAN network with O(100) switches and O(1000) links

Injecting faults based on real failure reports

Single priority traffic in a well-provisioned network

Multiple priority traffic in a well-utilized network

FFC prevents congestion with negligible throughput loss



Conclusions

- Centralized TE is critical to high network utilization but is vulnerable to control and data plane faults.

- FFC proactively handle these faults.
  - Guarantee: no congestion when **#faults ≤ k**.
  - Efficiently computable with low throughput overhead in practice.

FFC