Substation Networking

- Most networks in substation use either
  - » BaseT: specialized copper, twisted pair
    - – 10baseT means 10 megabits/second transfer rate
    - – Copper cables are often cheaper
    - – Network connections cheaper
  - » BaseF: fiber-optic cable
    - – Galvanic isolation
    - – Immune for electromagnetic interference
    - – Not susceptible to ground loops
    - – Longer cable runs possible
    - – Requires specialized tools

1

Failure Modes: Inside Station

- Broadcast Data Storm
  - » A network interface on an IED can fail in a mode that corrupts network
  - » Failed interface can continuously broadcast messages
  - » Different network management devices respond differently
    - – Hub: passes the storm on
    - – Router: limits
    - – Unmanaged switch
    - – Managed switch
- Failures of network links
- Failures of switches
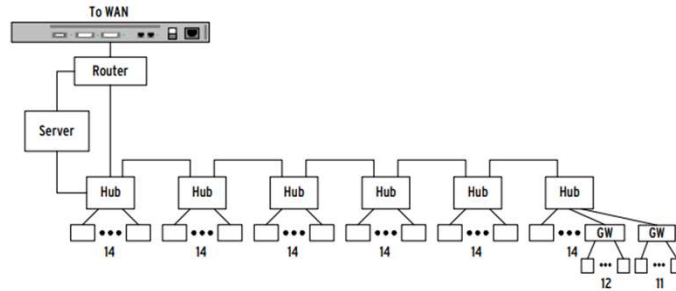- Protocols to manage situations

2

1

Shared Hub Lan

Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

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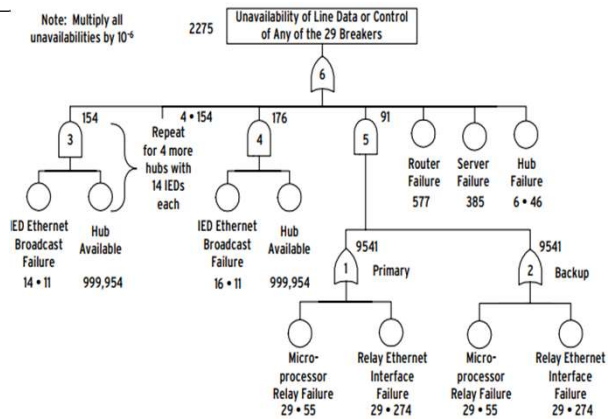
3

Shared Hub LAN Fault tree

Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

Figure 2: Shared Hub Fault Tree

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Switched LAN Fault tree

Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

Unavailability = $3921*10^{-6}$

Availability = 99.6079%

- Switches not as reliable as hubs.
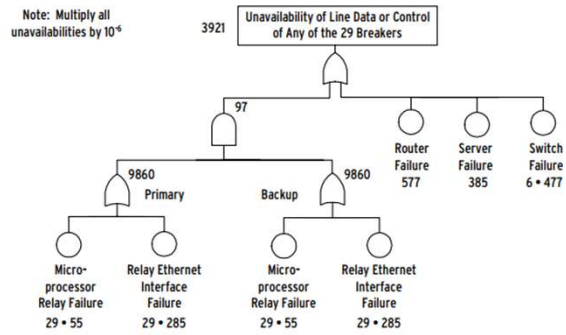- But no data storms

Figure 3: Switch Fault Tree

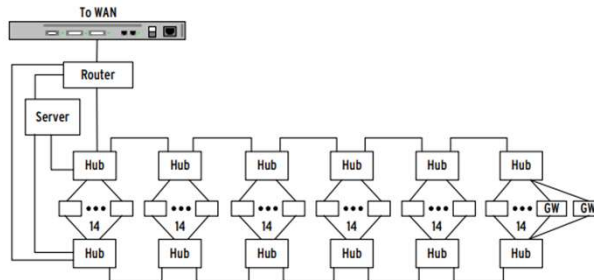

Redundant Shared Hub Lan

Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

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Redundant Shared Hub Lan

Note: Multiply all unavailabilities by 10^{-6}

1055 — Unavailability of Line Data or Control of Any of the 29 Breakers

91 — Router Failure 577 — Server Failure 385 — 1.5

9541 — Primary Protection — 9541 — Backup Protection — 1222 — Primary Network — 1222 — Backup Network

Micro-processor Relay Failure $29 \cdot 55$ — Relay Ethernet Interface Failure $29 \cdot 274$ — Micro-processor Relay Failure $29 \cdot 55$ — Relay Ethernet Interface Failure $29 \cdot 274$

Hub Failure $6 \cdot 46$ — 946 — Hub Failure $6 \cdot 46$ — 946

IED Ethernet Broadcast Failure $86 \cdot 11$ — Hub Available 999,954 — IED Ethernet Broadcast Failure $86 \cdot 11$ — Hub Available 999,954
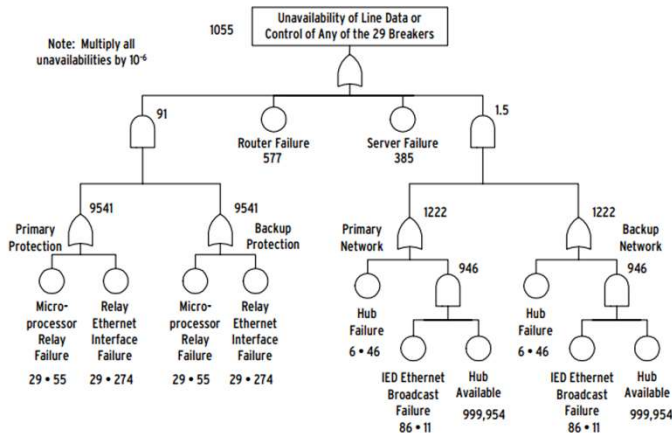
Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

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Redundant Servers, Routers, Switches

To WAN

Server — Server

Router — Router

Switch — Switch — Switch — Switch — Switch — Switch

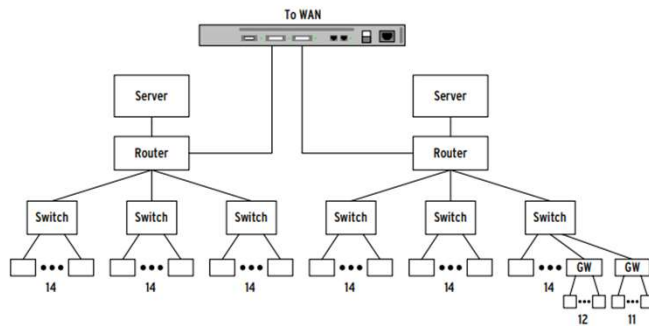14 — 14 — 14 — 14 — 14 — 14 — GW — GW

12 — 11

Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

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Redundant Servers, Routers, Switches

CS&ECE 444/544

Lecture 19

Note: Multiply all unavailabilities by 10⁻⁶ — 150 — Unavailability of Line Data or Control of Any of the 29 Breakers
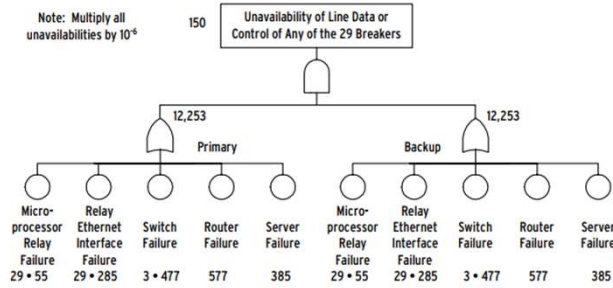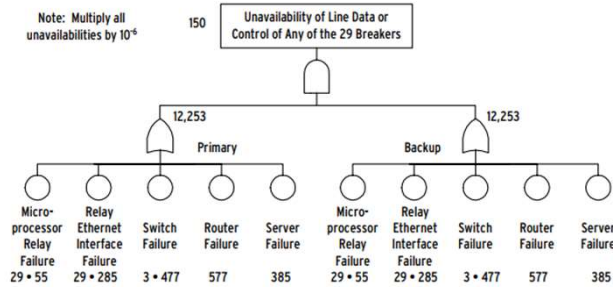
Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

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Redundant Servers, Routers, Switches

CS&ECE 444/544

Lecture 19

Note: Multiply all unavailabilities by 10⁻⁶ — 150 — Unavailability of Line Data or Control of Any of the 29 Breakers

Figure from: G.W. Scheer and D.J. Dolezilek "Comparing the Reliability of Ethernet Network Topologies in Substation Control and Monitoring Networks," 2nd *Annual Western Power Delivery Automation Conference, 2000*

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Availability Comparison

Table 3: Availabilities of Systems to Retrieve all Line Data and Operate Any Breaker

Ethernet LAN	Availability %	Predicted Annual Hours Out of Service
Switches	99.6079	34.3
Shared Hubs	99.7725	19.9
Redundant Switches	99.8932	9.3
Redundant Shared Hubs	99.8945	9.2
Redundant Servers, Routers, Switches	99.9850	1.3

Figure from: G.W. Scheer and D.J. Dolezilek
"Comparing the Reliability of Ethernet
Network Topologies in Substation Control
and Monitoring Networks," 2nd *Annual
Western Power Delivery Automation
Conference, 2000*

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Relay-to-relay communication

Table 6: Relay-to-Relay Communications in a Substation

Network	Availability %	Predicted Annual Hours Out of Service
Switches	99.7138	25
Shared Hubs	99.8778	10.7
Redundant Switches	99.9991	.07
Redundant Servers, Routers, Switches	99.9995	.04
Redundant Shared Hubs	99.9998	.01
Direct	99.9999	.00014

Figure from: G.W. Scheer and D.J. Dolezilek
"Comparing the Reliability of Ethernet
Network Topologies in Substation Control
and Monitoring Networks," 2nd *Annual
Western Power Delivery Automation
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Availability Comparison

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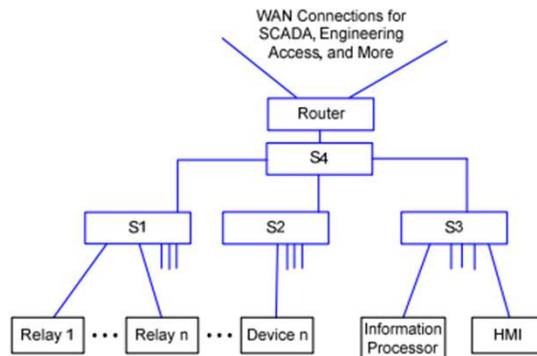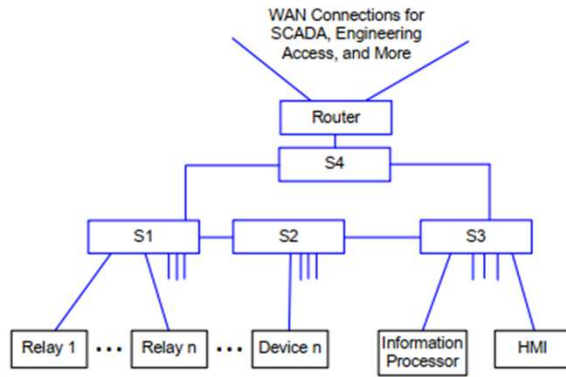
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Network Redundancy: Single Network

Figure from: V. Skendzic and G.W. Scheer "Performance of Redundant Ethernet Networks for Electric Substation Instrumentation and Control ," 11nd *Annual Western Power Delivery Automation Conference, 2000*

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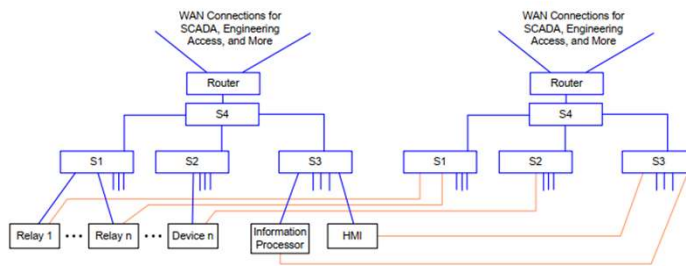
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Network Redundancy: Single Ring

Figure from: V. Skendzic and G.W. Scheer "Performance of Redundant Ethernet Networks for Electric Substation Instrumentation and Control ," 11nd *Annual Western Power Delivery Automation Conference, 2000*

Network Redundancy: Dual Networks with Failover

Figure from: V. Skendzic and G.W. Scheer "Performance of Redundant Ethernet Networks for Electric Substation Instrumentation and Control ," 11nd *Annual Western Power Delivery Automation Conference, 2000*

Network Redundancy:
Dual Networks with Failover

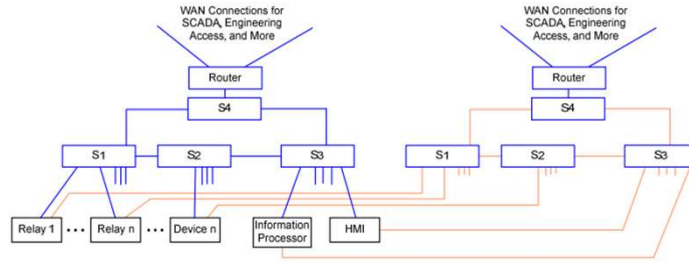*CS&ECE 444/544*

Lecture 19

Figure from: V. Skendzic and G.W. Scheer "Performance of Redundant Ethernet Networks for Electric Substation Instrumentation and Control ," 11nd *Annual Western Power Delivery Automation Conference, 2000*

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Network Redundancy:
Independent Dual Networks

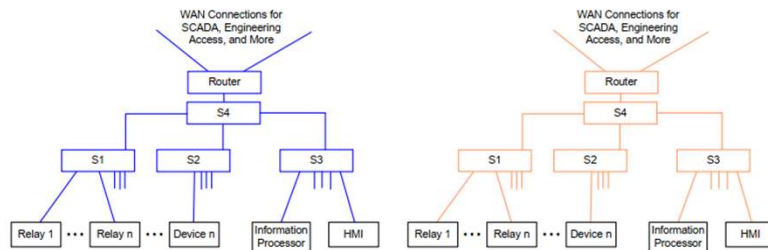*CS&ECE 444/544*

Lecture 19

Figure from: V. Skendzic and G.W. Scheer "Performance of Redundant Ethernet Networks for Electric Substation Instrumentation and Control ," 11nd *Annual Western Power Delivery Automation Conference, 2000*

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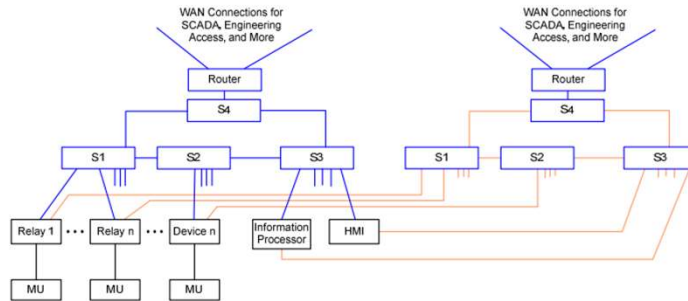
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Network Redundancy:
Add Process Bus Links

Figure from: V. Skendzic and G.W. Scheer "Performance of Redundant Ethernet Networks for Electric Substation Instrumentation and Control ," 11nd *Annual Western Power Delivery Automation Conference, 2000*

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Unavailability Comparison

TABLE III
COMPONENT RELIABILITY DATA

Component	MTBF	Unavailability (Parts Per Million [ppm])	Availability
Monitored Ethernet Cable	5000 years	1.1	99.9999%
Relay Ethernet Port	2500 years	2.2	99.9998%
Relay or Merging Unit	200 years	27	99.9973%
Ethernet Switch or Router	60 years	96	99.99040%

TABLE IV
SYSTEM RELIABILITY COMPARISONS

Topology	Unavailability ppm	
	Network Only	Network, Relays, and Merging Units
Single Network	561	1164
Single Network With Redundant Paths	265	868
Dual Networks With Failover	0.3	603
Dual Redundant-Path Networks With Failover	0.1	603
Independent Dual Networks With Redundant Devices	0.3	1.4
Dual Redundant-Path Networks With Point-to-Point Process Bus	0.1	1206
Independent Dual Networks With Redundant Devices and Point-to-Point Process Bus	0.5	1.6
Independent Dual Networks With Redundant Devices and Process Bus Network	0.8	2.3

Figure from: V. Skendzic and G.W. Scheer "Performance of Redundant Ethernet Networks for Electric Substation Instrumentation and Control ," 11nd *Annual Western Power Delivery Automation Conference, 2000*
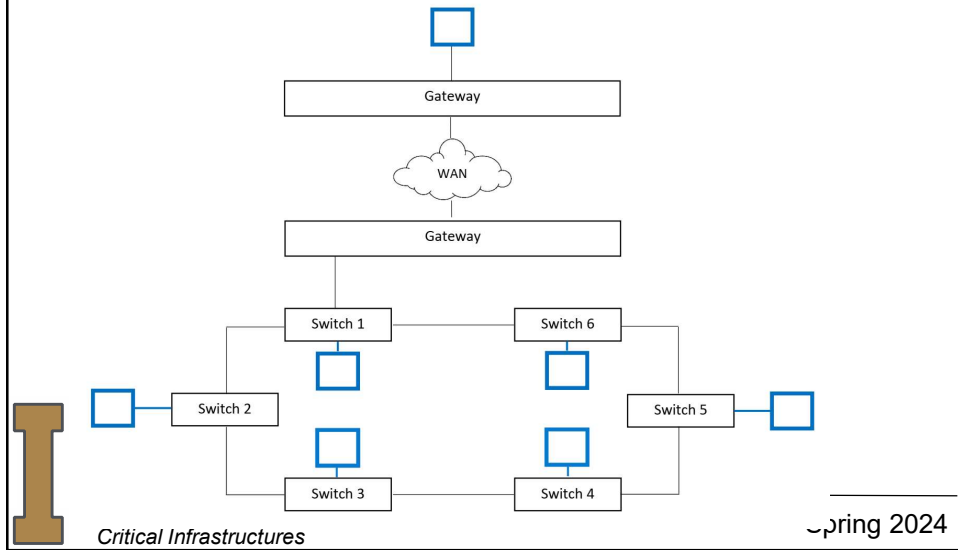
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Network Topology: Loop

Gateway

WAN

Gateway

Switch 1 · Switch 6

Switch 2 · Switch 5

Switch 3 · Switch 4

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Network Topology: Ladder

Gateway

Gateway

Switch 1 · Switch 2

Switch 3 · Switch 4

Switch 5 · Switch 6

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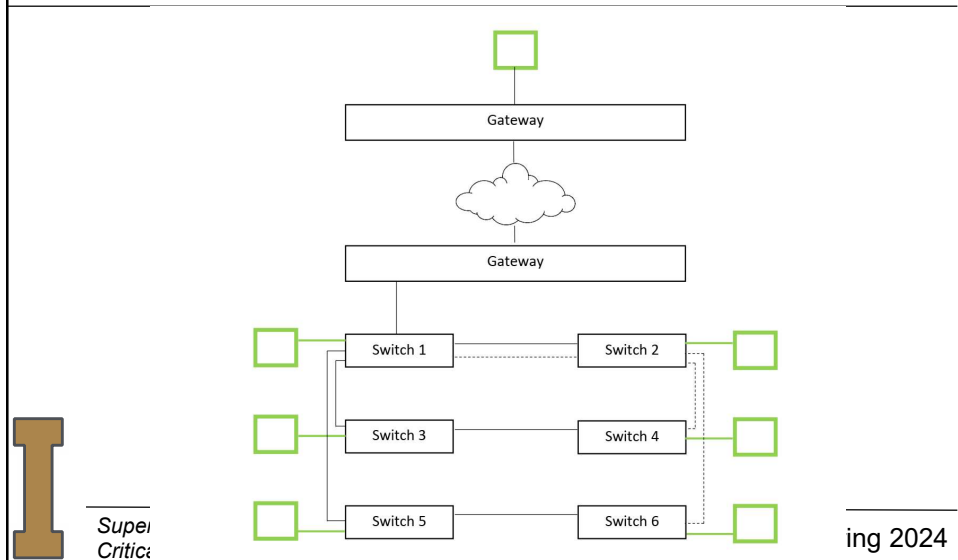
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Network Topology: Double Star

Gateway

WAN

Gateway

Switch 6   Switch 2

Switch 5   Switch 1   Switch 3

Switch 4

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