Tutorial:
Cut-Through Forwarding (CTF) in Bridges and Bridged Networks

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Use-Cases: Industrial Automation

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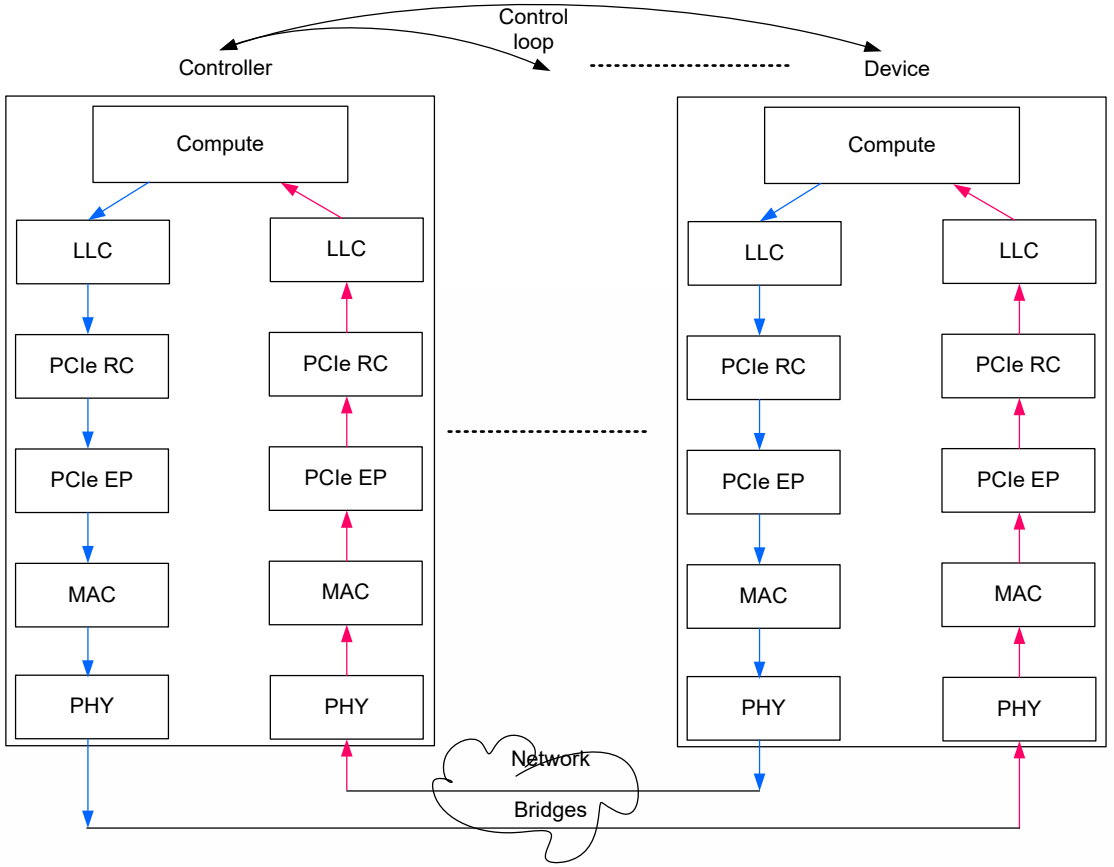
Networking Requirements: Principal Data Path (Control Loop)

Principle data path between the controller and a device :

- The entities which are involved into the guaranteed latency transmission for the control loop are depicted
- Latencies for link layer control, bus interface, MAC/PHY are incurred at the controller and the device
- Combined store & forward, bridge delay and PHY delay accumulate at each hop in the network.



Networking Requirements: Summary

Industrial applications, such as machine control, are typically connected in long line configurations. For these installations, to minimize wiring cost and complexity, typical installation uses “daisy chain” where each node has (2) external switched ports and an internal port that goes to the end-node.

A common application is motion control where fast loop times are required. 125 µs cycle rate is common for 100 Mbps. Even lower rates (62.5µs/31.25µs) are desired for 1 Gbps. To support this, low latency for messages through the network is a high priority.

Even Gigabit data rates are not sufficient to solve this problem. Combined store & forward, bridge delay and PHY delay exceed timing budgets. For instance, in a line topology of 64 hops, accumulated latency would exceed a 100 µs control loop even at Gigabit speeds.

- See http://www.ieee802.org/3/ad_hoc/ngrates/public/18_01/woods_nea_01a_0118.pdf

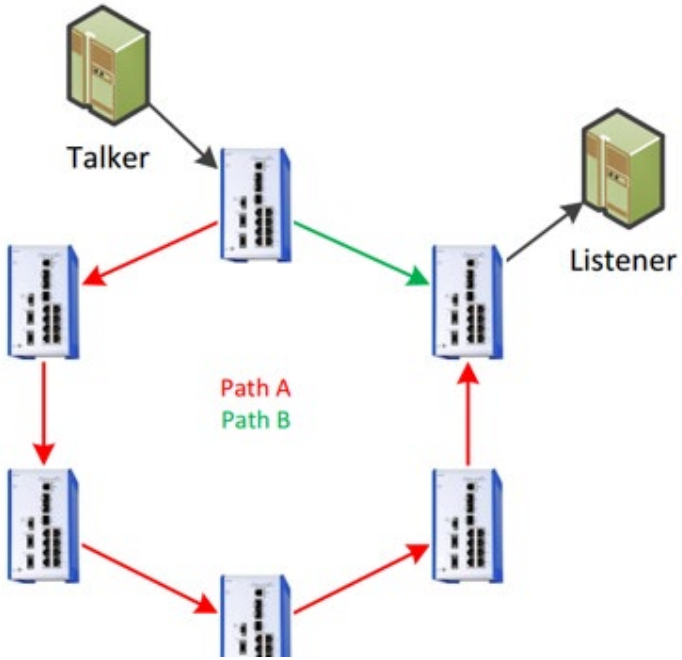
These systems often also have high EMC and there is a desire in some applications to support brown-field wiring. Often, these devices are resource, power and cost-constrained. For these applications 100Mb/s rates are desired.

Why Line Topologies?

- Physical constraints make cabling for star topologies impractical
- The construction of the application naturally lends itself to point-to-point connectivity
- They are, after all, assembly “lines”

Use Case 2 - Redundancy (ring topologies)

- Typical topology for redundancy in industrial networks is a ring:
  - Inherently different packet latency on the network along the different routes
  - Depending on the setup, packet latency on the two paths can have extreme deviation
  - Depending on the allowed reception window of redundancy mechanisms, ring size is limited
  - For instance, for a 300 byte packet and 100 us packet deviation:
    - At 100 Mbit/s: the max. tolerable difference in the path is consumed in 4 hops
    - At 1 Gbit/s: the max. tolerable difference in the path is consumed in 34 hops



Market Opportunity

Top 50 Global Automation Vendors *2019 Worldwide Revenue (US$ millions)*		
1	Siemens	$13,625
2	Emerson	$12,255
3	ABB	$11,222
4	Schneider Electric	$7,052
5	Rockwell Automation	$6,737
6	Fortive	$4,428
7	Mitsubishi Electric	$3,979
8	Honeywell	$3,756
9	Yokogawa Electric	$3,427
10	Ametek EIG	$3,323
11	Omron	$3,236
12	Endress+Hauser	$3,113
13	Phoenix Contact	$2,912
14	Spectris	$2,085
15	Sick AG	$2,013
16	IMI	$1,991
17	MKS Instruments	$1,900
18	Festo	$1,821

Top 50 Global Automation Vendors *2019 Worldwide Revenue (US$ millions)*		
19	Advantech	$1,765
20	TechnipFMC	$1,634
21	Fanuc	$1,561
22	GE	$1,550
23	Roper Technologies	$1,451
24	Baker Hughes	$1,447
25	Aveva	$1,395
26	National Instruments	$1,353
27	Flowserve	$1,244
28	Mettler-Toledo	$1,234
29	IFM	$1,174
30	Wika	$1,170
31	Wago	$1,120
32	Teledyne Instruments	$1,105
33	Yaskawa	$1,100
34	Beckhoff	$1,060
35	Belden	$1,050
36	Weidmuller	$927

Top 50 Global Automation Vendors *2018 Worldwide Revenue (US$ millions)*		
37	Harting	$881
38	Lenze	$880
39	azbil Group (Yamatake)	$863
40	Pepperl+Fuchs	$839
41	Hitachi	$815
42	Eaton	$806
43	Thermo Fisher Scientific	$798
44	Fuji Electric	$782
45	Samson	$777
46	Metso	$775
47	Bosch Rexroth	$775
48	Turck	$751
49	Krohne	$699
50	Horiba	$685
Total		**$123,343**

Source: Control Global, https://www.controlglobal.com/articles/2020/top-50-automation-companies-of-2019-under-siege/

Industrial Network Growth

Entire market is growing

- Fieldbus (58%), 7% growth
- Ethernet (38%), 20% growth
- Limited wireless adoption

With the advent of a common layer 2 (TSN), Industrie 4.0, China 2025, etc., strong growth is expected.

- Global industrial Ethernet market valued at USD $24B in 2016
- Expected to grow to $58.98 billion by 2022
- CAGR of slightly above 16.20% (2017 and 2022)
  - Source: Zion Market Research, 2017 - https://www.zionmarketresearch.com/news/global-industrial-ethernet-market