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Industrial Ethernet – Issues and Requirements

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RuggedCom Inc. - Industrial Strength Networks

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Presented at University of Toronto

for the

IEEE Instrumentation & Measurement Society / IEEE Communications Society

Key Topics Covered…

The Emergence of Industrial Ethernet – “*Ethernet everywhere!*”
- Industrial automation and process control applications
- Electric power utilities – substation automation applications
- Future growth and emerging dominance of Ethernet for industrial applications

The Industrial Environment – “*No place for the faint of heart!*”
- Key issues and requirements for harsh industrial / substation environments
- EPRI and Rockwell studies confirm what most engineers already knew.
- IEC 61000-6-2, IEC 61850-3, IEEE P1613 Standards to the rescue

Real-time, Deterministic Performance – “*Look Ma, No Collisions!*”
- Technological improvements in modern Ethernet technology - facts and myths.
- IEEE 802.3x, 802.1p, 802.1Q, 802.1w, IGMP Snooping / Filtering
- Fault tolerant network architectures.

A comparison of Industrial Ethernet protocols “ *Different Strokes..*”
- Offerings from major industrial automation OEM’s
- Key highlights.

The Emergence of Industrial Ethernet – "*Ethernet everywhere!*"

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"Industrial Ethernet"

Ethernet on the plant floor…

Ethernet – A Brief History: From back office to factory floor

❑Xerox PARC invention back in the 70's!

- *Original version based on CSMA/CD technology for use with multiple devices in a bus architecture over coax cable.*
- *Supported 10Base5 (5Mbps) and cheaper 10Base2 (2Mbps) speeds*

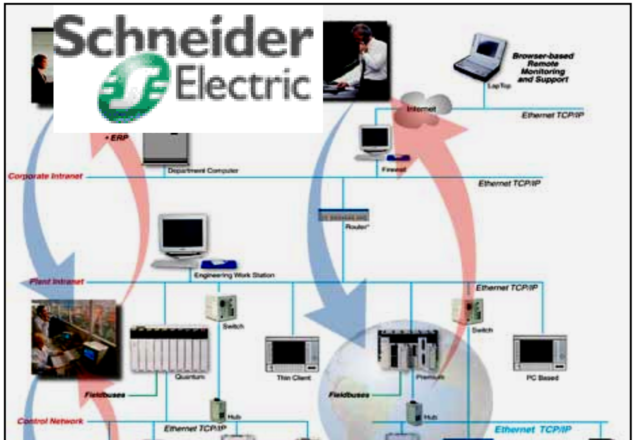
❑Dominant LAN technology at the enterprise layer in the 80's & 90's!

- *Higher speeds (10/100/1000Mbps) help drive the PC networking revolution.*
- *Switching Hub (Bridge) Technology eliminates collisions and improves performance.*

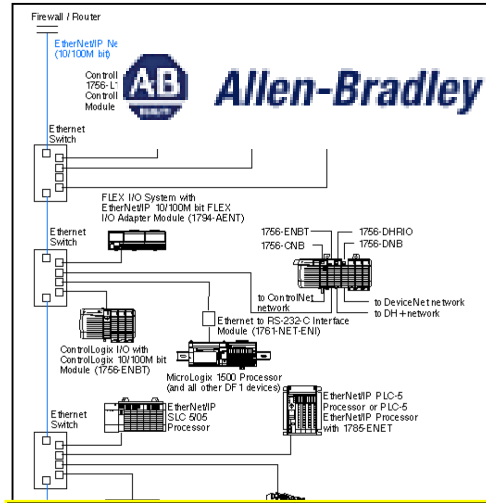
❑Emergence of Industrial Ethernet in the new millennium.

- *Major automation OEM's begin incorporating Ethernet ports into their devices.*
- *All popular industrial "Fieldbus" protocols ported to work over Ethernet*
- *Major automation OEM's begin to promote Ethernet for process control and factory automation.*

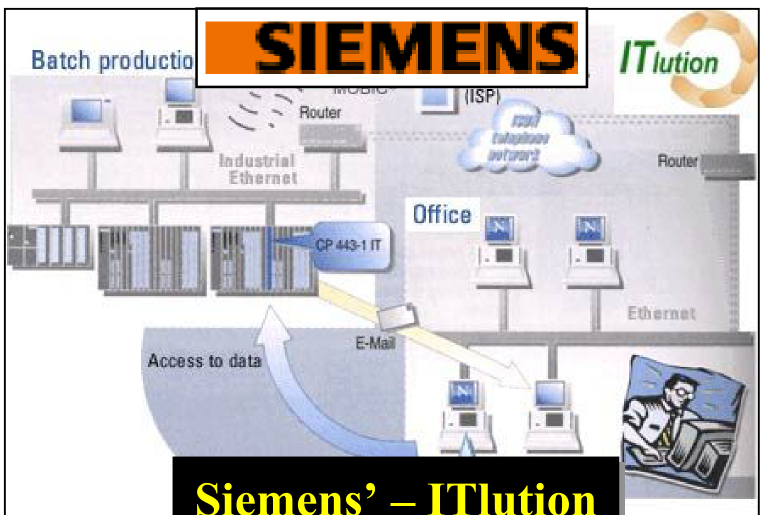
All Major Automation OEM's Have Offering…



Schneider's Transparent Factory



EtherNet/IP

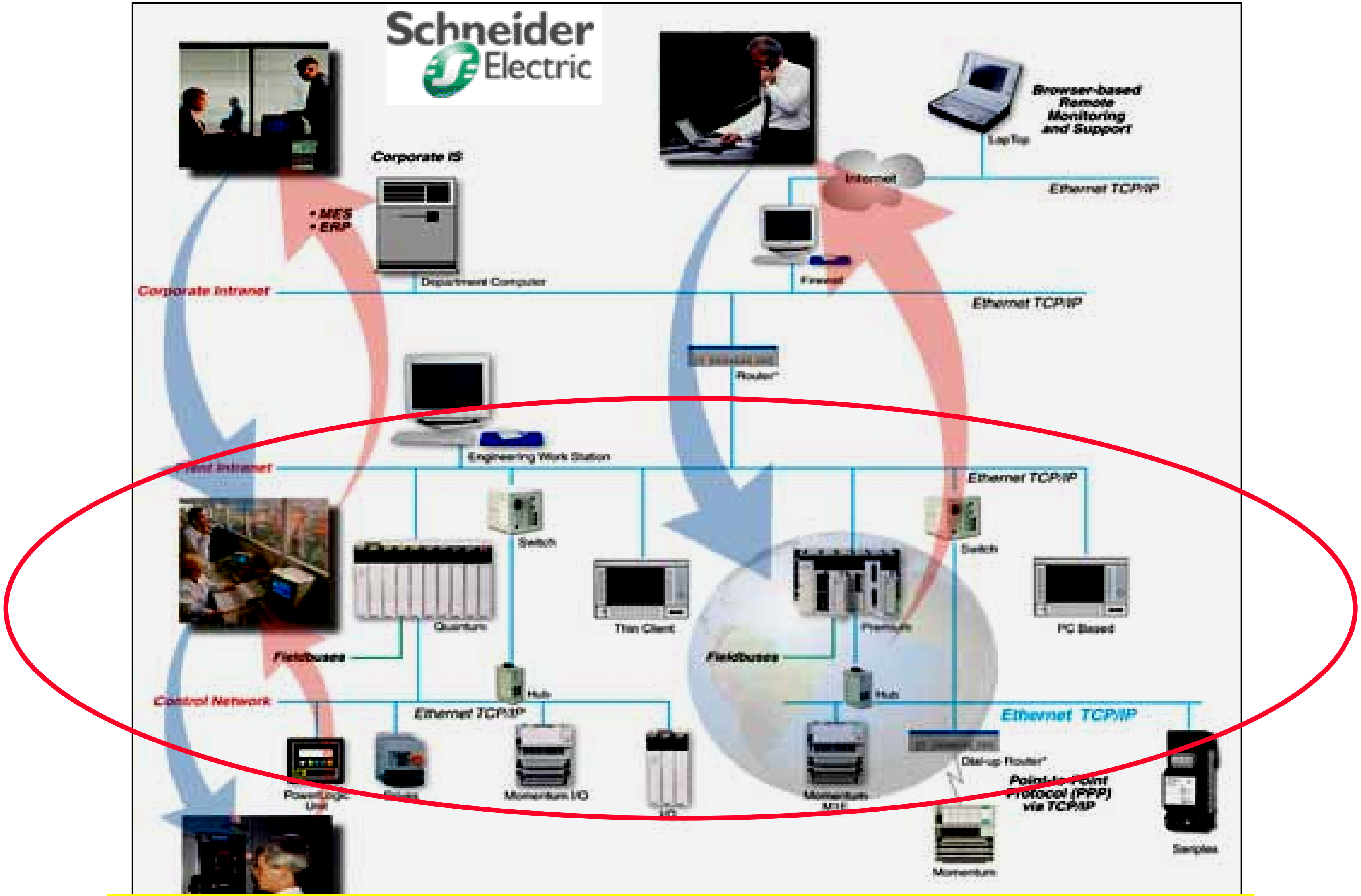


Siemens' – ITlution

ABB's - Industrial^{IT}

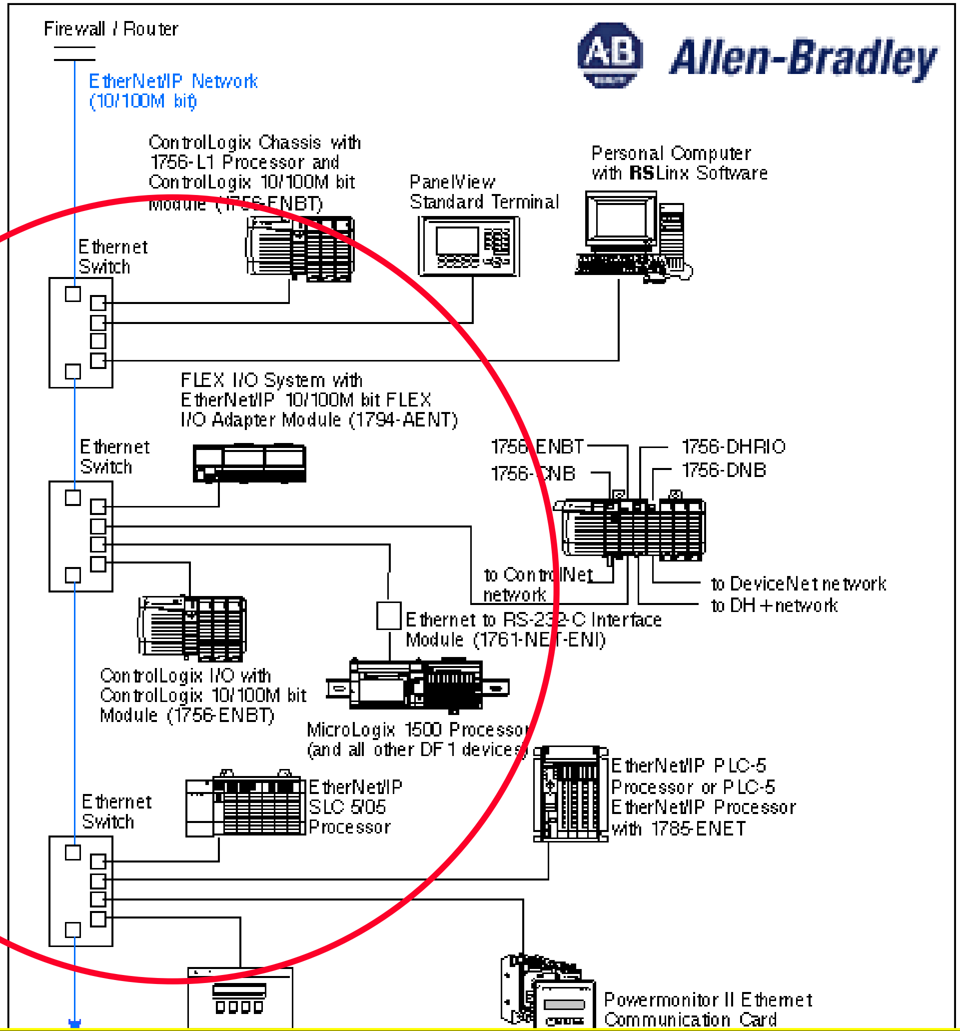
All have one thing in common – Ethernet technology on the factory floor!

Schneider Electric's – Transparent Factory



Schneider's - Transparent Factory, based on Modbus/TCP over Ethernet.

Allen-Bradley's – EtherNet/IP



A-B's - EtherNet/IP: The "IP" Stands for Industrial Protocol.
ControlNet & DeviceNet Application Layers over Ethernet.

"Ethernet in the Substation!"

Even electric utilities do it…

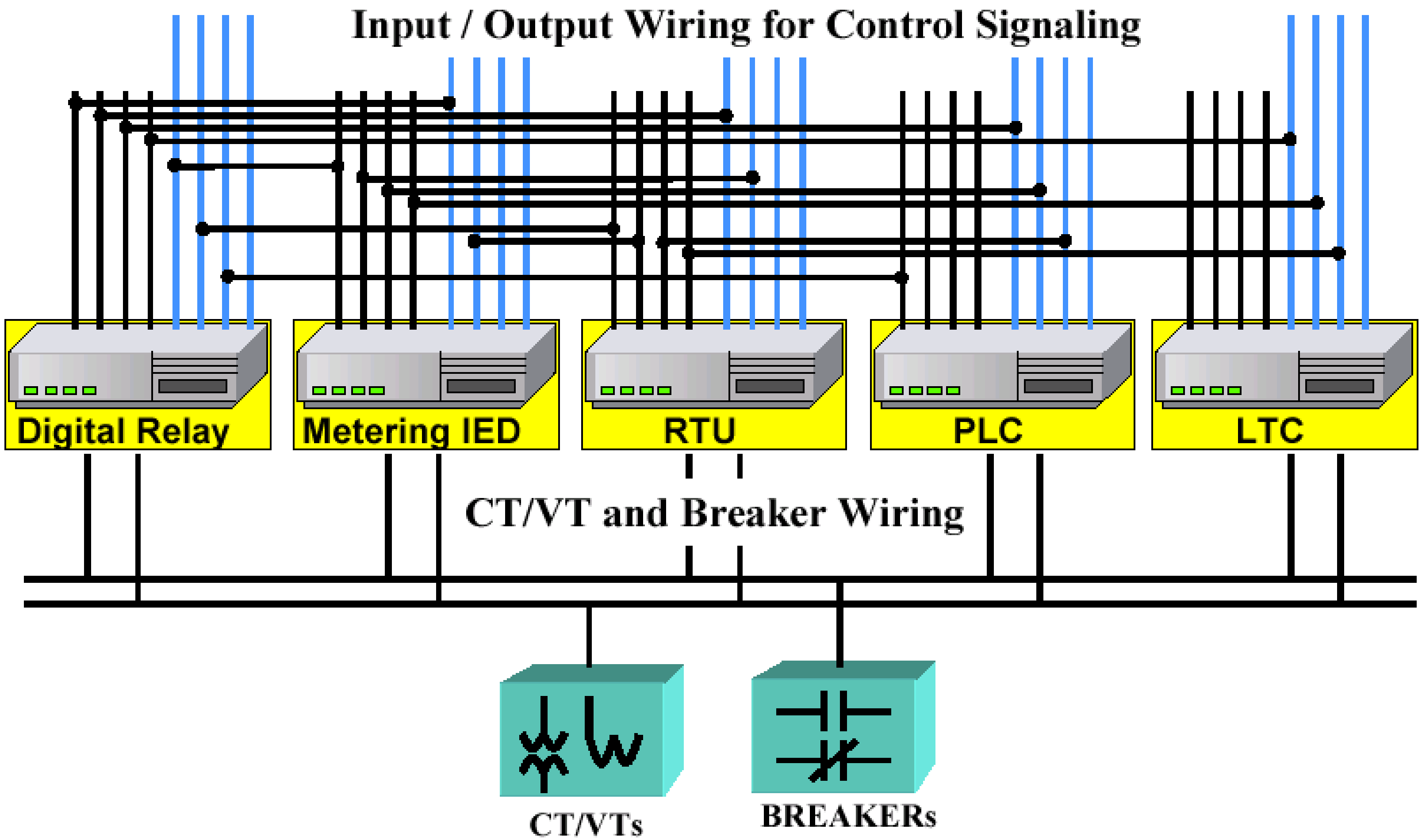
Ethernet in the Substation…Why?

- **Back in the 90's North American Utilities were seeking a common communications architecture for substation and utility automation.**
  - *Every IED vendor supported their own, often proprietary, protocols.*
  - *Protocol converters were required in order to integrate multi-vendor IEDs.*
  - *Costs were high, performance was low!*

- **Utilities and vendors under the auspices of EPRI developed the Utility Communications Architecture (UCA2.0 / IEC 61850)**
  - *A collection of standards to allow for a Utility communications architecture*
  - *Supporting: multi-vendor IED interoperability, real-time control over a substation LAN and a seamless flow of information across the entire Utility enterprise.*

- **Ethernet chosen as the underlying technology for UCA / IEC 61850**
  - *Ethernet is the most prevalent local area network technology in the world.*
  - *Large installed base: over 95% of all back office or enterprise layers.*
  - *Non-proprietary technology with multiple vendors.*
  - *No single IED vendor would have an advantage over the other.*

Traditional Substation



Inter IED control signaling done via wiring or low speed serial communications.

Limited to simple schemes due to cost and complexity of wiring and limited performance capabilities of communications.

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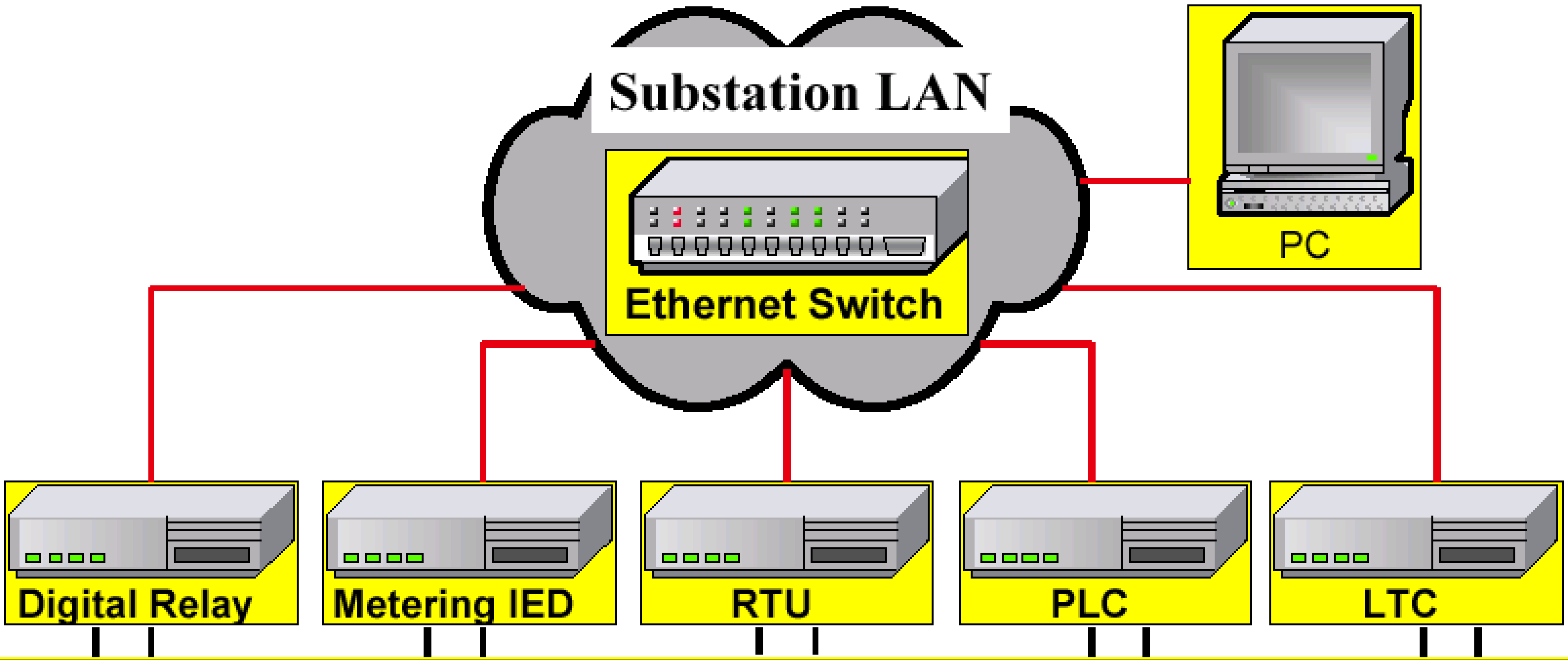
Connecting IEDs via the LAN



ALL IEDs are connected via a single connection (or dual redundancy) to the LAN.

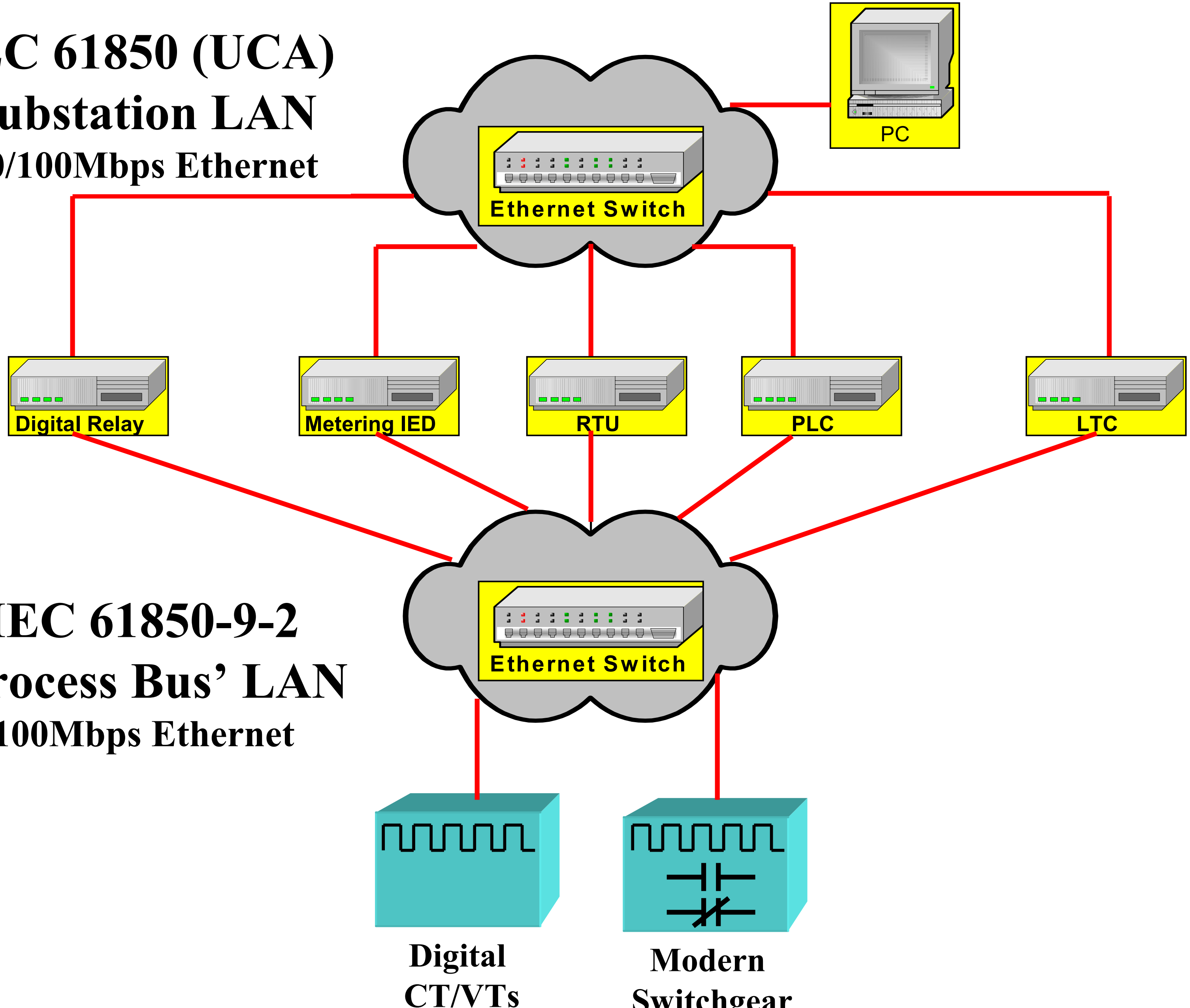
Simple or complex control schemes are possible with no increased wiring costs or complexity.

Other real-time data (e.g. analog, status) can be shared across ALL IEDs.

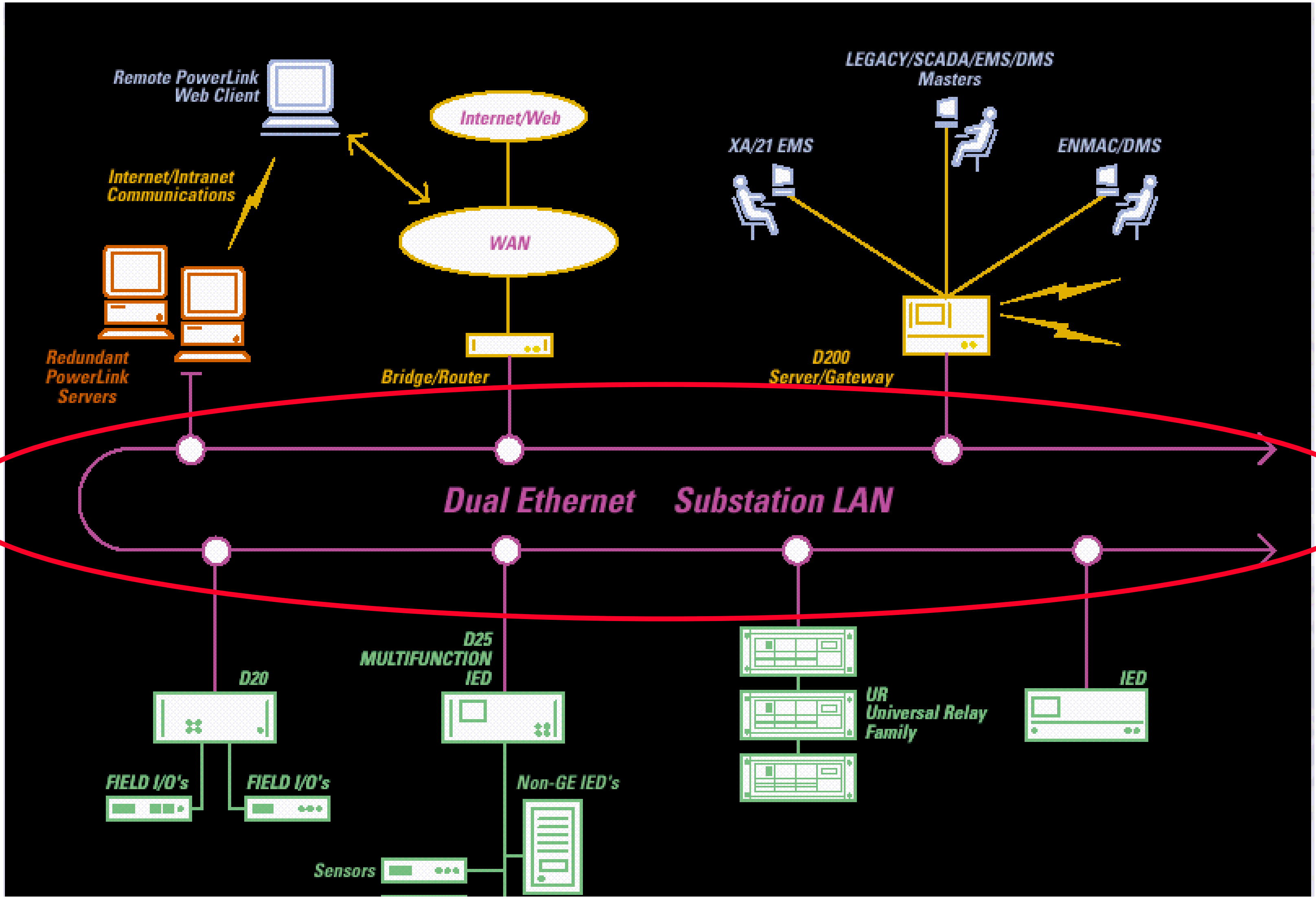
The LAN Based Substation

IEC 61850 (UCA) Substation LAN
10/100Mbps Ethernet

IEC 61850-9-2 'Process Bus' LAN
100Mbps Ethernet

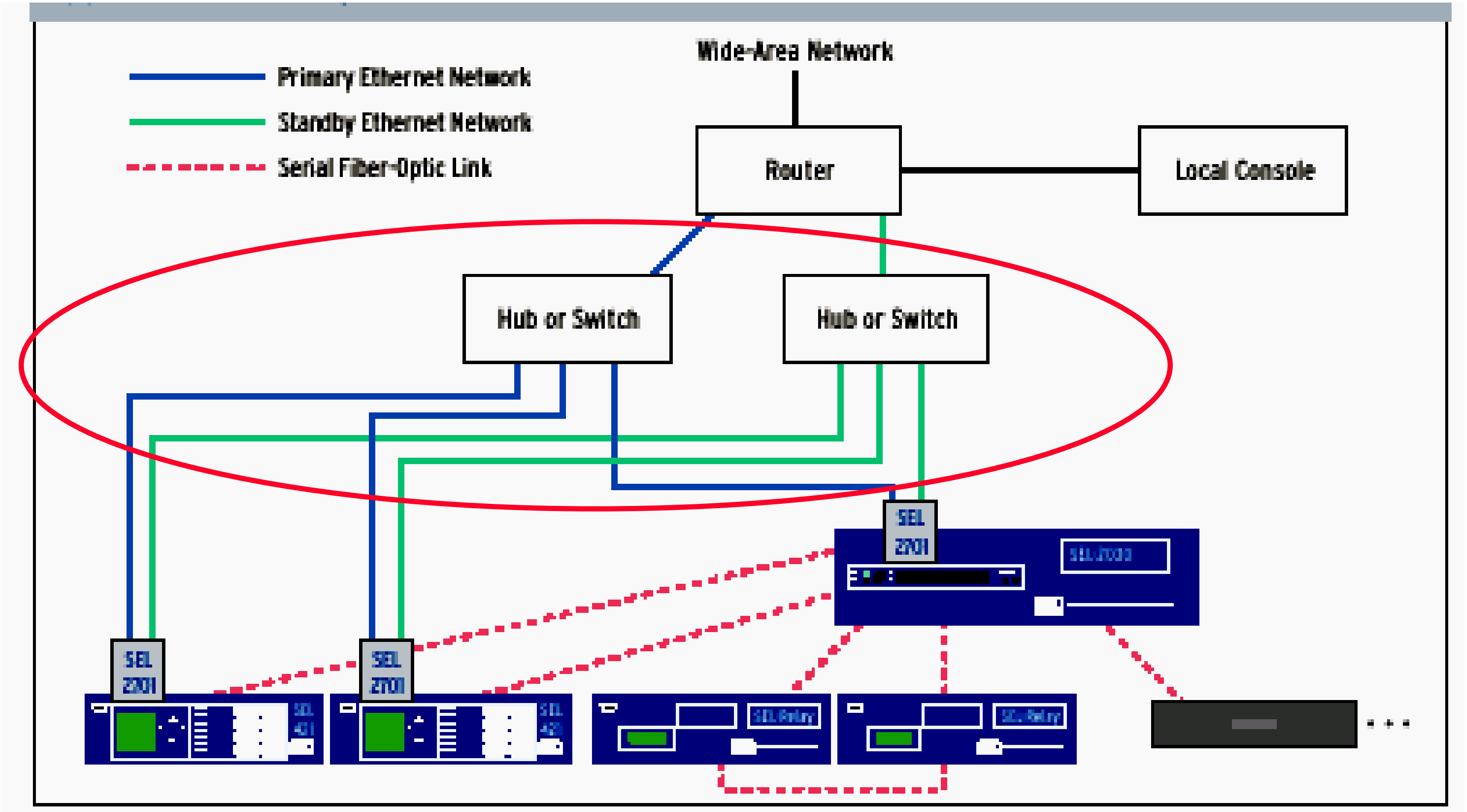


GE's Substation Vision



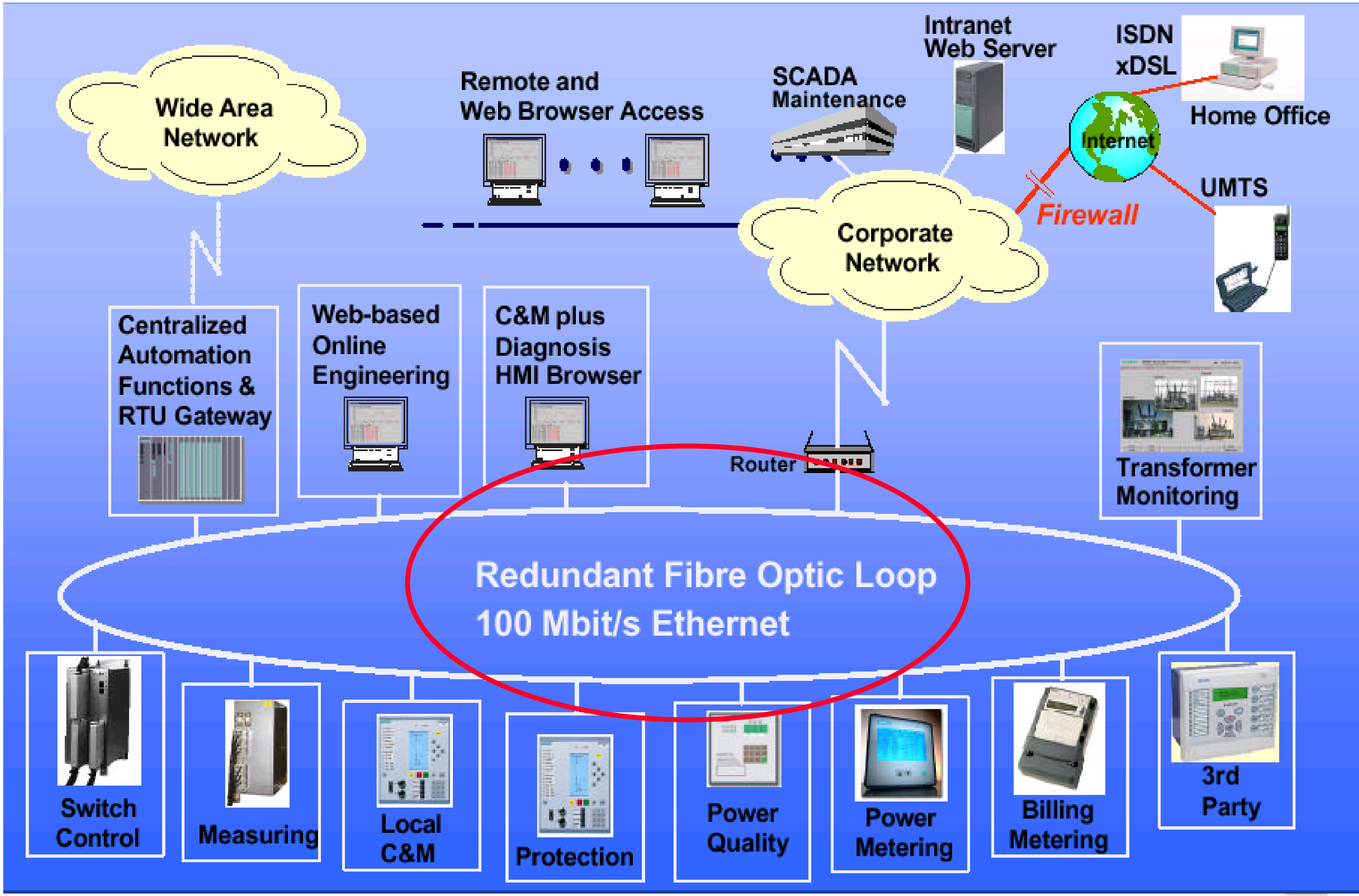
Substation Automation Applications (GE Energy Services)

SEL's Substation Vision



Substation Automation Applications (SEL Architecture)

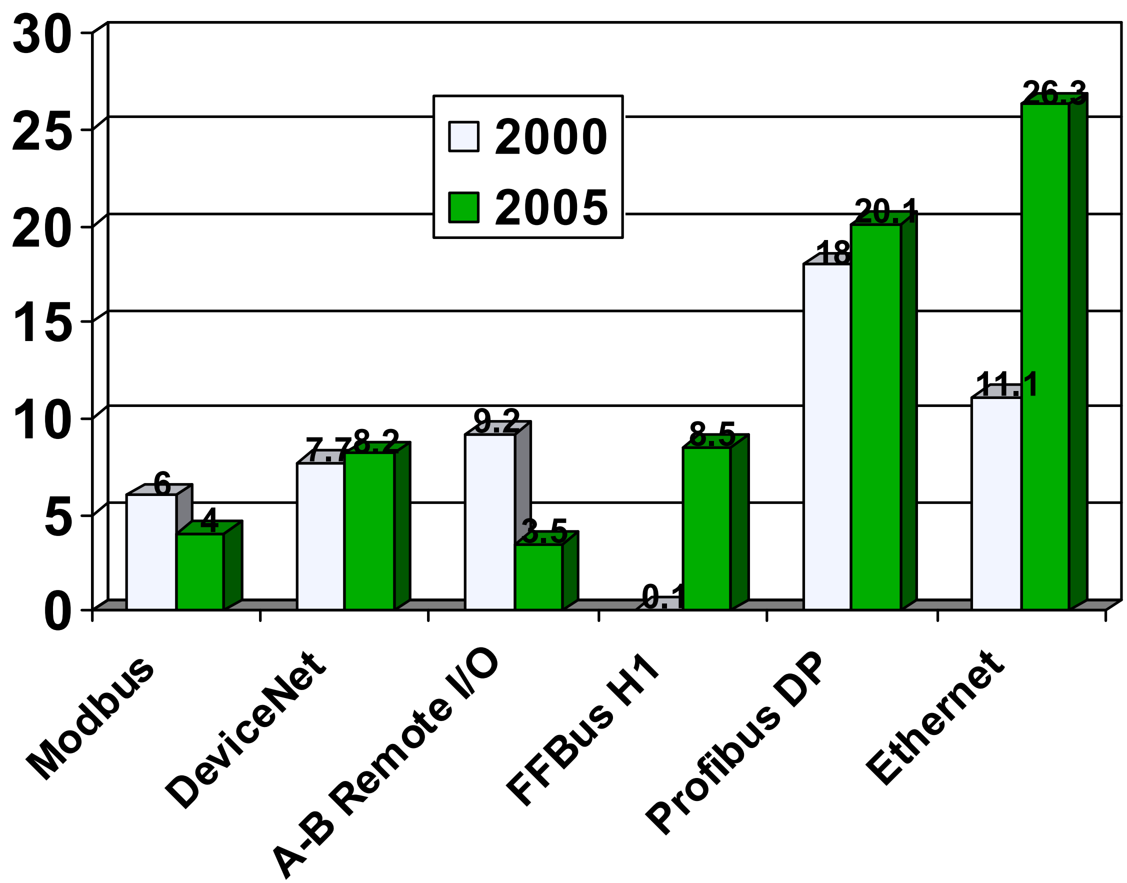
ABB/ALSTOM/Siemen's Vision – IEC 61850-9-2 Substation



Typical Utility Process Bus (IEC 61850) Network (Siemens PTD)

The Proliferation of Ethernet for Industrial/Process Control

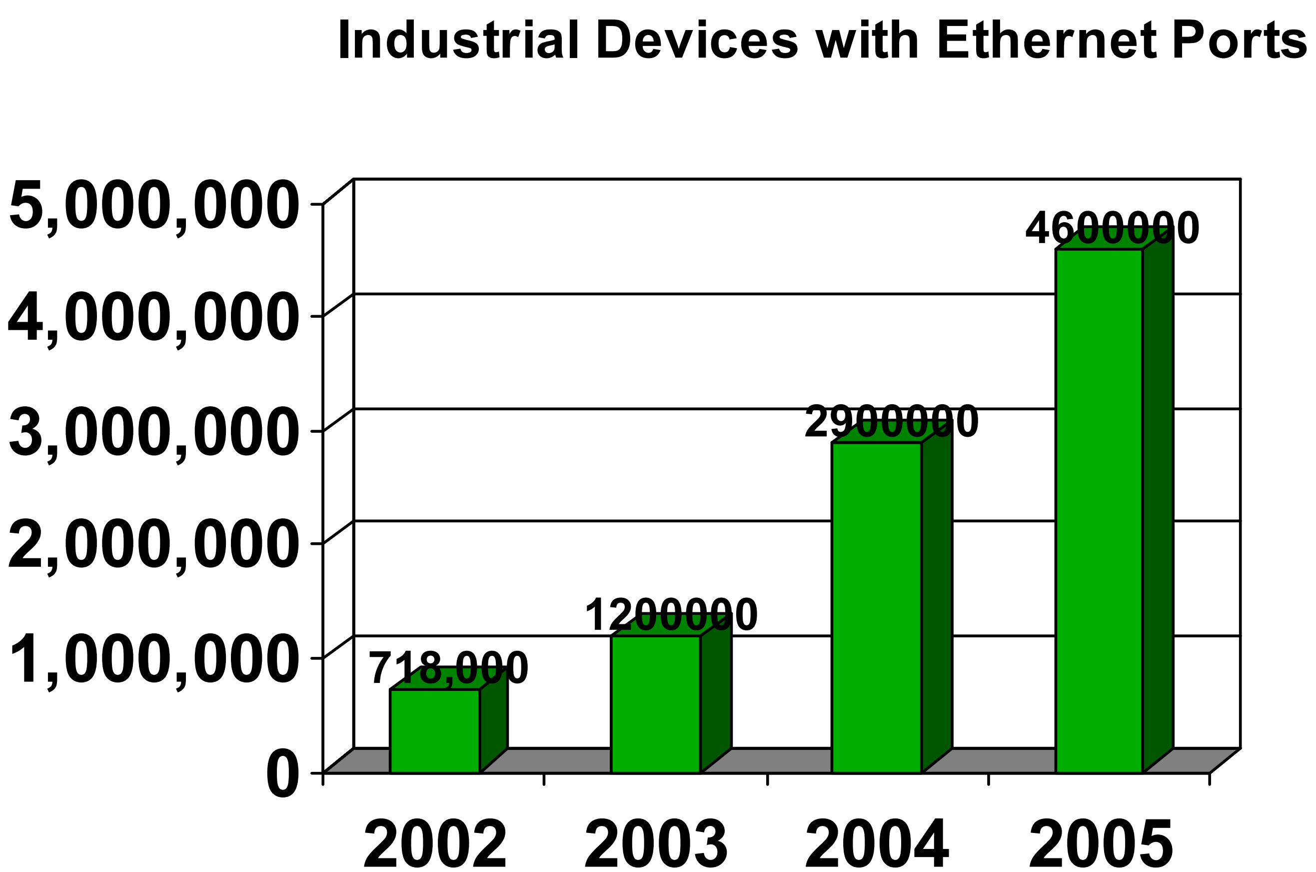
Worldwide Shipments of Industrial IED's by Network Interfaces (% Shipped)



Source: VDC "Global Markets and User Needs for Industrial Distributed/Remote I/O, Second Edition"

Ethernet is becoming *"the new RS232 for Process Control."*

Industrial Ethernet – Growth Projections



Source: Ethernet At The Device Level Worldwide Outlook by ARC Advisory Group, June 2001

CAGR = 110% (2002 – 2005)!

The Industrial Environment –
"No place for the faint of heart!"

What is “*Industrial*” Ethernet…

Ethernet designed for industry…

- ❑ Standard IEEE 802.3 in an industrialized design
- ❑ Higher temperature ranges
- ❑ Rugged and metal housing
- ❑ Fan-less products that withstand vibrations
- ❑ Industrial connectors and cables – CAT5E
- ❑ High speed redundancy
- ❑ EMC Immunity

Source: Bill King – Siemens Energy & Automation (ISA 2002 Conference Presentations)

- ❑ Higher Reliability and Availability

Good qualitative definition – but the devil is in the details…

Higher temperature ranges - how much higher?

EMC Immunity – which standards and what levels?

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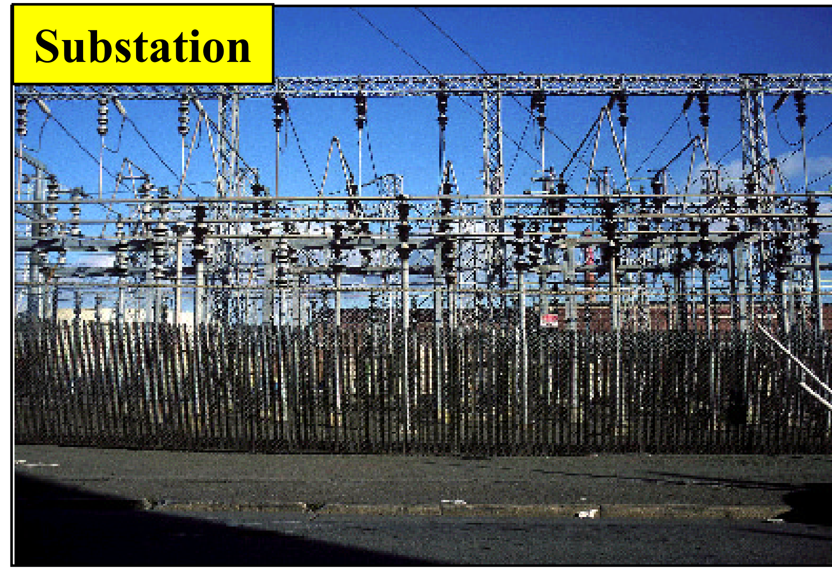
The Substation / Industrial Environment



Phenomena Encountered

- Electric Fields
- Magnetic Fields
- Electrostatic Discharge
- Conducted High Frequency Electrical Transients
- High Energy Power Surges
- Ground Potential Rise during ground faults
- Climactic Variation: Temperature & Humidity
- Seismic / Vibration
- Pollution: Dust, Metallic Particles, Condensation, Solar Radiation

IEC 61000-6-2…the bare minimum!

IEC 61000-6-2 –Generic Immunity Requirements for Industrial Environments

CE Requirements				
IEC 61000-6-2 (Immunity)	Generic Immunity Standard for Industrial Environments		Test Levels	Pass/Fail Criteria
IEC 61000-4-2	ESD	Enclosure Contact	+/- 4kV	B
		Enclosure Air	+/- 8kV	B
IEC 61000-4-3	Radiated RFI	Enclosure ports	10 V/m, 80 to 1000Mhz	A
IEC 61000-4-4	Burst (Fast Transient)	Signal ports	+/- 1kV @ 5kHz	B
		D.C Power ports	+/- 2kV @ 5kHz	B
		A.C. Power ports	+/- 2kV @ 5kHz	B
IEC 61000-4-5	Surge	Signal ports	+/- 1kV line-to-earth	B
		D.C Power ports	+/- 0.5kV line-to-earth/line	B
		A.C. Power ports	+/- 2kV line-to-earth, +/- 1kV line-to-line	B
IEC 61000-4-6	Induced (Conducted) RFI	Signal ports	10V @ 0, 5-80 MHz	A
		D.C Power ports	10V @ 0, 5-80 MHz	A
		A.C. Power ports	10V @ 0, 5-80 MHz	A
		Earth ground ports	10V @ 0, 5-80 MHz	A
IEC 61000-4-8	Magnetic Field	Enclosure ports	30 A/m @ 50, 60 Hz	A
IEC 61000-4-11	Voltage Dips & Interrupts	A.C. Power ports	>95% reduction for 250 periods	C

* Performace criterion A refers to continuous operation of the DUT as intednded during, and after test. Performance criterion B refers to spontaneous recovery after the test with no loss of function or operational performance. Performance criterion C refers to allowable temporary loss of function with recovery through the device controls.

IEC 61000-6-2 required for CE mark compliance for electronic equipment (e.g. PLC's) in industrial environments.

IEC 61000-6-2 should be the <u>minimum</u> requirement for networking equipment in industrial environments.

What are industrial (factory floor) users specifying?

The following excerpt was taken from an RFP specification document from a major manufacturer who is intent is to use Ethernet on the factory floor:

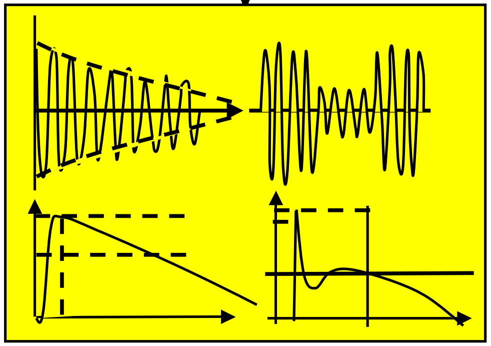
Required and Desired Features of Industrial Ethernet Switches

1. *The primary requirement for an industrial Ethernet switch is that it be environmentally hardened to operate under the same extremes in operating conditions (temperature, vibration, humidity, etc.) as an industrial PLC (Programmable Logic Controller).*

Industrial users are often taking the common sense approach in specifying that the Ethernet networking equipment be us robust as the IED's connecting to it.

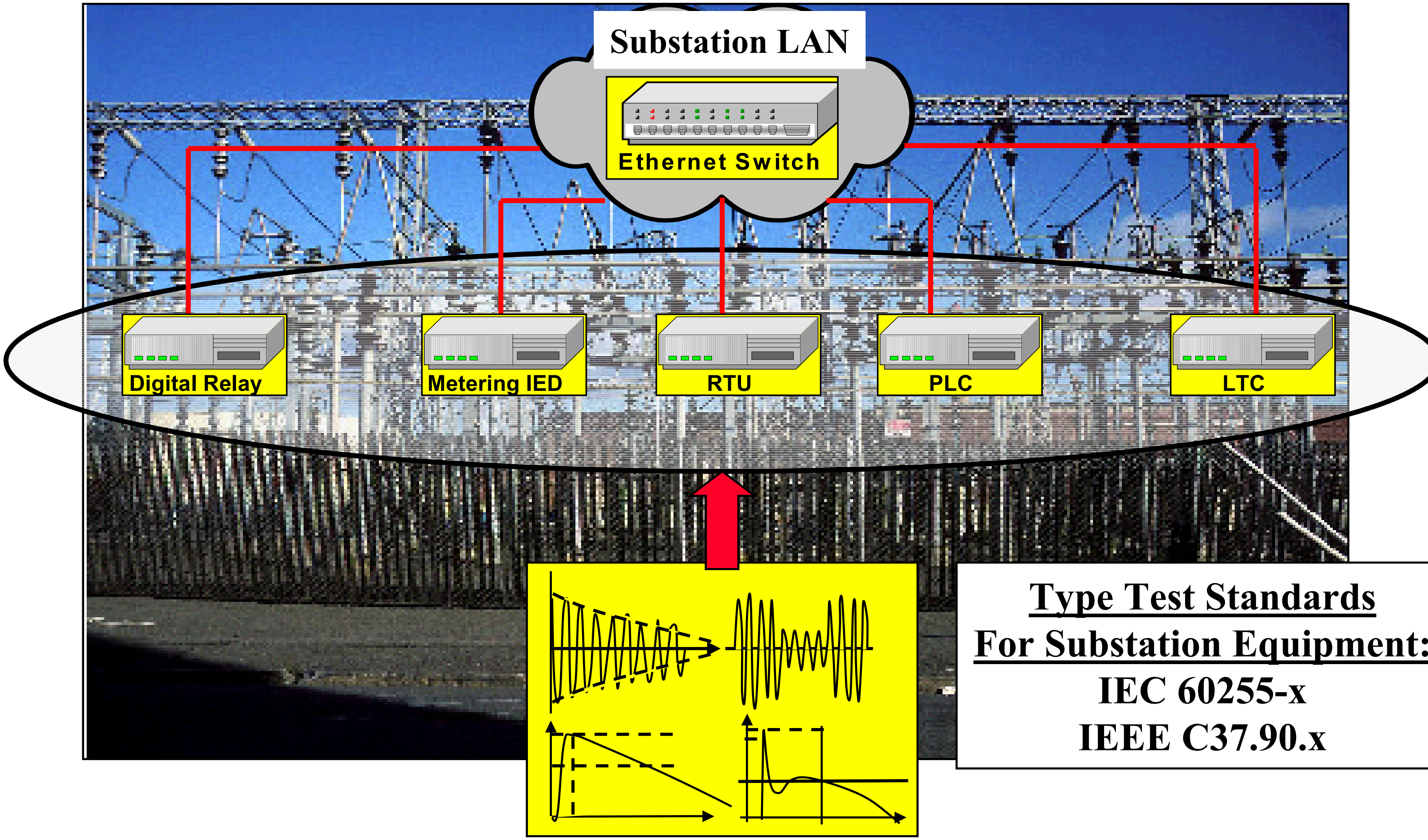
EMI Phenomena - Frequency of Occurrence

Continuous Phenomena	Transient Phenomena (High Occurrence)	Transient Phenomena (Low Occurrence)
• Radiated RFI • Induced RFI • Power freq. Magnetic Field • Slow Voltage Variations • Harmonics, Interharmonics • Ripple on d.c. power supply • Power Frequency Voltage	• Electrostatic Discharge • Voltage Dips • Lightning • HV Switching by Isolators • Reactive Load Switching	• Power Frequency Variation • Power System Faults • Short Duration Power Freq. Magnetic Fields



Devices in industrial / substation environments must deal with a combination of EMI phenomena which are continuous and transient.

Devices are *'Hardened'* for the Substation



<u>Type Test Standards</u>
<u>For Substation Equipment:</u>
IEC 60255-x
IEEE C37.90.x

Devices connected to the substation LAN are specifically 'Hardened' for the substation environment.
What about the Ethernet LAN?

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IEC 61850-3 –Communications networks and systems in substations

NORME INTERNATIONALE
INTERNATIONAL STANDARD

CEI
IEC
61850-3
Première édition
First edition
2002-01

Réseaux et systèmes de communication dans les postes –

Partie 3:
Prescriptions générales

New IEC Standard (Jan/2002)
"Communications networks and systems in substations"

NORME INTERNATIONALE
INTERNATIONAL STANDARD

CEI
IEC
870-4
Première édition
First edition
1990-03

Matériels et systèmes de téléconduite

Quatrième partie:
Prescriptions relatives aux performances

Telecontrol equipment and systems

Part 4:
Performance requirements

Reliability

SPÉCIFICATION TECHNIQUE
TECHNICAL SPECIFICATION

CEI
IEC
TS 61000-6-5
Première édition
First edition
2001-07

Compatibilité électromagnétique (CEM) –

Partie 6-5:
Normes génériques –
Immunité pour les environnements de centrales électriques et de postes

Electromagnetic compatibility (EMC) –

Part 6-5:
Generic standards –
Immunity for power station and substation environments

EMC

NORME INTERNATIONALE
INTERNATIONAL STANDARD

CEI
IEC
870-2-2
Première édition
First edition
1996-08

Matériels et systèmes de téléconduite –

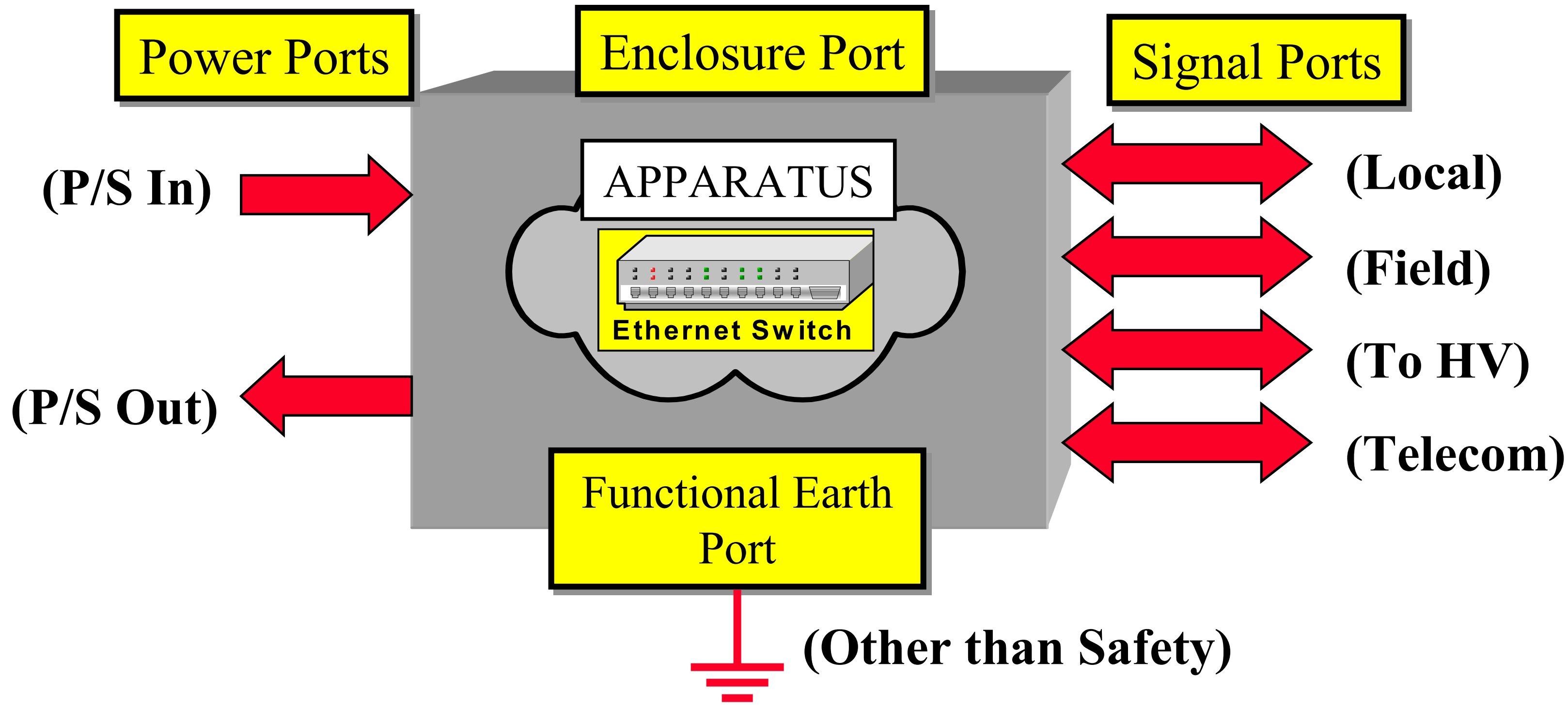
Partie 2:
Conditions de fonctionnement –
Section 2: Conditions d'environnement (influences climatiques, mécaniques et autres influences non électriques)

Telecontrol equipment and systems –

Part 2:
Operating conditions –
Section 2: Environmental conditions (climatic, mechanical and other non-electrical influences)

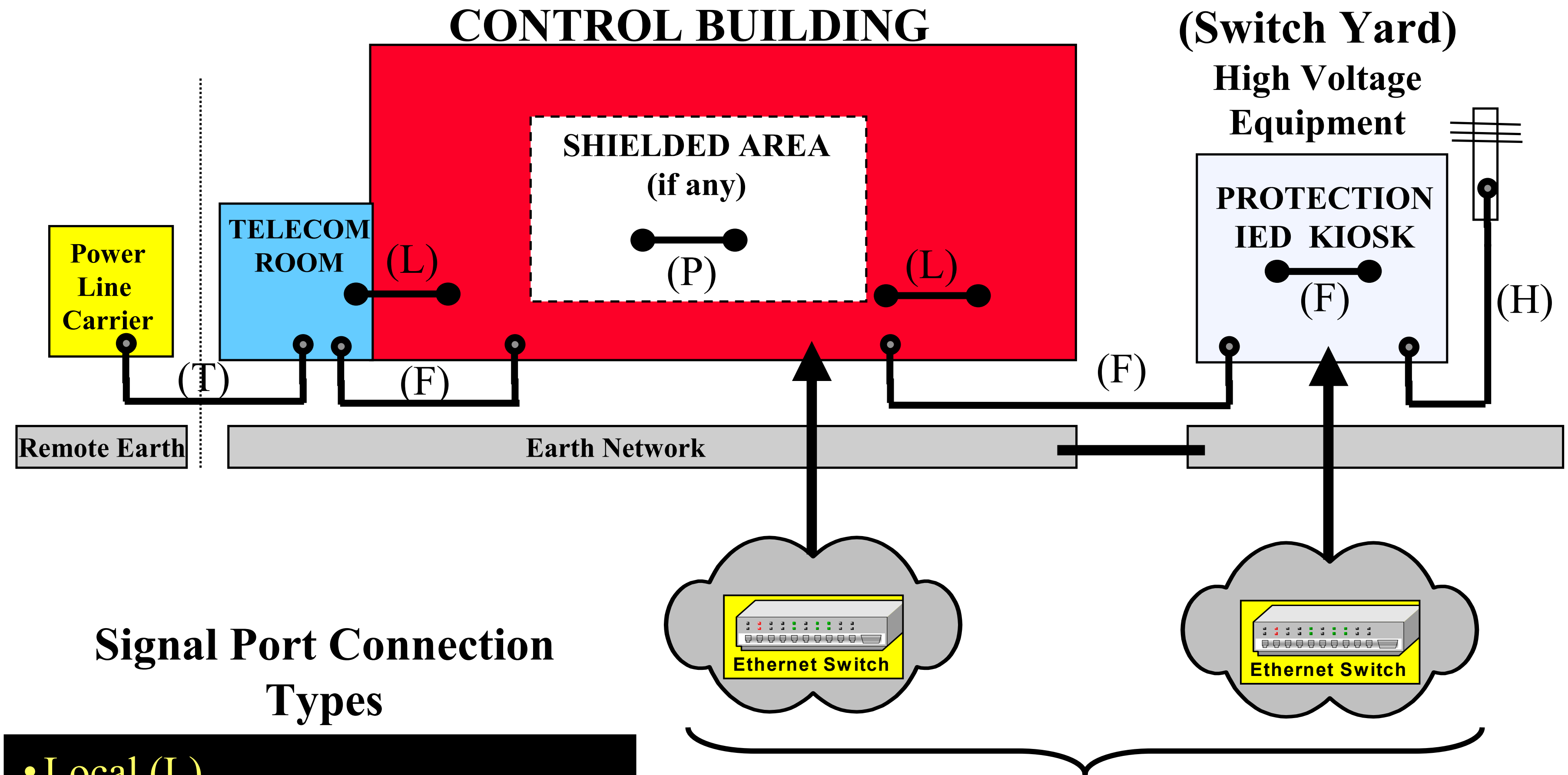
Environmental

IEC 61850-3 (61000-6-5): Apparatus Port Definitions …



A *port* is defined as a "*particular interface of the specified apparatus with the external electromagnetic environment*"
Type tests are defined and assigned for each specific port type.

IEC 61850-3 (61000-6-5): Substation Definitions



Typical Locations of Substation Ethernet Equipment

Signal Port Connection Types

- Local (L)
- Field (F)
- HV Equipment (H)
- Telecom – Power Line Carrier (T)
- Protected (P)

IEC 61850-3…EMI Immunity Requirements

UTILITY IEC 61850-3 (61000-6-5) Communications Networks and Systems In Substations (Jan 2002)				
TEST	Description		Test Levels	Severity Levels
IEC 61000-4-2	ESD	Enclosure Contact	+/- 6kV	3
		Enclosure Air	+/- 8kV	3
IEC 61000-4-3	Radiated RFI	Enclosure ports	10 V/m	3
IEC 61000-4-4	Burst (Fast Transient)	Signal ports	+/- 4kV @ 2.5kHz	x
		D.C. Power ports	+/- 4kV	4
		A.C. Power ports	+/- 4kV	4
		Earth ground ports[3]	+/- 4kV	4
IEC 61000-4-5	Surge	Signal ports	+/- 4kV line-to-earth, +/- 2kV line-to-line	4
		D.C. Power ports	+/- 2kV line-to-earth, +/- 1kV line-to-line	3
		A.C. Power ports	+/- 4kV line-to-earth, +/- 2kV line-to-line	4
IEC 61000-4-6	Induced (Conducted) RFI	Signal ports	10V	3
		D.C Power ports	10V	3
		A.C. Power ports	10V	3
		Earth ground ports[3]	10V	3
IEC 61000-4-8	Magnetic Field	Enclosure ports	40 A/m continuous, 1000 A/m for 1 s	N/A
IEC 61000-4-29	Voltage Dips & Interrupts	D.C. Power ports	30% for 0.1s, 60% for 0.1s, 100% for 0.05s	N/A
		A.C. Power ports	30% for 1 period, 60% for 50 periods	N/A
IEC 61000-4-11			100% for 5 periods, 100% for 50 periods[2]	N/A
IEC 61000-4-12	Damped Oscillatory	Signal ports	2.5kV common, 1kV differential mode @ 1MHz	3
		D.C. Power ports	2.5kV common, 1kV differential mode @ 1MHz	3
		A.C. Power ports	2.5kV common, 1kV differential mode @ 1MHz	3
IEC 61000-4-16	Mains Frequency Voltage	Signal ports	30V Continous, 300V for 1s	4
		D.C. Power ports	30V Continous, 300V for 1s	4
IEC 61000-4-17	Ripple on D.C. Power Supply	D.C. Power ports	10%	3

Issued January 2002 – in recognition of the proliferation of Ethernet in the Substation.

**More tests and higher test levels than IEC 61000-6-2.
Reflects the substation environment.**

IEC 61850-3 (61000-6-5): Performance Criteria

<table>
<tr><th colspan="4">IEC 61000-6-5 Table 7 - Performance Criteria for the most relevant functions</th></tr>
<tr><th colspan="4">(in descending order of criticality)</th></tr>
<tr><th rowspan="2">Functions</th><th colspan="3">Functional requirements versus electromagnetic phenomena</th></tr>
<tr><th>Continous phenomena</th><th>Transient phenomena with high occurance</th><th>Transient phenomena with low occurance</th></tr>
<tr><td>Protection and teleprotection</td><td colspan="3" rowspan="3"></td></tr>
<tr><td>On-line processing and regulation</td></tr>
<tr><td>Metering</td></tr>
<tr><td>Command and Control</td><td colspan="2" rowspan="3">** No Delays or Data Loss **</td><td>Short delay</td></tr>
<tr><td>Supervision</td><td>Temporary loss, self recovered</td></tr>
<tr><td>Man-machine interface</td><td>Stop and reset</td></tr>
<tr><td>Alarm</td><td rowspan="7"></td><td colspan="2">Short delay, temporary wrong indication</td></tr>
<tr><td>Data transmission and telecommunication</td><td>No loss, possible bit error rate degradation</td><td>Temporary loss</td></tr>
<tr><td>Data acquisition and storage</td><td colspan="2">Temporary degradation</td></tr>
<tr><td>Measurement</td><td colspan="2">Temporary degradation, self recovered</td></tr>
<tr><td>Off-line processing</td><td>Temporary degradation</td><td>Temporary loss and reset</td></tr>
<tr><td>Passive monitoring</td><td>Temporary degradation</td><td>Temporary loss</td></tr>
<tr><td>Self-diagnosis</td><td colspan="2">Temporary loss, self recovered</td></tr>
</table>

IEEE P1613 – Coming soon…

IEEE P1613
Draft Standard Environmental Requirements for Communications Networking Devices Installed in Electric Power Substations

Prepared by the C2 TF1 Task Force of the IEEE Power Engineering Society Substations Committee

Abstract: Service conditions, electrical ratings, thermal ratings and environmental testing requirements are defined for communications networking devices to be installed in electric power substations. This standard establishes a common reproducible basis for designing and evaluating communications networking devices for use in this harsh environment.

Keywords: communications networking device, modems, Ethernet hubs, switches, routers, bridges, firewalls, auto dialers, power apparatus, temperature range, humidity, derating, voltage rating, temperature rise, insulation test, dielectric test, impulse test, SWC test, fast transient test, RFI test, ESD test, environmental requirements.

IEEE working on North American equivalent of IEC 61850-3.

IEEE P1613…EMI Immunity Requirements

IEEE P1613 – Draft Standard Environmental Requirements for Communications Devices Installed in Electric Power Substations

TEST	Description		Test Levels	Severity Levels
IEEE C37.90.3	ESD	Enclosure Contact	+/- 8kV	N/A
		Enclosure Air	+/- 15kV	N/A
IEEE C37.90.2	Radiated RFI	Enclosure ports	35 V/m	N/A
IEEE C37.90.1	Fast Transient	Signal ports	+/- 4kV @ 2.5kHz	N/A
		D.C. Power ports	+/- 4kV	N/A
		A.C. Power ports	+/- 4kV	N/A
		Earth ground ports[3]	+/- 4kV	N/A
IEEE C37.90.1	Oscillatory	Signal ports	2.5kV common mode @ 1MHz	N/A
		D.C. Power ports	2.5kV common & differential mode @ 1MHz	N/A
		A.C. Power ports	2.5kV common & differential mode @ 1MHz	N/A
IEEE C37.90	Dielectric Strength	Signal ports	2kVac	N/A
		D.C. Power ports	2kVac	N/A
		A.C. Power ports	2kVac	N/A

Borrows heavily from existing IEEE C37.90.x standards for Protective Relaying devices.

Fewer tests than IEC 61850-3 but with test levels just as high and higher in the case of Radiated RFI: 35V/m v.s. 10V/m !

Defines *two classes* of devices:
Class 1 **devices allow communications errors or loss during EMI type tests.**
Class 2 **devices allow <u>zero</u> communications errors or loss during EMI type tests.**

EPRI Tests: EMI Susceptibility of STP Copper Cables

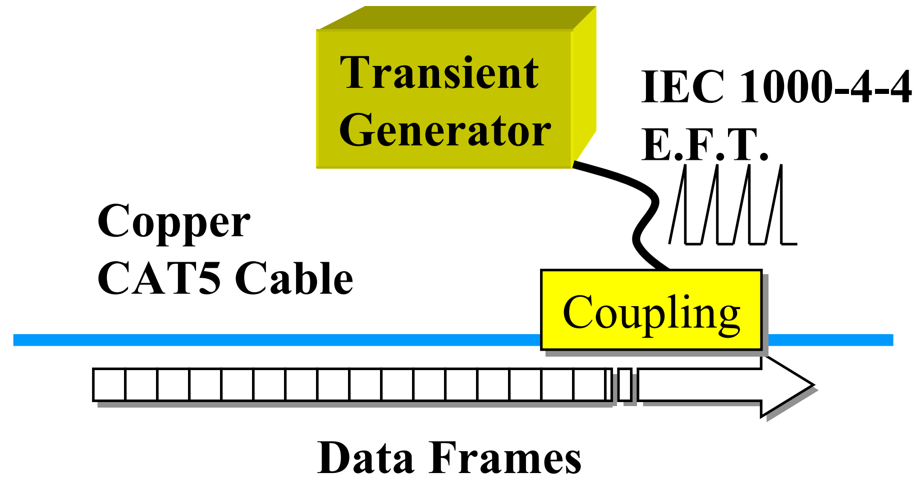
EPRI (AEP) 1997 EMI Immunity Testing

UCA Substation Integrated Protection, Control and Data Acquisition

Electro-Magnetic Immunity Tests of Shielded Twisted Pair Copper Cable for 100 Mbps Ethernet

Final Report

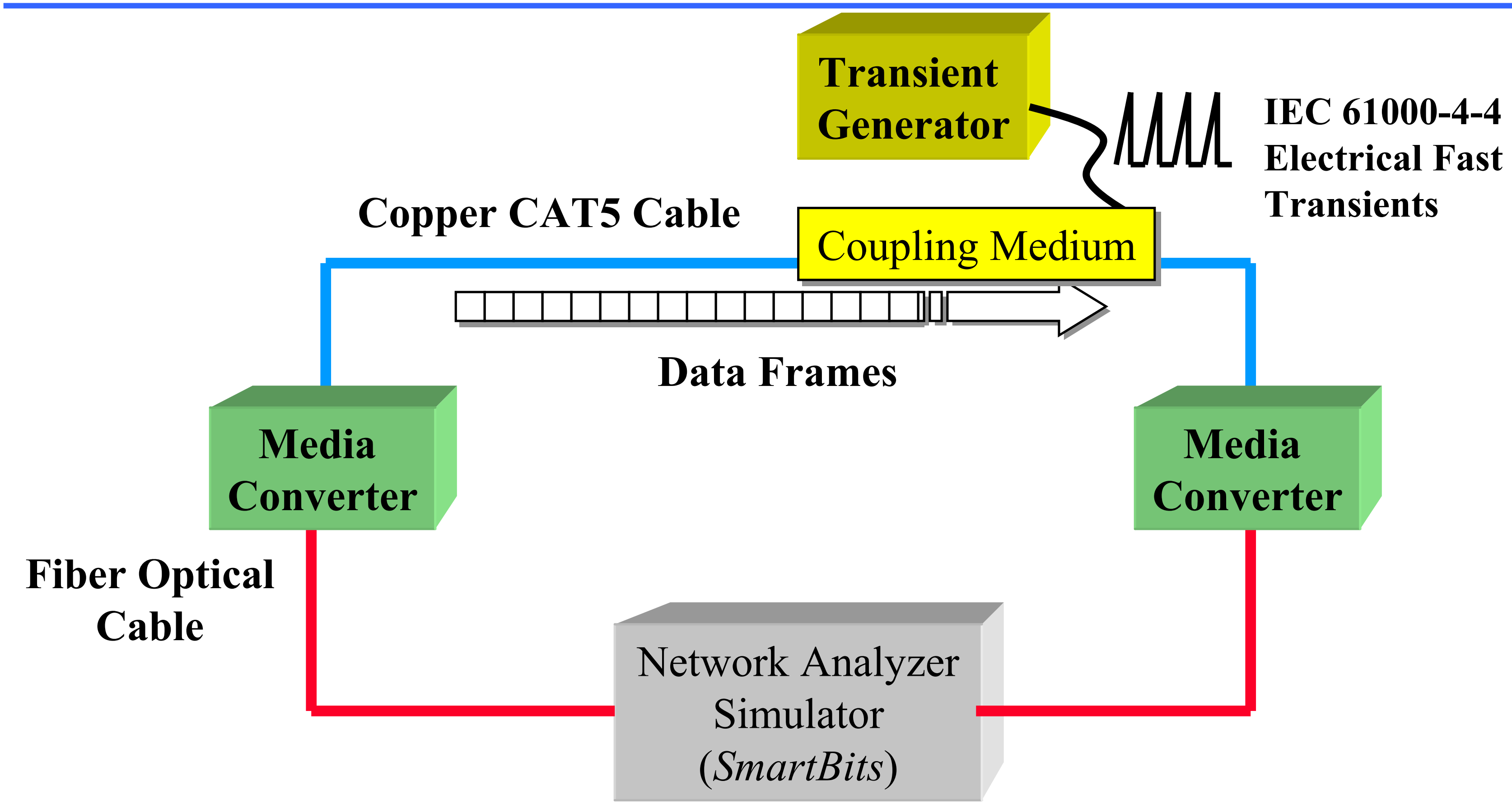
January 31, 1997



SUMMARY CONCLUSIONS AND RECOMMENDATIONS

These tests clearly demonstrate that shielded and unshielded twisted pair cables are not suitable as LAN media UCA substation automation. The results clearly show that fast electrical transients have an adverse impact on ethernet communications using these cables. While protocols at various layers can mitigate the adverse effects, these cables does not exhibit the immunity to fast electrical transients required to support protective "tripping" over the LAN. It is recommended that a fiber optic media be used to connect all Intelligent Electronic Devices engaged in protection in a UCA substation.

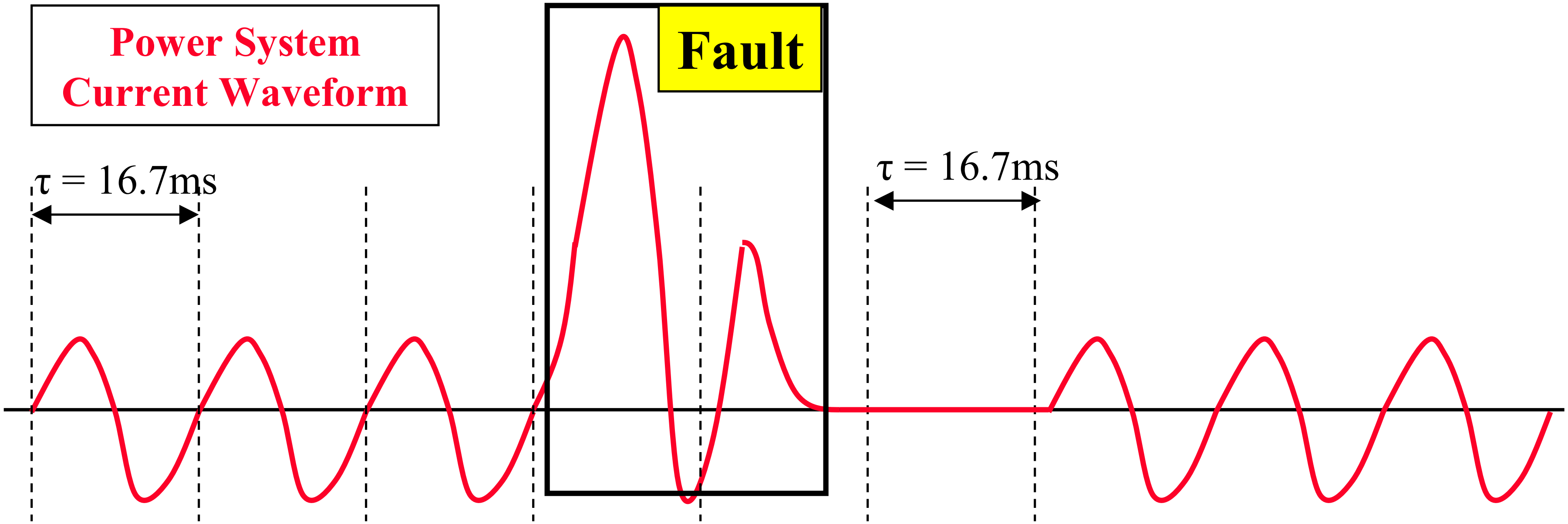
The EPRI Tests (2002): A closer look…



- Electrical Fast Transients (IEC 61000-4-4) Applied to CAT5 cable
- Resultant Frame Loss:
  - 32% @ 1kV
  - 66%@ 2kV
  - 75% @ -2kV

Unacceptable Performance For Real-Time Control!

Real-time Performance - An Illustrative Example During a Power System Fault...

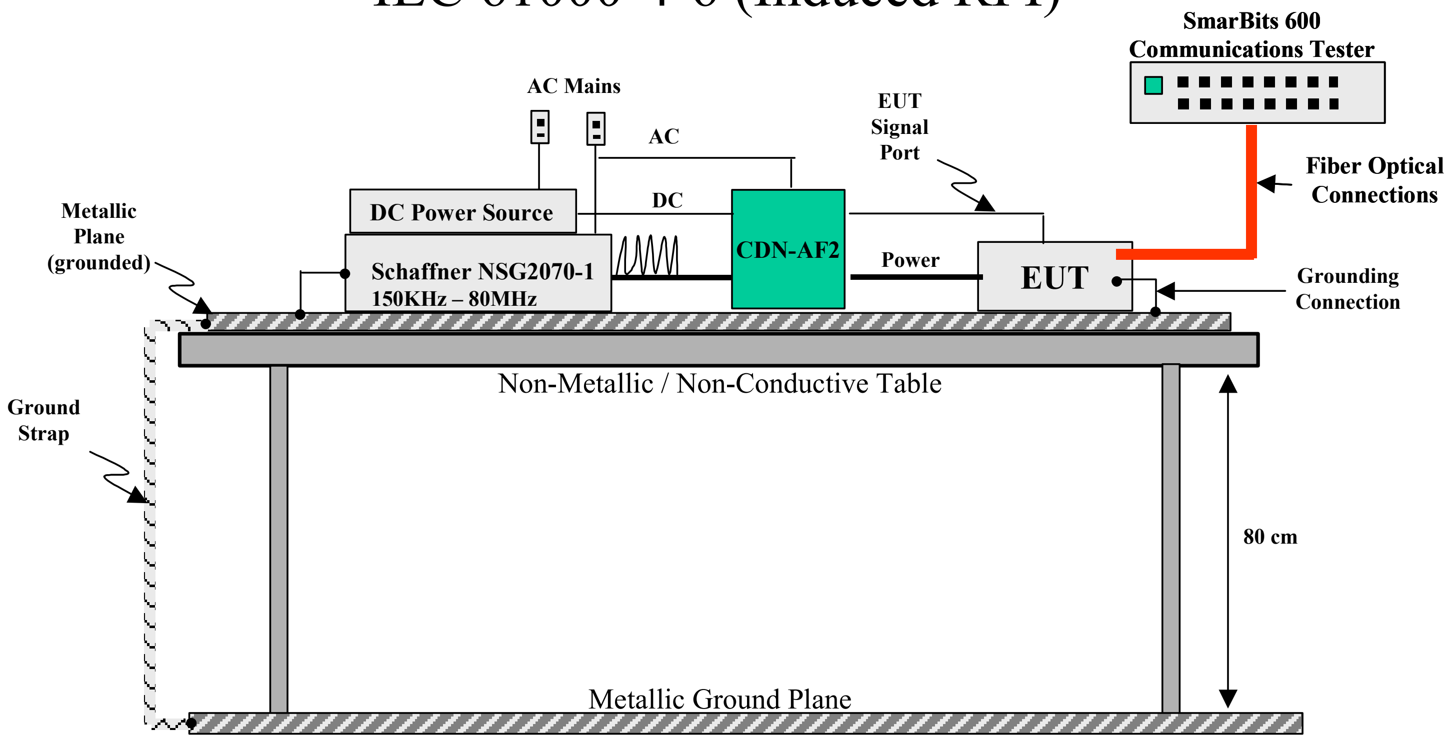


- ***Fault*** **period will be period of:**
  - **High levels of transient EMI phenomena!**
  - **Sub-cycle (i.e. ≤ 16.67ms) processing by IEDs and critical communications performance by the LAN in (< 4ms)!**
- **Can't afford frame errors, delays or loss of communications!**

Industry Studies…confirm what most of us already knew!

Rockwell Automation - Study CMR of CAT-5 Cable

IEC 61000-4-6 (Induced RFI)



- **Induced RFI (IEC 61000-4-6) Applied to CAT5 cable to test CMR.**
- **Common mode noise coupling will occur via adjacent cabling**
- **Resultant Bit Error Rate:**
  - **22% @ 10Vrms (noise coupled)!**
- **Error rates of this magnitude render the network useless!**

Real-time, Deterministic Performance –

"Look Ma, No Collisions!"

Key advances in Ethernet technology for real-time control!

- ❑ IEEE 802.3x Full Duplex Operation
- ❑ IEEE 802.3p Priority Queuing
- ❑ IEEE 802.3Q VLAN
- ❑ IEEE 802.3w Rapid Spanning Tree
- ❑ IGMP Snooping (Multicast Filtering)

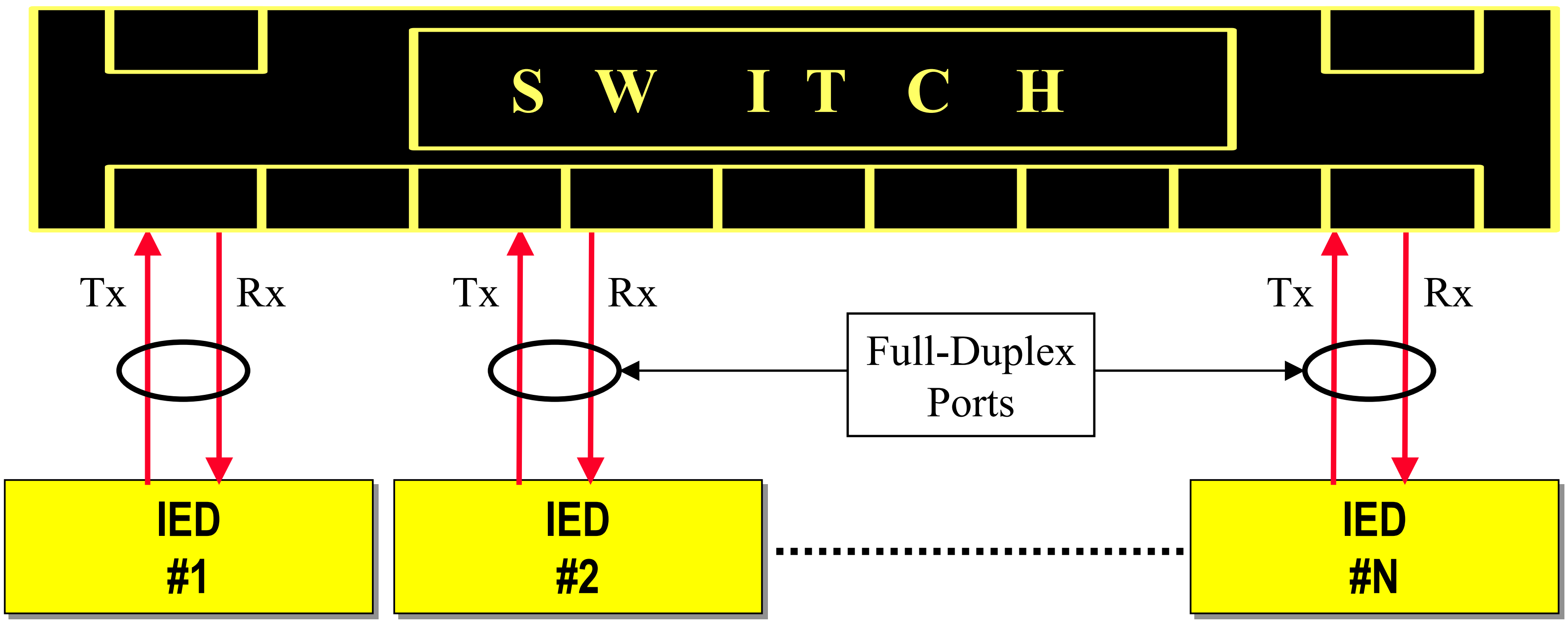
- **Modern Ethernet technology is well suited for real-time control!**

- **The age old knock against Ethernet of "lack of deterministic performance" is more a red herring than reality when it comes to modern Ethernet.**

Look ma no collisions…

Q. How do you make Ethernet "deterministic" or how do you prevent collisions from occurring on an Ethernet network?

Ans. You use an Ethernet switching hub (i.e. Switch) with full-duplex ports – IEEE 802.3x!



Ethernet Switches with full-duplex ports don't have collisions!

Minding your “p’s” and “Q’s”

Standard Ethernet Frame – IEEE 802.1

SYNCH PREAMBLE	MAC DESTINATION ADRESSS	MAC SOURCE ADRESSS	LENGTH OR TYPE	DATA	FCS

Ethernet Frame with new VLAN – IEEE 802.1Q & Priority IEEE 802.1p Tag.

SYNCH PREAMBLE	MAC DESTINATION ADRESSS	MAC SOURCE ADRESSS	802.1p PRIORITY	802.1Q VLAN ID	LENGTH OR TYPE	DATA	FCS

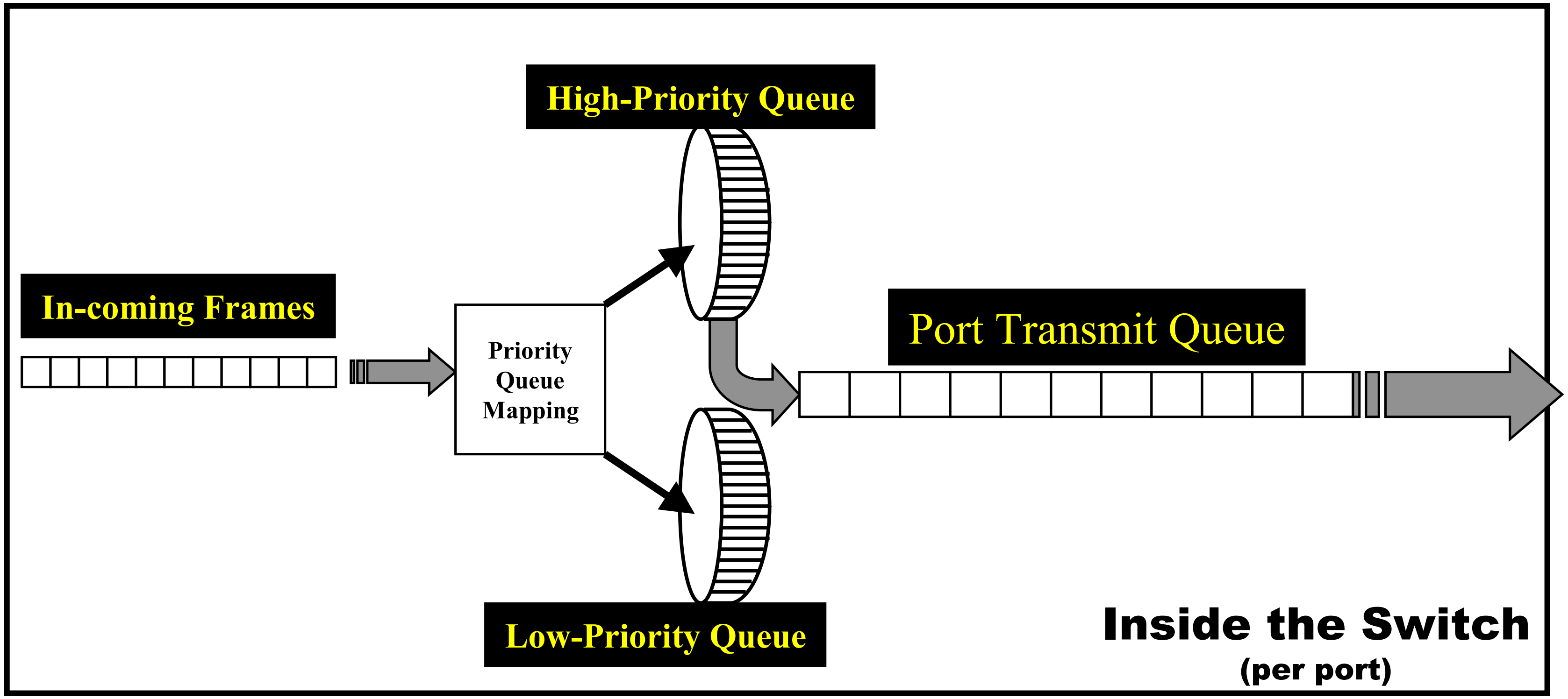
IEEE 802.1Q VLAN Tag (802.1p PRIORITY + 802.1Q VLAN ID)

- Allows priority tagging of mission critical frames – 802.1p
- Allows isolation & grouping of IEDs into virtual LANs – 802.1Q VLAN

Minding your "p's" and "Q's"

Q. How do I make sure during periods of heavy traffic that critical messages make to it through without delay?

Ans. You tag them with a higher priority – IEEE 802.1p.



IEEE 802.1p allows prioritization for critical messages!

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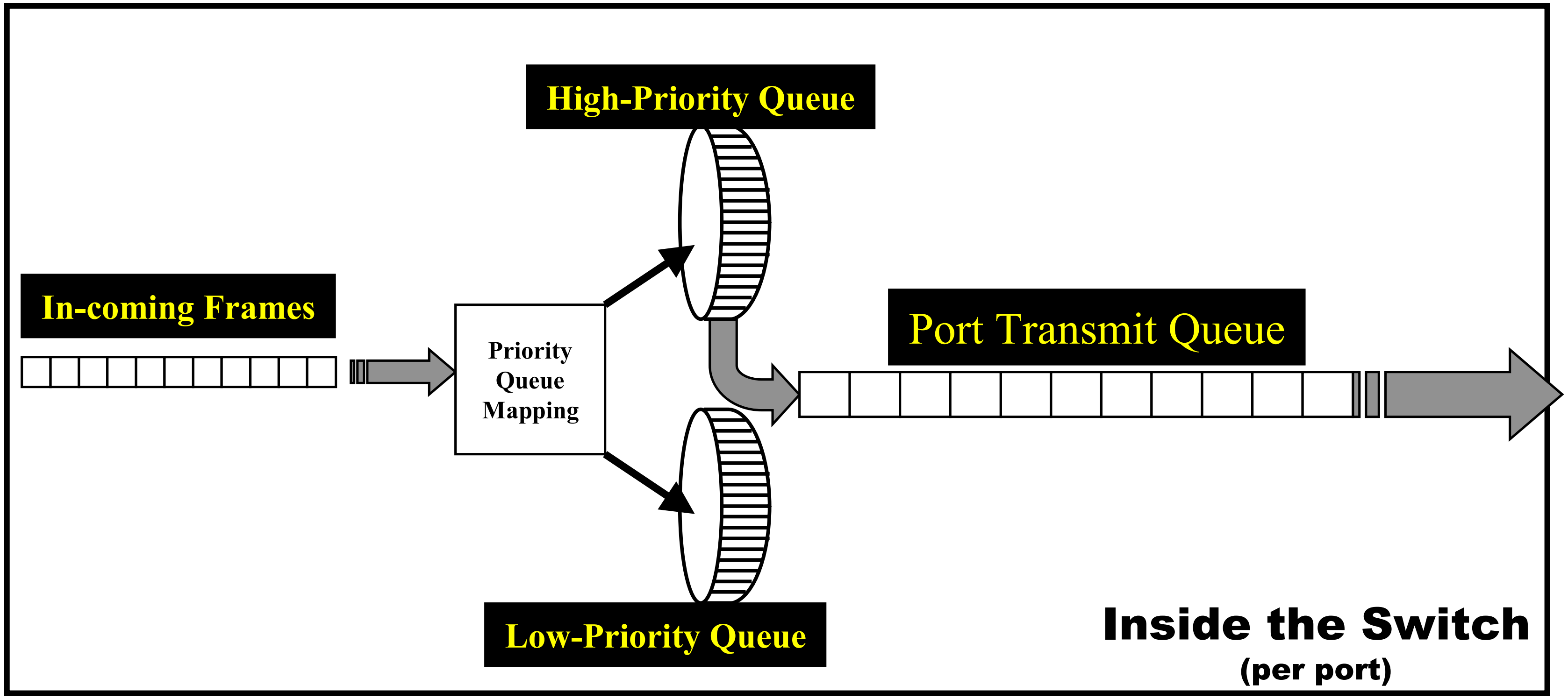
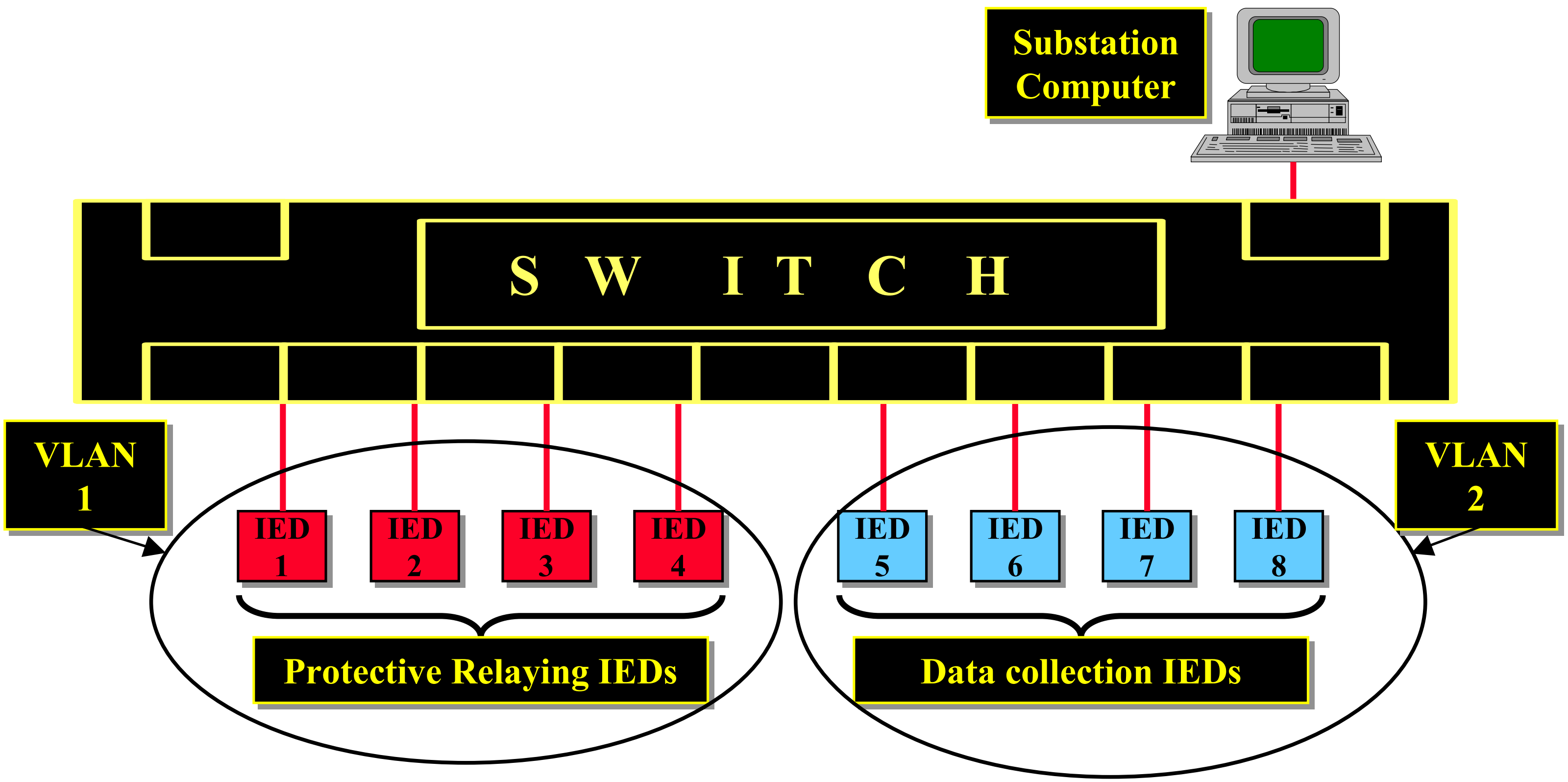
An IEEE 802.1p Priority example…



- "Real-time" control packets can be assigned to higher priority.
- Ensures real-time control messages will get through even during network congestion.
- Priority can be 'tag header' based <u>or</u> MAC address <u>or</u> port based for legacy IEDs.

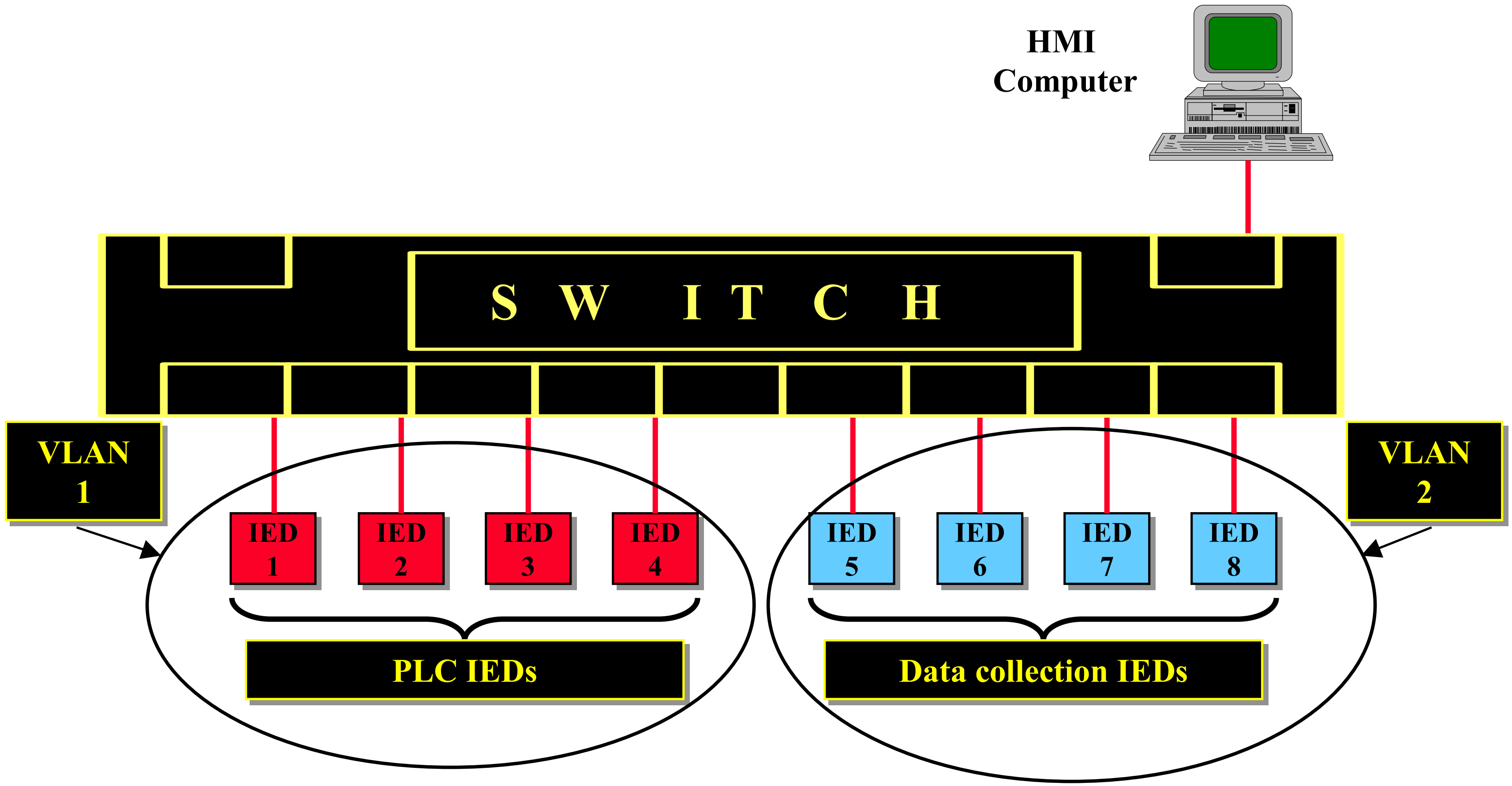
Q. How do you segregate network traffic between devices used for data collection and those utilized for real-time control?

Ans. You assign them to different VLAN's – IEEE 802.1Q.



IEEE 802.1Q allows segregation of devices into VLAN's !

An IEEE 802.1Q VLAN example..



- Traffic from data IEDs in VLAN 2 isolated from IEDs in VLAN 1
- HMI Computer can communicate to both
- VLAN can be 'tag header' based <u>or</u> MAC address <u>or</u> port based for legacy IEDs.

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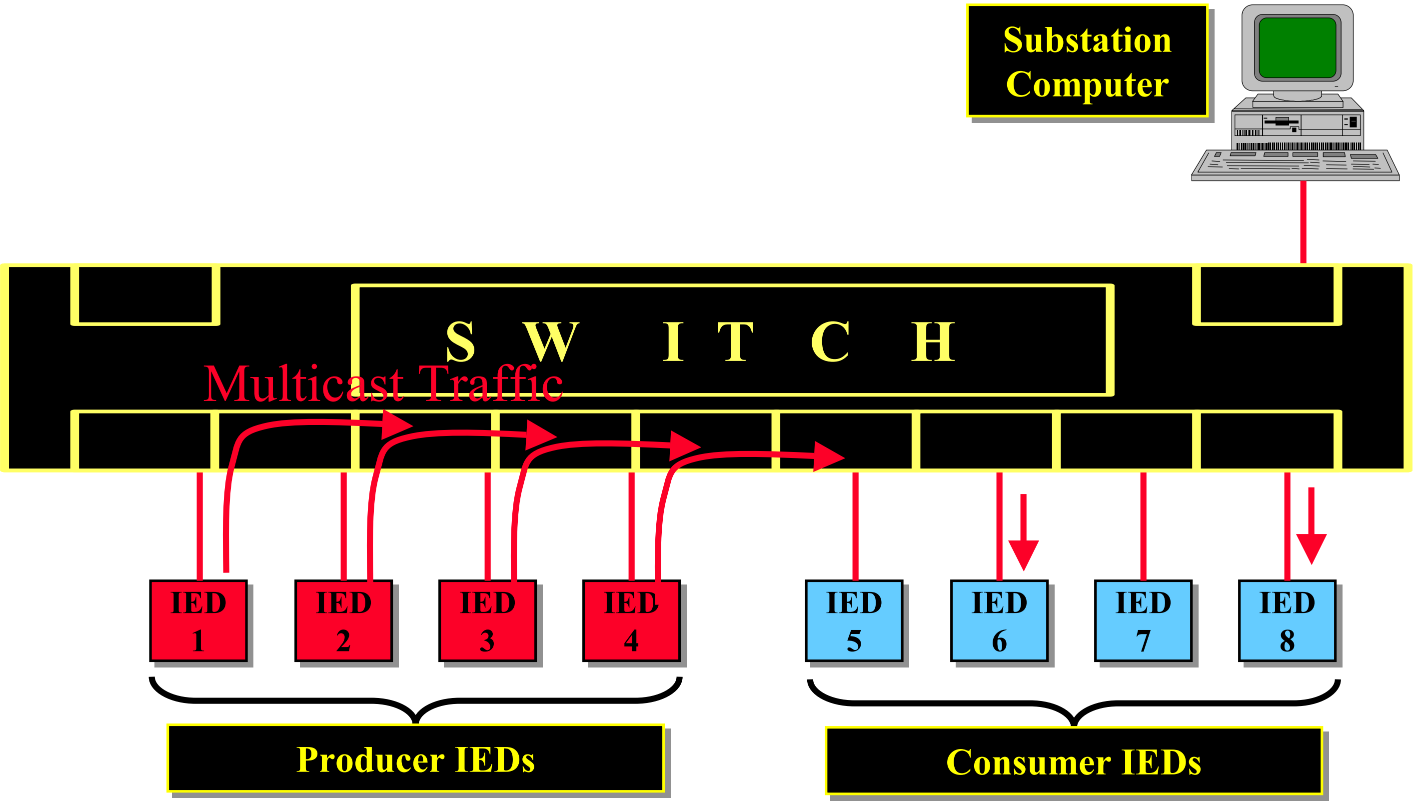
IGMP – Management for Multicast Messaging..



- Multicast Traffic from Sensor IEDs can be assigned by the Switch to specific Consumer IEDs.

- For example, Multicast Traffic from the Producer IEDs 1, 2, 3 & 4 can be assigned only to the consumer IEDs which require it (e.g. IEDs 6 & 8).

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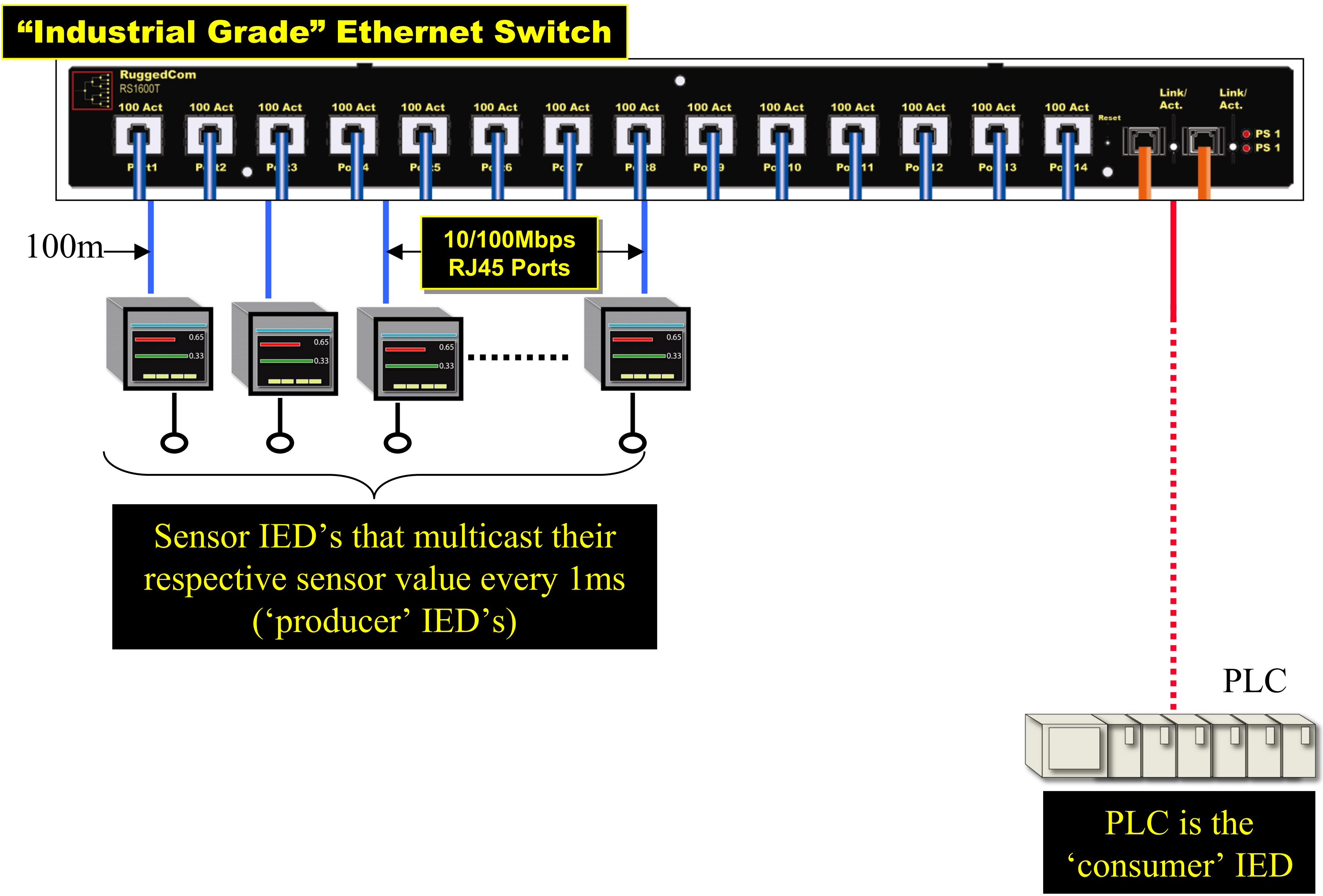
How Real-Time can an Ethernet network be?



Bandwidth Example – Calculations

Given X number of producer IED's and one consumer IED:

1. Port Bandwidth of consumer device (On uplink port) = $BW_{Consumer}$ (Mbits/second)
2. Frame size generated by producer IED's = FS (in bits)
3. IED Period of reporting by producer devices =$T_{Producer}$ (ms)

Given a 16 port full-duplex 100Mbps Ethernet Switch with:

- $BW_{Consumer}$ = 100Mb/s

The maximum number of possible frame bits @ 100% utilization of this port is defined as:

- BW_{MAX} = 100,000,000 bits/second

(This number represents total traffic including CRC and preamble)

For this analysis assume the following:

- The frame size generated by producer devices , FS=64 bytes in length.
- The period of IED reporting, $T_{reporting}$ = 1 ms (i.e. 1000 times / second)

Therefore, it can be calculated that each producer device will consume:

- 64 bytes x 8 bits/byte x 1000/s = 512kbits/s of bandwidth.

Therefore one can conclude the following:

- Each IED consumes (512,000)/(100,000,000) = **0.512 %** of bandwidth each second
- (100,000,000) / (512,000) = 195. This implies **195** producer devices can be used before the maximum channel BW is reached. At this point channel flow control would kick in to relieve the pressure.

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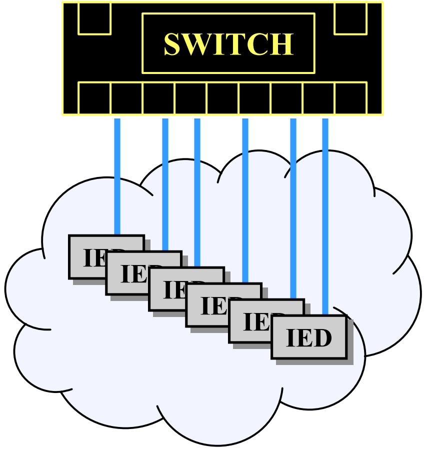
Bandwidth Calculations for Different Reporting Periods and Frame Sizes

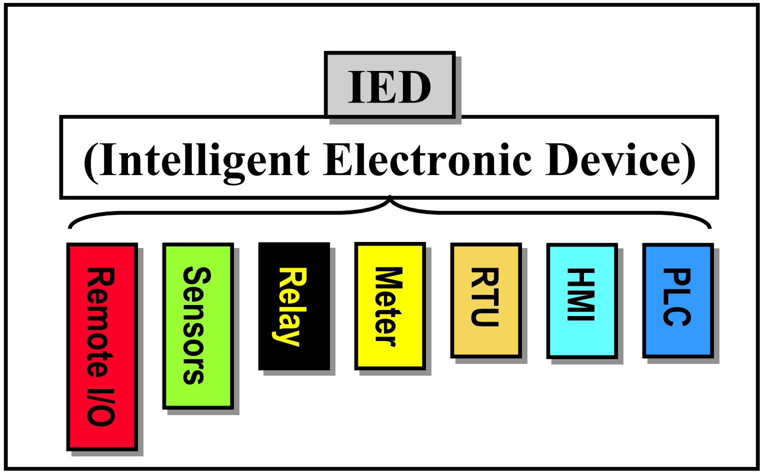
Effect of multi-cast messaging-based data collection on Uplink Bandwidth				
Frame Size (Bytes)	**Consumer IED Reporting Period (ms)**	**Uplink Bandwidth Available (Mb/s)**	**Percent Utilization of Consumer Uplink (%)**	**Max # Possible Producer IEDs** (See Note)
64	1	100	0.512	195
64	0.5	100	1.024	97
64	0.25	100	2.048	48
64	0.1	100	5.12	19
128	1	100	1.024	97
256	1	100	2.048	48
512	1	100	4.096	24
128	0.5	100	2.048	48
256	0.25	100	8.192	12
512	0.1	100	40.96	2

Bandwidth scales linearly allowing for a wide variety of possible configurations.

Support of IGMP (Internet Group Management Protocol) allows for multicast message filtering and producer-subscriber groupings. Equivalent Layer 2 protocol is – GMRP.

Network Architectures for Connecting IEDs on the Factory Floor

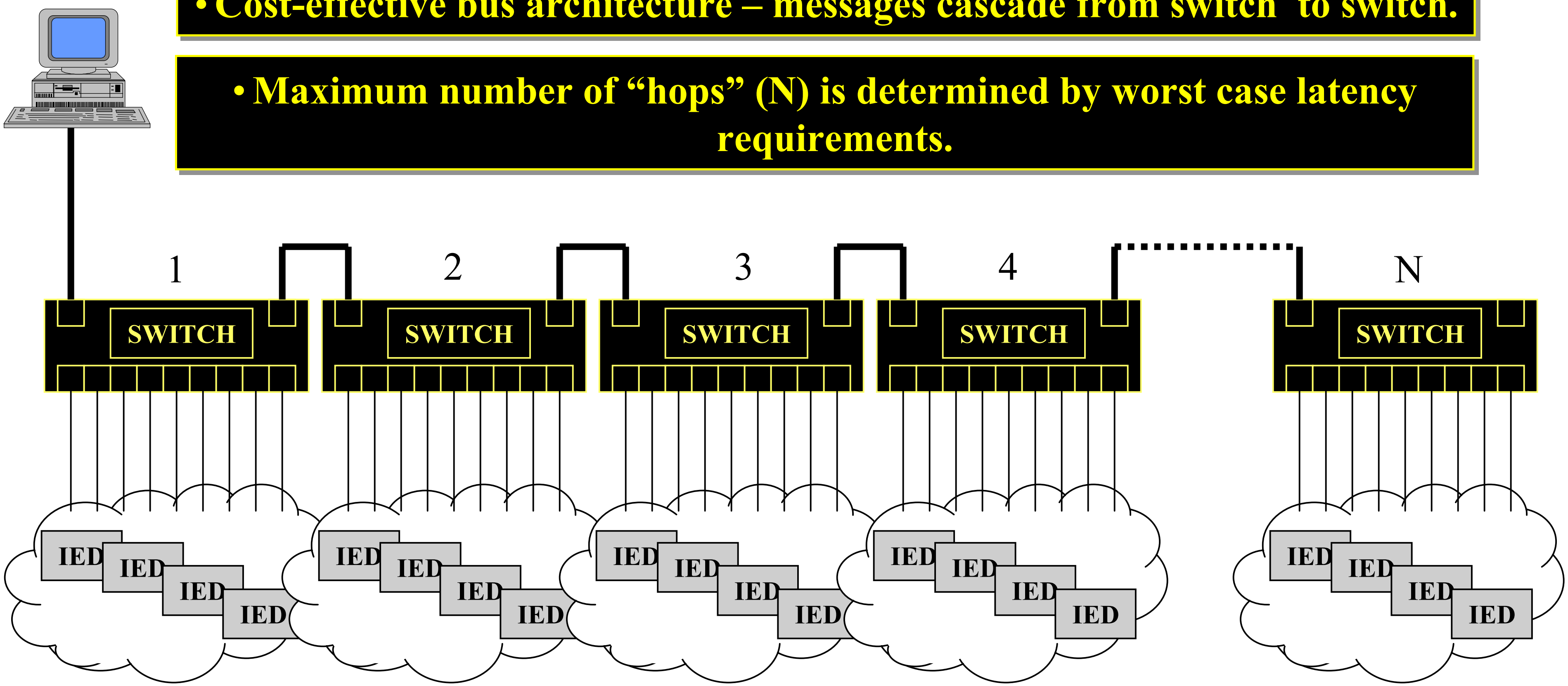




CASCADING ARCHITECTURE

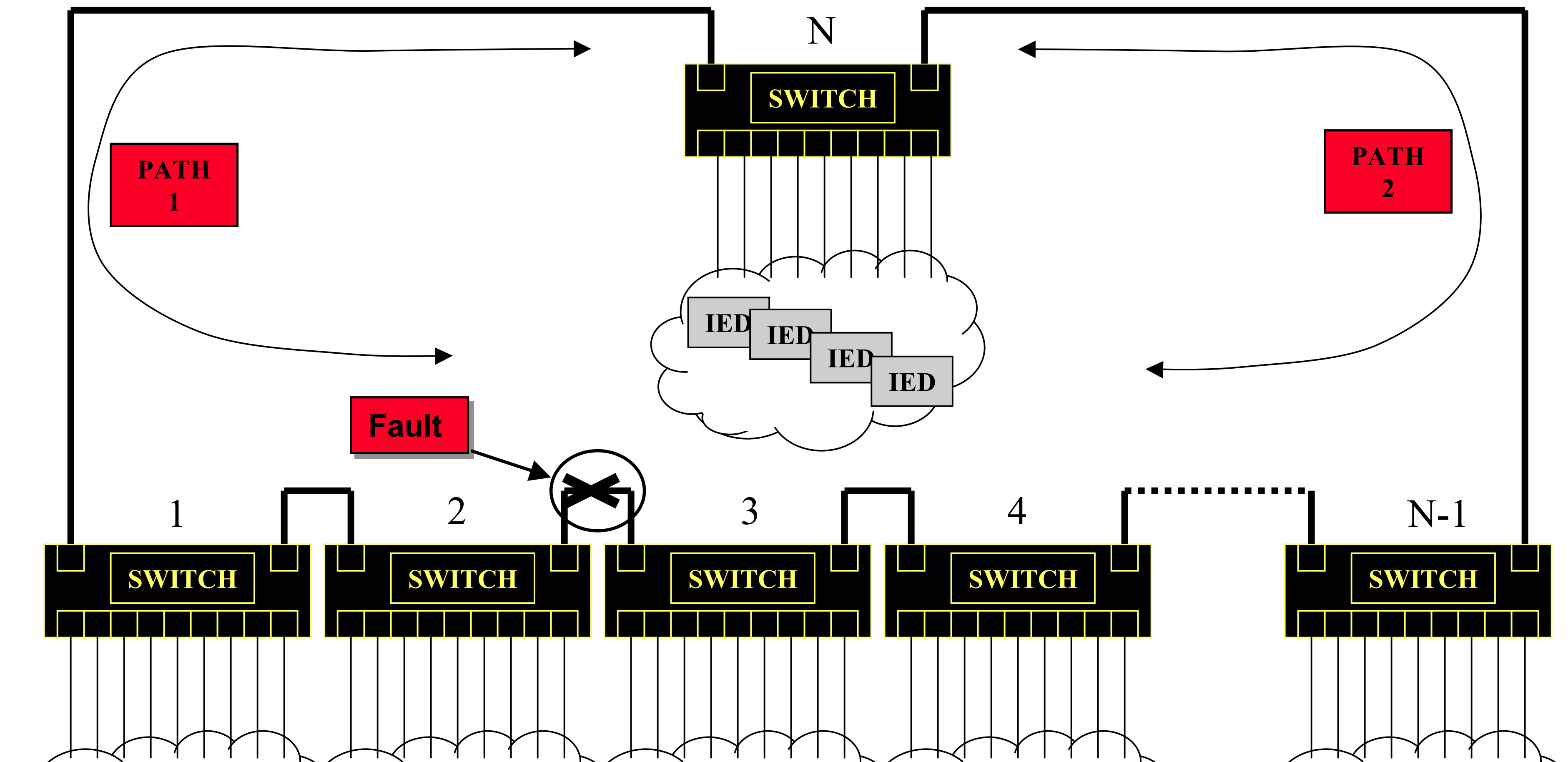
• Cost-effective bus architecture – messages cascade from switch to switch.

• Maximum number of "hops" (N) is determined by worst case latency requirements.



• Typical Switch Latency =5us + Frame Time (100Mbps Port)
• Therefore, for a 64 byte frame (512 bits): the frame time = 5.12us (100Mbps)
  • Total Latency per switch "hop" = 5us + 5.12us = 10.12us
  • For N = 10 the worst case latency would be: 10 x 10.12us = 101.2us.

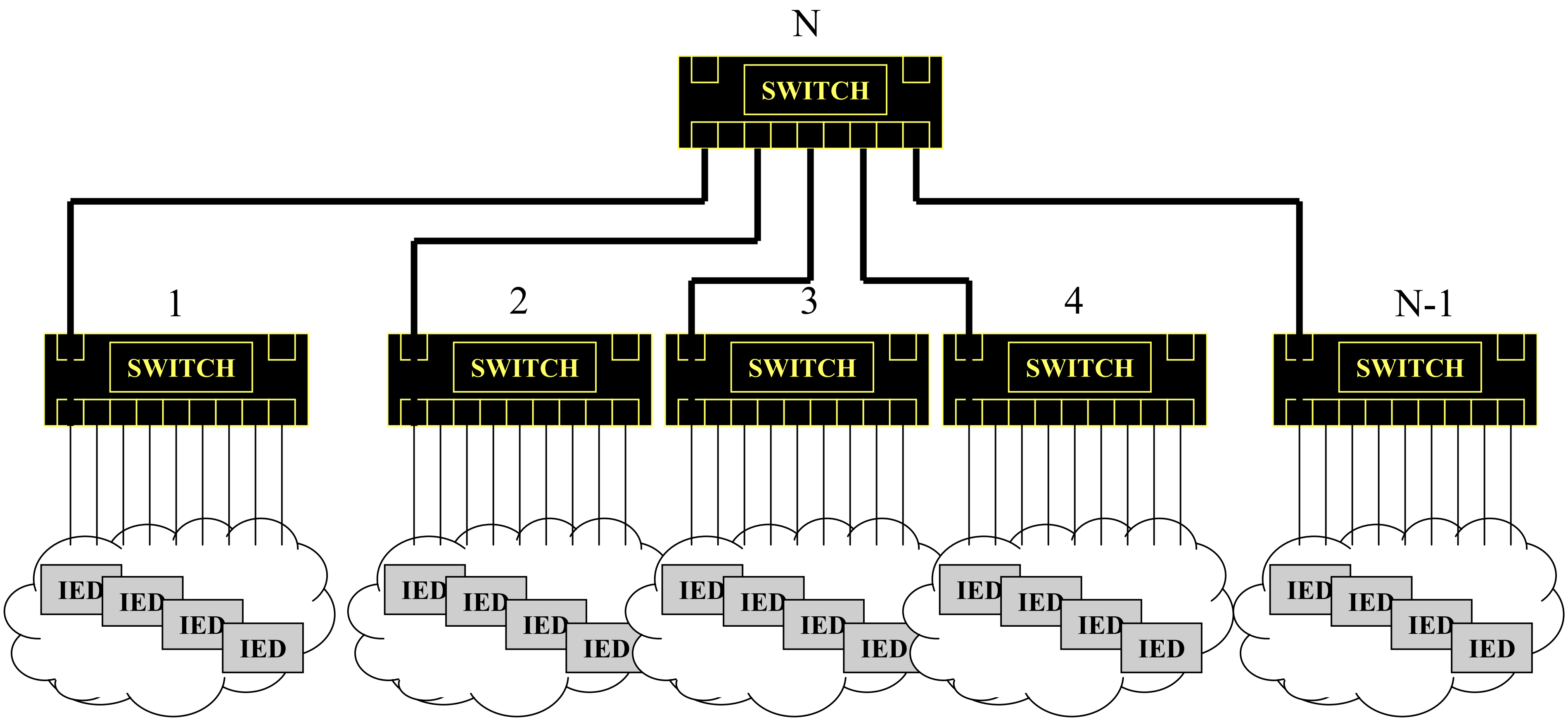
RING ARCHITECTURE



- Fault Tolerant Ring Architecture!

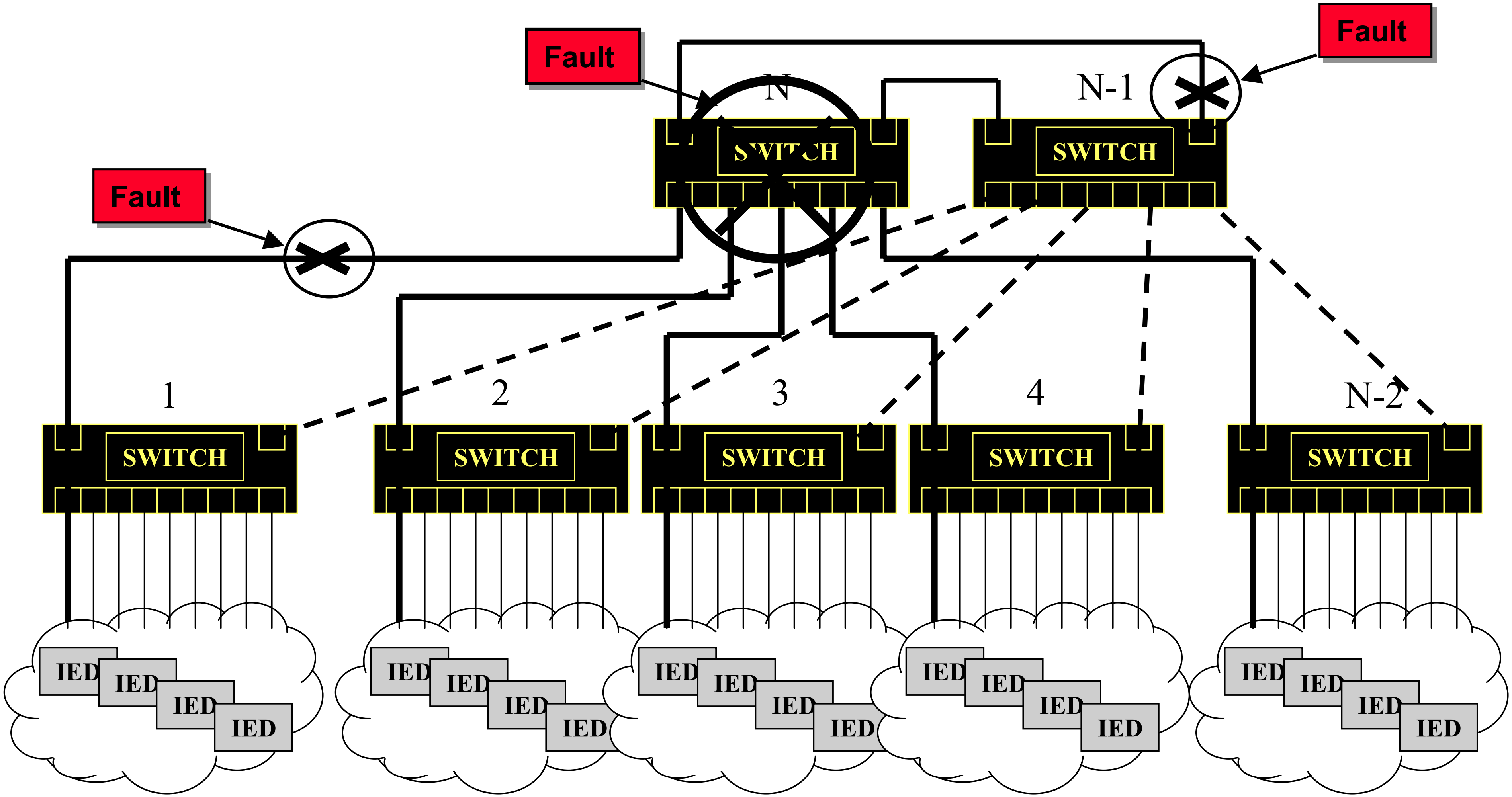
- Rapid (i.e. ms) Reconfiguration via IEEE 802.1w *Rapid Spanning Tree!*
- Typical reconfiguration times < 50ms for ring with 10 switches.

STAR ARCHITECTURE



- **Low-Latency Architecture – Any IED to IED communications requires only two 'hops'.**

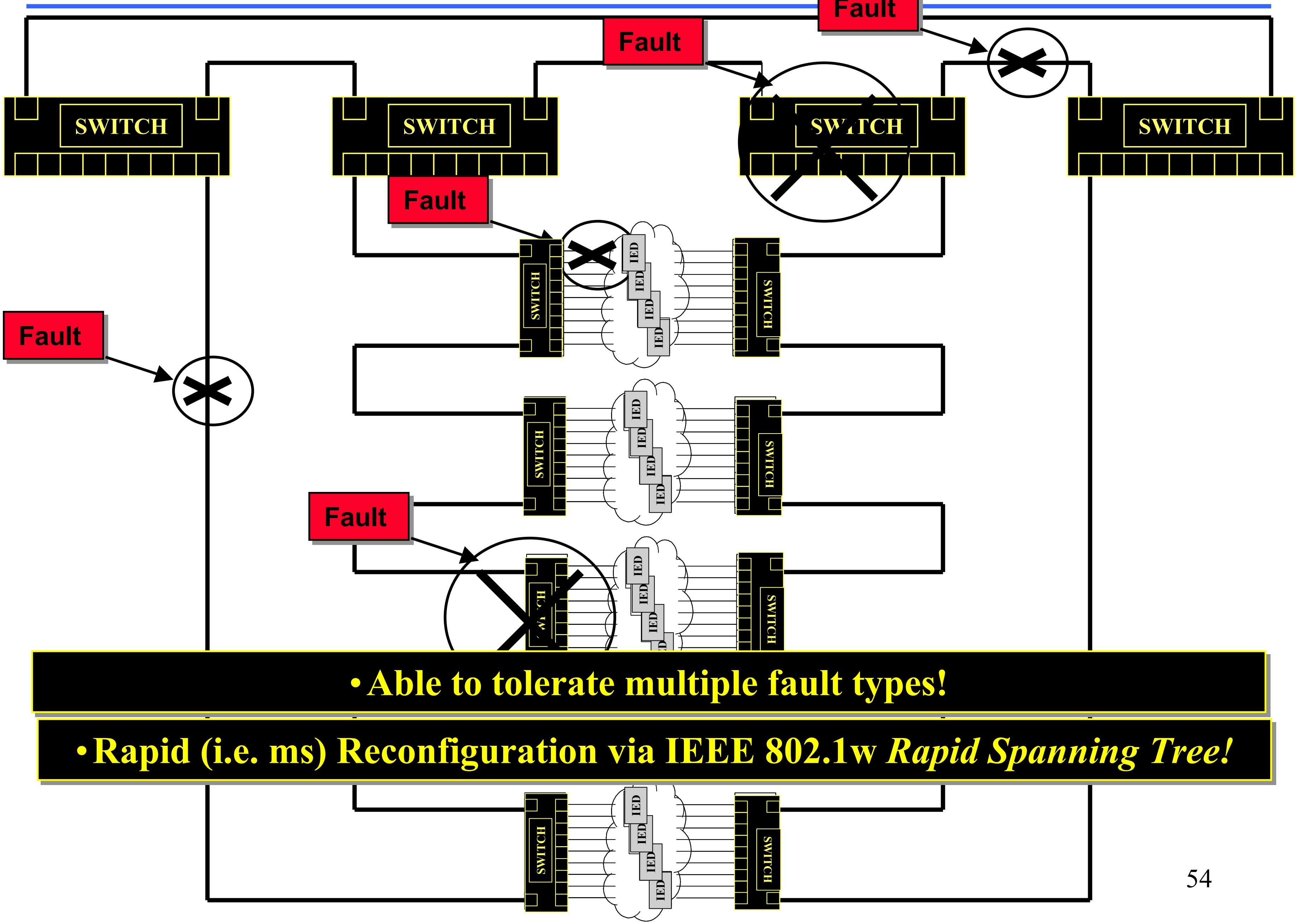
Fault Tolerant Hybrid (Star/Ring) ARCHITECTURE



• Low-Latency, Fault Tolerant Architecture.

• Able to tolerate failure of uplink or backbone switches.

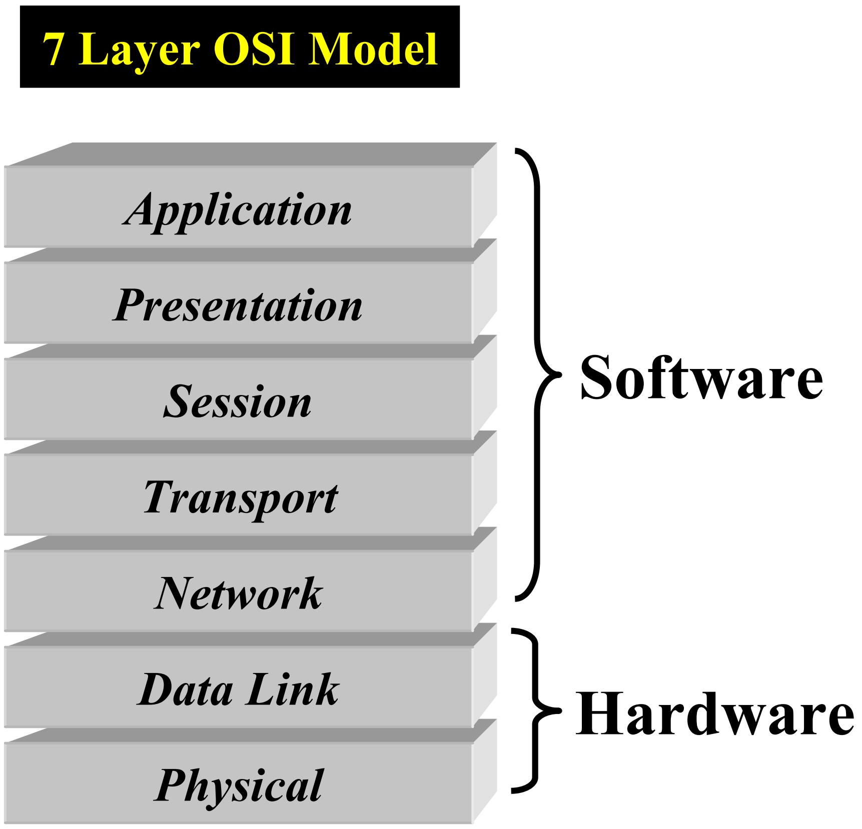
High Redundancy Architecture via IED's with Dual Ethernet Ports



- Able to tolerate multiple fault types!
- Rapid (i.e. ms) Reconfiguration via IEEE 802.1w *Rapid Spanning Tree!*

A comparison of Industrial Ethernet protocols - *" Different strokes for different folks!"*

7 Layer OSI Model

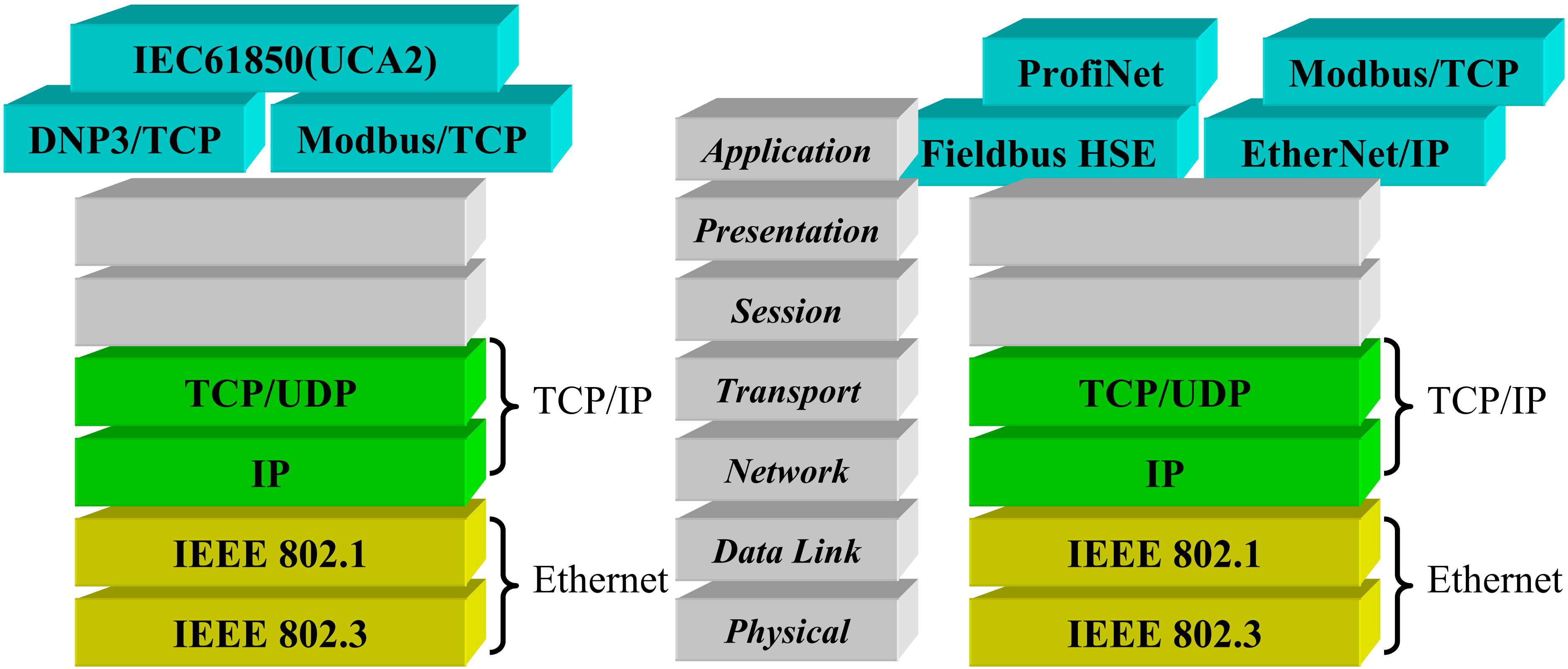


•Used to describe any network or protocol.
•Helps us compare "apples to apples".

Different strokes for different folks…

The Substation Automation Sector

The Process Automation Sector



Substation Automation Sector:

- Bottom half is pretty much consistent.
- *Application Layer* is dominated by a few players. Trend is towards 61850.

Process Automation Sector:

- Bottom half is pretty much consistent.
- *Application Layer* is still being hotly contested by major OEM's.

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Fieldbus Protocols Over Ethernet

Rockwell's – EtherNet/IP

- Released by ControlNet International and ODVA. The "IP" stands for "Industrial Protocol"
- Uses the CIP (Control & Information Protocol) Application Layer from ControlNet and DeviceNet.
- *PROS:*
  - Supports Object Oriented communications model
  - Supports publisher-subscriber model
- *CONS:*
  - Difficulty in supporting legacy A-B protocols.

Schneider's – Modbus/TCP

- Released in March 1999 "Open Modbus/TCP Specification"
- Uses the Modbus Application Layer (MBAP) bundled with TCP/IP
- *PROS:*
  - TCP and Modbus are widely supported
  - Easy to implement
- *CONS:*
  - Does not support object oriented communications model (i.e. you still need to know register addresses of every device!)
  - Does not support publisher-subscriber model

Siemen's (PTO) – ProfiNet

- Released by Profibus Trade Organization
- Based on Microsoft's DCOM protocol
- *PROS:*
  - DCOM supports Object Oriented communications
  - Major vendor backing (Siemens)
- *CONS:*
  - Does not support publisher-subscriber model
  - Poor real-time control?

Foundation Fieldbus' – HSE

- HSE = High Speed Ethernet - using 100Mbps Ethernet
- Uses the Application Layer from their H1 standard with TCP/IP (UDP)
- *PROS:*
  - Supports Object Oriented Communications Model
  - Supports Publisher Subscriber model
  - Supports Network Management
  - Major Vendor Support
- *CONS:*
  - Limited support outside process control sector

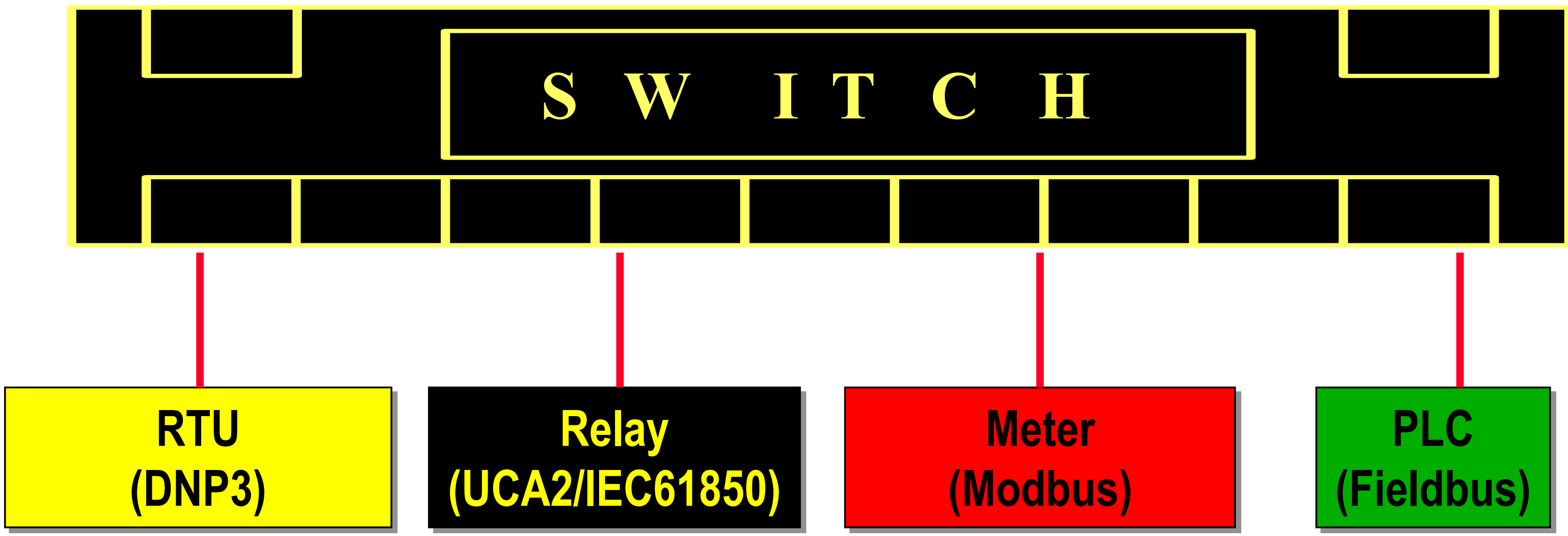
Source: ISA Training Institute – "Is Ethernet Ready for the Plant Floor" online seminar.

No convergence (i.e. One protocol) on the horizon for industrial/process automation sectors…yet!

Can't we all just get along…

Q. How do you get multiple devices which communicate using different protocols to coexist on a common network?

Ans. You use Ethernet!



Ethernet allows multiple protocols to coexist on the same network!

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Key Takeaways…

- **Industrial Ethernet requires network devices (e.g. Switches) to operate reliably in industrial environments.**
  - *IEC 61850-3, IEEE P1613 specifically define EMI and Environmental requirements for substation environments.*
  - *IEC 61000-6-2 should be minimum requirement for EMI immunity in industrial environments.*
  - *Other requirements, depending on industry sector may be Class 1 Division 2 (Petrochem), IP67/NEMA 4x (Mining).*

- **For real-time control applications Industrial Ethernet devices and network equipment should support:**
  - *IEEE 802.3x Full-Duplex operation for collision free operation*
  - *IEEE 802.1p Prioritization to allow real-time critical messages to get through.*
  - *IEEE 802.1Q VLAN to allow isolation of critical IEDs from non-critical IEDs .*
  - *IEEE 802.1w Rapid Spanning Tree to allow fault-tolerant ring architectures with rapid (i.e. <50ms) reconfiguration times.*
  - *IGMP Snooping / Multicast filtering to prevent multicast intensive protocols (e.g. EtherNet/IP) from inundating non participating IEDs on the LAN.*

Thank you.