

Ethernet as a Channel for Protective Relaying

by John Benckenstein

14 Years ago I presented: “System Reliability Improvements through use of Fiber Optics”

- I predicted multiplexed communications would take the lead over:
 - Pilot Wire
 - Direct Fiber
 - Audio Tones
 - Power-Line Carrier
- I was right!
- Single fiber solution still viable
- Multiplexed channels with self-healing routes are preferred
- “Nothing will ever come along to replace this”.

Something New is Here Now

- I was wrong, this new Ethernet is worth a good look
- It is ready today to handle all of your substation communications requirements, including Protective Relaying
- How did this happen?
 - Bandwidth Requirements have Grown by an Order of Magnitude
 - Pursuit of the Mythical Smart Grid
 - Up to you Relay Engineers how fast this technology is adopted
- Most of us here are “Techies” to a degree
 - At office we are conservative and resist change
 - At home, we jump on any new technology

Ethernet is High Tech “Under the Covers”

- It has the features you want, without the complexity
- Over the past 35 years a lot of really smart people took their time to create this new Ethernet just for you.
- Don't let the acronyms scare you - RMON, SNMP, Telnet, VLANs (Port-based and Tag-based), GVRP, Port-mirroring, CLI, Port Security, STP, BootP, DHCP, IGMP Snooping, 802.1p, or QoS,
- Remember STP, VLAN, QoS
 - Spanning Tree Protocol
 - Virtual Local Network
 - Quality of Service
- Your Smart Grid needs more bandwidth
- Can Ethernet provide you with the same level of comfort, flexibility, capacity and performance as SONET?

Ethernet Timeline and Future

- Communications Infrastructure changes every 5 to 10 years in IT departments.
- As these systems are being replaced today, they are finding less SONET and more Ethernet systems to choose from.
- Your relays last 15 to 20 years.

What is a Relay Engineer to Do?

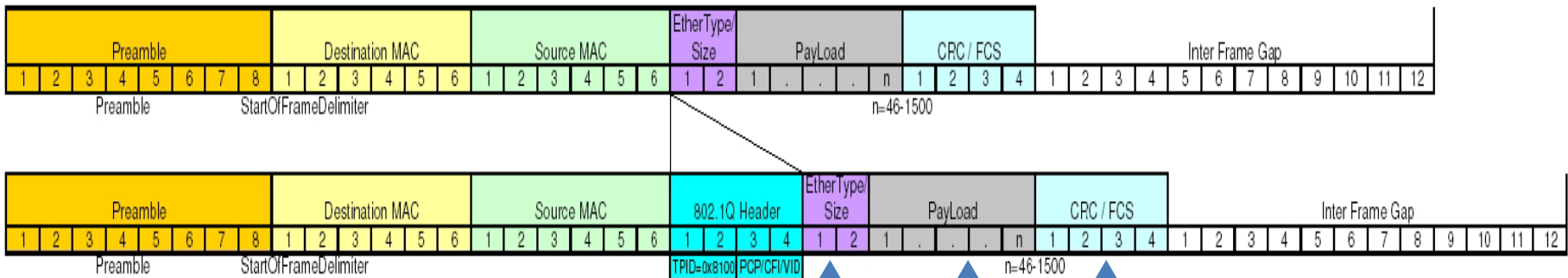
- Fortunately there are a few companies specializing in relay communications using packet technology.
- Your traditional channel types can be interfaced with new packet over Ethernet multiplexers.
 - Audio tone
 - ANSI C37.94
 - RS422, G703.2
 - Direct Contacts
 - RS232 (Mirrored bits)
 - HCB-1 pilot wire
- These broadband multiplexers meet IEEE1613

Basics of Ethernet

- To transfer ANY type of channel over a digital medium (like TDM or Ethernet) the data must be sampled at precise 125 uSec intervals producing a series of 8-bit **bytes** representing those sample points.
- The difference with Ethernet starts AFTER the **byte** is created.
- In TDM this **byte** becomes a DS0 channel, which may be 1 of 24 in a T1 system, or 1 of 2016 in an OC-3 system.
- In a packet system this **byte** is put into a packet with selectable bandwidth through the Ethernet. (Can put several **bytes** into one packet.)

Layer 2 Packet (Frame) Format

This part is used by the multiplexer



VLAN/QoS (optional)

Determines protocol used in payload

Payload is 46 to 1500 bytes

CRC/Frame Check Sequence

Typical Layer 2/3 Switch



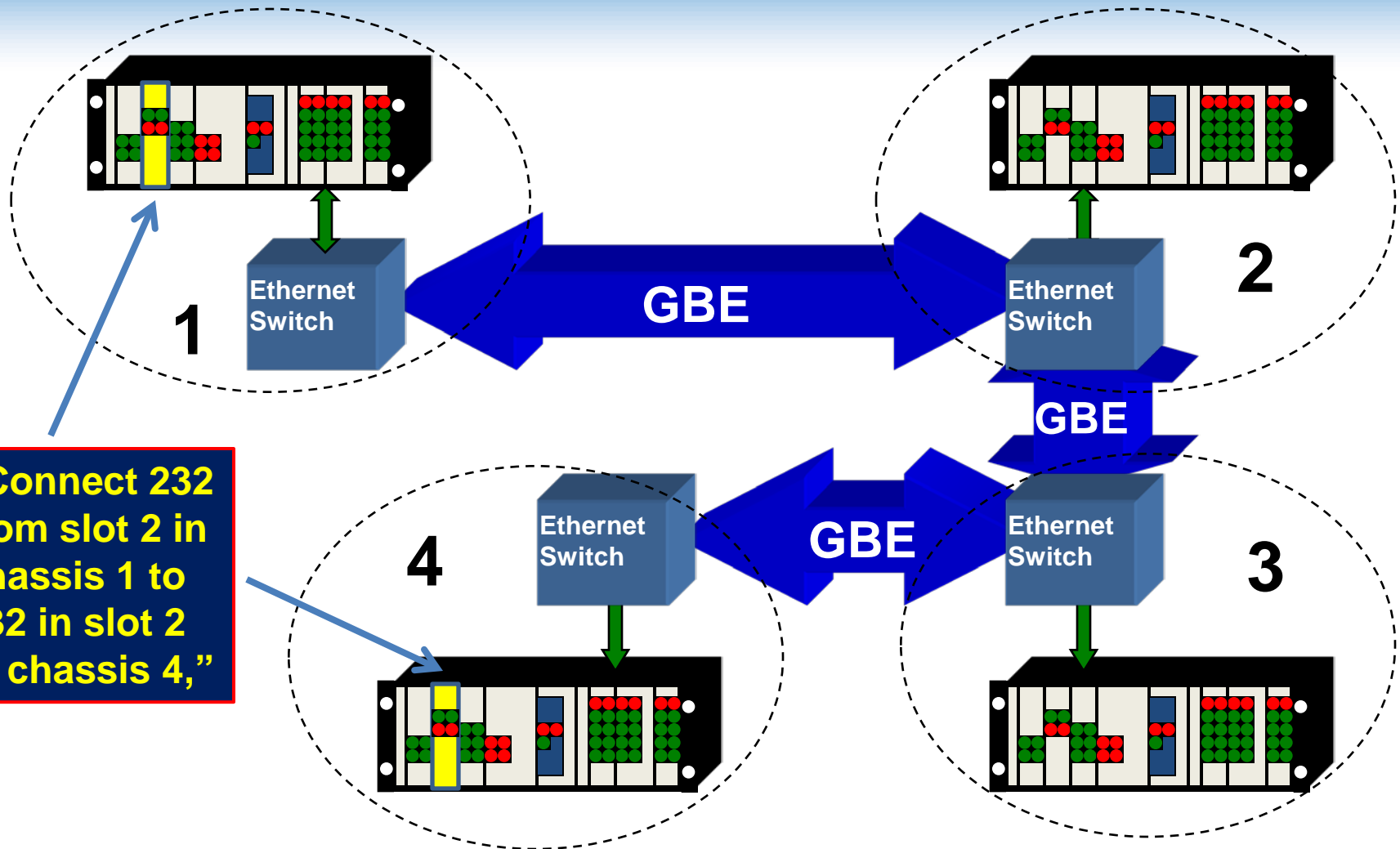
GigE SFP (Small Form-factor Pluggable)



Two SFP Optical GigE ports

Eight 10/100 ports
Mix of Optic and
Electrical

Mapping Channels in Ethernet



“Connect 232 from slot 2 in chassis 1 to 232 in slot 2 in chassis 4,”

Mapping in TDM vs. Packets

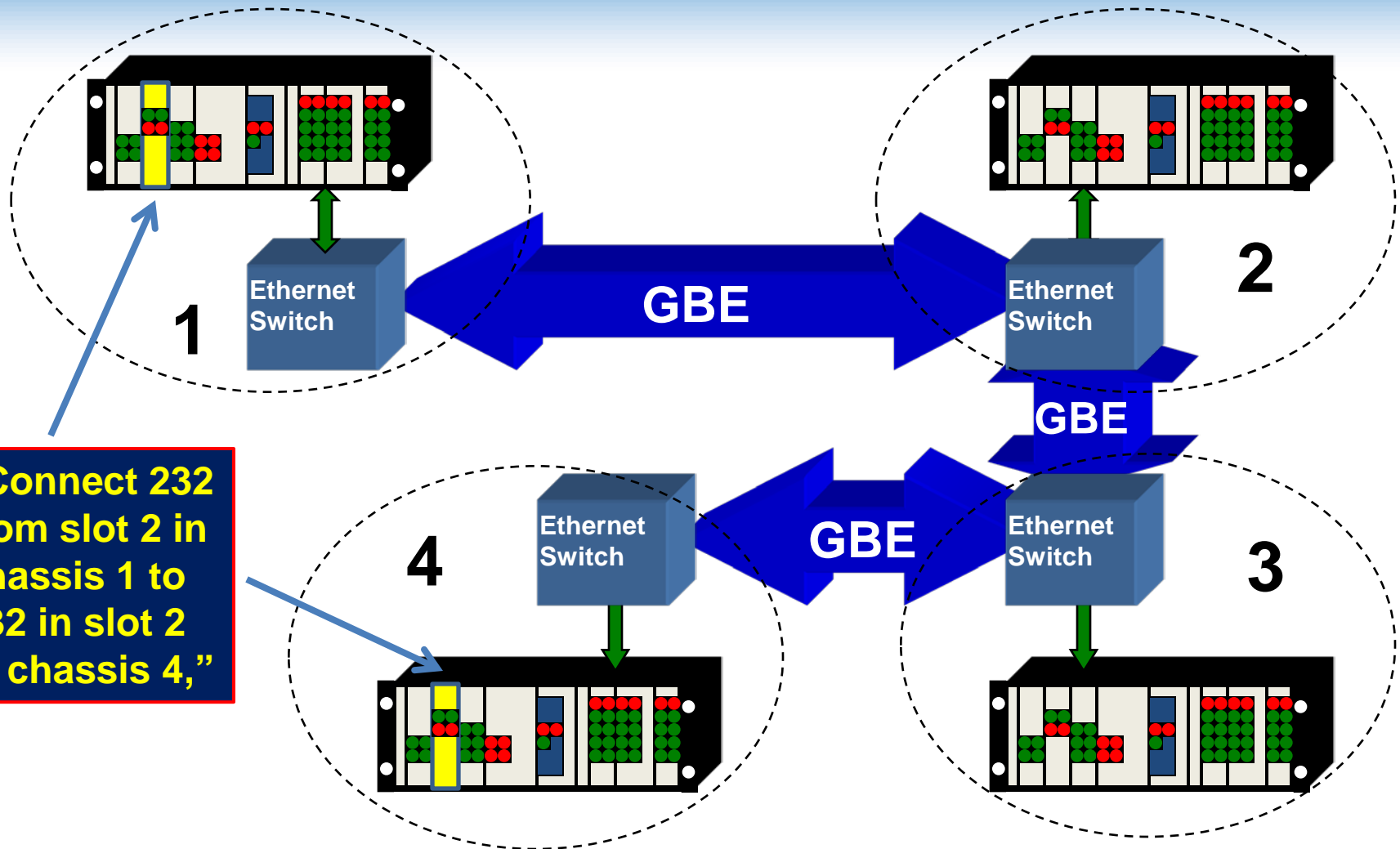
TDM Mapping

- Hardware
 - System Control Module
 - Framers
 - Time Slot Aligners
 - DACS
 - Optical Drivers
- Software
 - Learn physical network configuration
 - Map Origin Timeslot to port
 - Map Destination Time slot to Port
 - Map all pass-through time slots
 - Apply channel application settings

Packet Connection

- Hardware
 - System Control Module
 - DACS
 - Switch
- Software
 - Connect source to Destination
 - Set control settings per channel
 - Apply channel application settings

Mapping Channels in Ethernet

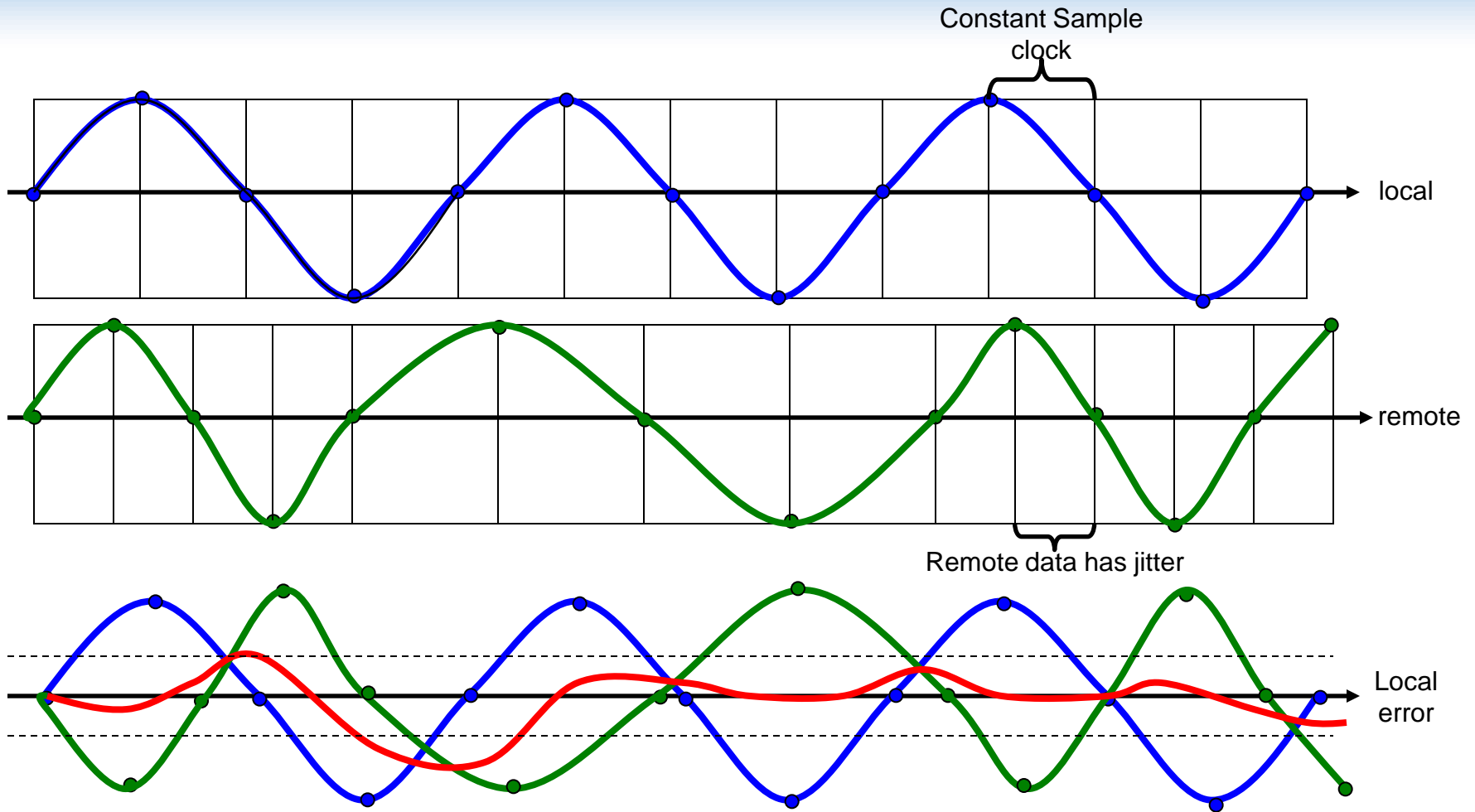


“Connect 232 from slot 2 in chassis 1 to 232 in slot 2 in chassis 4,”

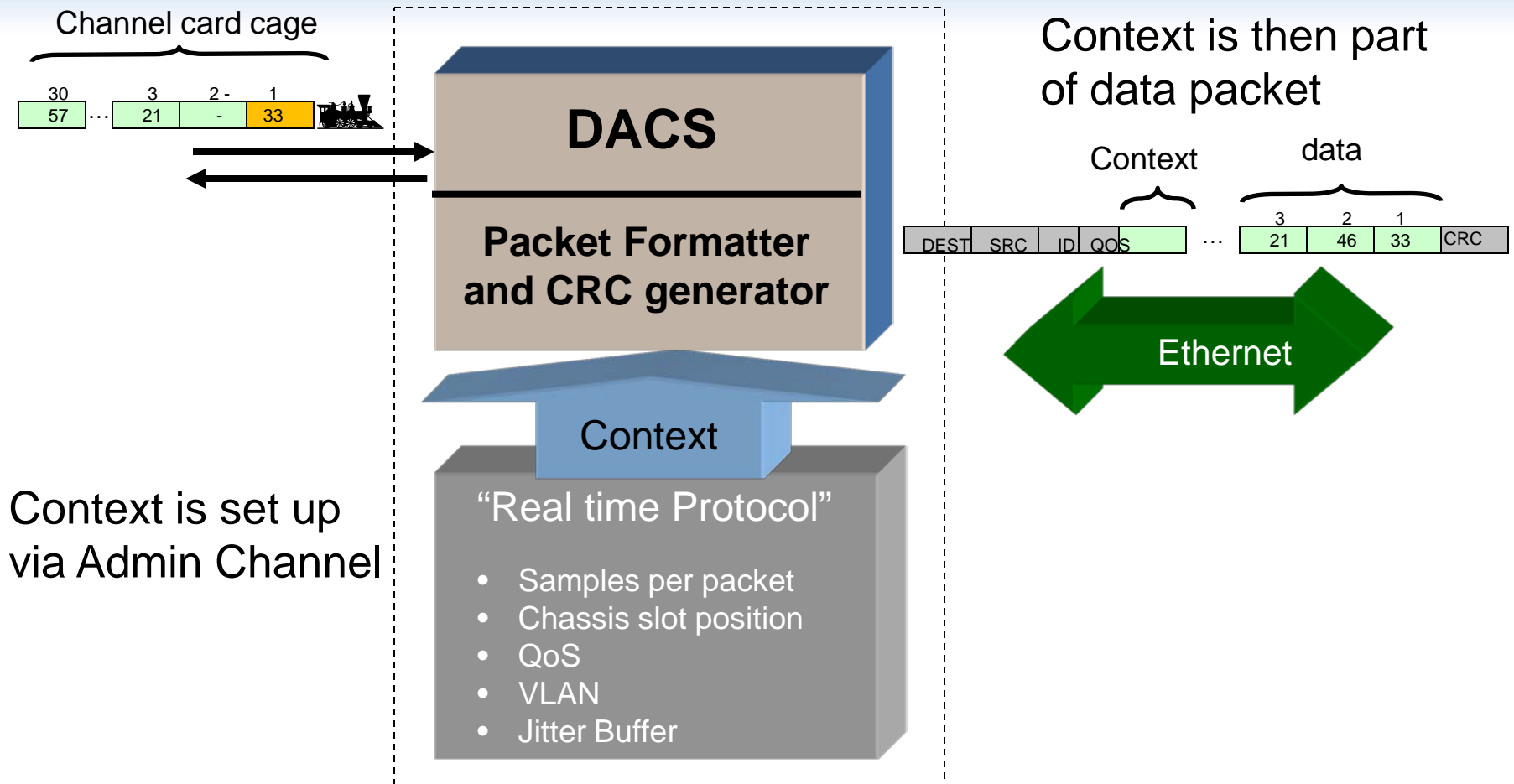
Administrative Settings

- Password control
- Network Aware
- Channel-specific application settings
- SOE: Sequence of Events, Alarm Status
- Ethernet and TDM performance monitor
- Network and TDM Clock sources
 - IRIG or NTP for real-time clock, BITS for network
- Settings that control how data is passed through network
 - Source and Destination Mapping (TDM and Packet)
 - VLAN: Virtual Local Area Network
 - QoS: Quality of Service
 - Bandwidth Economy
 - Jitter Buffer

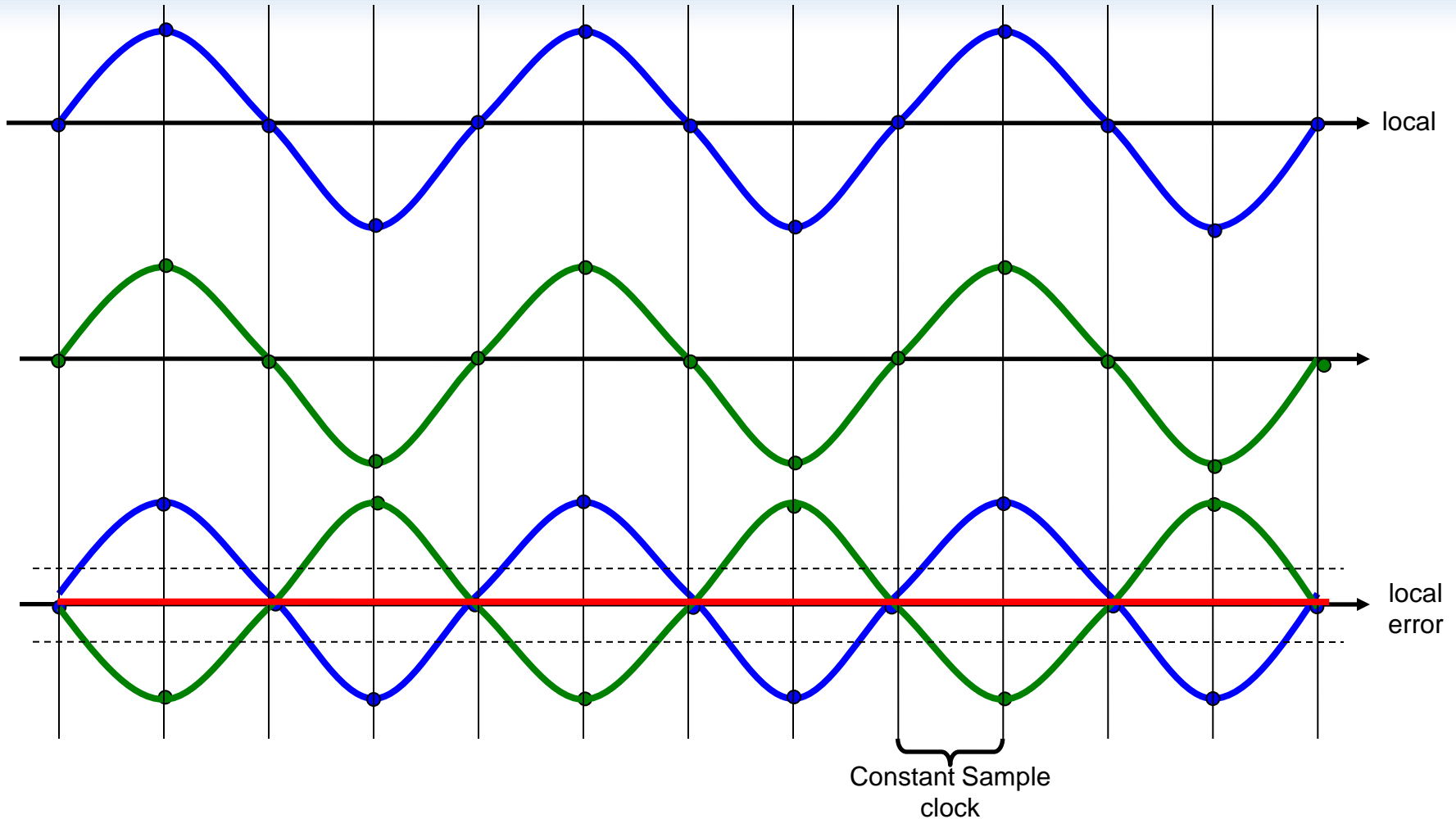
Effect of Jitter on Received Data



How Context is Inserted into Frame



Proper Clock Recover with Zero Jitter



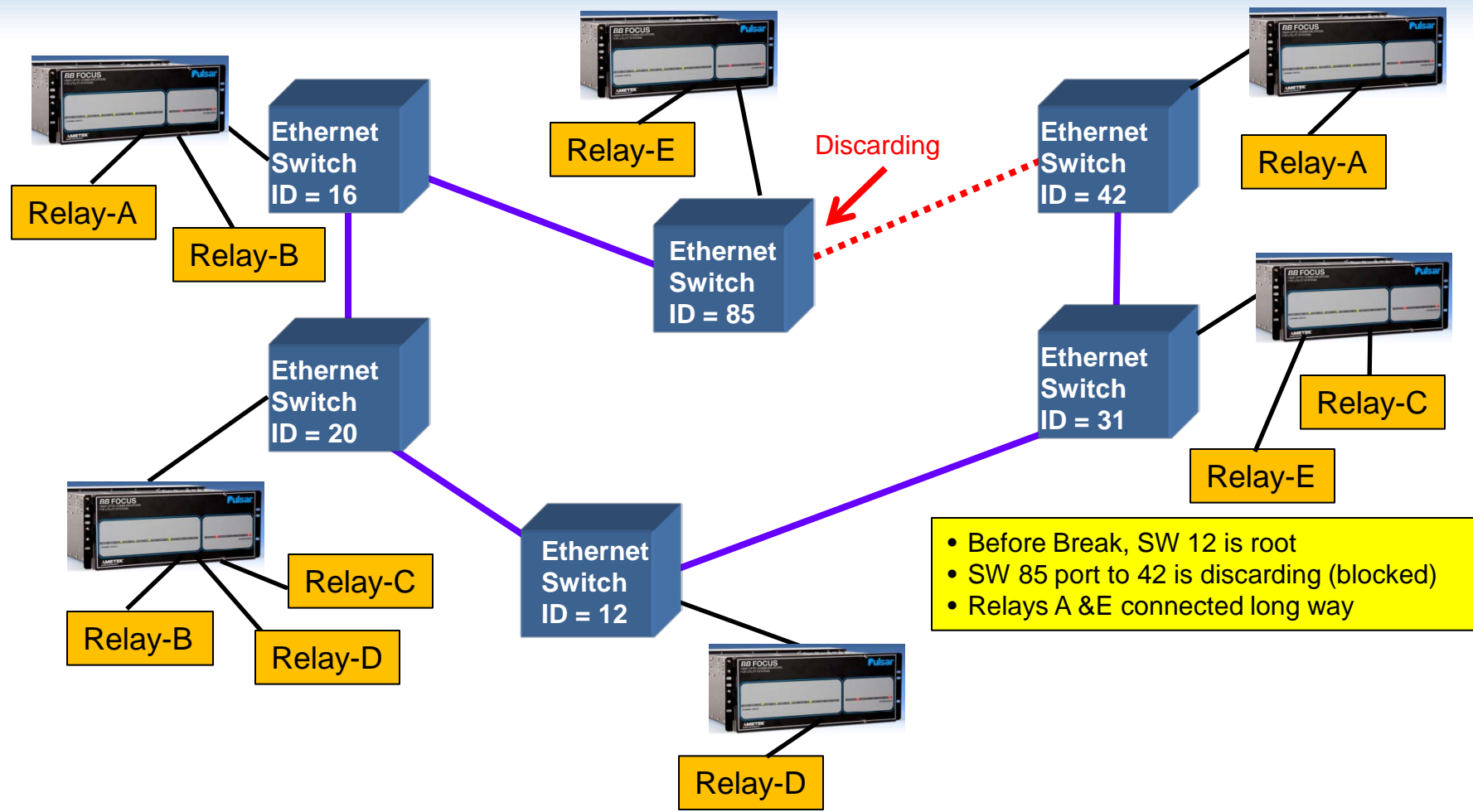
Three Hurdles to Accept Ethernet as a Channel for Protective Relaying

- Is there a Redundant Path Option when my Primary Fiber Path is Broken?
- Is my Channel Latency Deterministic and Low Enough?
- Do I have sufficient Bandwidth? How Scalable is my System?

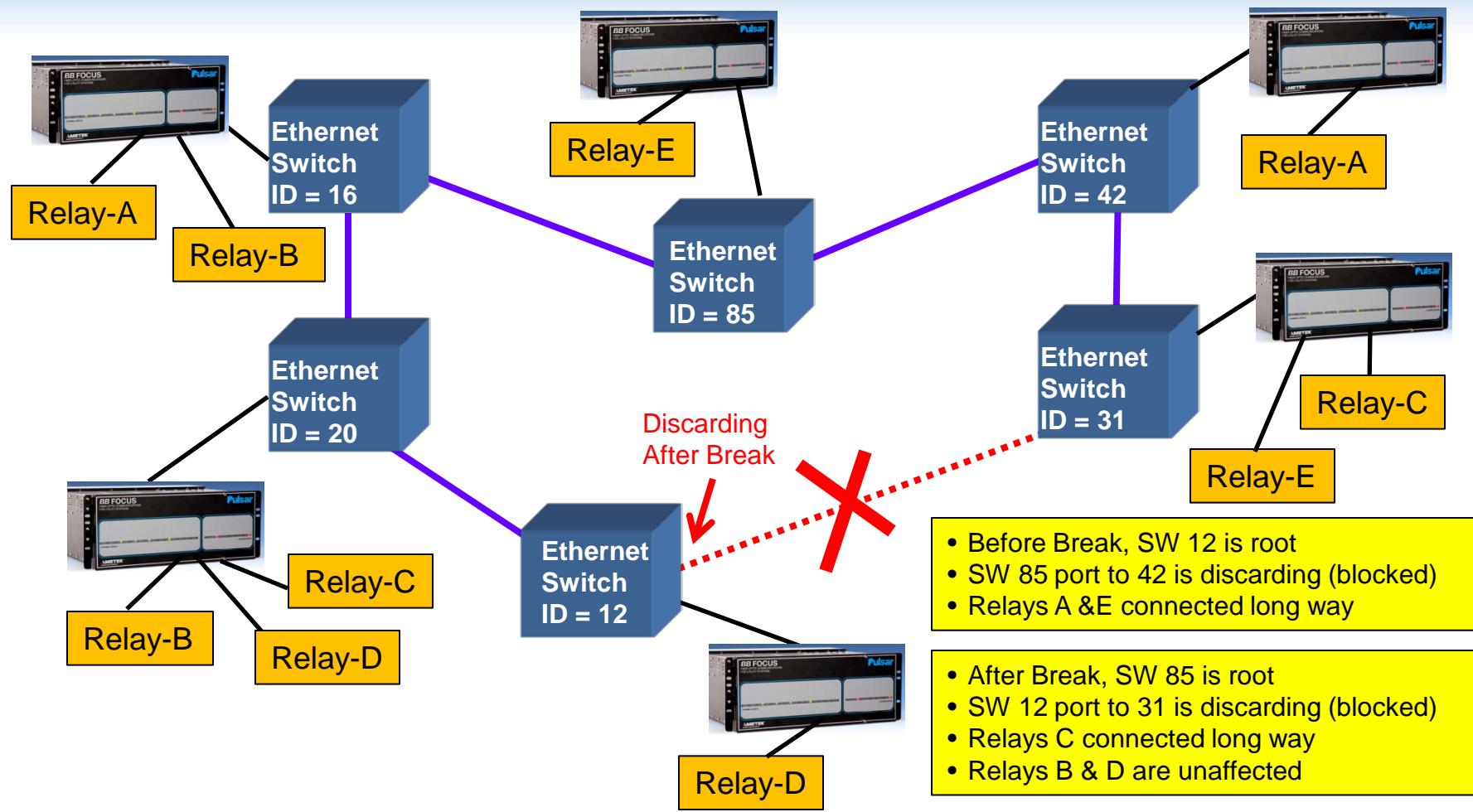
One of Three Hurdles to Accept Ethernet as a Channel for Protective Relaying

- Is there a Redundant Path Option when my Primary Fiber path is Broken?
 - TDM System have various types of self-healing rings
 - APM, ILS, Mini-DACS, FFHS, Path Switched, Line Switched, BLSR, UPSR, etc.
 - All effectively remap the broken channels the opposite direction around the ring.
 - May require some manual preconfiguring to obtain fastest switching times
 - Expect 25 to 150 mS recovery times
 - Packet over Ethernet uses variations of STP (Spanning Tree Protocol)

Spanning Tree Protocol, in a Ring



Spanning Tree Protocol, in a Ring



One of Three Hurdles to Accept Ethernet as a Channel for Protective Relaying

- What is the recovery speed when my primary fiber path is broken?
 - TDM: Expect 25 to 150 mS recovery times
 - Packet over Ethernet: Expect 25 to 50 mS recovery times
 - With MSTP, Packet networks offer something not available in TDM. Near zero-delay switching.
- Redundancy in Packet Network is equivalent to or better than TDM

Two of Three Hurdles to Accept Ethernet as a Channel for Protective Relaying

- Is my Channel Latency Deterministic and Low Enough?
 - TDM will yield a faster end to end time than Ethernet
 - TDM delay is a function of
 - Channel card processing delay
 - Speed of light delay
 - Pass-through node delay (125 to 250 uSec)
 - Packet over Ethernet delay is all the above, plus
 - Channel card processing delay
 - Speed of light delay
 - Pass-through delay in Ethernet is MUCH less than in TDM at under 10 uSec .
 - Jitter buffer delay
 - Frames per packet (Bandwidth Economy) delay,

RS232 Latency over Packets

Network – Two nodes Broadband FOCUS	Jitter Buffer Setting	Bandwidth Economy Setting	Bandwidth Utilization (kbps)	Security Setting (mSec)	Latency (mSec)
RS-232	4	4	1,420	n/a	2.76
RS-232	4	8	720	n/a	3.22
RS-232	4	16	392	n/a	6.24
RS-232	4	32	228	n/a	12.2
RS-232	4	64	146	n/a	24.2
RS-232	4	128	105	n/a	48.2

Three of Three Hurdles to Accept Ethernet as a Channel for Protective Relaying

- Do I have sufficient Bandwidth?
- How Scalable is my System?

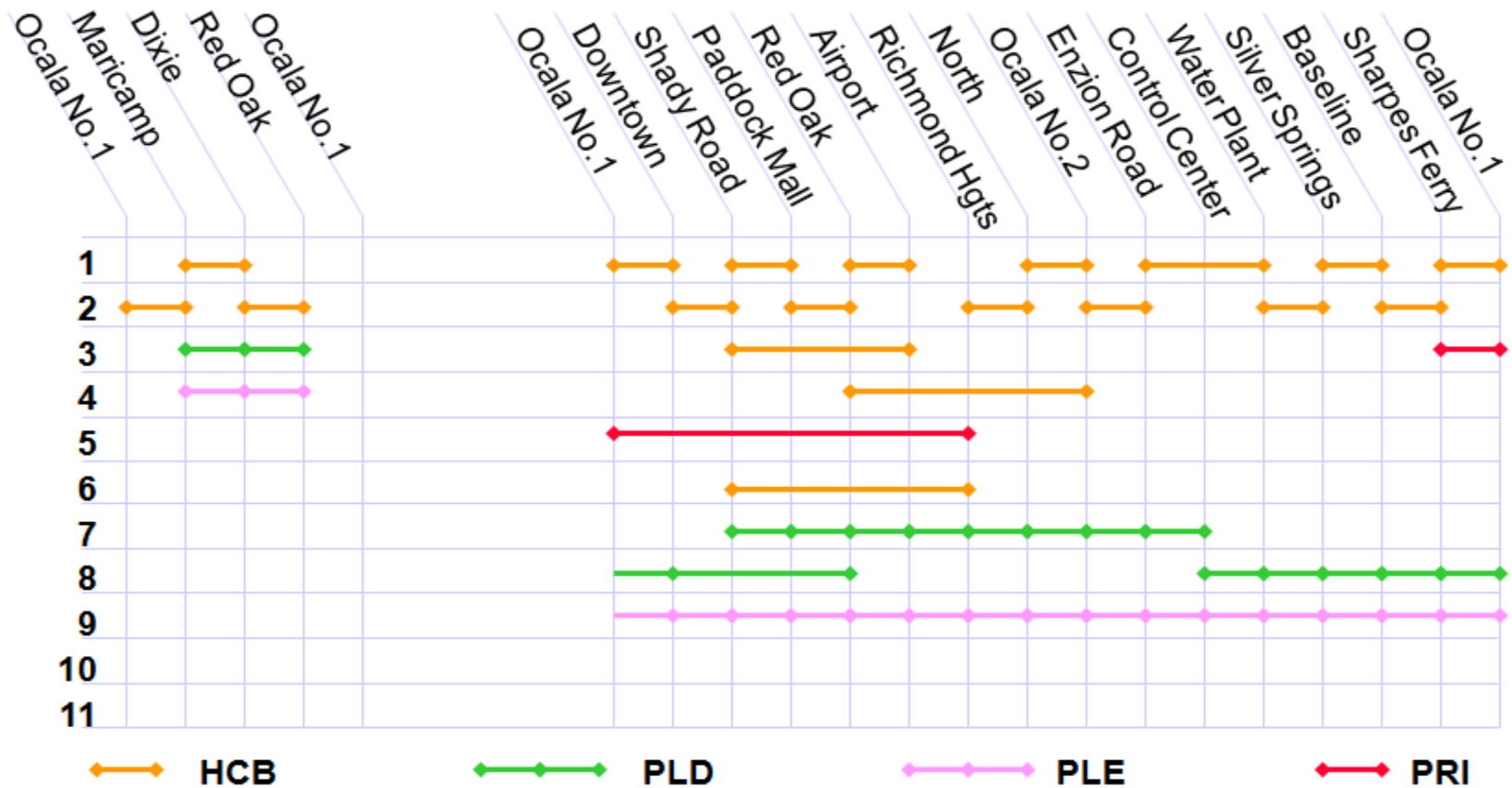
What is the Right Way to Measure a Single Channel's Bandwidth?

- Does a single DS0 really occupy only 64kbps of bandwidth in TDM?
 - Yes, but don't forget an entire VT1.5 is usually mapped point to point so if you only have one DS0 between those end points, then you are really using 1.544 Mbps.
 - All channel types use this "64kbps" including HCB, 232, DTT
 - Latency is generally less than 1 mS for all channel types, except Transfer trip (2 to 4 mS)
- What bandwidth do these channel types use in Ethernet?
 - HCB requires 5.5 Mbps to achieve under 1 mS latency
 - 232, DTT, (Not HCB) can likely use settings for about 6 mS extra latency and 392kBps bandwidth
 - When you consider average of 4 channels per VT, then bandwidth usage equal to TDM.

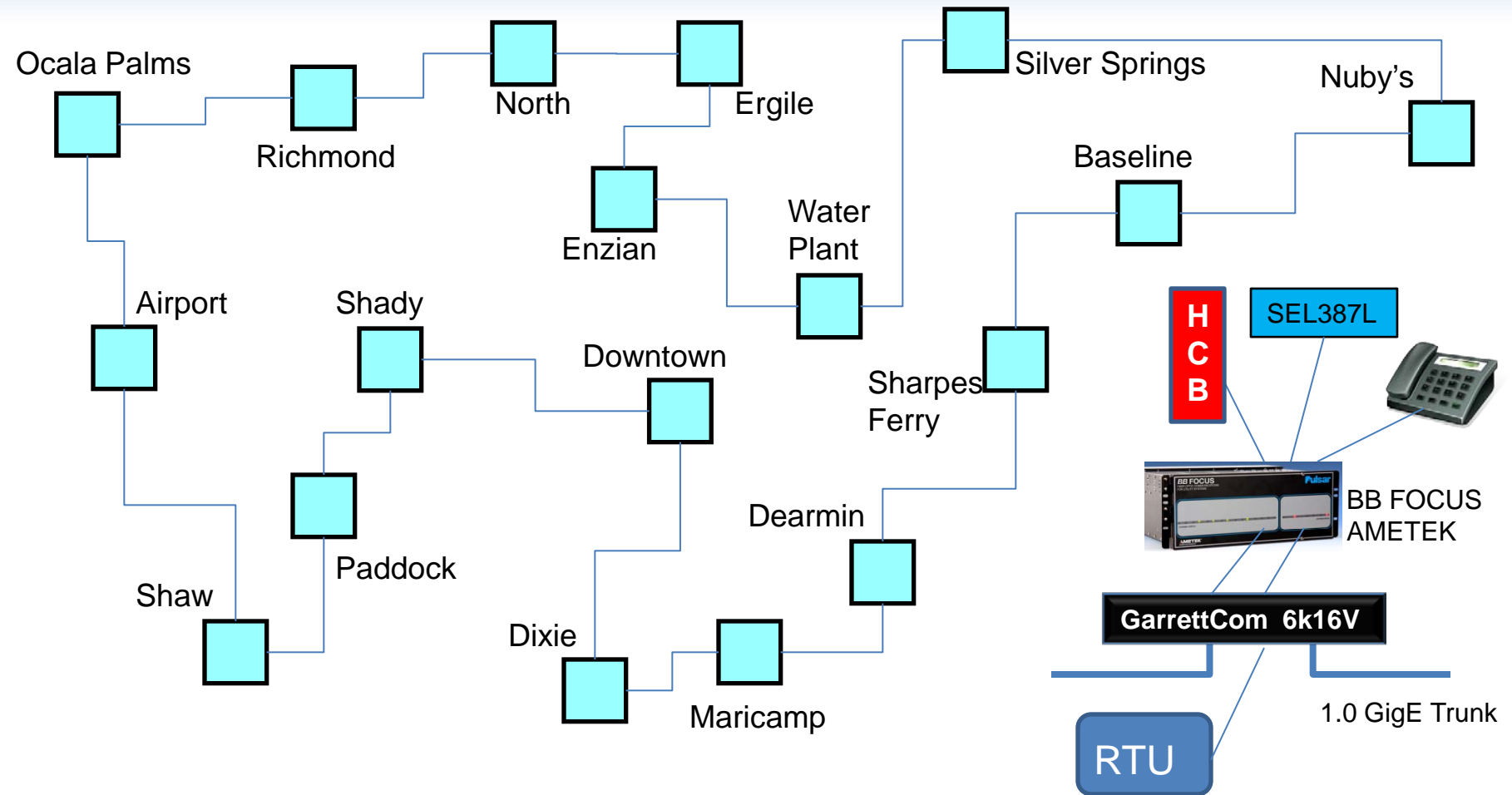
Three of Three Hurdles to Accept Ethernet as a Channel for Protective Relaying

- How Scalable is my System?
 - Packet over Ethernet:
 - Scalable by replacing one standard item, the switch.
 - 1.0 GigE common now; 10 GigE already here ;100 GigE coming
 - TDM
 - Must replace optics, DACS and/or VT mapper
- Packet system is more scalable than TDM and nearly future-proof

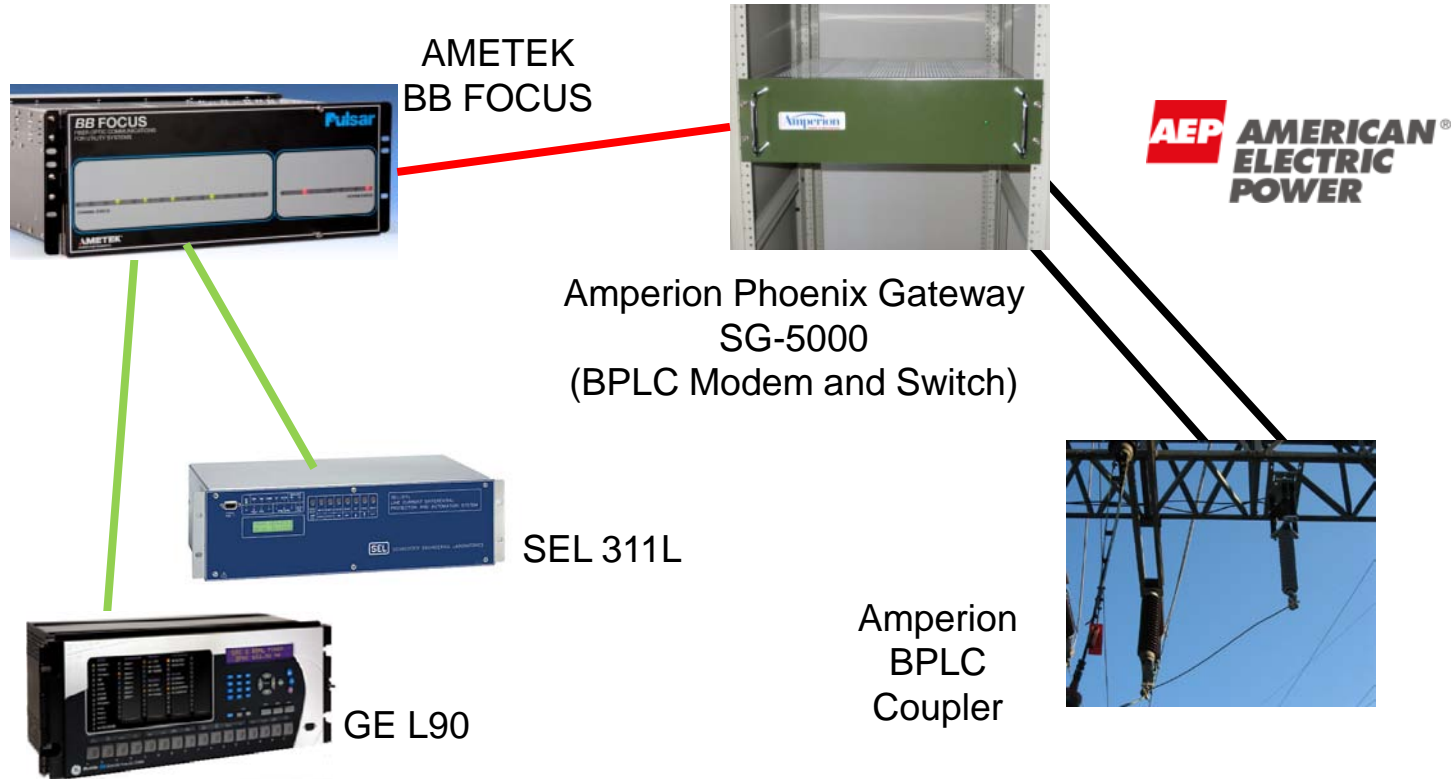
Ocala Utility Services – FOCUS (as installed in 1995)



Ocala Utility Services– BB FOCUS (as installed in 2010)

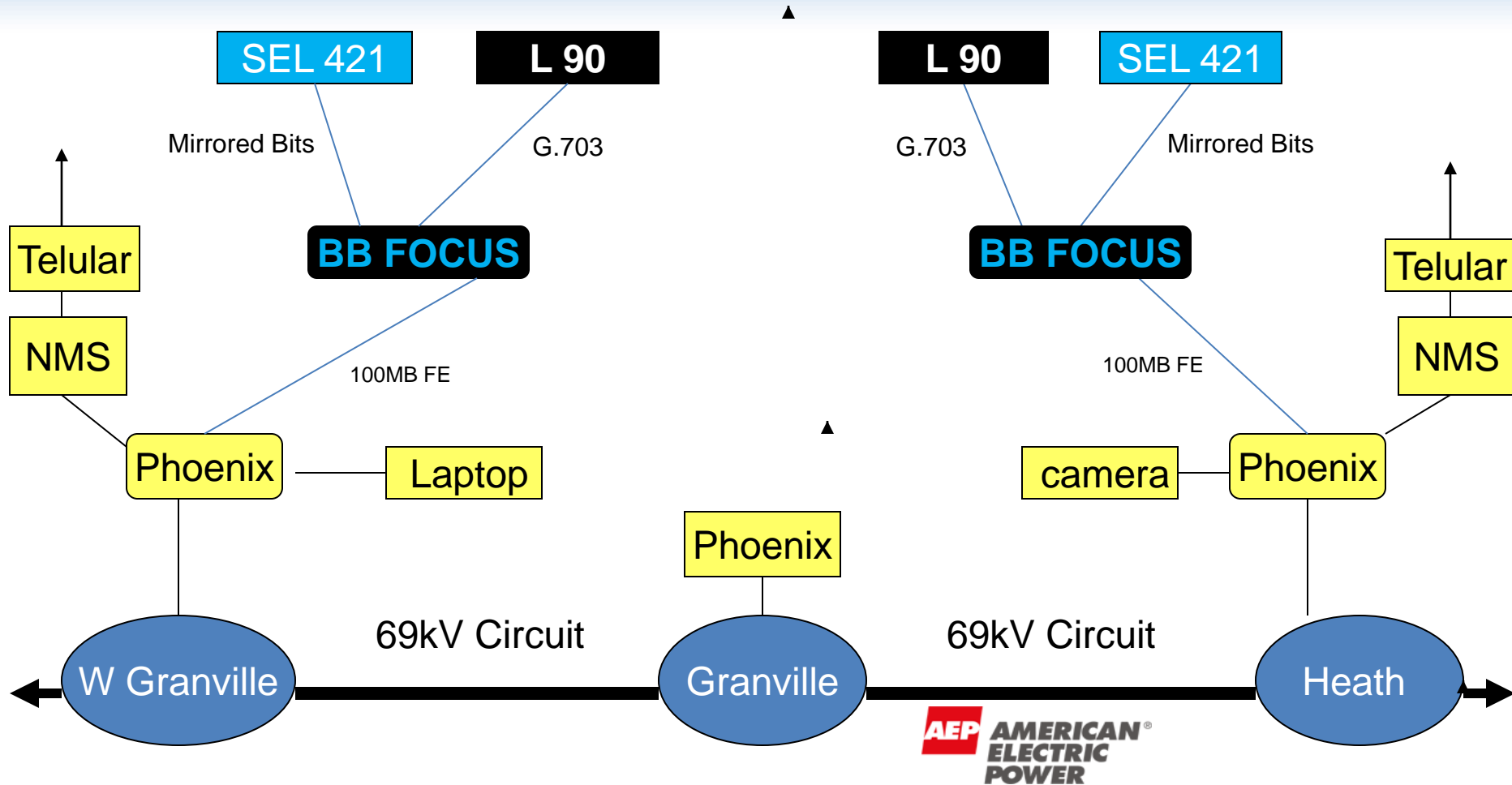


American Electric Power BPLC Installation



Five Mile 69kV Network at AEP

Field trials 2010



Field Test Results Summarized for L90

- Relay trip time for faults at 50% of line ranged from 38 to 42 milliseconds
- Similar results for faults at 5% and 95 %
- No trips for external faults
- Results were similar to tests in lab prior to field implementation
- Results were about 20 milliseconds slower than a point to point fiber channel