



# Analysis of In-Service Line Current Differential Protection Circuits: Comparing SONET With Packet-Switched Network Performance

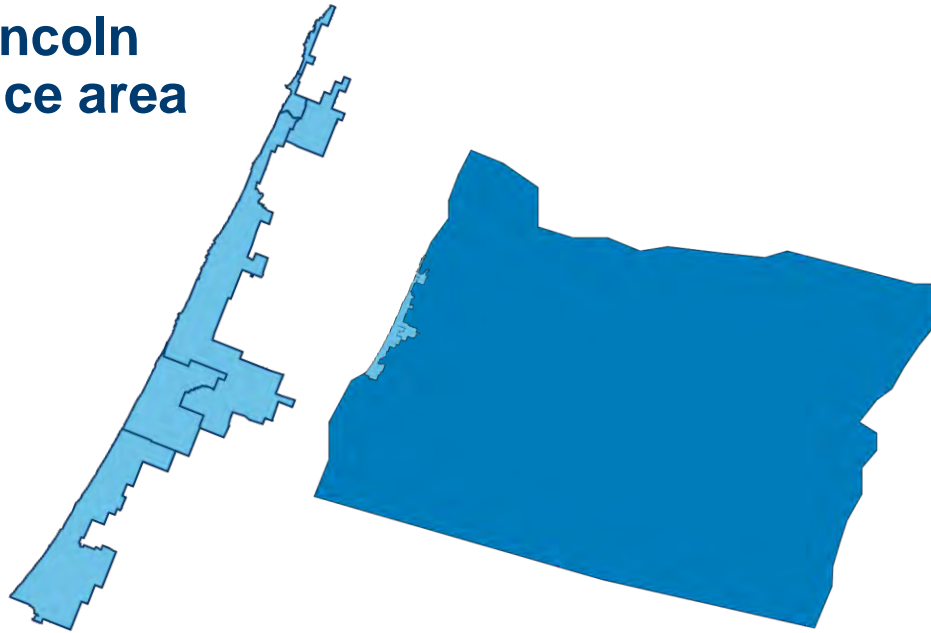
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## Central Lincoln PUD service area



## Central Lincoln PUD telecom network timeline

1.8 GHz analog microwave and  
small fiber-optic cable  
(pre-1993)

“IS becomes IT”  
and SCADA request for  
proposal (1997)

### Bonzai pipeline

Federal Communications Commission – narrowband and 2 GHz relocation  
Central Lincoln PUD – GIS systems and digital phone system

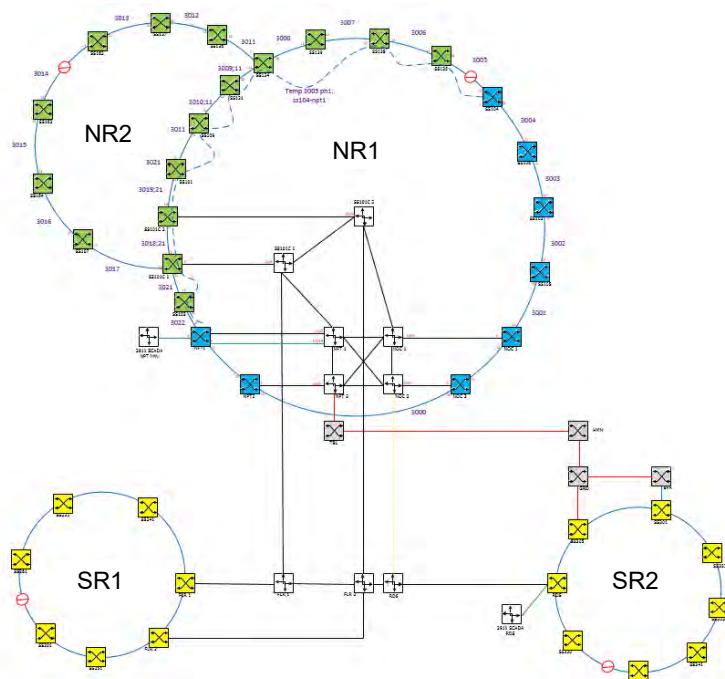
# CLPUD telecom network timeline

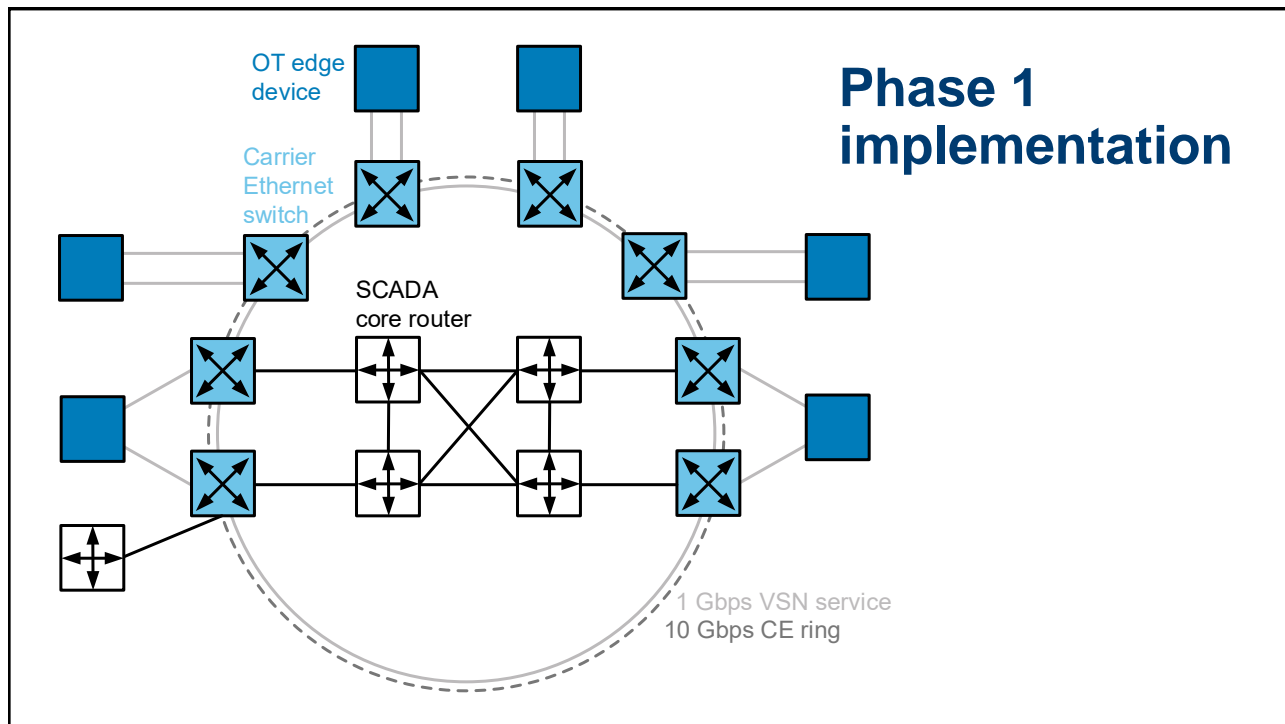
Smart grid investment grant  
(2009)

Next-generation  
requirements

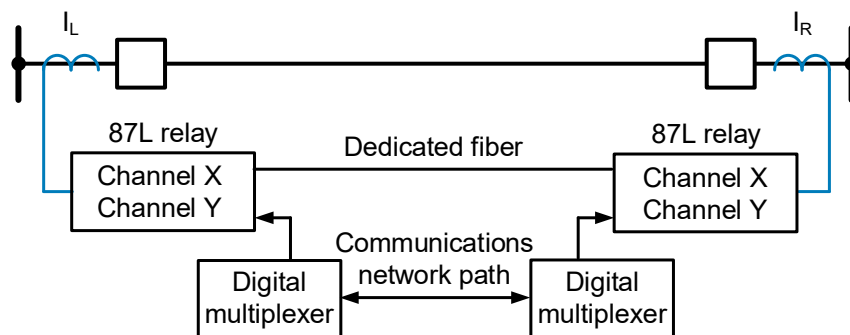
End of life for operations  
and maintenance

## WAN topology





## Central Lincoln PUD 87L communication channel architecture



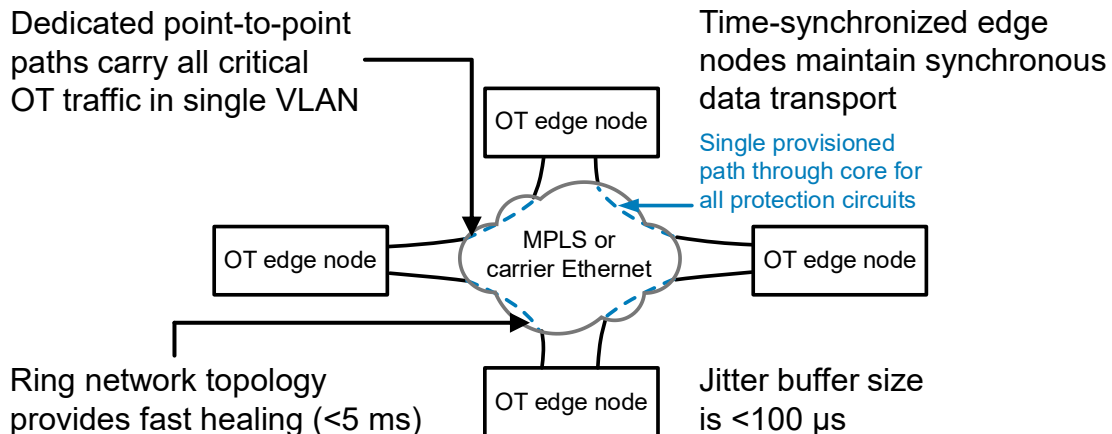
- Four relay circuits analyzed over two-week period
- Two SONET / TDM circuits
  - Two packet network circuits

## Line current differential is hardest protection scheme to support over packet

Low latency	Low asymmetry	Fast healing
5 ms or less for 3-cycle fault clearing	Less than 0.5 ms for high sensitivity	5 ms or less with minimal packet loss

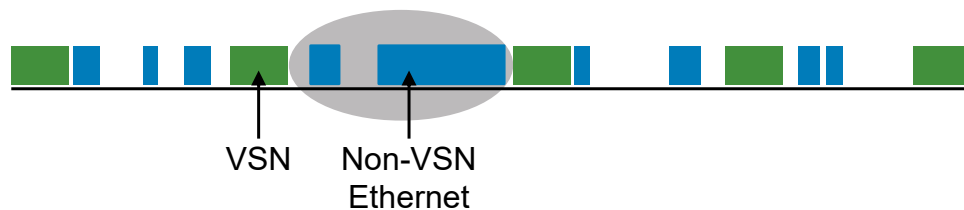
## VSN ring topology

Dedicated point-to-point paths carry all critical OT traffic in single VLAN



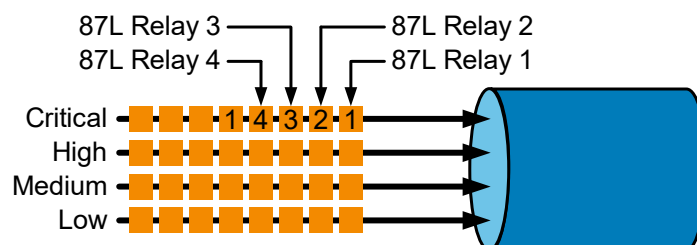
## VSN Ethernet traffic

- Has standard Layer 2 Ethernet with new Ethertype
- Interoperates with MPLS-IP, MPLS-TP, Carrier Ethernet, and SDN
- Has VSN packet spacing that allows for maximum-sized Ethernet frames to fit between packets
- Maintains low jitter transport through any core network



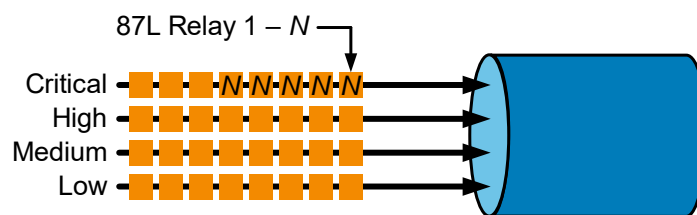
## Ethernet queues cannot give every 87L circuit equal priority

- Data from each relay must wait for turn in queue before being sent over shared Ethernet channel
- Subsequent packets are delayed longer with more 87L circuits



## VSN solves queue conflict

- Data from all relays are aggregated into single VLAN
- Incremental queuing delays are removed as more teleprotection circuits are added to network

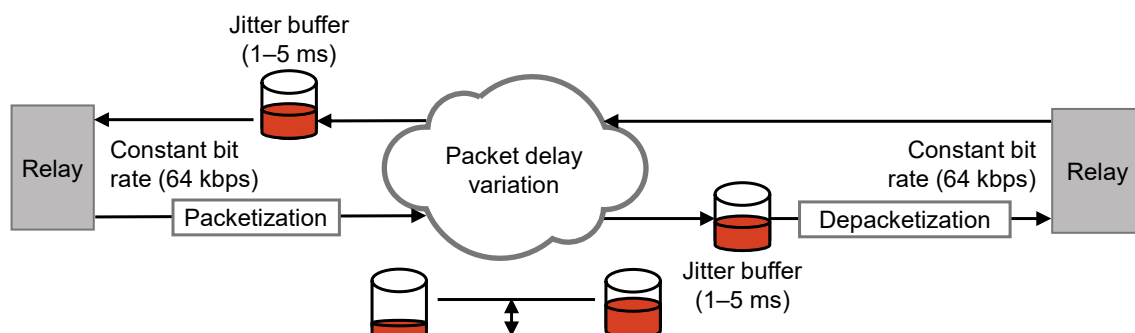


## Pseudowire jitter buffers contribute to asymmetry

Jitter buffer pointer level difference creates asymmetry

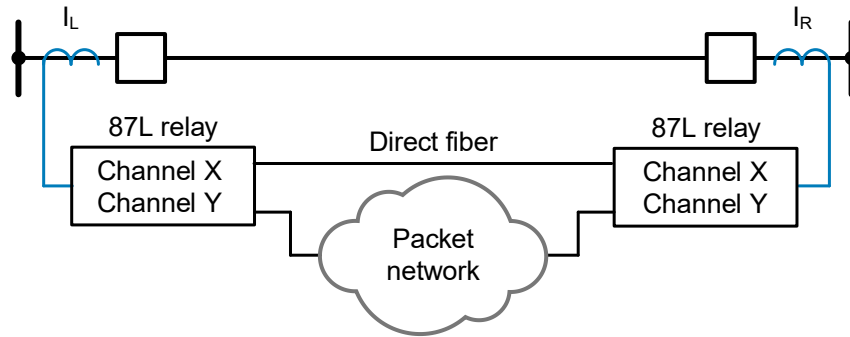
Packet-based pseudowires need to monitor and reset level regularly

Jitter buffer reset typically results in loss of channel



# Understanding asymmetry impact on 87L

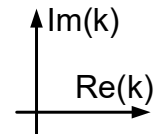
## Alpha plane



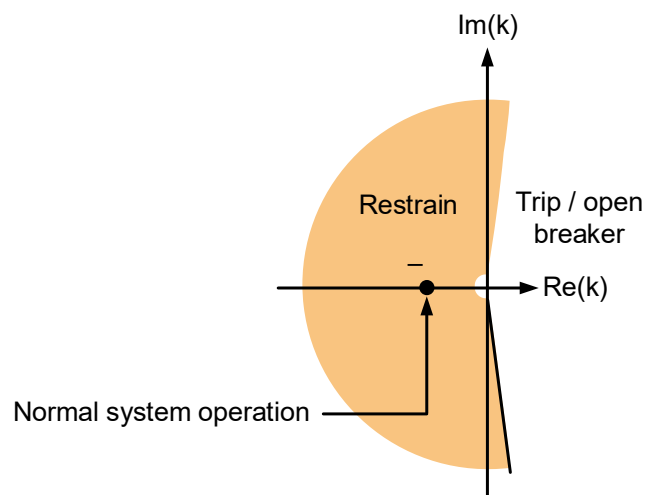
Currents are expressed as complex ratio

$$k = \frac{I_R}{I_L}$$

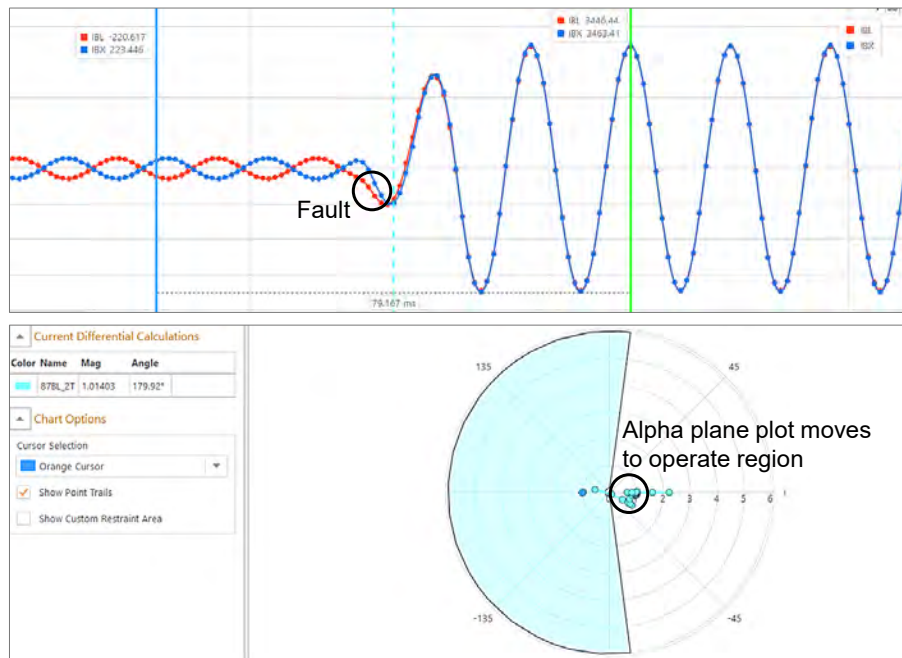
**Alpha plane** is graphical representation of that ratio



## Alpha plane basics





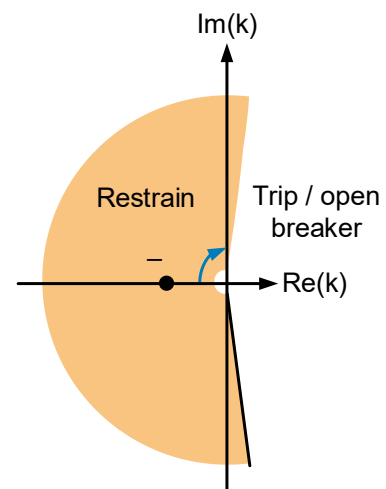


## Asymmetry degradation over time causes alpha plane data shift

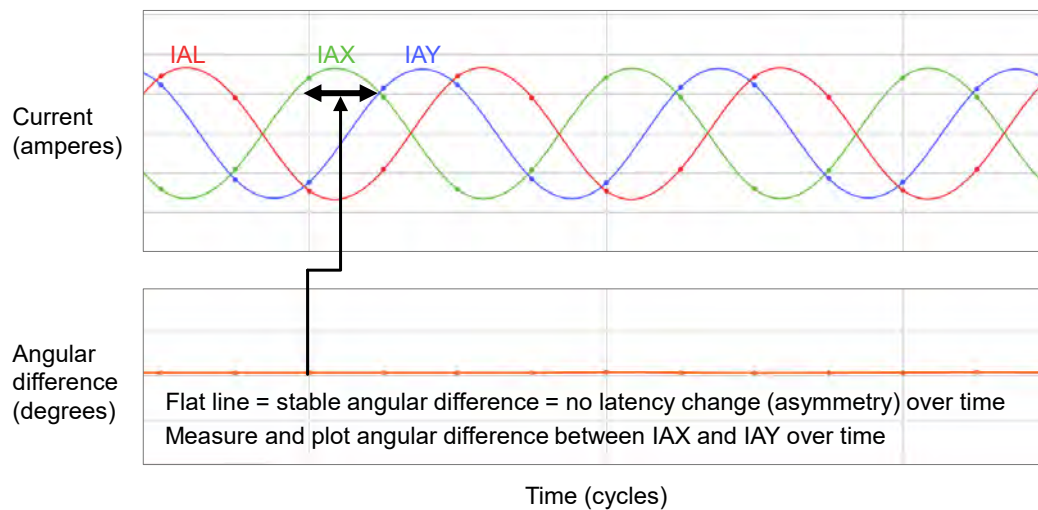
Annular mask provides asymmetry tolerance, which results in **loss of sensitivity** and **decrease in security**

Excessive asymmetry skews differential current calculations from restraint to operate region

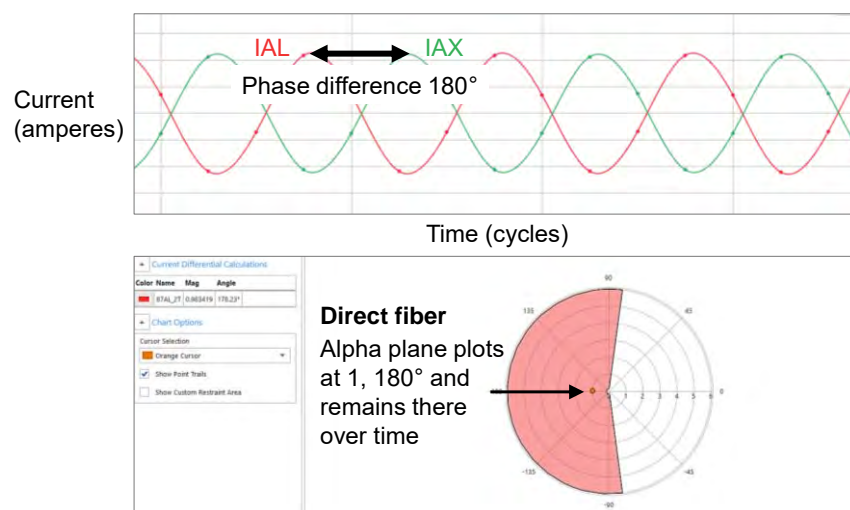
**Measure alpha plane data over time** to validate network performance



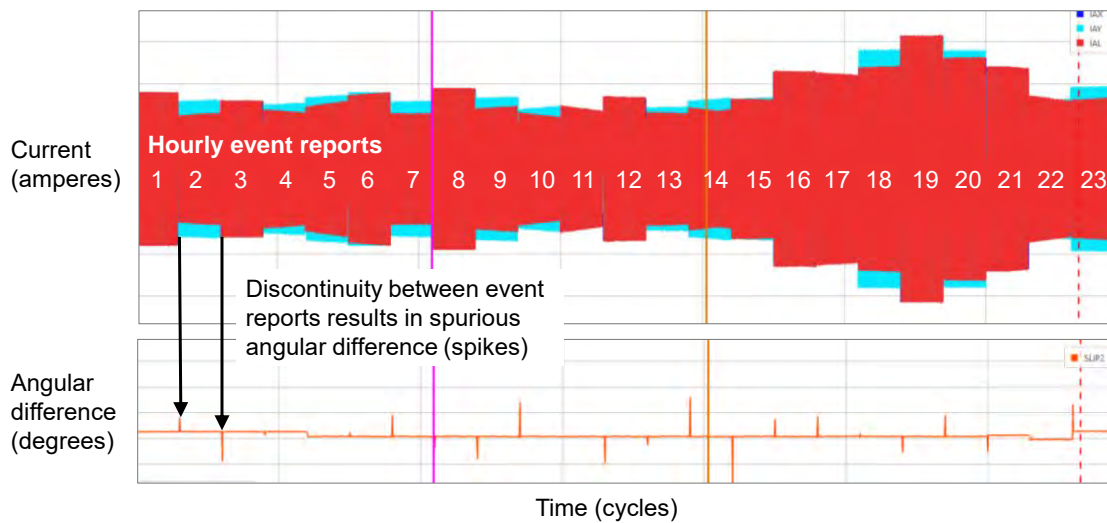
## How analysis is performed



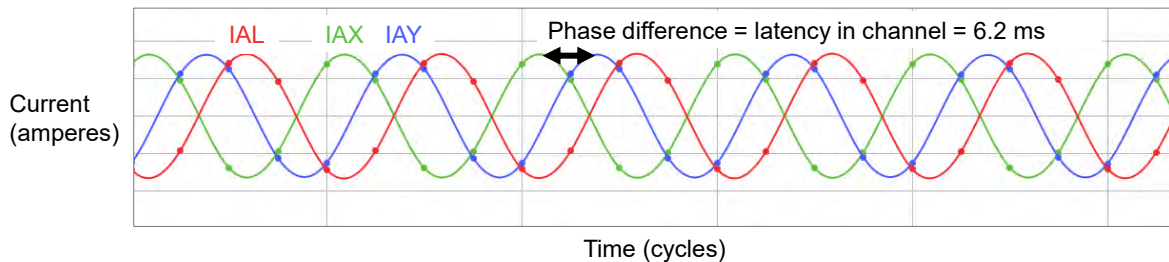
## Direct fiber provides ideal reference



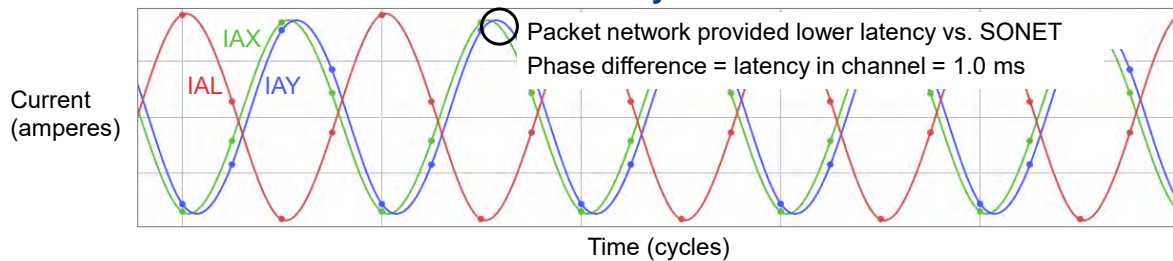
## Event reports are captured hourly



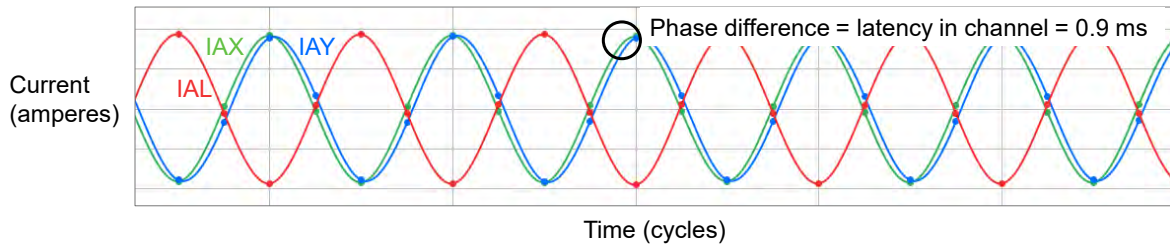
## Direct fiber vs. SONET Circuit 1 latency



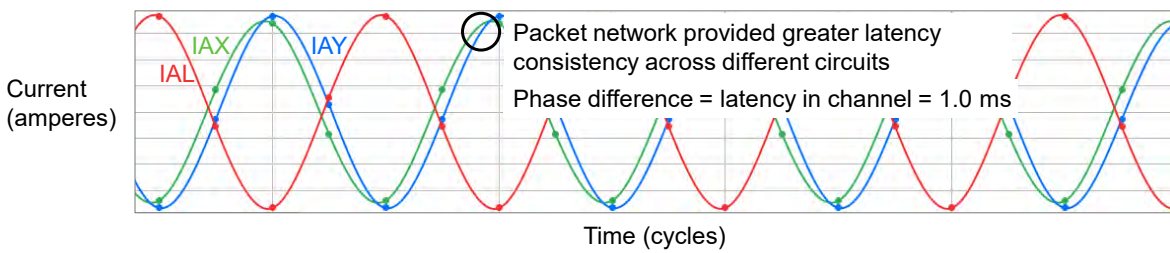
## Direct fiber vs. VSN Packet Circuit 1 latency



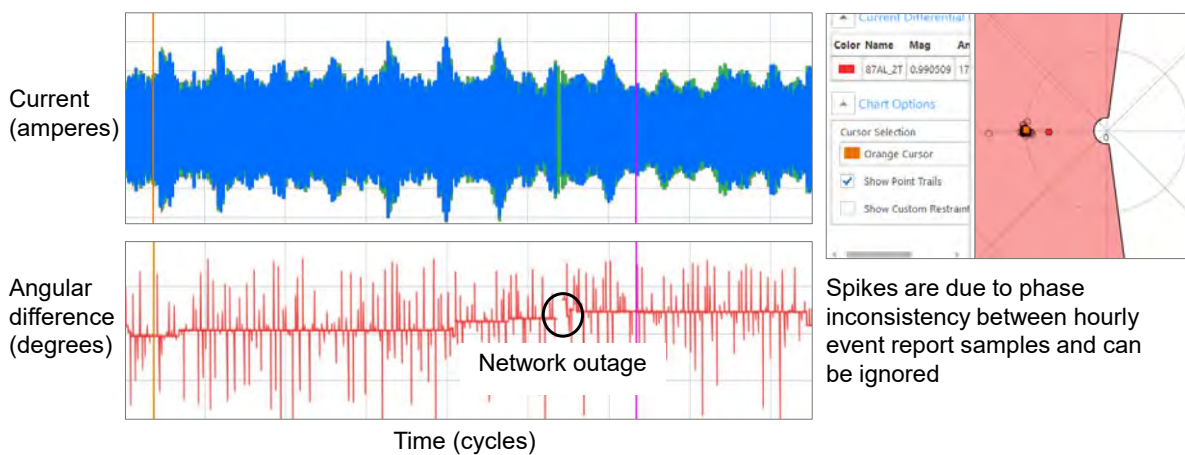
## Direct fiber and SONET Circuit 2 latency



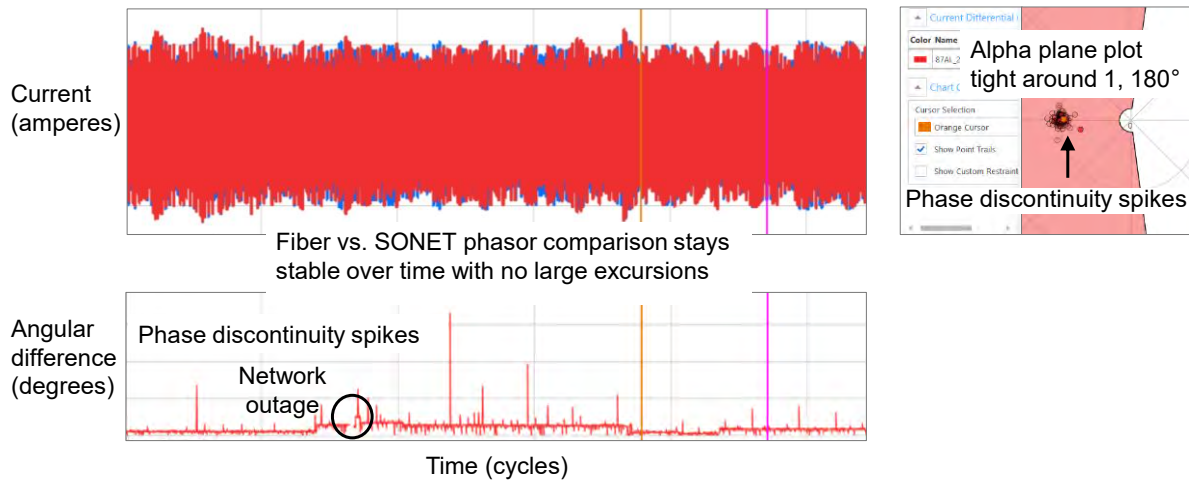
## Direct fiber and VSN Packet Circuit 2 latency



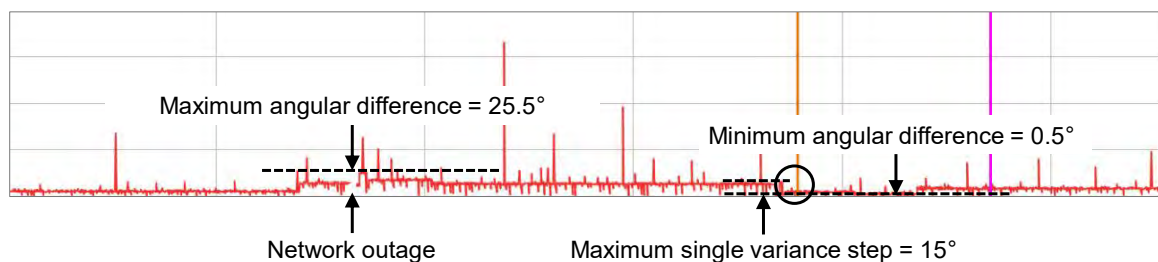
## SONET Network 1 performance over two weeks



## SONET Network 2 performance over two weeks

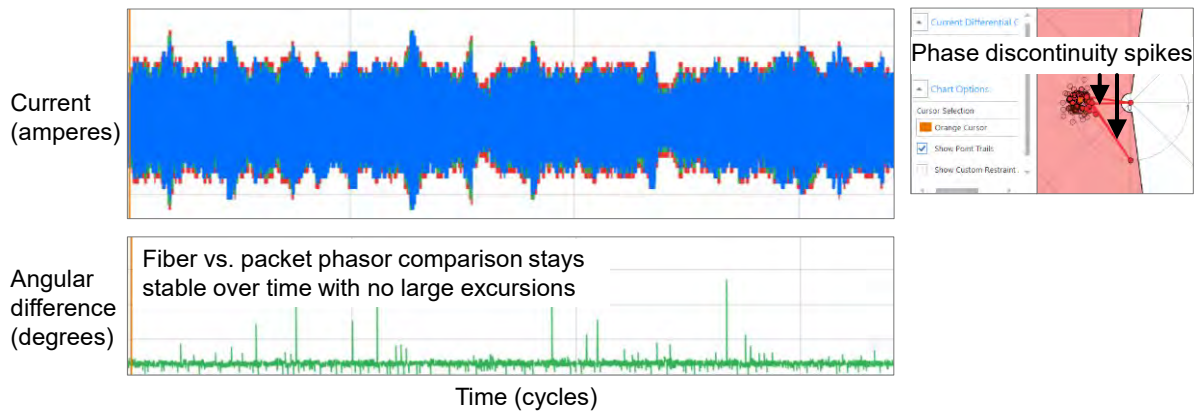


## Detailed analysis of SONET Network 2

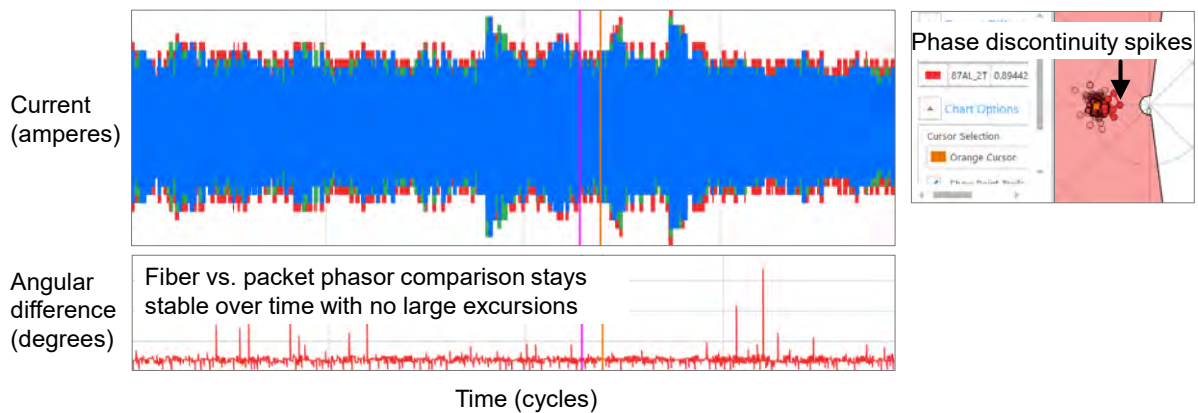


Measurement	Value
Minimum angular difference	0.5°
Maximum angular difference	25.5°
Angular difference variance	25°
Maximum single variance step	15°
Maximum estimated asymmetry	0.7 ms

## VSN Packet Network 1 performance over two weeks

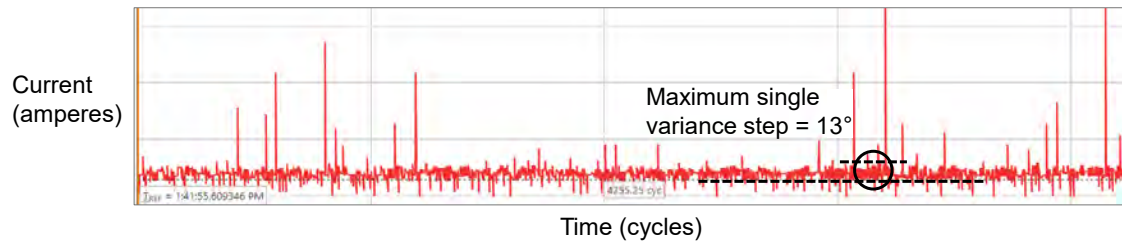


## VSN Packet Network 1 performance over two weeks





## VSN Packet Network 2 detailed analysis



Measurement	Value
Minimum angular difference	13°
Maximum angular difference	26°
Angular difference variance	13°
Maximum single variance step	13°
Maximum estimated asymmetry	0.6 ms

## Summary of results

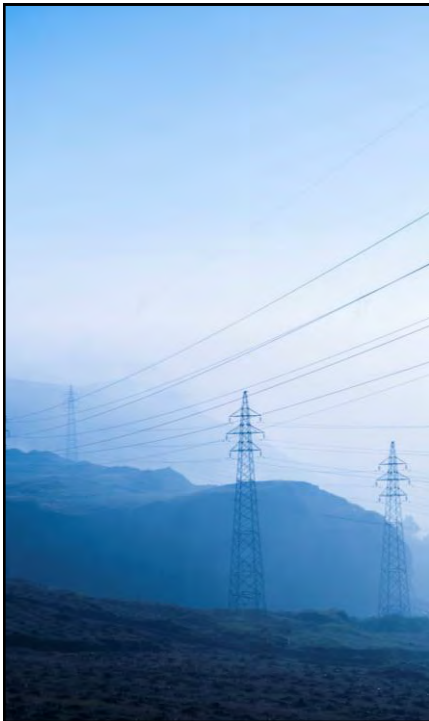
	SONET Circuit 1	SONET Circuit 2	VSN Packet Circuit 1	VSN Packet Circuit 2
Latency	6.2 ms	0.9 ms	1.0 ms	1.0 ms
Maximum angular variance	39°	25°	14°	13°
Maximum single step variance	18°	15°	13°	13°
Maximum estimated latency step change	0.8 ms	0.7 ms	0.6 ms	0.6 ms

## Conclusions

VSN over packet provides equivalent performance to SONET

Studying performance over time identifies channel stability and availability issues

Angular difference measurement approach is a valuable tool to assess communication channel suitability for line current differential



## Questions?