IP/MPLS in the Mobile Radio Access Network (RAN)

An IP/MPLS Forum Sponsored Tutorial

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Nikhil Shah
VP, International Development, IP/MPLS Forum
Director, Mobile/FMC Segment, Juniper Networks

Himanshu Shah
Member, IP/MPLS Forum
Sr. Principle engineer, Ciena

Agenda

1. **Introduction to the IP/MPLS Forum**
2. **MPLS in the RAN Backhaul**
   - Issues, trends, and enablers of the transition to IP/MPLS in evolving RAN backhaul architectures
3. **MPLS Basics**
   - MPLS fit and operation in the mobile RAN network and the support of end-to-end SLAs, QoS, and high availability features
4. **MPLS Pseudowires**
   - The latest Pseudowire (PWE3) enablers for legacy network migration (TDM and ATM) and their operation over IP/MPLS RAN backhaul networks
5. **MPLS OAM and Protection**
   - Operations, Administration and Management (OAM) capabilities of IP/MPLS RAN backhaul networks
6. **Packet Synchronization and Timing**
7. **MPLS Mobile Backhaul Initiative – MMBI**
8. **IP/MPLS in the RAN**

Introduction to the IP/MPLS Forum

- IP/MPLS Forum is an international, industry-wide, non-profit association of service providers, equipment vendors, testing centers and enterprise users
  - Created with the name change of the MFA Forum (Oct 2007) to reflect renewed focus on driving global industry adoption of IP/MPLS solutions in the market, by focusing on standards initiatives for IP/MPLS such as inter carrier interconnect (ICI), mobile wireless backhaul, and security.
- Objectives: Unify service providers, suppliers and end users on common vision of IP/MPLS based solutions

Awareness	Migration	Systems-Level Solutions
• Promote global awareness of the benefits of IP/MPLS • Empower the telecom industry to migrate from legacy technologies to IP/MPLS-based next generation networking	• Guide the telecom end user to make the leap from legacy technologies to IP/MPLS-based services	• Drive implementation of standards for IP/MPLS based solutions • Validate implementations and advance interoperability of standardized IP/MPLS based solutions

- Deliverables: Technical Specifications, Test Plans, Technical Tutorials, Collateral

Focus Areas of MPLS Forum

- **Current Work Items**
  - IP/MPLS Wireless Backhaul network architectures
    - Wireless evolution pushes IP/MPLS technology out to base stations, LTE, etc.
  - MPLS InterCarrier Interconnect
  - Packet Based GMPLS Client to Network Interconnect
  - Generic Connection Admission Control (GCAC) Requirements for IP/MPLS Networks
  - BGP Controlled L2 VPNs
  - MPLS Over Aggregated Interface
  - Voice Trunking format over MPLS
  - TDM Transport over MPLS using AAL1

  The Forum is also planning several industry driven future Work Items.
- **Service Provider Council**
- **Public Interoperability Events**
- **Technical Tutorials**
- Next meeting:
- Vancouver/ June, Beijing/September-08

To join the Forum contact Alysia Stewart Johnson
[ajohnson@ipmplsforum.org]
Executive Director, IP/MPLS Forum
T: +1.510.492.4057 / F: +1.510.492.4001

Technical Tutorials

Introduction to MPLS	**½ and full day**
MPLS L2/L3 VPNs	**½ day**
MPLS VPN Security	**½ day**
Traffic Engineering	**½ day**
GMPLS	**½ day**
Migrating Legacy Services to MPLS	**½ day**
MPLS OAM	**½ day**
Voice over MPLS	**½ day**
Multi-service Interworking over MPLS	**½ day**
Multicast in MPLS/VPLS Networks	**½ day**
IP/MPLS in the Mobile RAN	**½ day**

New tutorials based upon demand

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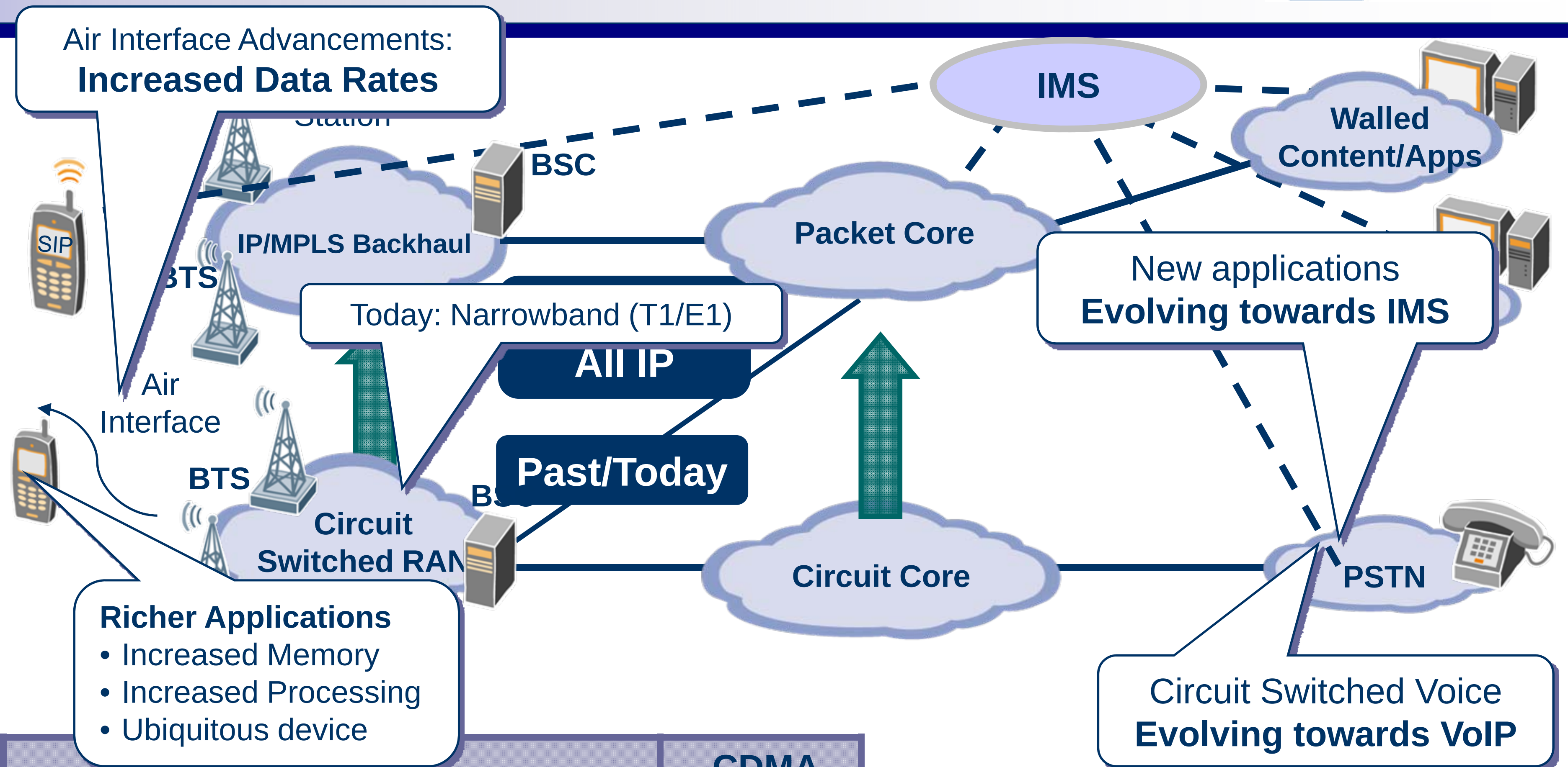
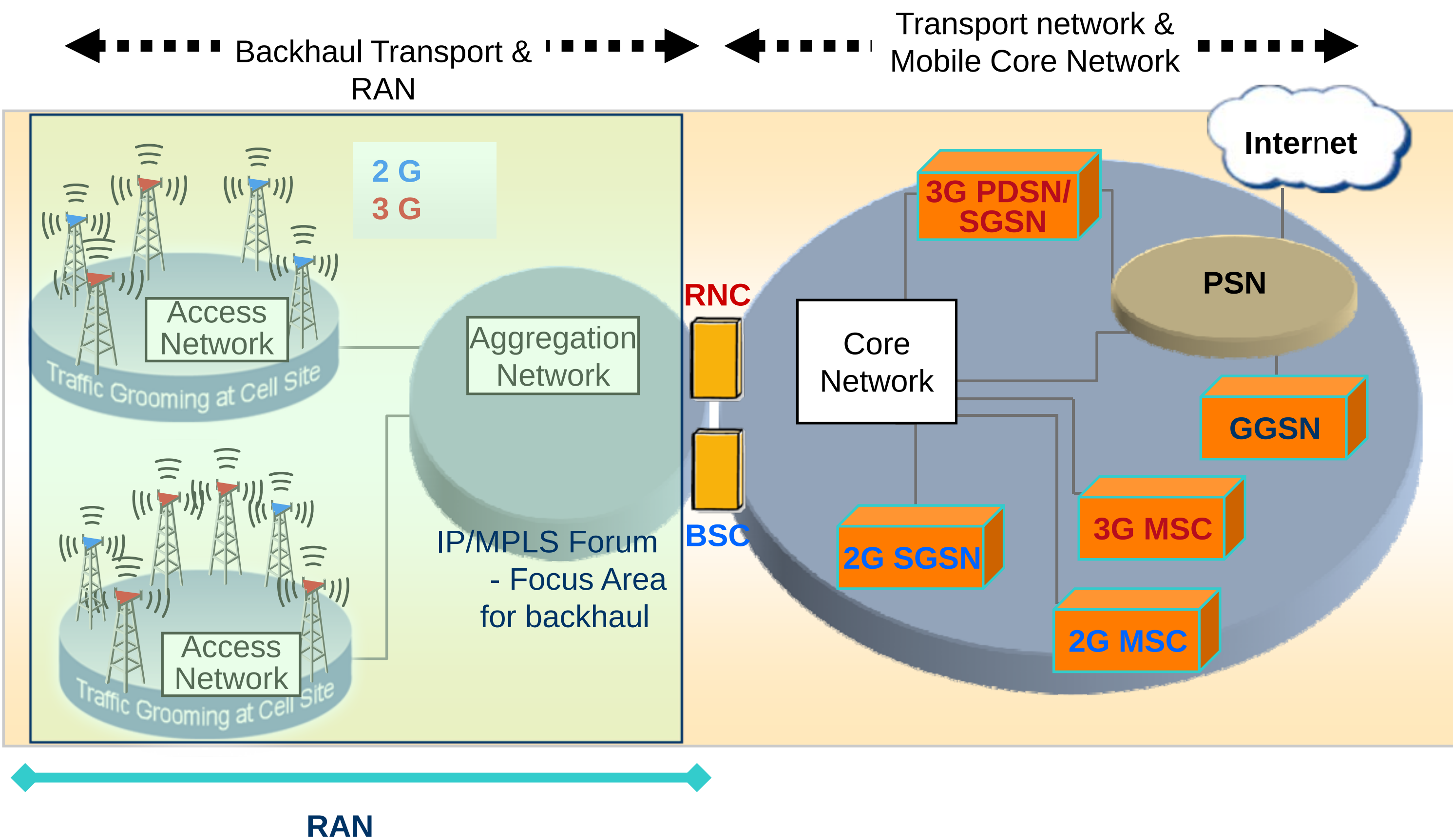
Wireless Network Framework



Terminology	WCDMA/UMTS	CDMA 2000/1x
Base Station	Node-B	BTS
Base Station Controller	RNC	BSC
Circuit Edge devices	MSC	MSC
Packet Edge devices	SGSN, GGSN	PDSN

Technology	Data Services
GSM/UMTS	EDGE, GPRS
CDMA	CDMA2000, 1xRTT, EV-DO
4G	LTE, UMB, Mobile WiMAX

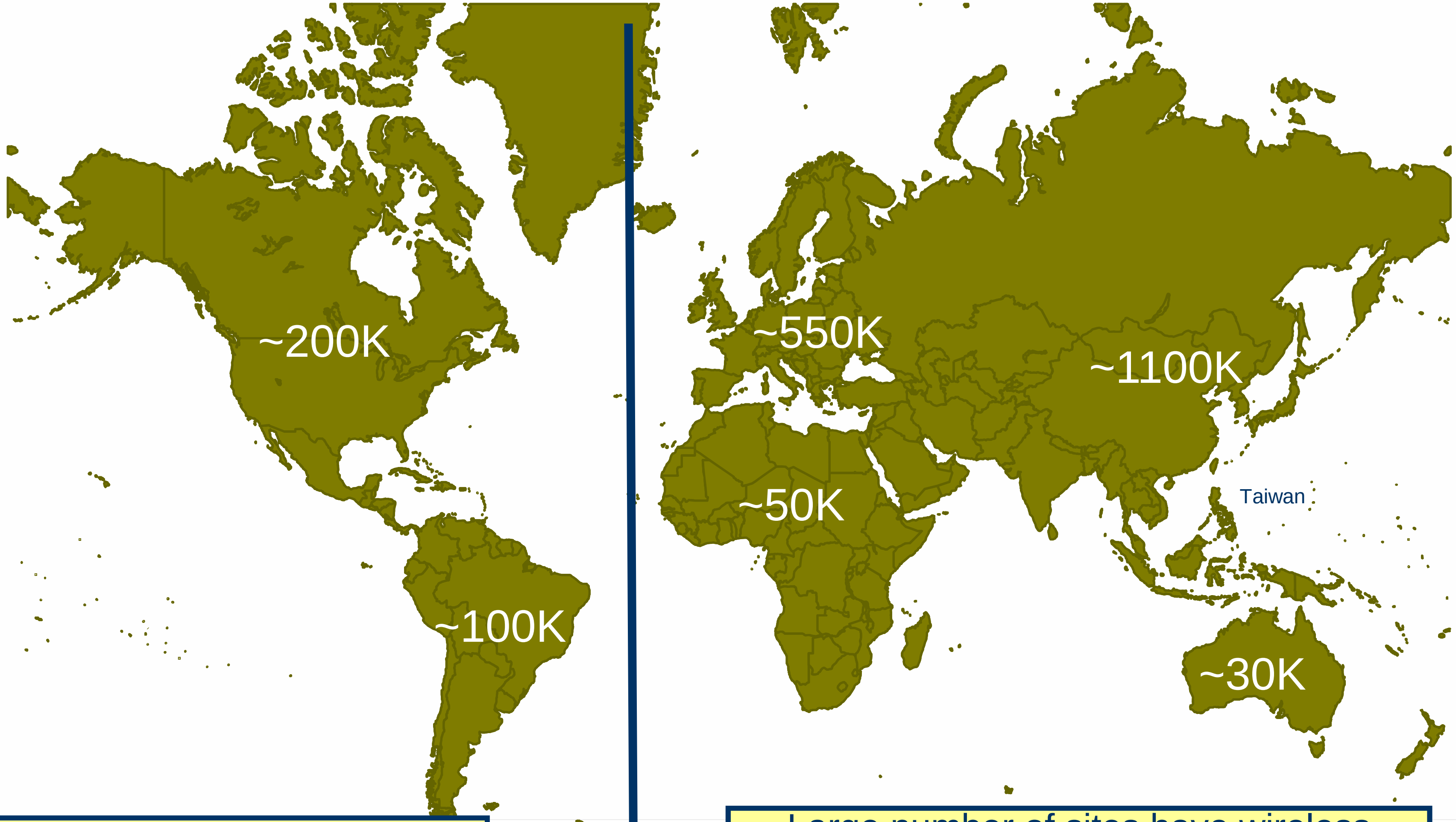
Mobile Network – End-to-End View



Defining Mobile backhaul network :

Network that connects cell sites with regional mobile hub/controller sites (e.g. network that connects Base Stations/Node Bs to BSC/RNC)

Global Cell Site Coverage



Majority of Copper Backhaul
Mobile Providers rely on
Wireline Providers for Backhaul

Large number of sites have wireless (microwave) backhaul. Mobile operators operate / own backhaul

Source, Carrier Ethernet Academy

Fundamental Problems Drive Mobile Backhaul Transformation

IP/MPLS FORUM

Compelling events are driving backhaul transformation

- Diversity in network infrastructure
- Traffic growth and new service introduction
- Introduction of IP base stations
- Need for service assurance

Direct implications for the network architecture

Efficient migration from TDM to packet	Scaleable Bandwidth at lower cost per bit	Evolution paths for CDMA and GSM/UMTS	Strict SLAs backed by differential IP QoS	Improved operational management and accuracy

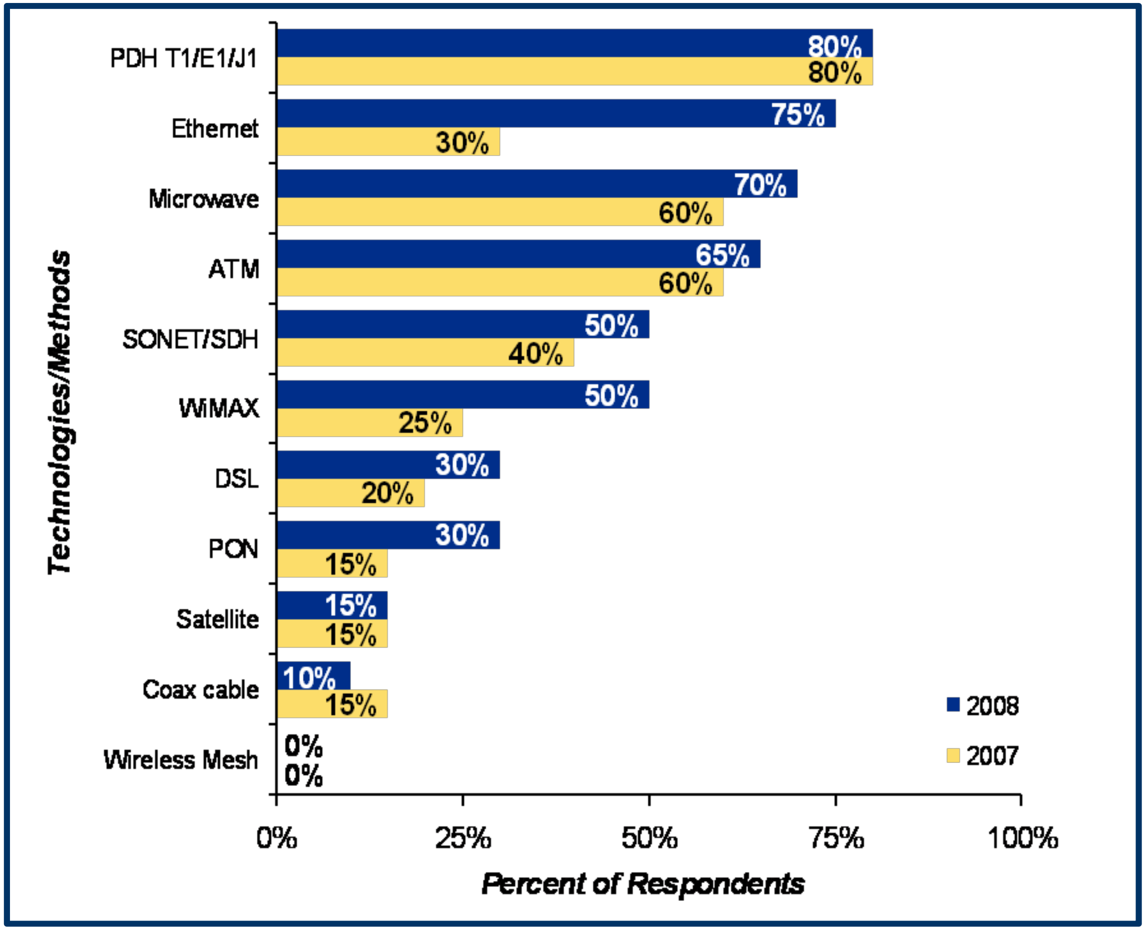
RAN Backhaul Business Drivers

- **Mobile Operators spend ~30% of total OPEX on transport services***
  - $22B globally
- **Access Bandwidth Growth (EV-DO, HSPA, LTE….)**
  - 2G operators require 1 or 2 T1/E1 (leased) per base station
  - 3G - incremental of 2 to 4 T1/E1s per base station (Data Driven)
  - 200–400% increase in required backhaul and associated OpEX
- **RAN is increasingly becoming a strategic asset**
  - Area of major investment for operator
  - Lease vs. Own
- **Mobile backhaul requires diverse and co-existent technologies**
  - 2G (TDM), 3G (ATM in UMTS), 4G (IP/Ethernet in LTE/UMB, WiMAX)
  - Large number of 2G and 3G cell sites are collocated
- **Provisioning/planning needs to be simplified**
  - Avoid truck rolls
- **RAN sharing with other operators**
  - Need a way to separate/secure traffic and maintain SLAs

***Source: Yankee Group**

Technologies for RAN Backhaul

- Adoption of Ethernet as a backhaul technology doubles to 2008
- Operators migrating RANs to converged, packet-based architectures
- Microwave used extensively in Europe and Asia

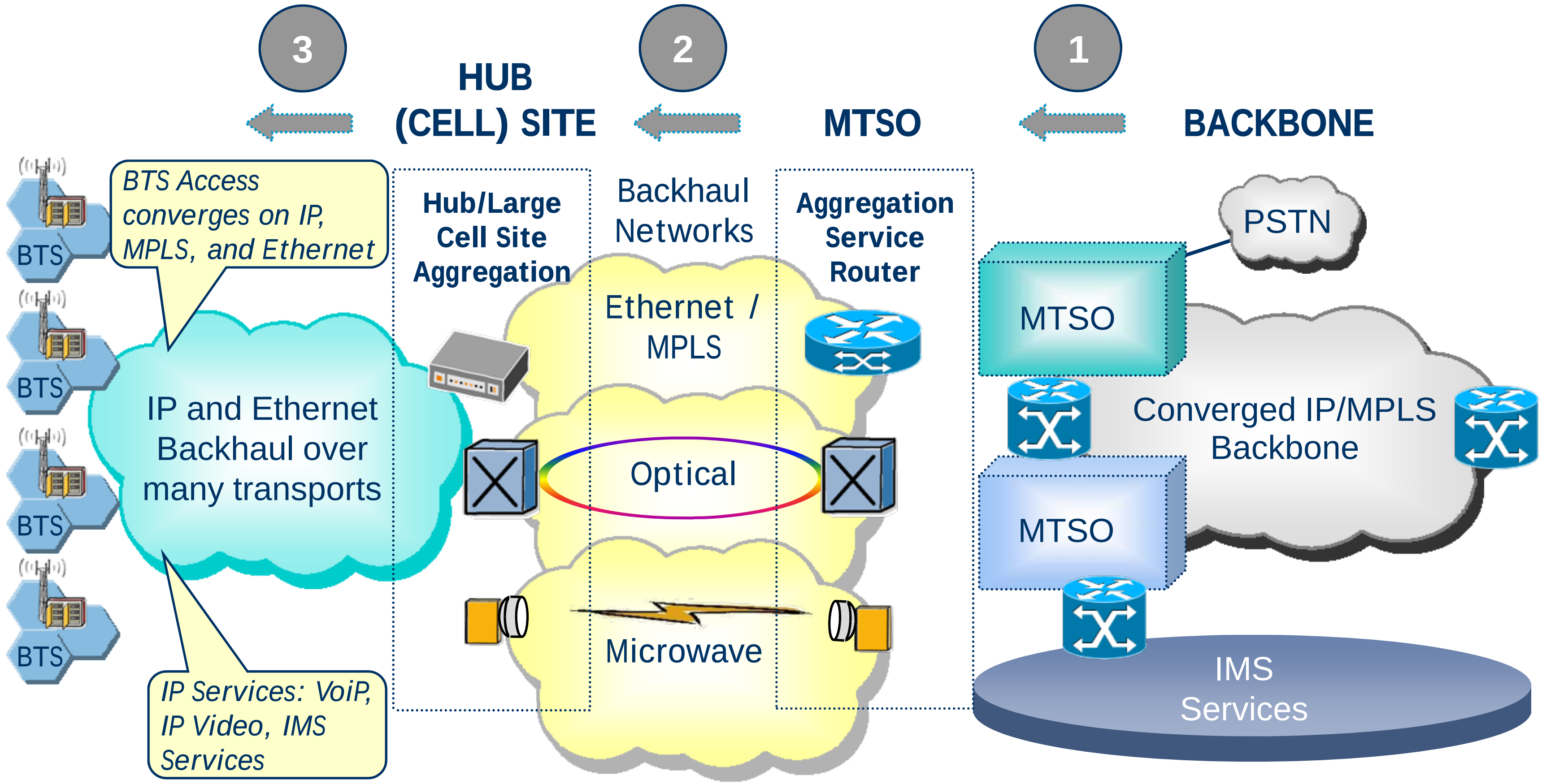


- **Multiple options for backhaul transport**
- **Varies based on geography, availability, volume, inter/intra carrier relationships**

Source: Infonetics

Mobile Transport Architecture

- Many RAN access / aggregation transport options
- New IP Services (Video, VoIP, IMS) are QoS sensitive and Bandwidth intensive
- IP/MPLS Packet Backbone capabilities move to the RAN



Packet based backhaul aims to solve the RAN requirements

- Help to cut down OPEX:
  - Cost drivers are similar to ‘Core”
  - Extend IP/MPLS towards backhaul
- Supporting Bandwidth Growth
  - N*T1 vs. Ethernet interface
- RAN is increasingly becoming a strategic asset
  - Lease vs. Own
  - Discussion around future proofing investment
- Backhaul requires diverse and co-existent technologies
  - Pseudowires facilitates co-existence of legacy technologies
  - Migration to converged network
- Provisioning/planning needs to be simplified
  - Advanced OAM, Troubleshooting

IP/MPLS

Why MPLS?

- MPLS is THE unifying technology for various backhaul types
- MPLS is proven in Service Provider deployments globally – it delivers on its promises
- MPLS adds carrier-grade capabilities
  - *Scalability* - millions of users/end points
  - *Resiliency* - high availability including rapid restoration
  - *Manageability* – ease of troubleshooting & provisioning
  - *Traffic Engineering plus QoS* – predictable network behavior
  - *Multiservice* – support for 2G, 3G ATM and IP RAN
  - *Traffic isolation* – VPNs to ensure separation of OAM from signalling / bearer planes, partitioning of multi-operator traffic

Why IP/MPLS in Mobile Backhaul ?

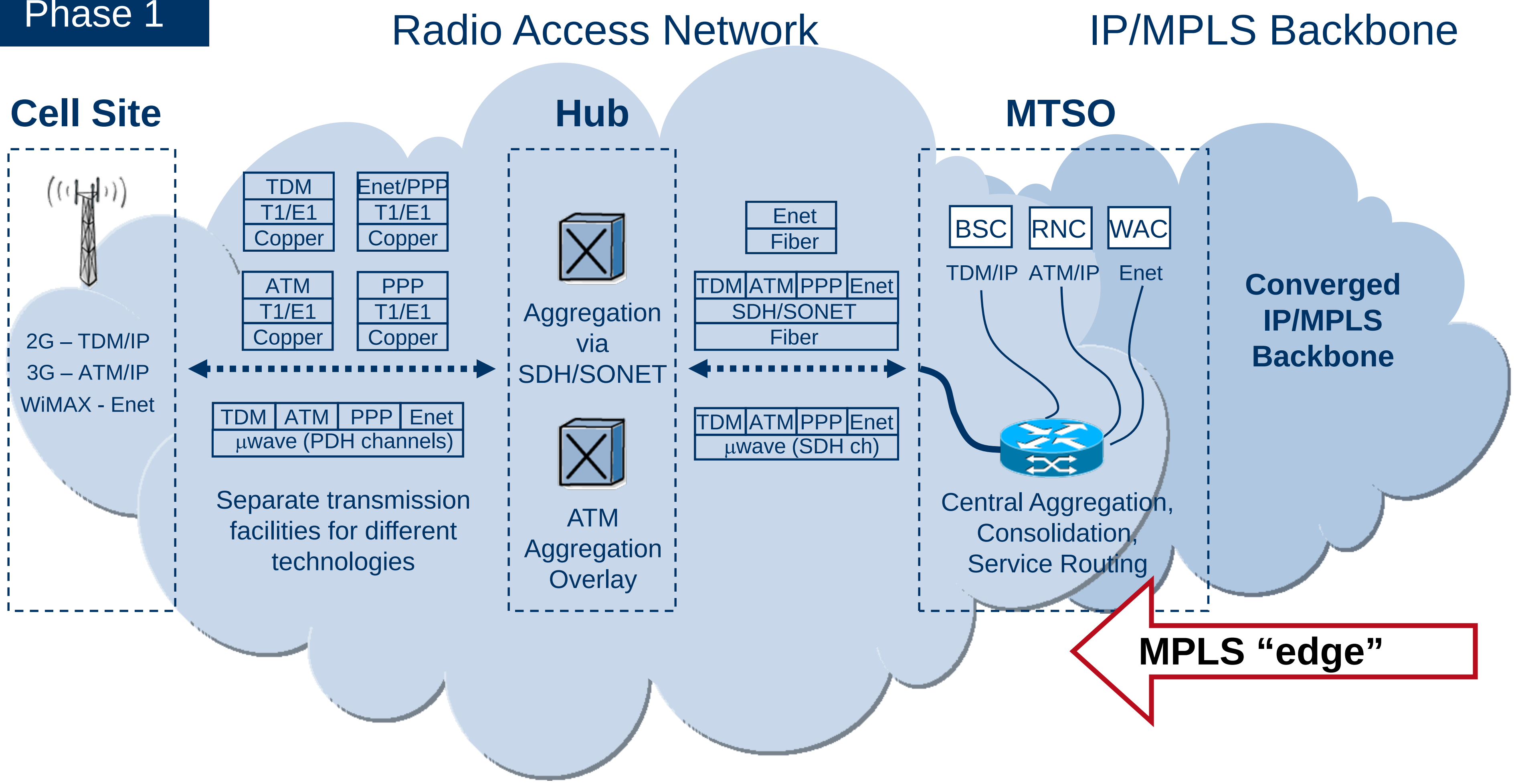
- **Backhaul requires co-existence of multiple transport options**
  - MPLS is proven mechanism to support ATM, TDM, Ethernet, HDLC emulation (Pseudowires)
  - Allows legacy RAN equipment to continue to be utilized (CAPEX protection) while leveraging the advantages of new packet transport options
- **Packet Backhaul needs to support multi-media traffic**
  - Voice/VoIP, Video, SMS,
  - MPLS –TE enables advanced QoS capability
  - Improved network utilization, Better ROI
- **Reliability is critical**
  - MPLS offers faster convergence and interoperable mechanisms for failure detection and recover
- **Backhaul is increasingly becoming a strategic asset**
  - MPLS at cell site enabled carriers to offer new revenue generating services (i.e. L2/L3 VPNs)

IP/MPLS

Scalability	Resiliency	*Multi-Service*	*manageability*	TE/QOS

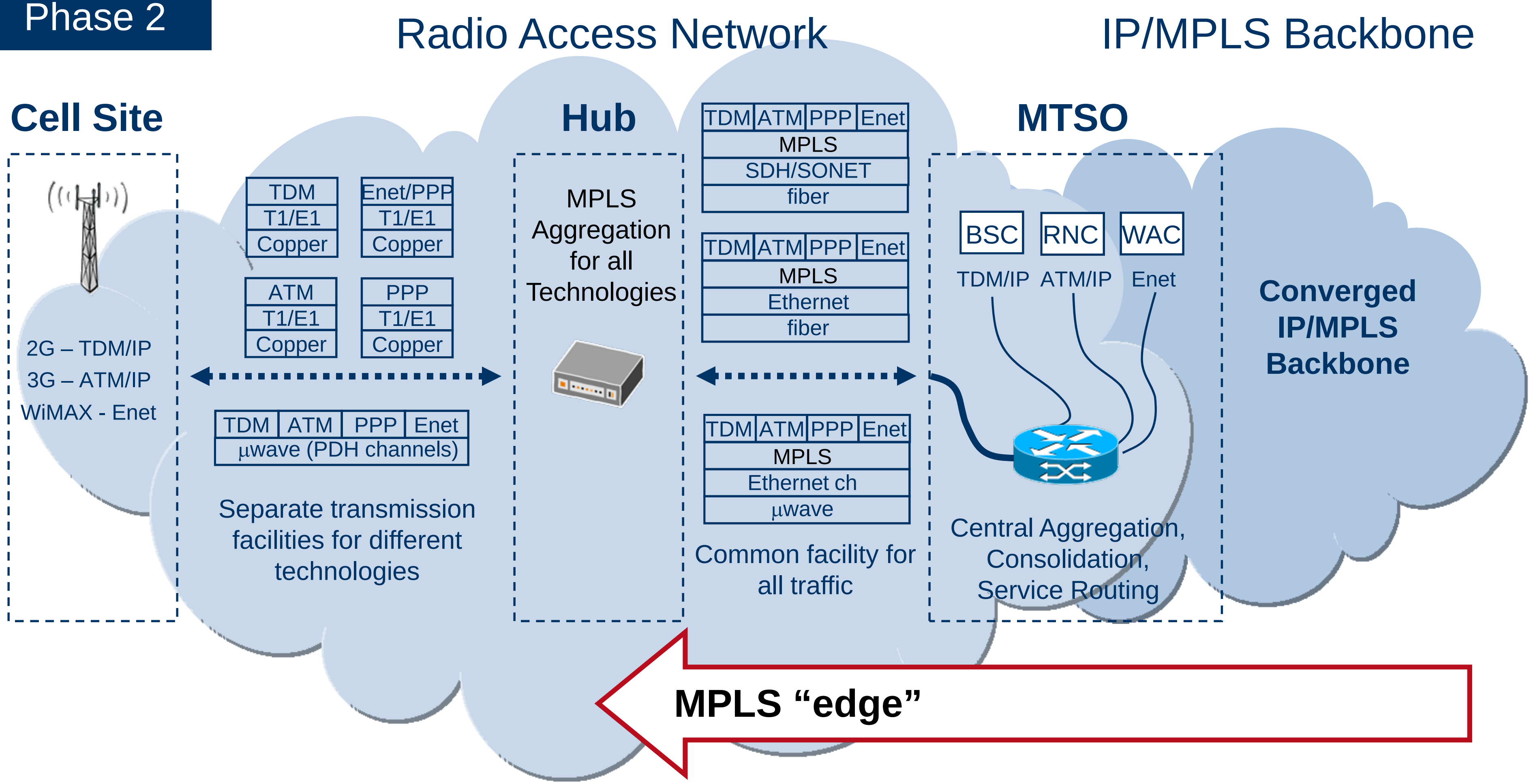
Multi-phase IP/MPLS migration into RAN Transport

Phase 1

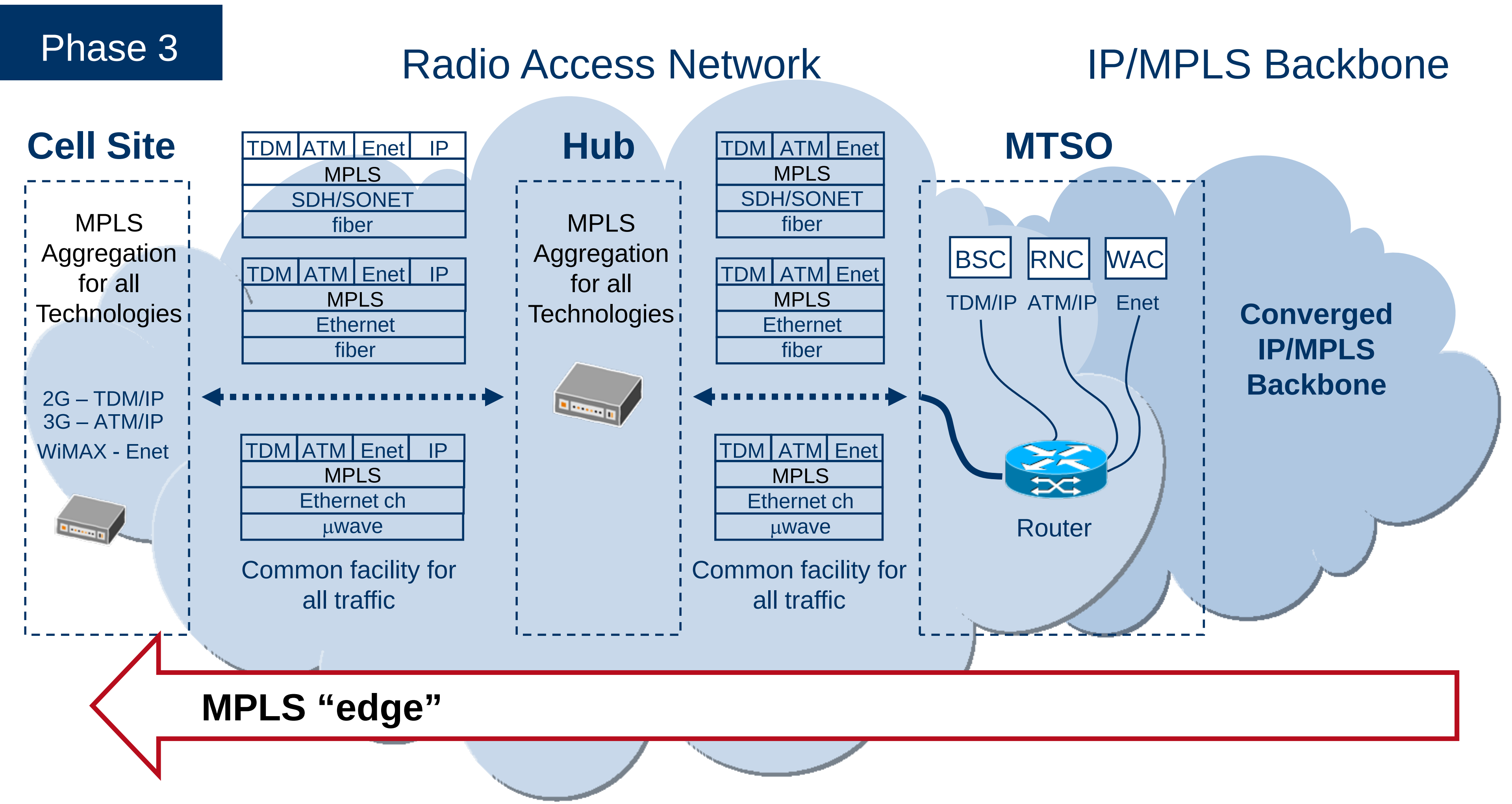


Multi-phase IP/MPLS migration into RAN Transport

Phase 2



Multi-phase IP/MPLS migration into RAN Transport



IP/MPLS is agnostic to transmission techniques in Access

What is MMBI ?

- **MPLS in Mobile Backhaul Initiative**
  - **Work item embraced by IP/MPLS Forum**
  - **Defining role IP/MPLS technologies in Mobile backhaul (including WiMAX)**

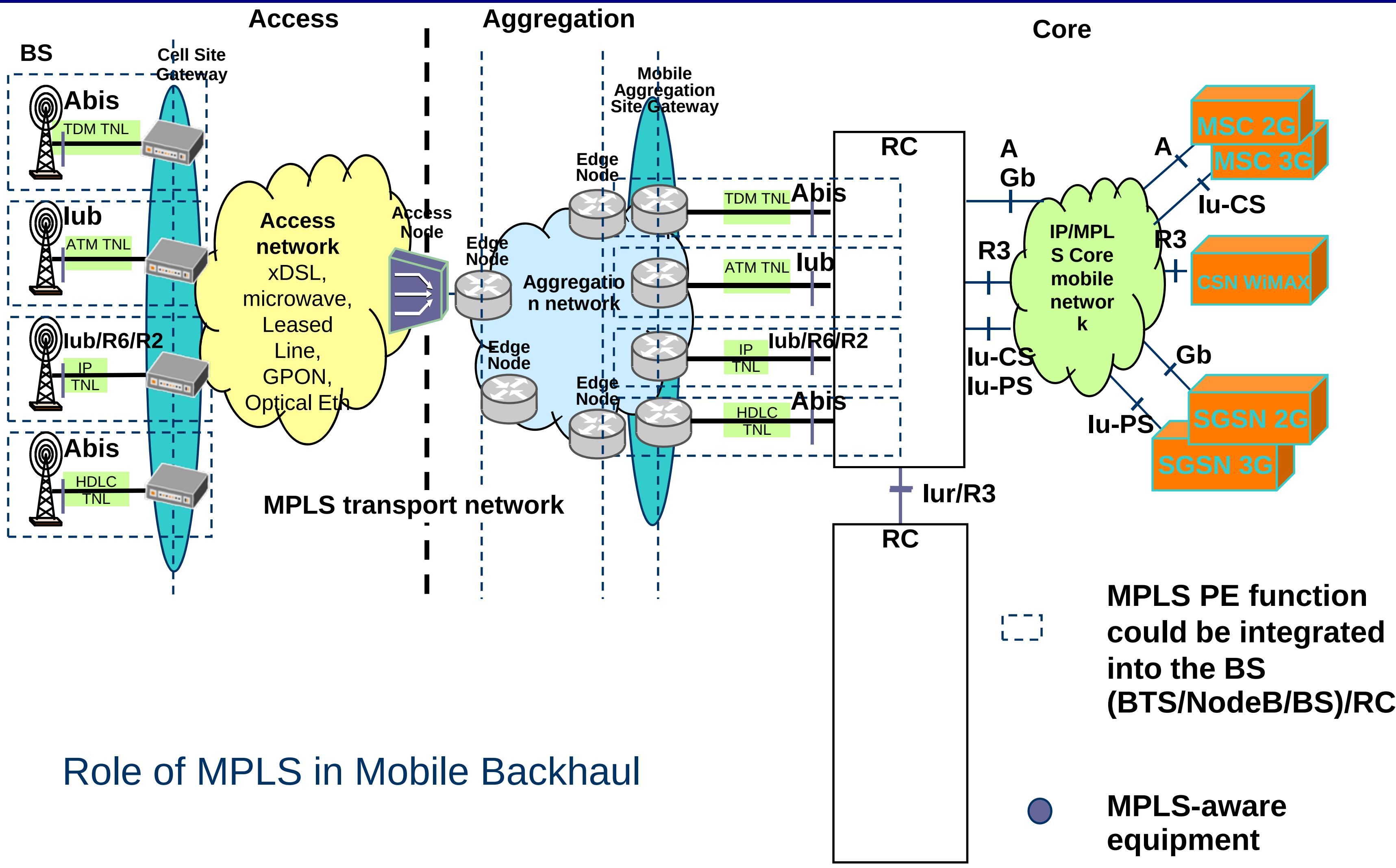
- **IP/MPLS Forum launched the industry wide initiative in 2Q 2007**
  - **Visit www.ipmplsforum.org**
  - **http://www.ipmplsforum.org/pressroom/MFA_Forum_mobile_backhaul_PRfinal.pdf**

- **MPLS has been globally deployed in wireline, wireless and converged core networks.**
- IP/MPLS Forum aims to complement the cost benefits of Ethernet with the proven track record of MPLS
- In recent years, IP/MPLS Forum has published implementation agreements to facilitate the migration of ATM and TDM to MPLS-based infrastructure

What MMBI aims to solve/ facilitate ?

- Faster mobile broadband deployment
  - HSPA/HSPA+/LTE, EV-DO/UMB, WiMAX
- Enhanced experience for mobile users with new data services and application, along with voice
  - Location based service, VoIP, gaming, etc
- Future-proof investments
- Improve mobile operator's bottom line and simplify operations
  - Converging technology specific backhaul networks to single multi-service packet infrastructure
  - Based on proven benefits of IP/MPLS while leveraging cost-benefits of Ethernet

MMBI Reference Architecture (more on this later)



Role of MPLS in Mobile Backhaul

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Section - 3 Agenda

- MPLS Basics

- MPLS Architecture
  - MPLS terminology and operation
  - Resiliency and Protection

MPLS Definition

- Multiprotocol Label Switching (MPLS) is a network technology that enables network operators to implement a variety of advanced network features, both to serve their customers and to enhance their own network utilization.
- These features are a result of the transformation of the connectionless per-hop behavior of an Internet Protocol (IP) network into a connection-oriented forwarding along MPLS Label Switched Paths (LSP).
- MPLS operates over enhanced IP routers, using enhanced IP protocols and leveraging IP Operations Administration and Management (OAM) systems. Thus, MPLS can be viewed as an extension of IP, rather than its replacement.
- MPLS works with both IPv4 and IPv6, it is complementary to IPv6 and can facilitate the IPv6 transition.

Label-Switching and MPLS

- Concept of “Label Switching” has been with the industry for over 20 years.
- Operation: add an independent “label” to user’s packets and use this label to forward the packets through the network.
- Primary advantages of labels in <u>initial</u> schemes:
  - Label can be precisely controlled
  - Hardware and software can be optimized around the label
- Examples of a label-switching technique in connection-oriented services: ATM, Frame Relay.
- MPLS is also a “labeling scheme” but the principal difference is that MPLS uses the same routing and end-point addressing schemes as IP.

Network Engineering vs. Traffic Engineering

- **Network Engineering**
  - **"Put the *bandwidth* where the *traffic* is"**
    - **Physical cable deployment**
    - **Virtual connection provisioning**
- **Traffic Engineering**
  - **"Put the *traffic* where the *bandwidth* is"**
    - **On-line or off-line optimisation of routes**
    - **Ability to diversify routes**

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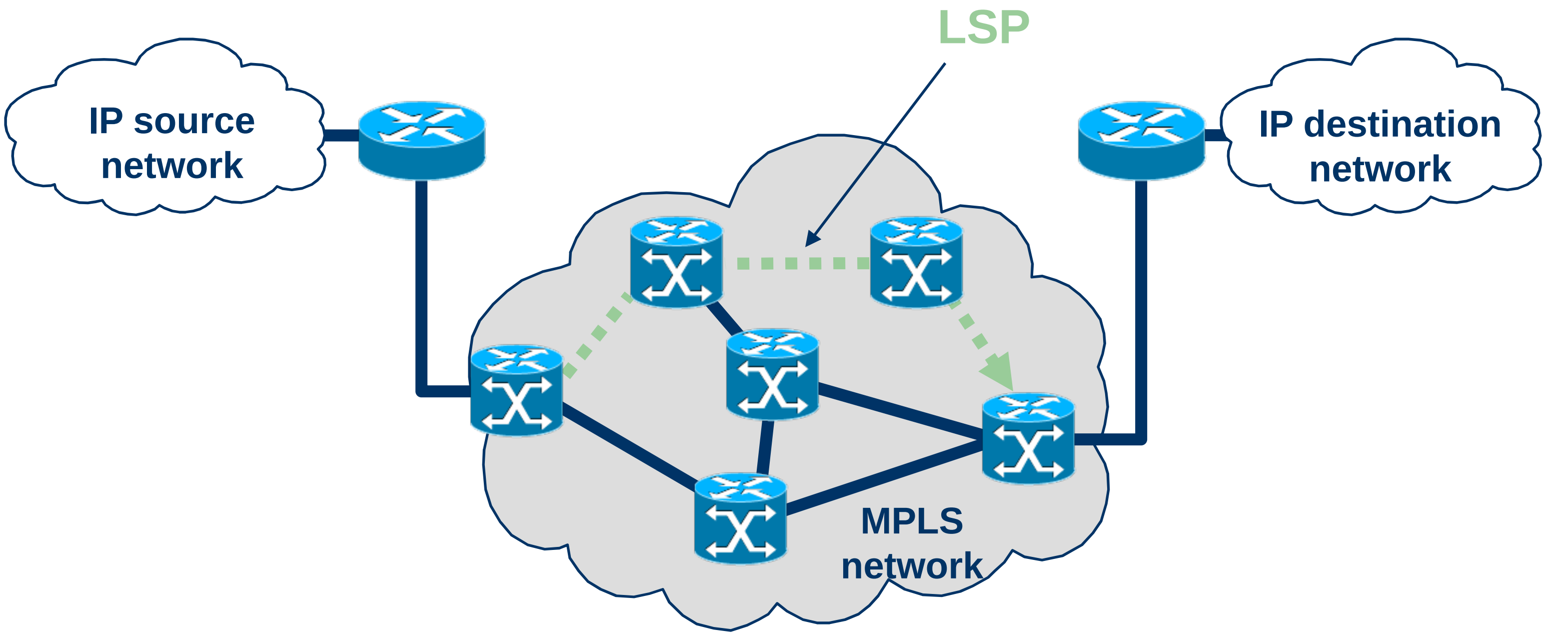
Data Plane vs. Control Plane

- Data Plane carries user information
- Control Plane creates the paths over which the Data Plane operates
- IP:
  - Data Plane: routing table lookup for egress interface
  - Control Plane: routing protocols
- ATM:
  - Data Plane: ATM header lookup
  - Control Plane: PNNI
- MPLS:
  - Data Plane: label pushing, swapping and popping
  - Control Plane:
    - Extended routing protocols (e.g., ISIS-TE)
    - Label distribution protocols (e.g., RSVP-TE)
    - Discovery protocols (e.g., BGP)

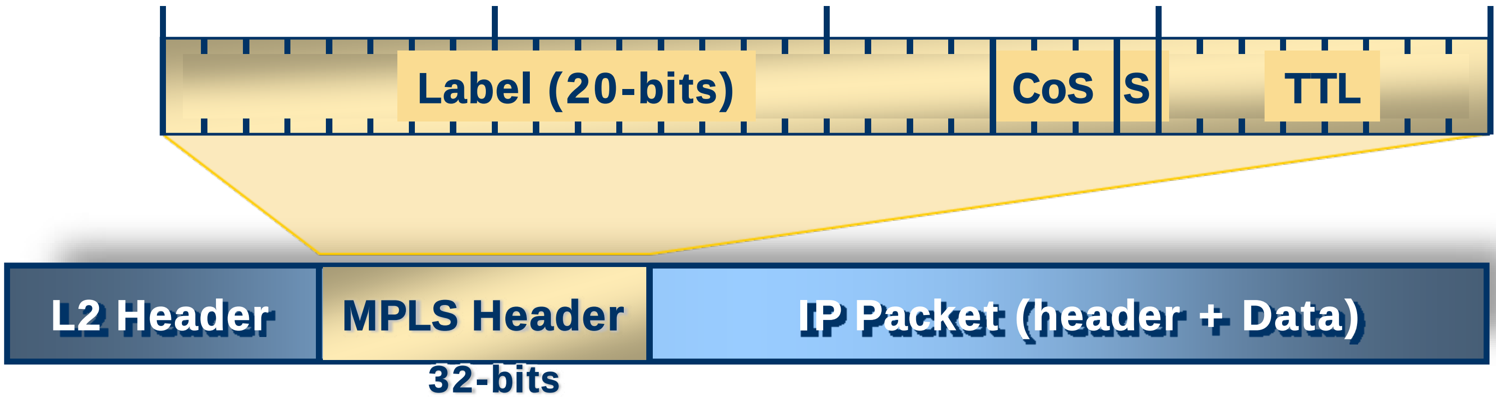
Label Switched Path (LSP)

- LSP is the path followed by labelled packets that are assigned to the same FEC



- FEC is Forwarding Equivalence Class
  - •This class is formed based on the equivalence in forwarding, i.e., "forwarding equivalence" FEC-to-label binding mechanism
  - Flow (stream, traffic trunk) of IP packets – forwarded over same LSP
  - FEC-to-label binding mechanism binding is done once, at the ingress

MPLS Header



- Fields
  - Label
    - short, fixed-length packet identifier
    - unstructured
    - link-local significance
  - Experimental (CoS)
  - Stacking bit
  - Time to live
- IP packet is encapsulated by ingress LSR
- IP packet is de-encapsulated by egress LSR
- Label stacking” means shim header stacking

Providing Resiliency with MPLS

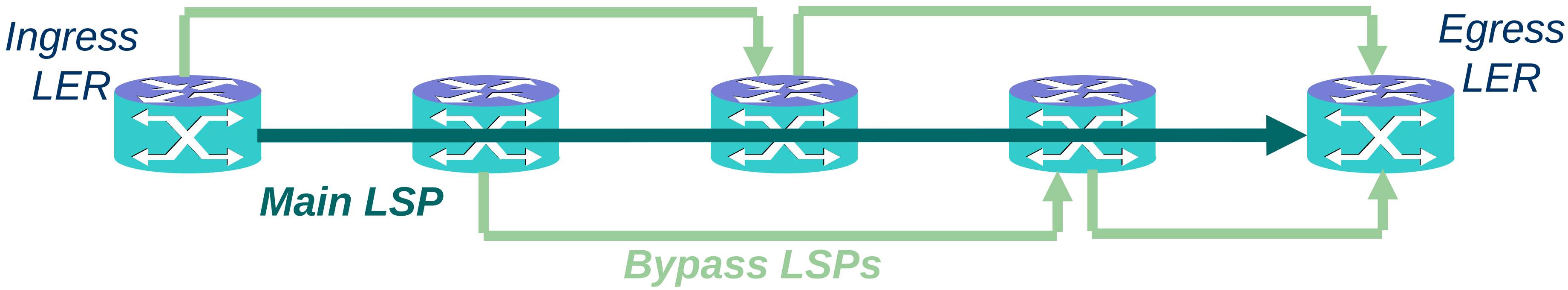
- Lower Layers
  - Partial or full mesh
  - Automatic Protection Switching strategies of SONET/SDH
- MPLS Layer
  - Outage
    - Protection and Re-routing procedures
  - Administrative
    - Re-optimization and Preemption
- IP Layer
  - IGP convergence algorithms

IGP: Internal gateway protocol

Carrier-Grade IP/MPLS *Protection*

- **Restoration time**
  - Recovery times smaller than IGP convergence times. 50ms fail-over possible.
  - Failover transparent to edge service protection mechanisms
- **Resource efficiency**
  - Leverages statistical gains over use of optical or SDH/SONET layers
- **Service differentiation**
  - MPLS enables granular levels of protection. This helps service differentiation (QoS, protection)
- **Node protection**
  - Service awareness assist in node protection or protection of layer 2 traffic
- **Robustness**
  - Route pinning avoids transient LSP behavior when SPF routing changes
- **Interoperability**
  - MPLS provides standardized protection in multi-vendor environments
  - RFC 4090: FRR extensions to RSVP

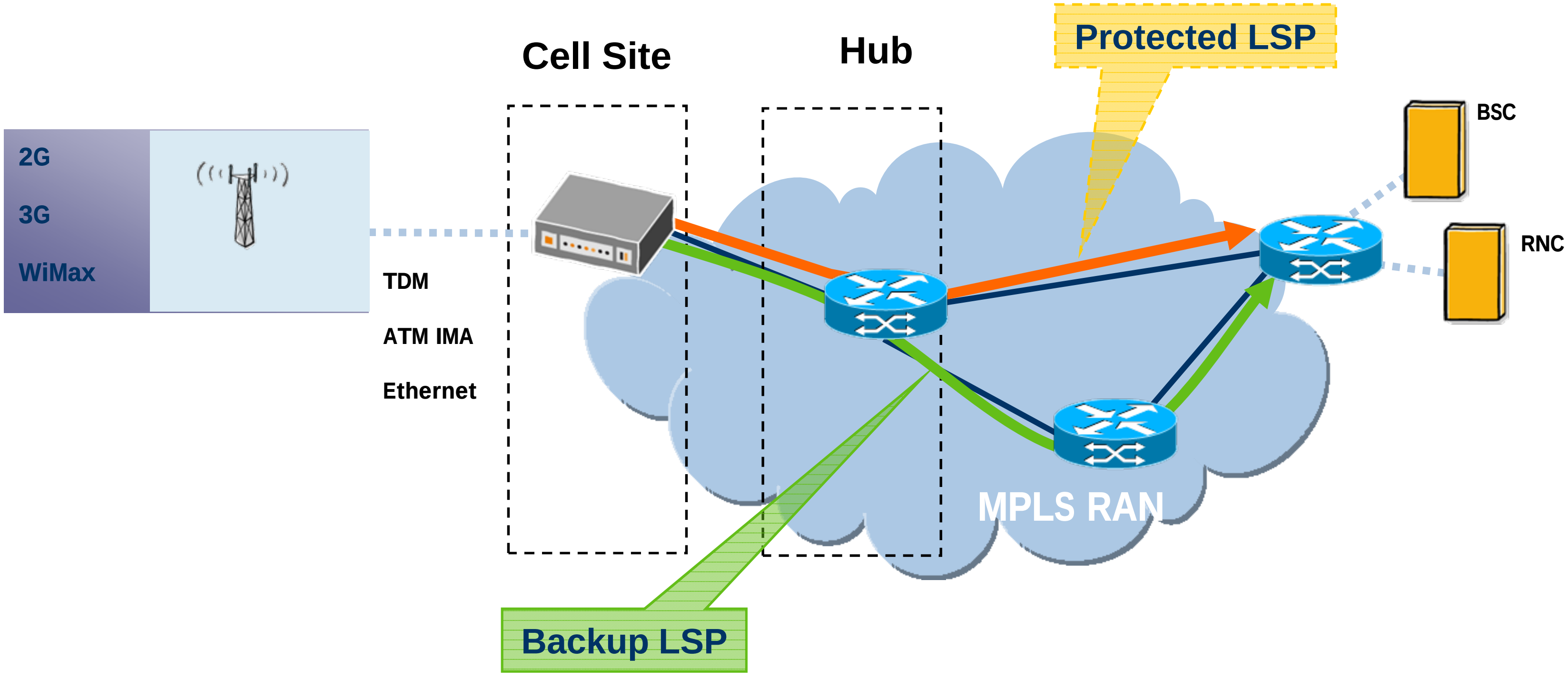
MPLS Tunnel Protection:
Fast Reroute



- **Create a bypass LSP around each component of the primary LSP**
- **In an outage, the LSR adjacent to the failure uses 'label stacking' to redirect the primary LSP to the bypass LSP**
- **At the penultimate hop *of the bypass* the top label *for the bypass LSP* is popped**
  - **Effectively, the bypass merges into the primary LSP**

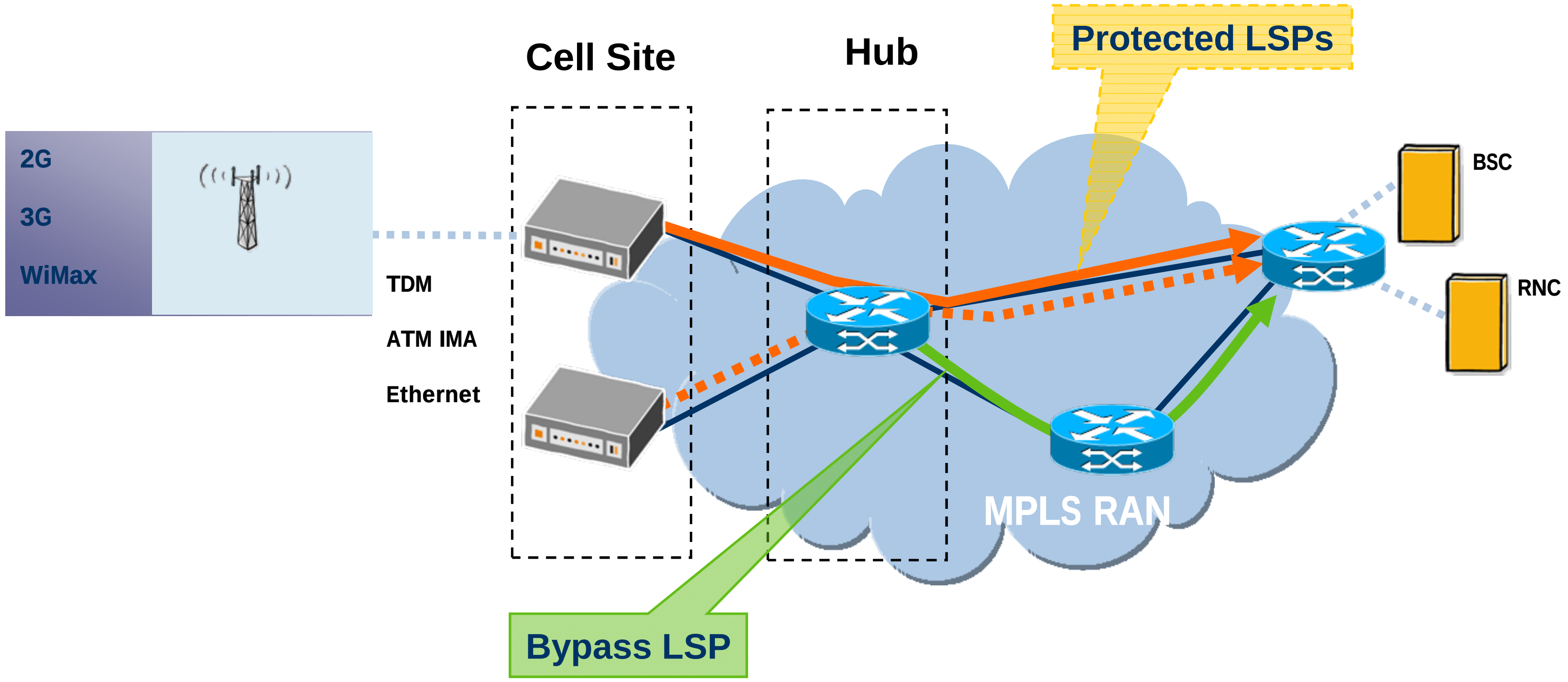
MPLS Protection of the outer tunnel

- **RSVP-TE Path Protection**
  - Hot or cold standby; disjoint primary/backup
  - Restoration depends on the network size, fault propagation delay (~100 msec range)
  - Protected path relies on CSPF



MPLS Protection of the outer tunnel

- **RSVP-TE Fast Reroute for Local Protection**
  - NNHOP bypass tunnels backup LSPs passing through bypassed segment
  - Facility: 1:n protection or Detour: 1:1 protection
  - Link and node protection; sub 50 msec recovery
  - Protected path relies on CSPF



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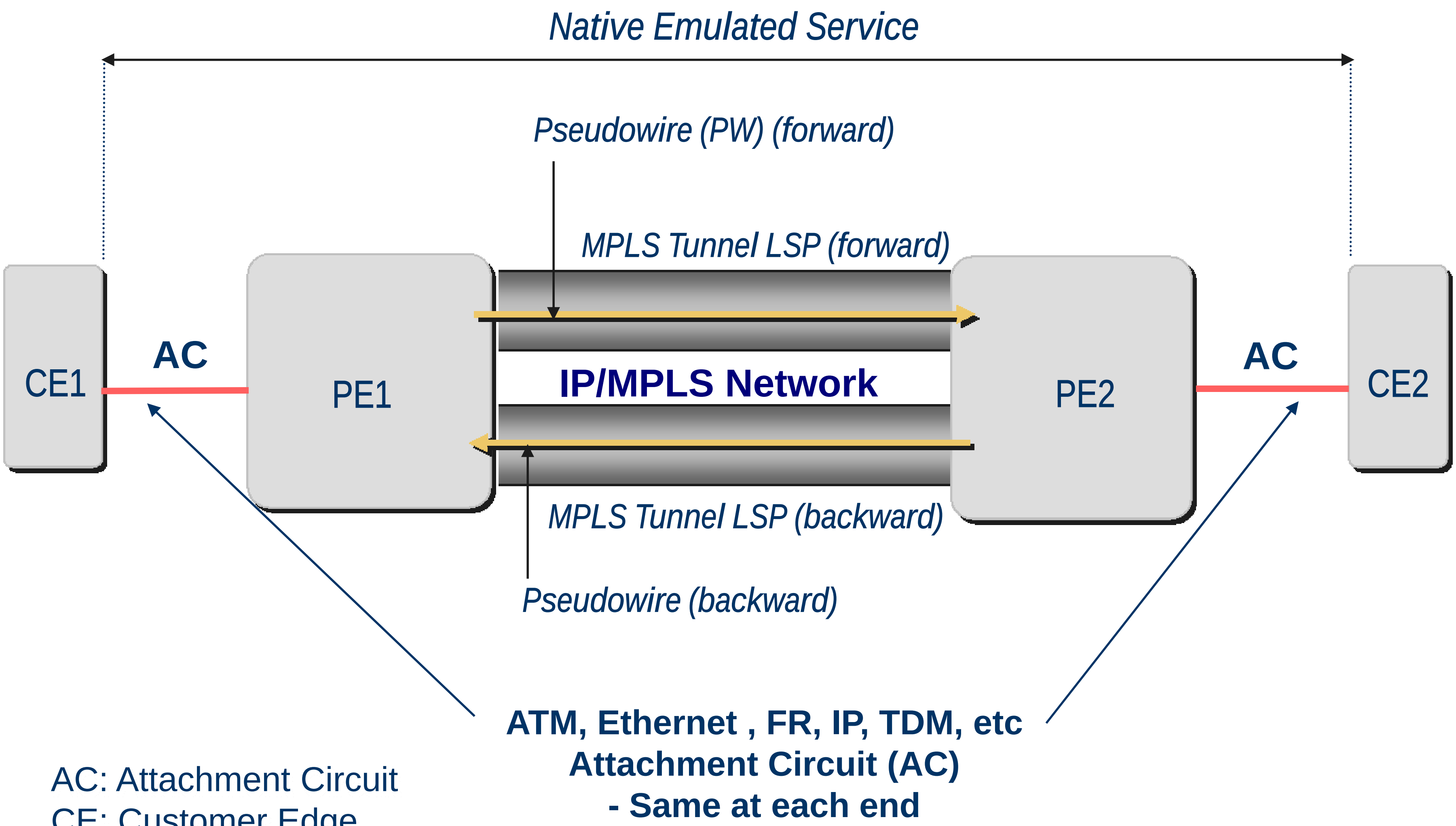
What is PWE3?

- PWE3 – "Pseudowire Emulation Edge-to-Edge" – Working Group assigned to study carriage of "Legacy and New Services" over MPLS
- Protocol encapsulations can be carried over MPLS
  - Legacy Services under consideration are:
    - FR, ATM, SONET & SDH, DS0, DS1, DS3, …
  - And new services such as:
    - Ethernet, VLANs, etc.

MPLS Pseudowire
Reference Model



AC: Attachment Circuit
CE: Customer Edge
PE: Provider Edge

MPLS Point-to-Point Services

Label Stacking

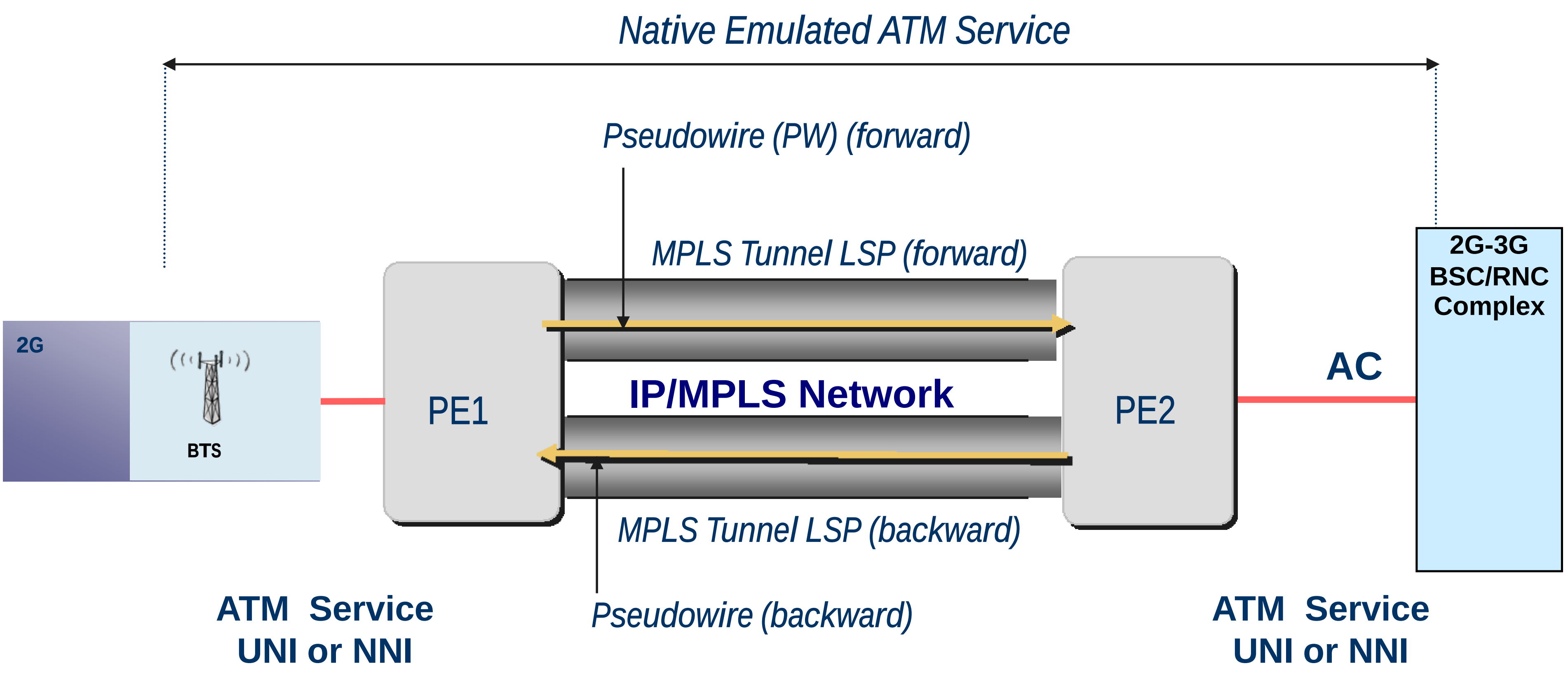
Tunnel Header	PW Header	VC Encaps Information	Layer 2 payload
1	2	3	

- **Three Layers of Encapsulation**
  1) **<u>Tunnel Header:</u> Contains information needed to transport the PDU across the IP or MPLS network**
  2) **<u>Pseudowire Header (PW):</u> Used to distinguish individual emulated VCs within a single tunnel**
  3) **<u>Emulated VC Encapsulation:</u> Contains the information about the enclosed PDU (known as Control Word)**
- **Tunnel Header determines path through network**
- **Pseudowire Header identifies VLAN, VPN, or connection at the end point**
- **All services look like a Virtual Circuit to MPLS network**

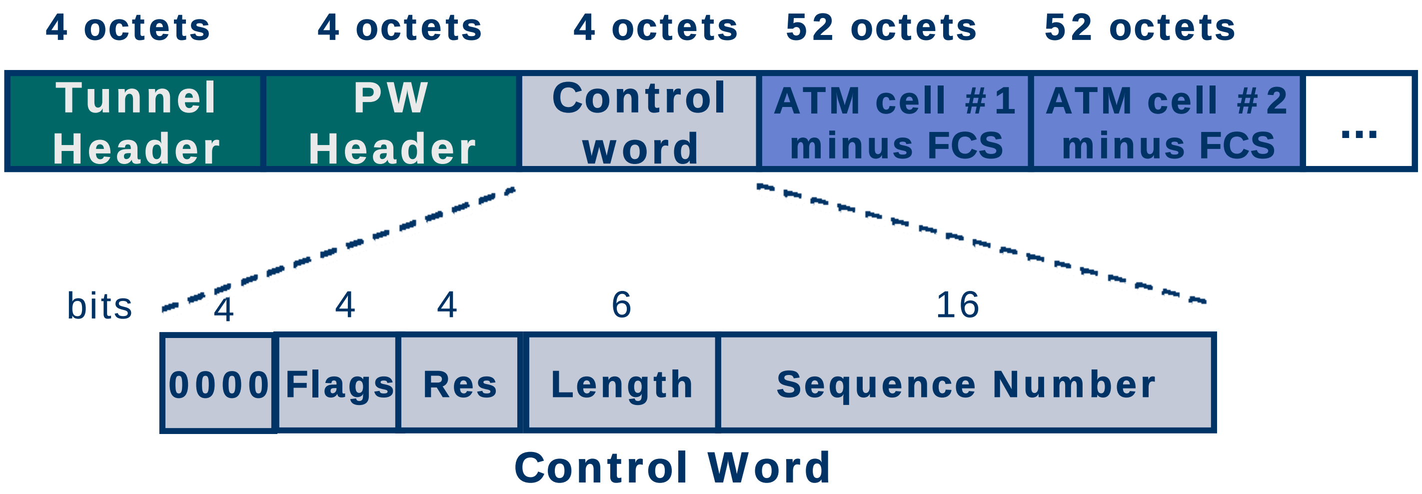
Layer 2 Encapsulation *PWE3*

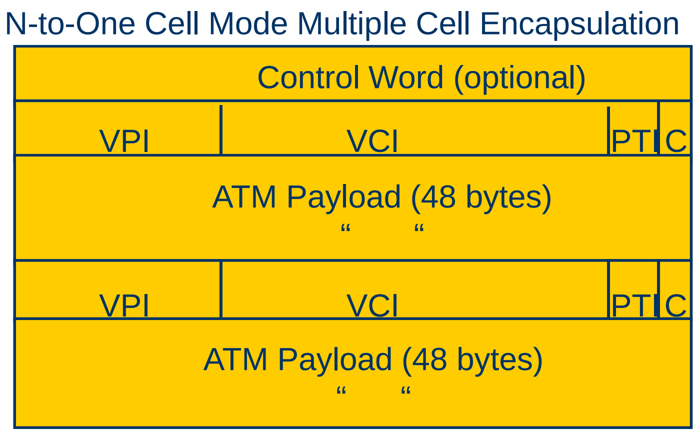
- ATM cell and ATM AAL5 ← 3G R99/R3 UMTS
  - RFC 4717
- TDM ← 2G
  - RFC 4553
- Ethernet / 802.1q VLAN ← 3G to 4G
  - RFC 4448
- PPP/HDLC ← CDMA
  - RFC 4618
- Structure-aware TDM Circuit Emulation (CESoPSN)
  - Draft-ieft-pwe3-cesopsn-07.txt

ATM Service Transport with a PW
Reference Model



ATM Cell Mode Encapsulation for Transport over MPLS

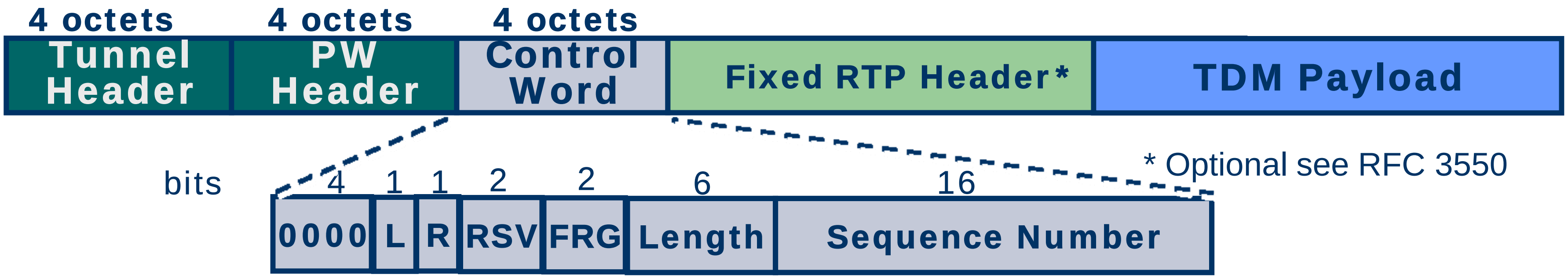




- **2 modes:**
  - **One-to-One Cell Mode - maps one ATM VCC (or VPC) to one PW**
  - **N-to-One Cell Mode - maps one or more ATM VCCs (or VPCs) to one PW** *(shown above);* **only required mode for ATM support**
- **Ingress performs no reassembly**
- **Control word is <u>optional</u>: If used, Flag and Length bits are not used**

RFC 4717

Structure-Agnostic TDM Encapsulation for Transport over MPLS (SAToP)



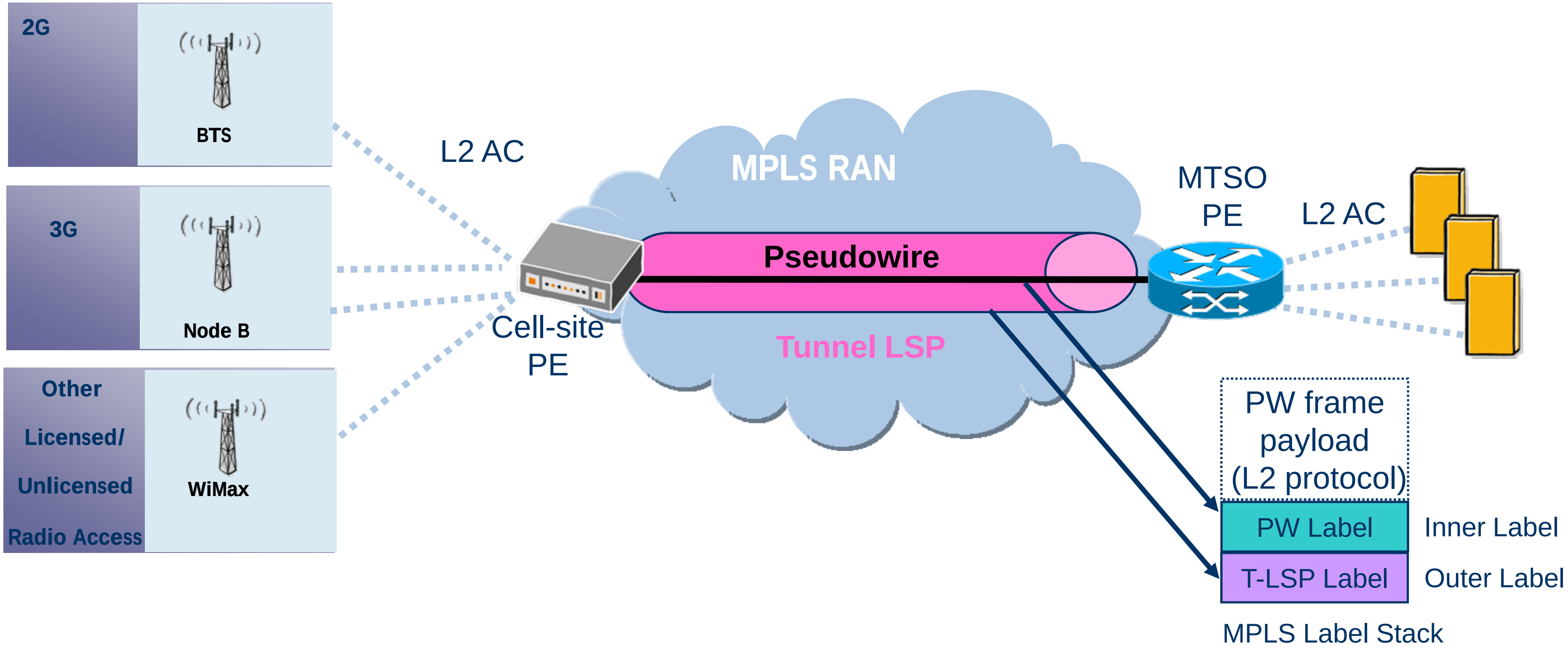
SAToP Control Word

- **Structure agnostic transport for TDM (T1, E1, T3 and E3) bit streams**
  - **Ignores structure imposed by standard TDM framing**
  - **Used in applications where PEs do not need to interpret TDM data or participate in TDM signaling**
- **SAToP Control Word allows:**
  - **Detection of packet loss or mis-ordering**
  - **Differentiation between MPLS and AC problems as causes for emulated service outages**
  - **Conservation of MPLS network bandwidth by not transferring invalid data (AIS)**
  - **Signaling of faults detected at PW egress to the PW ingress**
- **SAToP Control word includes:**
  - **L = Indicates TDM payload is invalid due to an attachment circuit fault (May omit payload to conserve MPLS bandwidth)**
  - **R = Set by MPLS-bound IWF to indicate local CE-bound IWF is in packet loss state (i.e., has lost a pre-configured number of consecutive packets)**
  - **RSV and FRG = Set to 0 by MPLS bound IWF and ignored by CE bound IWF**

RFC 4553

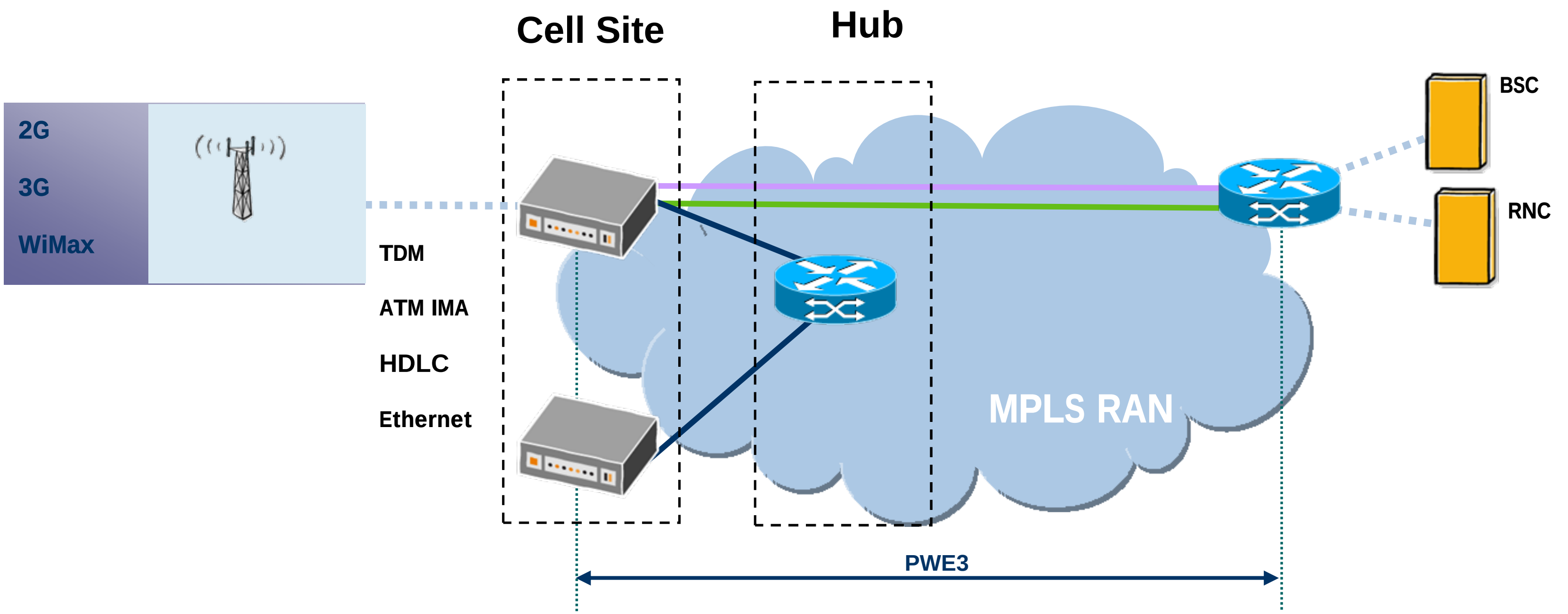
MPLS Pseudowires for Backhaul

- **Pseudowires**
  - Emulate a native layer 2 service, such as TDM, ATM VC/VP, FR VC, Ethernet, etc
- **Many PWs carried across MPLS network in a tunnel LSP**
  - PWs can utilise features of the MPLS network for resiliency, QoS, etc



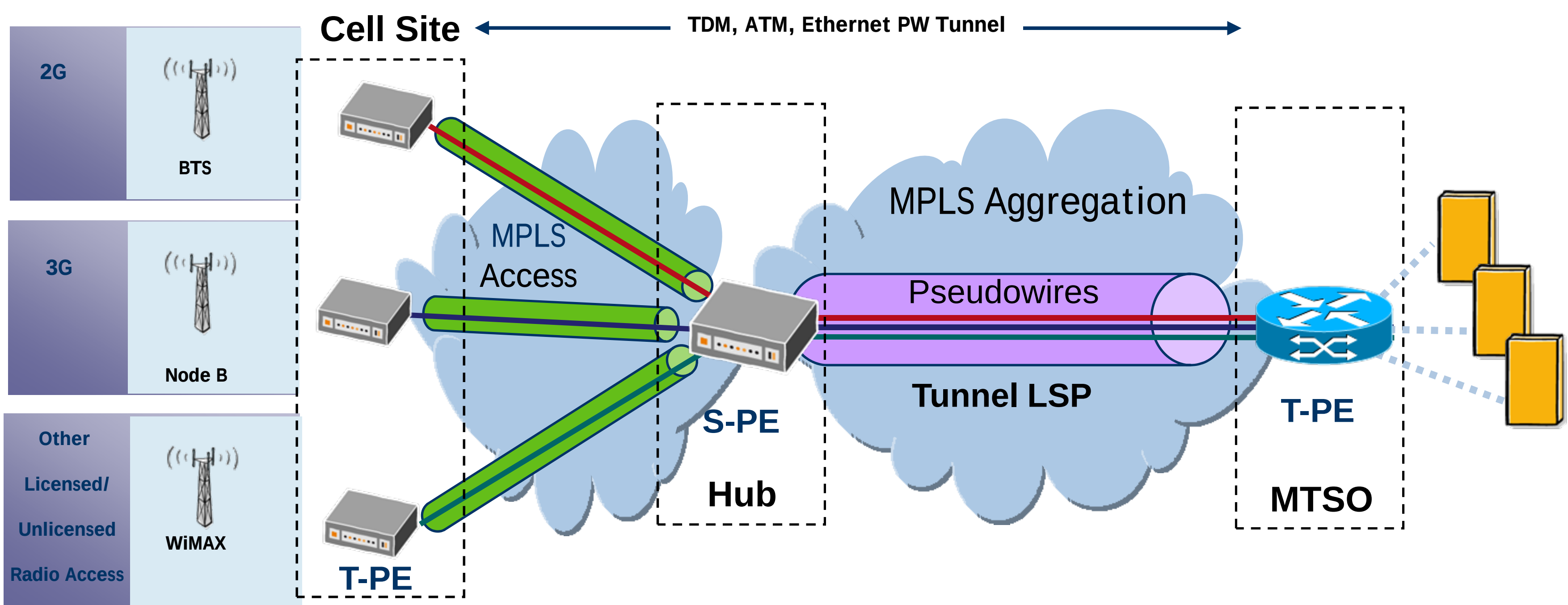
PWE3 at the Cell Site

- **ATM/TDM/Ethernet MPLS PWE3 from cell Site to MTSO**
  - PW switching at hub site can be considered to groom into a reduced set of LSPs trunks
  - Dynamic MPLS end-to-end or Static-to-Dynamic PW switching
  - Service classification reflected into EXP bits of LSP trunk



Multi-Segment PW for Backhaul

- **draft-ietf-pwe3-ms-pw-requirements and draft-ietf-pwe3-ms-pw-arch:**
  - A static or dynamically configured set of two or more contiguous PW segments that behave and function as a single point-to-point PW
  - Scalability – to hundreds of base stations connecting to RNC/BSC site
  - Multi-domain operation – including *multi-provider backhaul networks*
  - Multi-technology operation – leverage mechanisms from non-MPLS access infrastructures



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   - Operations, Administration and Management (OAM) capabilities of IP/MPLS RAN backhaul networks
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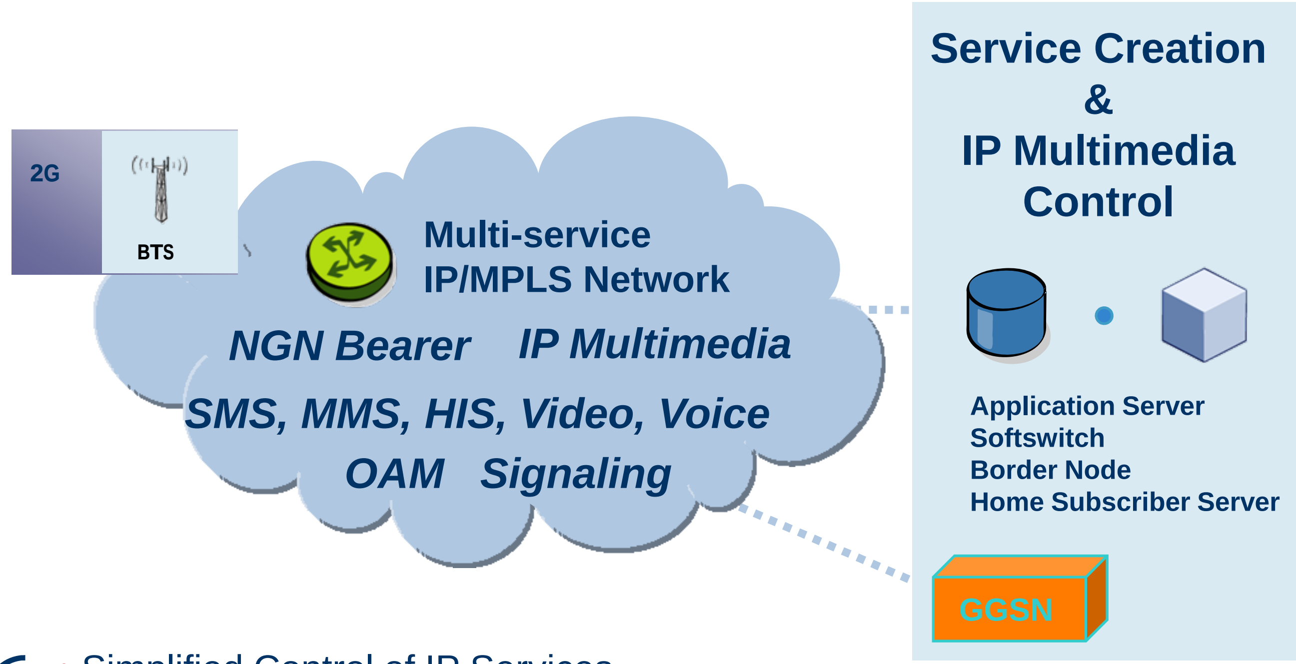
8. **IP/MPLS in the RAN**

OAM and Provisioning
Mobile Backhaul



- Operator expertise in voice/wireless/TDM
- Prefer to automate provisioning and minimize CLI training and script development

Need

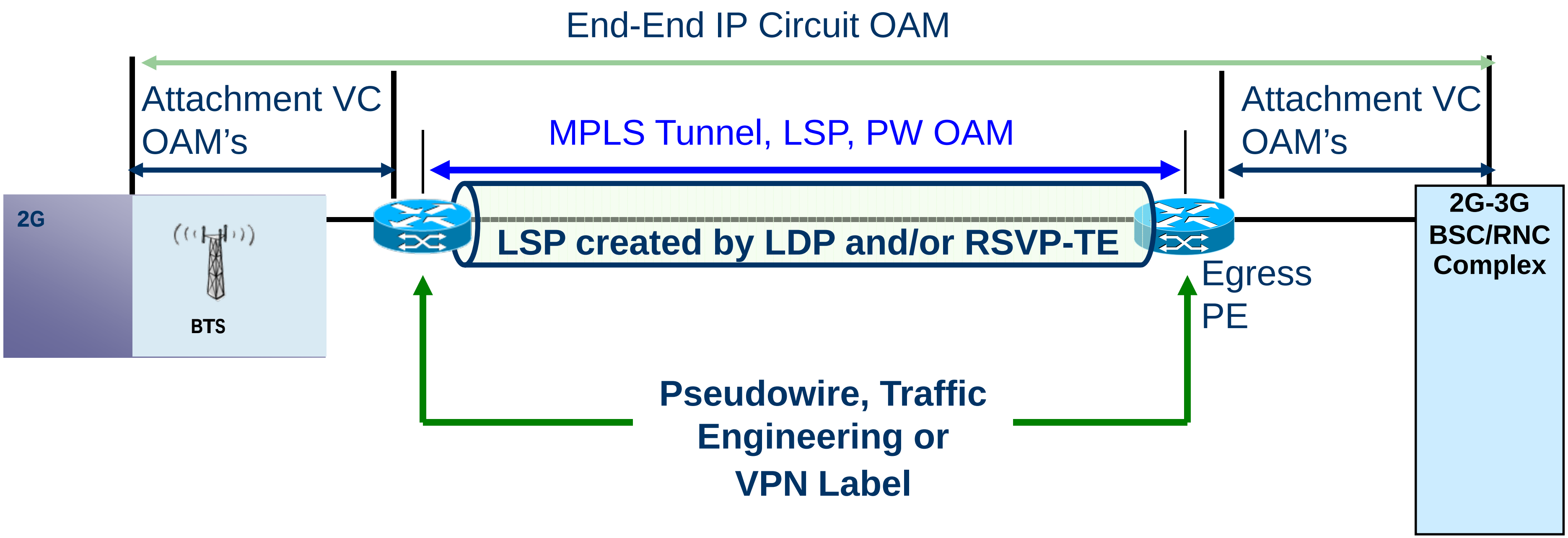
- Simplified Control of IP Services
  - **Configuration through a user-friendly graphical interface**

  Improved operator efficiency and accuracy
- Service-Oriented Platform Enables Service-Oriented Provisioning
  - **Provisioning is done at service level, not on individual port level**

  Increased Service offering flexibility and consistency
- Service Templates
  - **Common network-wide parameters, eliminating many input errors**

  Fast reliable deployment of services, network parameters & policies

Where does MPLS OAM fit



- **MPLS OAM mechanisms applicable between BTS and MTSO**

OAM and Service Assurance
Mobile Backhaul

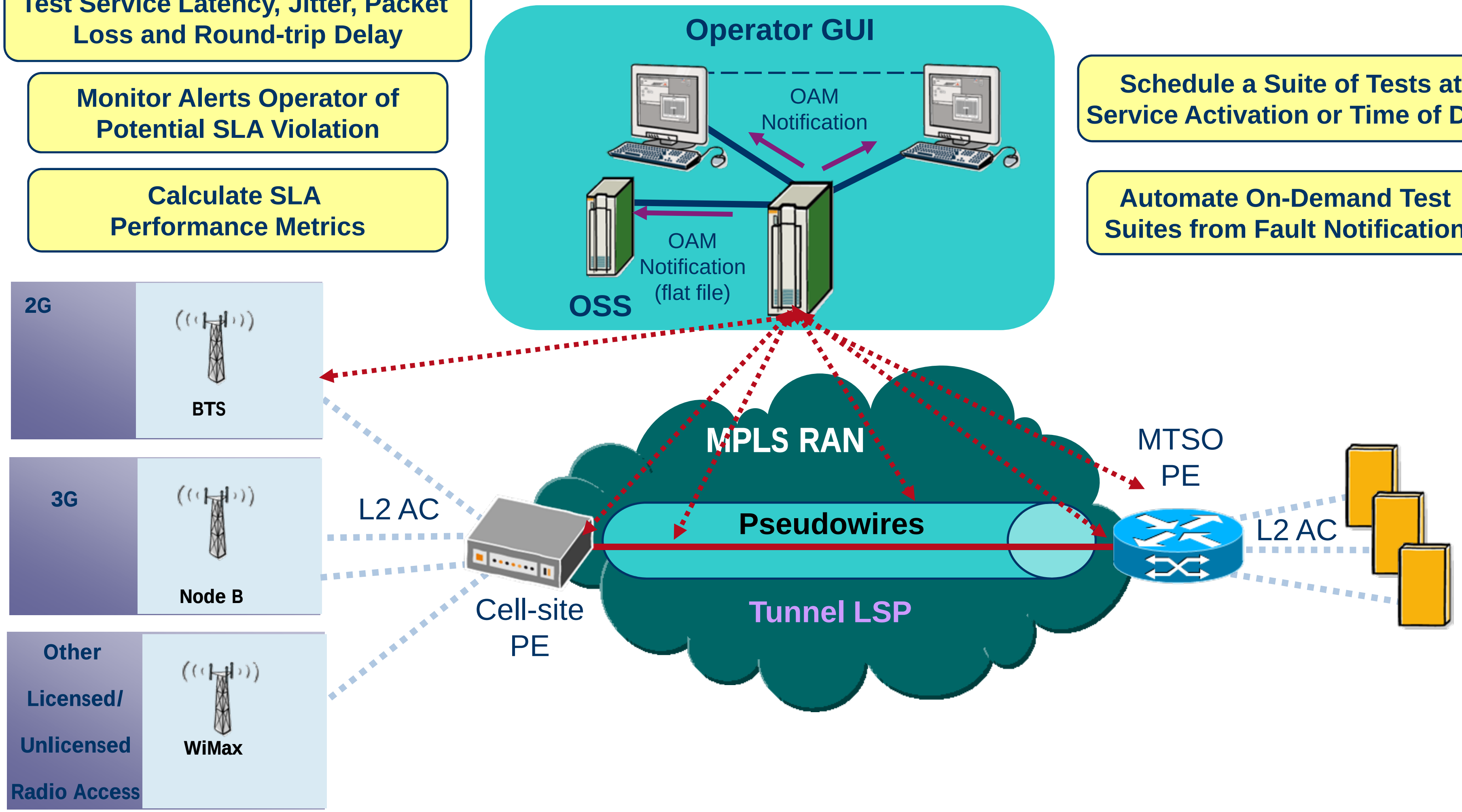
Test Service Latency, Jitter, Packet Loss and Round-trip Delay

Monitor Alerts Operator of Potential SLA Violation

Calculate SLA Performance Metrics

Schedule a Suite of Tests at Service Activation or Time of Day

Automate On-Demand Test Suites from Fault Notification



Simple, Powerful end-to-end tests to verify Service Delivery

LSP Ping - Overview

- LSP Ping is MPLS specific variation of traditional ICMP ping/traceroute ad hoc tool
  - Ping is simple e2e loopback
  - Traceroute uses TTL to incrementally verify path
- Ping paradigm useful for craftsperson initiated testing
  - TELNET/CLI
- LSP Ping is augmented with a number of TLVs processed by the receiver to extend functionality
- As LSP is unidirectional, and Ping is bi-directional, Ping is augmented with options for distinguishing real problems from return path problems

BFD - Overview

- Simple, fixed-field, hello protocol.
  Easily implemented in hardware.
  Very useful as a fault-detection mechanism.
- Nodes transmit BFD packets periodically over respective directions of a path
- If a node stops receiving BFD packets some component of the bidirectional path is assumed to have failed
- Applicable to tunnel end-points

MPLS Pseudowires for Backhaul: *OAM Requirements*

- **OAM needed for reactive & proactive network maintenance**
  - Quick detection and localization of a defect
  - Proactive connectivity verification and performance monitoring
- **OAM tools have a cost and revenue impact to carriers**
  - Reduce troubleshooting time and therefore reduce OPEX
  - Enable delivery of high-margin premium services which require a short restoration time
- **Top level requirements**
  - Provide/co-ordinate OAM at relevant levels in IP/MPLS network
  - Proactive and reactive mechanisms, independent at all levels

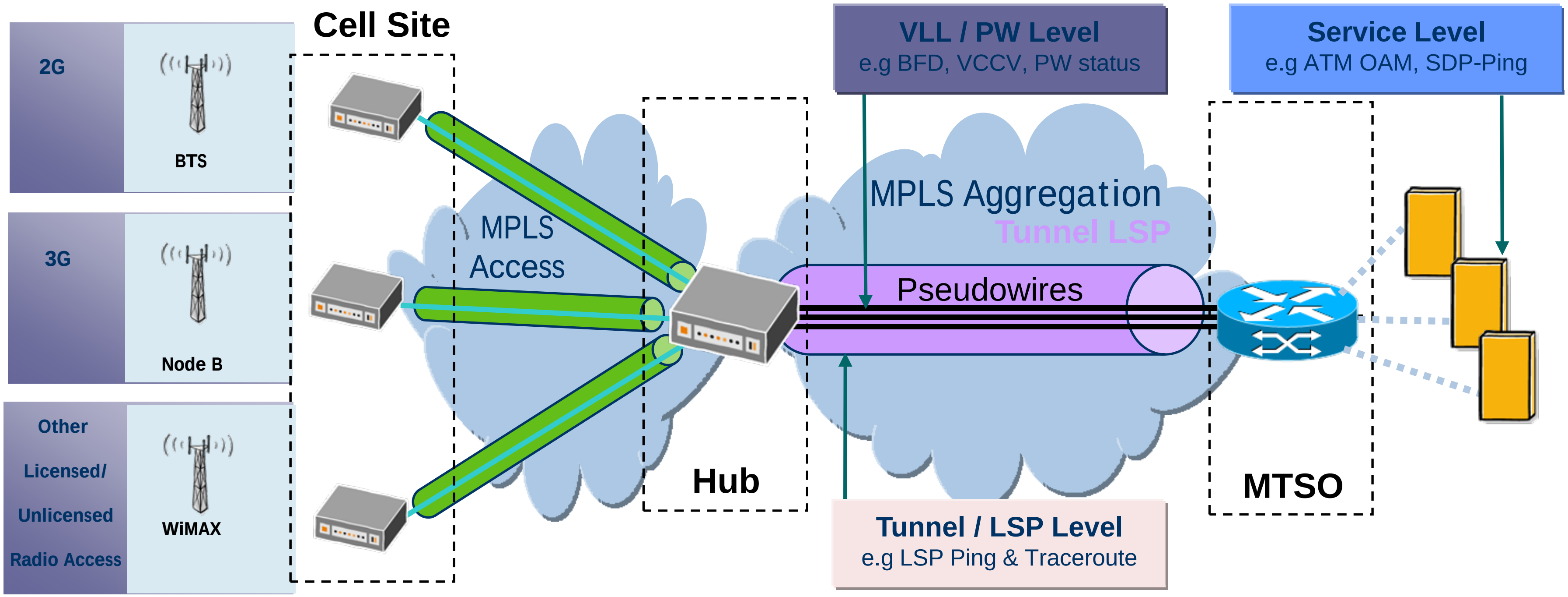
Service Level
e.g ATM OAM, MAC-Ping

VLL / PW Level
e.g VCCV, PW status

Tunnel LSP Level
e.g LSP ping

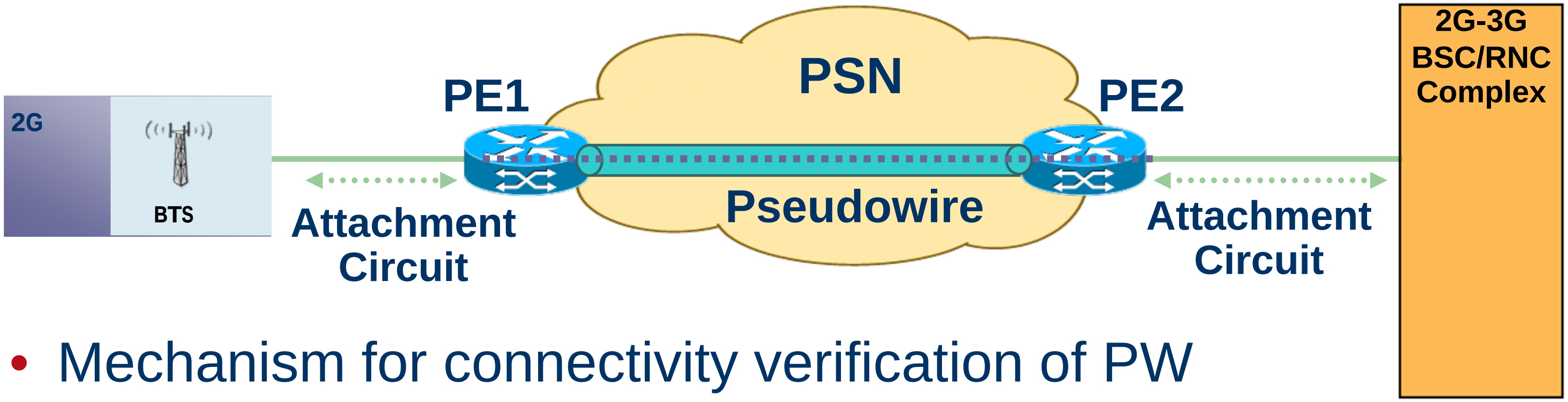
Service-Aware OAM Toolkit

- **Tool set for reactive & proactive network operation and maintenance**
  - **Defect detection, proactive connectivity verification, and performance monitoring**
  - **Provide/co-ordinate OAM at relevant levels in IP/MPLS network**
    - **Services Level: ATM, FR, ENet OAM, EFM, loopback, SAA**
    - **Tunnel LSP Level: LSP ping and LSP Traceroute**
    - **Pseudo Wire Level: PW Status, VCCV-BFD, TDM, FR, ATM notifications**



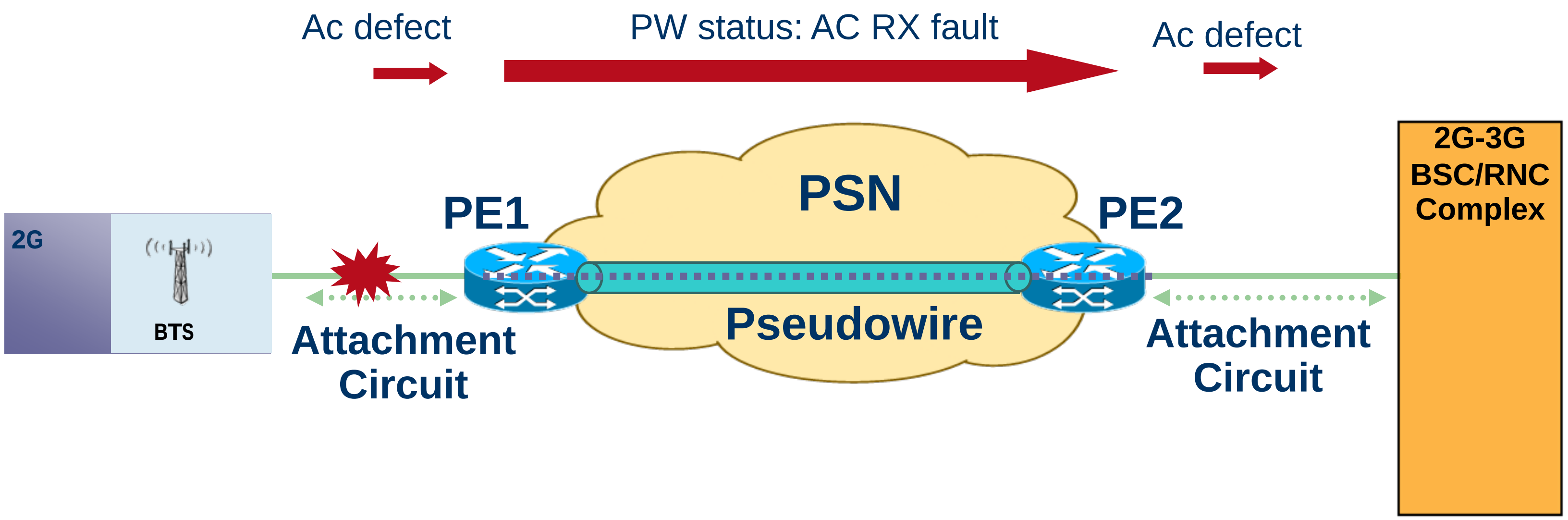
Quickly isolate and troubleshoot faults to reduce MTTR

Virtual Circuit Connection Verification (VCCV)



- Mechanism for connectivity verification of PW
- Multiple PSN tunnel types
  - MPLS, IPSec, L2TP, GRE,…
- Motivation
  - One tunnel can serve many pseudo-wires
  - MPLS LSP ping is sufficient to monitor the PSN tunnel (PE-PE connectivity), but not PWs inside of tunnel
- Features
  - Works over MPLS or IP networks
  - In-band CV via control word flag or out-of-band option by inserting router alert label between tunnel and PW labels
  - Works with BFD, ICMP Ping and/or LSP ping

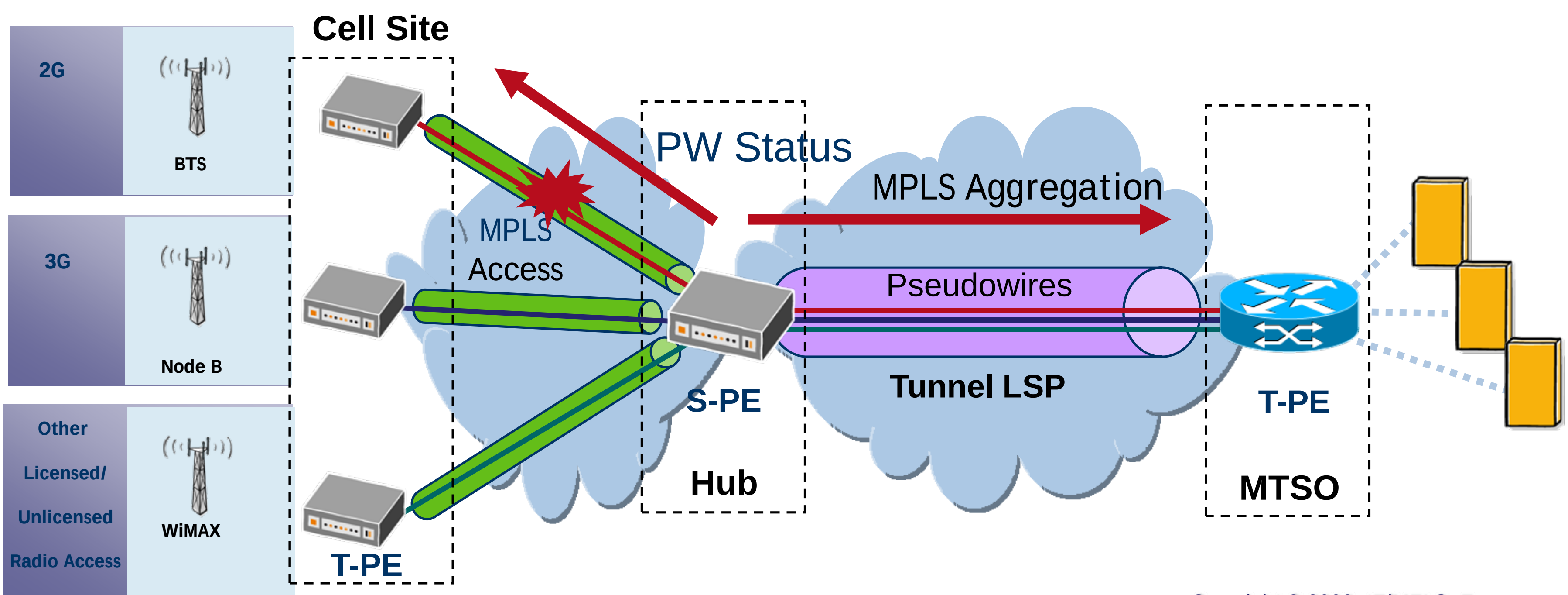
PW Status Signaling



- **PWs have OAM capabilities to signal defect Defect notifications:**
  - **Defect status mapped between AC and PW in the PE**
  - **PW status signaling propagates defect notifications along PW**
    - **Extension to T-LDP signaling**

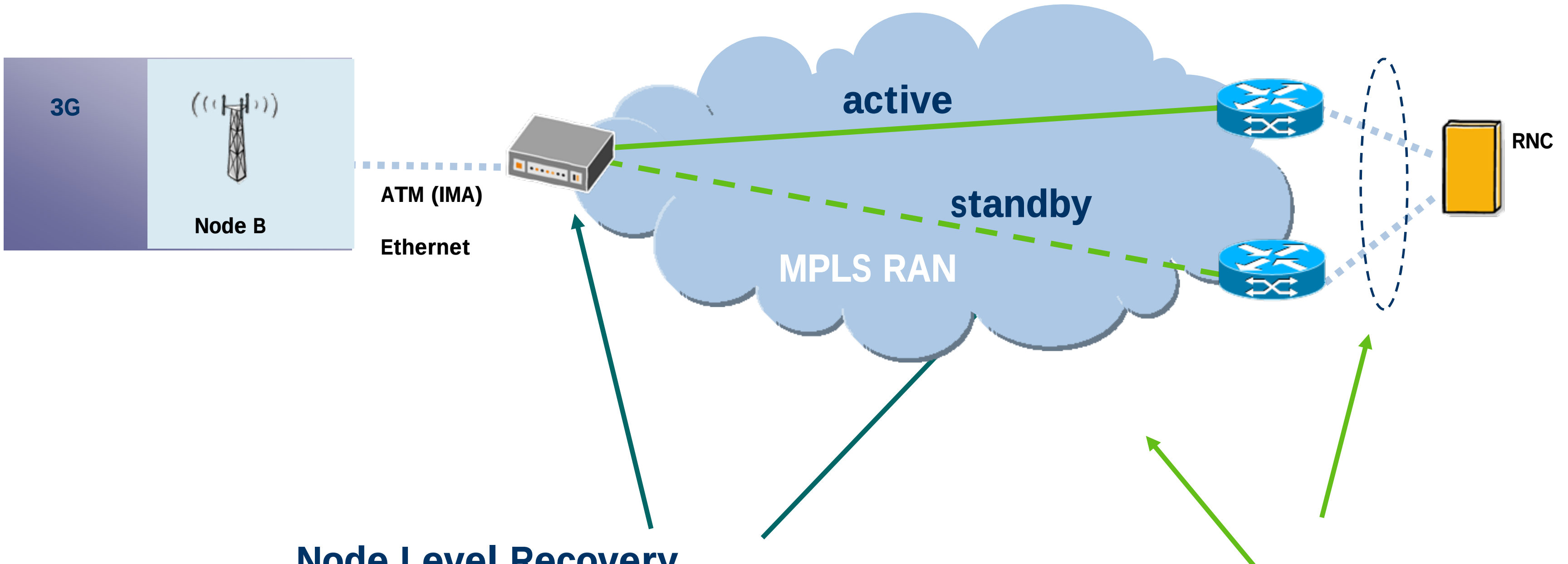
PW Status Signaling: Multi-segment PWs

- **PW status signaling also works for MS-PWs**
- **S-PEs:**
  - **Transparently pass remote defect notifications**
  - **Generate notifications of local defects**



MPLS Network Reliability

Both node level and network level recovery are required



Node Level Recovery

- Non-stop routing for ALL protocols (LDP, OSPF, BGP, IS-IS, multicast, PIM-SM)
- Non-Stop Service for ALL services (VPLS, VLL, IP-VPN, IES, multicast)

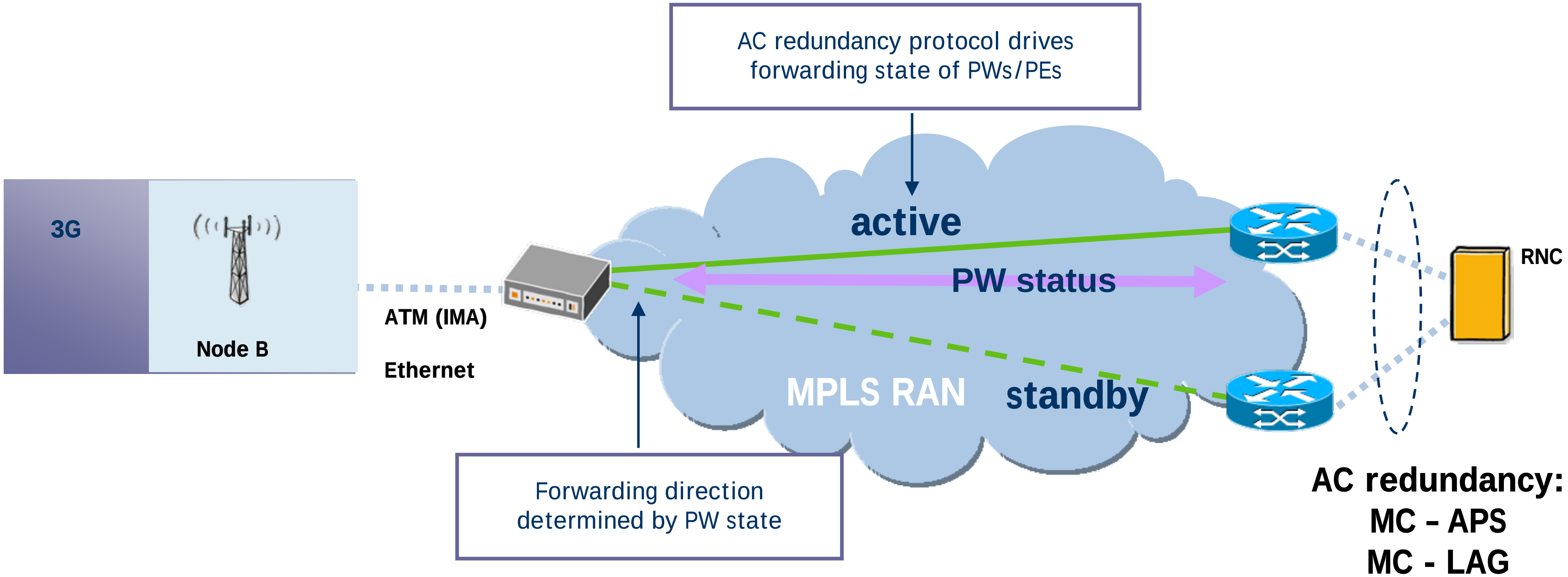
Network Level Recovery

- Dual-homing w/o RSTP
- MPLS FRR
- MPLS Standby Secondary
- Sub 50 ms restoration
- End-to-end path protection

PW Redundancy

Protects against PE and AC failures

- PE configured with multiple pseudowires per VLL service with multiple end-points
- Local precedence indicates primary PW for forwarding if multiple PWs are operationally UP
- PW status exchanged end-to-end to notify PEs of operational state of both PWs & ports / attachment circuits (PW Status Notification).



draft-muley-pwe3-pw-redundancy- & draft-muley-dutta-pwe3-redundancy-bit-

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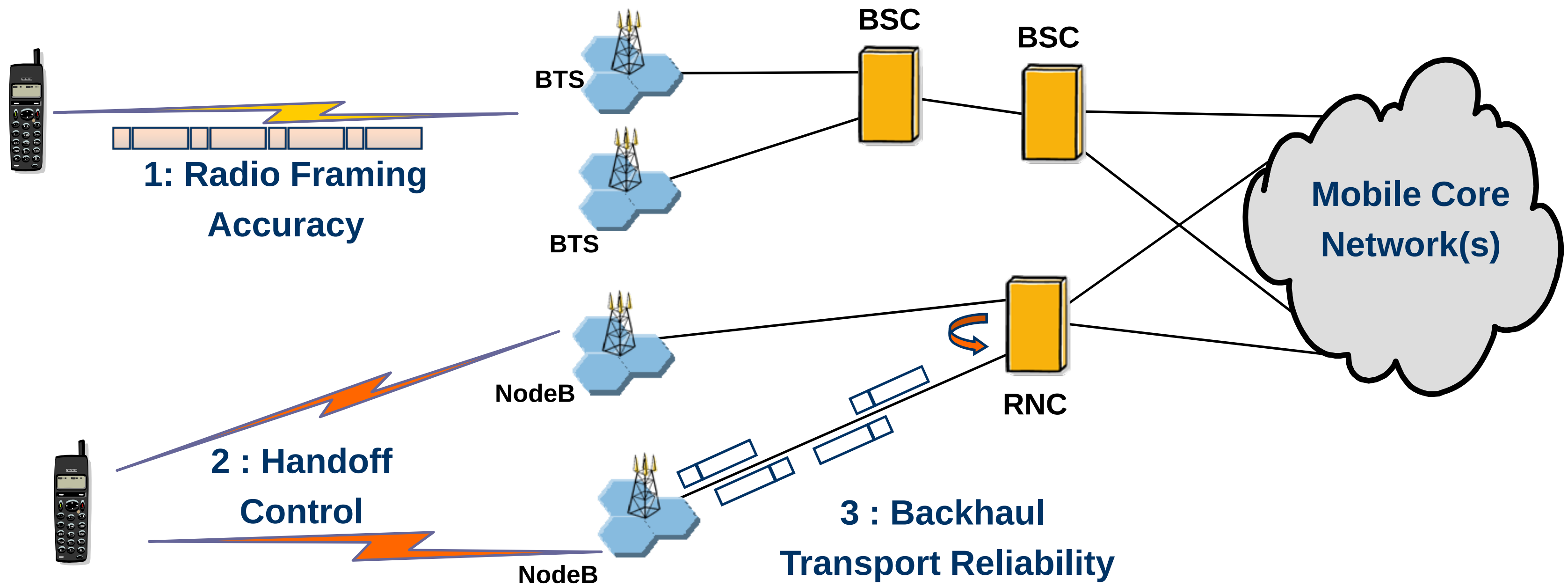
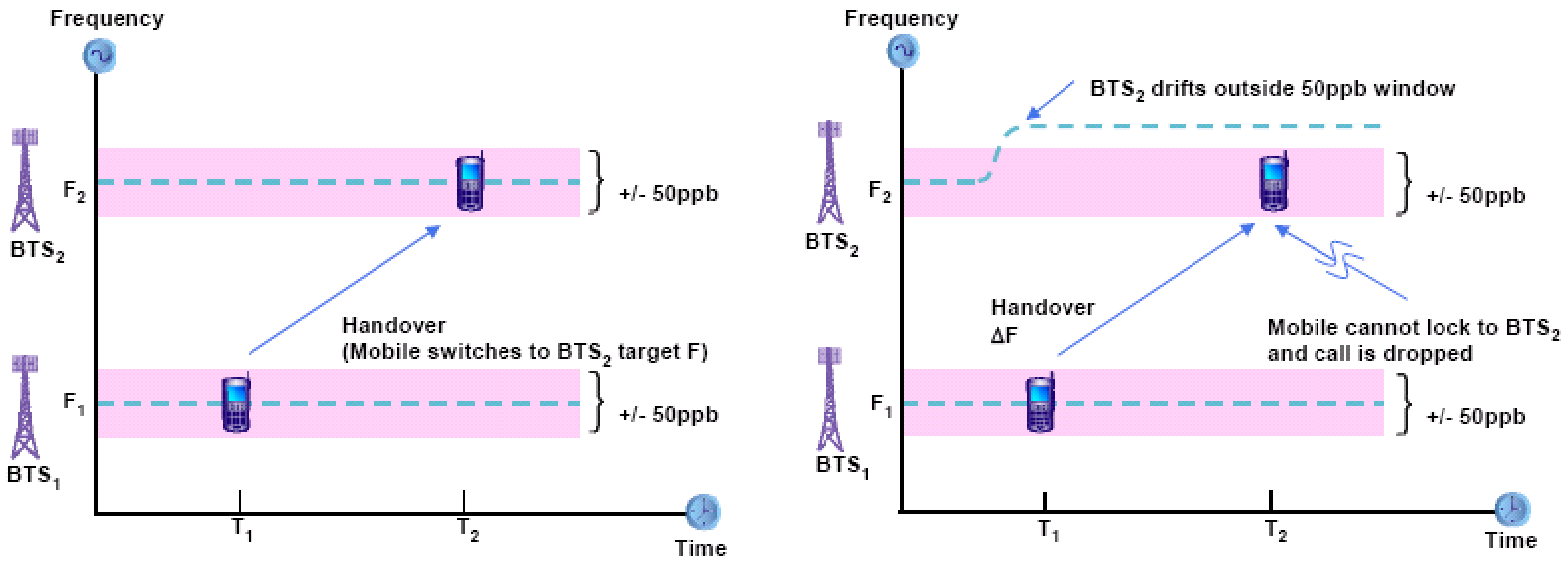
The Need for Synchronization in Mobile Networks

- Synchronization is vital across many elements in the mobile network
- In the Radio Access Network (RAN), the need is focused in three principal areas:

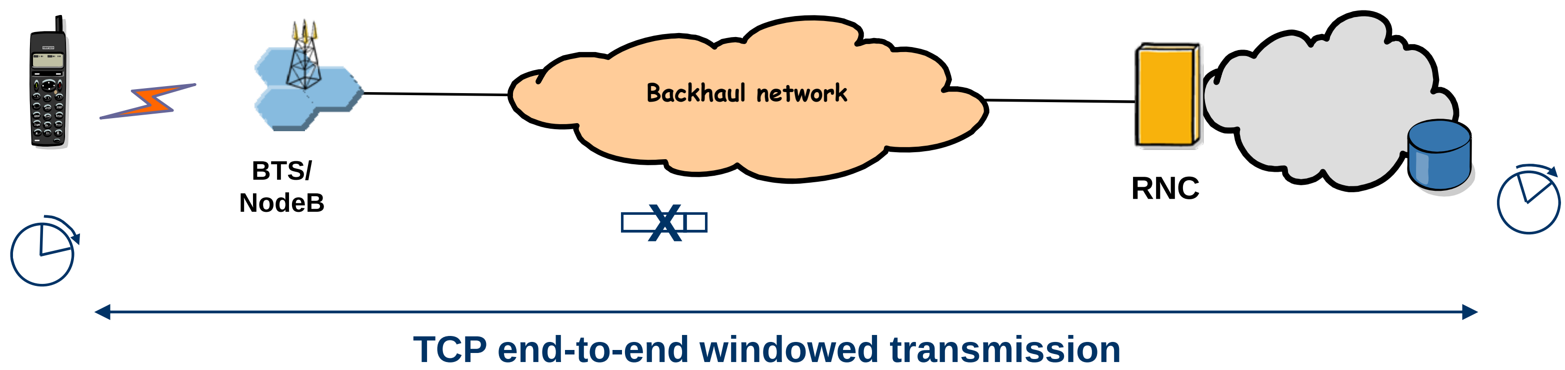


Handoff Control For Reliable Mobility Performance



- Synchronization is vital to ensure service continuity (i.e successful handoff)
- Studies have shown significant reduction in call drops when good synchronization is in place; enhanced QoE

Backhaul Transport Reliability



- Wander and Jitter in the Backhaul and Aggregation Network can cause underflows and overflows
- Slips in the PDH framing will cause bit errors leading to packet rejections
- Packet rejections lead to retransmissions and major perceptible slow down in TCP windowed sessions

Clock distribution methods

- Physical layer clock
  - Using synchronous TDM interfaces, e.g. PDH/SDH
  - Using synchronous Ethernet as per G.8261/G.8262
- GPS synchronization
- Clock distribution over packet network
  - IEEE 1588 v2 – ITU-T Q13/SG15 currently developing a telecom profile for IEEE 1588 v2
- Adaptive & Differential Clock Synchronization

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MMBI Scope

- Focus on MPLS technology to bring solutions to transport mobile traffic (user plane and control plane) over access, aggregation and core networks.
- Covers 2G, 2.5G, 3G and mobile WiMAX networks, including evolution from 2G and 2.5G to 3G and beyond
- Consider RAN and Core equipments with range of physical interfaces (e.g. E1, STM1, DSL, FE, GE, etc.) and technologies (PDH, SDH, ATM and ATM/IMA, PPP, FR, Ethernet, etc.), either directly attached or through an intervening access network
- Different kinds of access transmission technologies: pt-to-pt access (xDSL, microwave, P2P Fiber), pt-to-mp access (GPON)
- Address coexistence of legacy and next generation mobile equipment in the same network infrastructure.
- Support a smooth migration strategy for network operators as newer TNLs (Transport Network Layers) are introduced and legacy TNLs are phased out

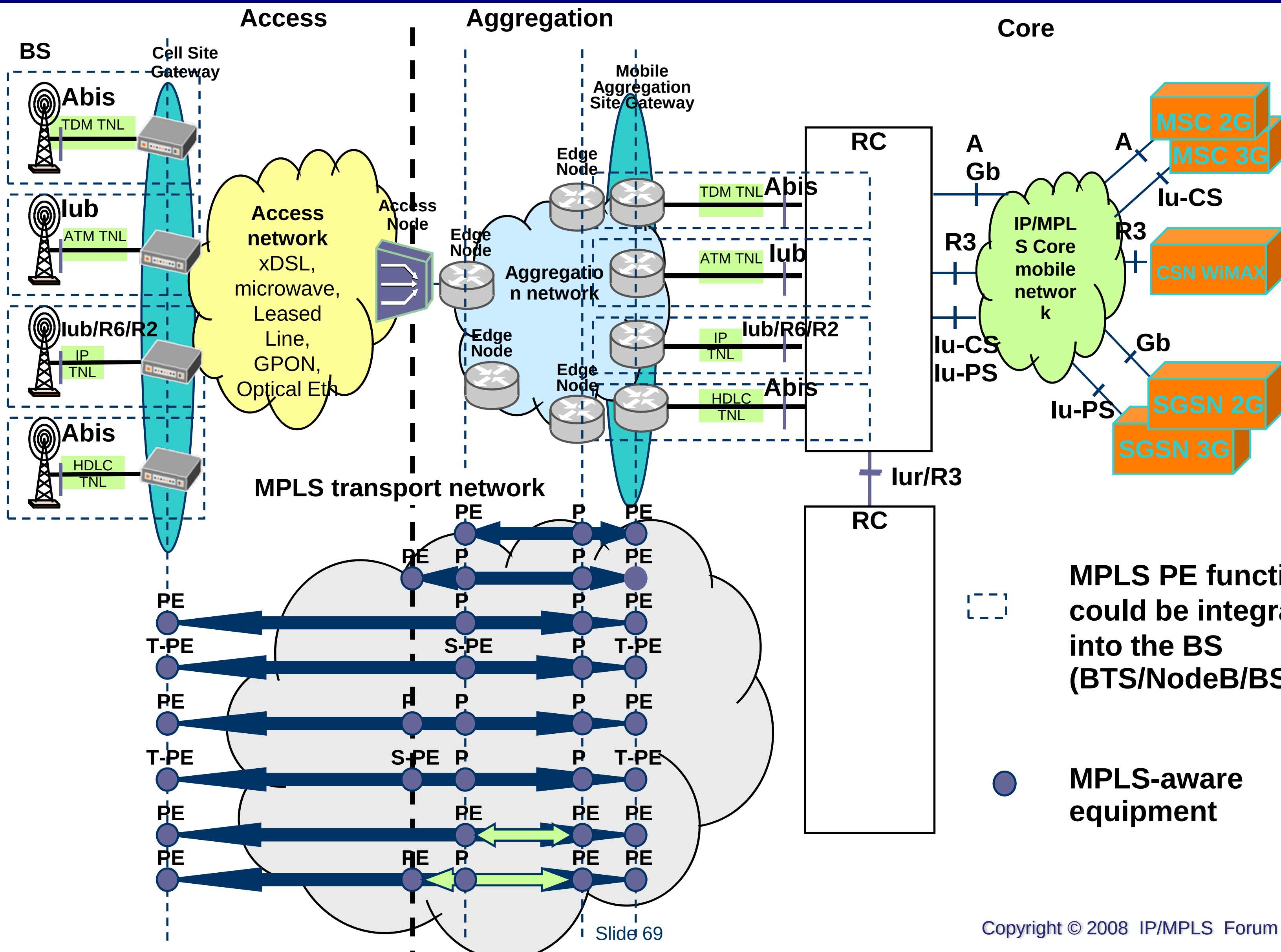
MMBI Scope *(continued)*

- MPLS facilities in Access and/or Aggregation networks leased from a third party, and which may be shared by more than one mobile operator
- Converged access/aggregation network supporting both wireline, e.g. residential and enterprise, and wireless services.
- QoS for support of distinct service types (e.g. real-time services and associated delay and jitter requirements)
- A mechanism for supporting clock distribution to the base stations, including frequency, phase and time synchronization
- Resiliency capabilities to support the reference architecture, including failover times appropriate for wireless backhaul networks. Example capabilities are dual attachment at the BSC/RNC and methods for failover.
- OAM to support the reference architecture

MMBI Architecture and Use Cases

- Deployment Scenarios -- Location for MPLS functions is intended to be flexible
  - MPLS interworking functions could be located either:
    - In the edge node, or
    - in the access node, or
    - in the access gateway or
    - directly integrated into the base station.
- TNL (Transport Network Layer) Scenarios – Support for a range of access technologies at base stations and controller elements
  - Case 1: TDM TNL
    - Base stations and controller elements communicating using TDM bit streams
  - Case 2: ATM TNL
    - Base stations and controller elements communicating using ATM cells
  - Case 3: IP TNL
    - Base stations and controller communicating using IP packets
  - Case 4: HDLC TNL
    - Base stations and controller elements communicating using HDLC-encoded bit streams (e.g. CDMA)

MMBI Reference Architecture



MPLS PE function could be integrated into the BS (BTS/NodeB/BS)/RC

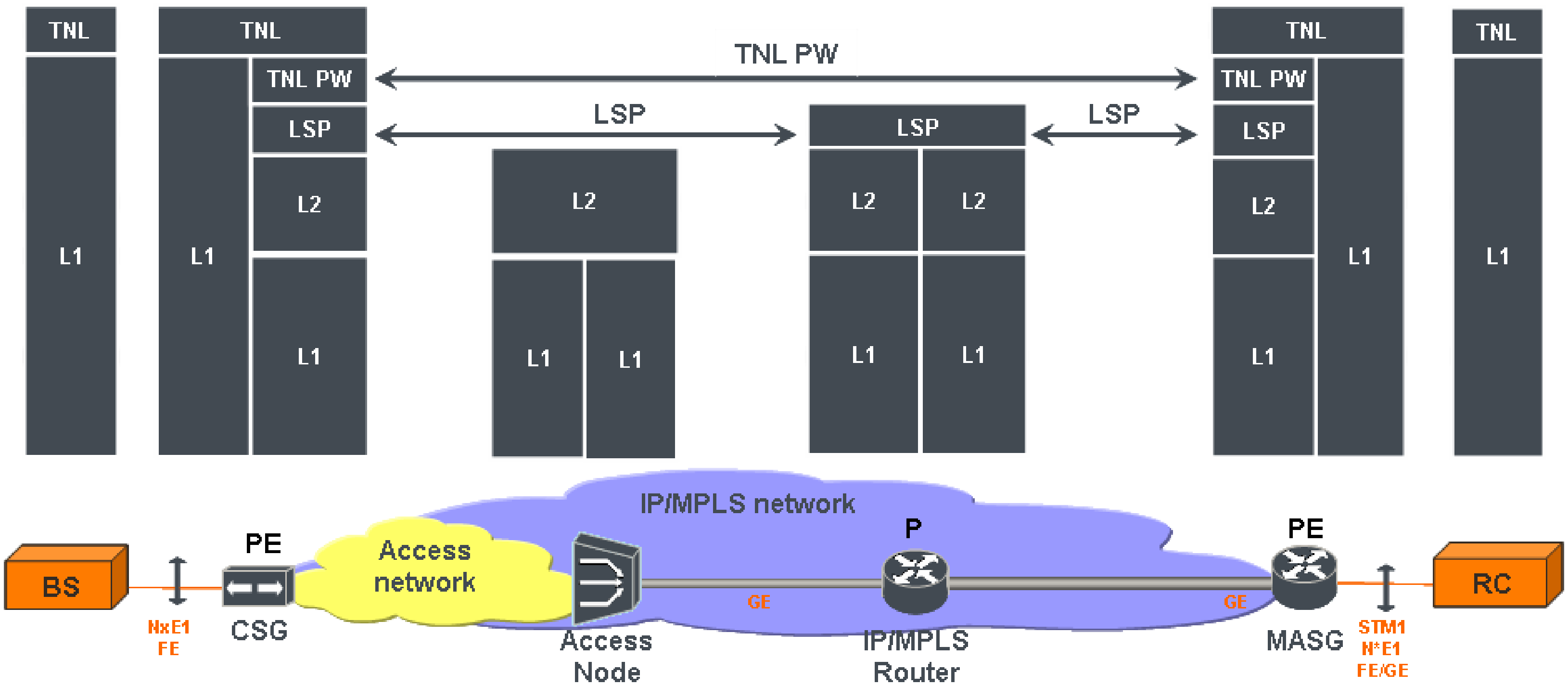
MPLS-aware equipment

Multiple TNLs – Corresponding to Successive Generations of Mobile Architecture

Network	Specification	TNL
GSM/GPRS/EDGE (2G/2.5G)		TDM
UMTS	R3, R99/R4	ATM
	R99/R5, R6, R7	ATM
		IP
CDMA 1x-RTT	IS-2000	HDLC or TDM
CDMA 1x EV-DO	IS-856	IP
Mobile WiMAX	WiMAX Forum Network Access Architecture R1.1	IP

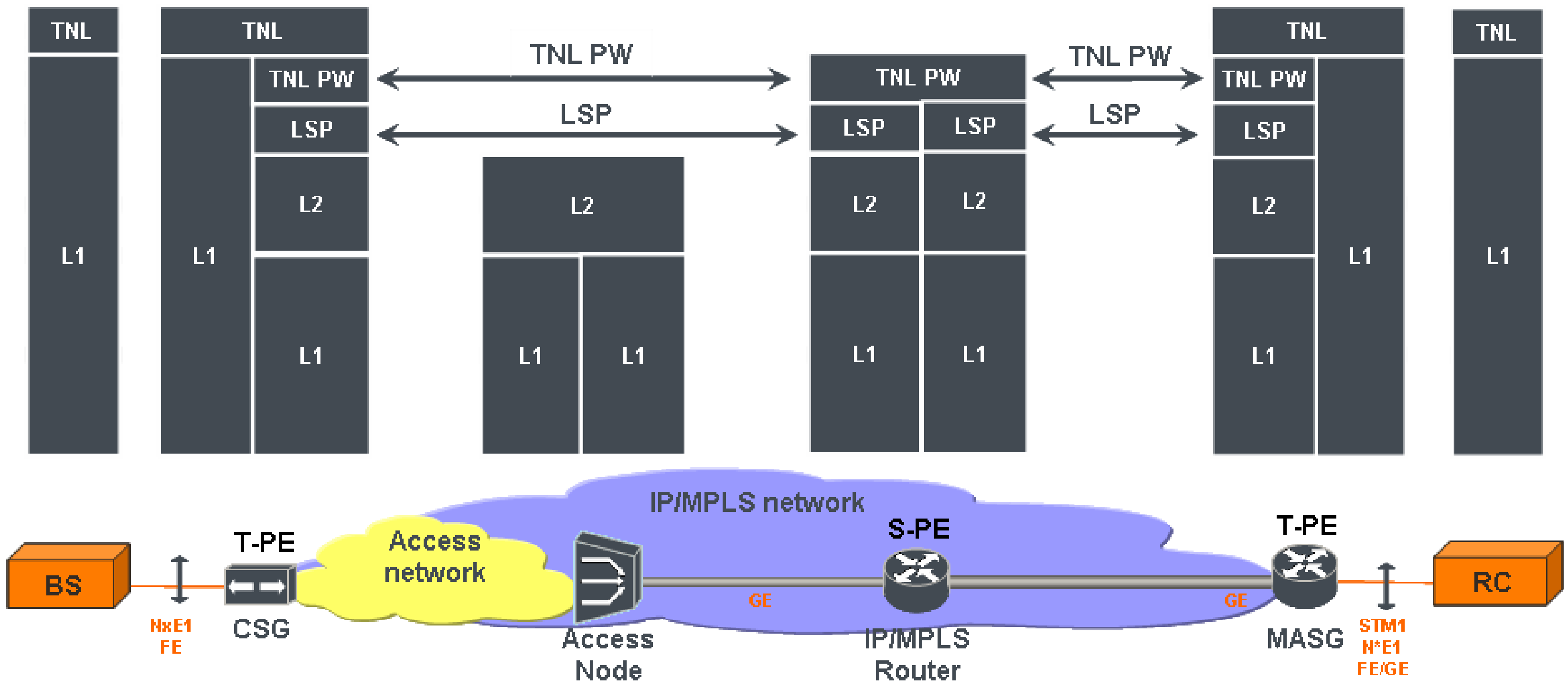
Generic TNL Protocol Stack

Example of SS-PW Deployment



- PW extends from PE to PE
  - Each TNL Type supported by corresponding TNL PW
  - In deployment scenario shown, PW extends from Cell Site Gateway (CSG) to Mobile Aggregation Site Gateway (MASG)

Generic TNL Protocol Stack
Example of MS-PW Deployment



- PW extends from T-PE to T-PE; switched at S-PE
  - Each TNL Type supported by corresponding TNL PW
  - In deployment scenario shown, PW extends from Cell Site Gateway (CSG) to Mobile Aggregation Site Gateway (MASG)

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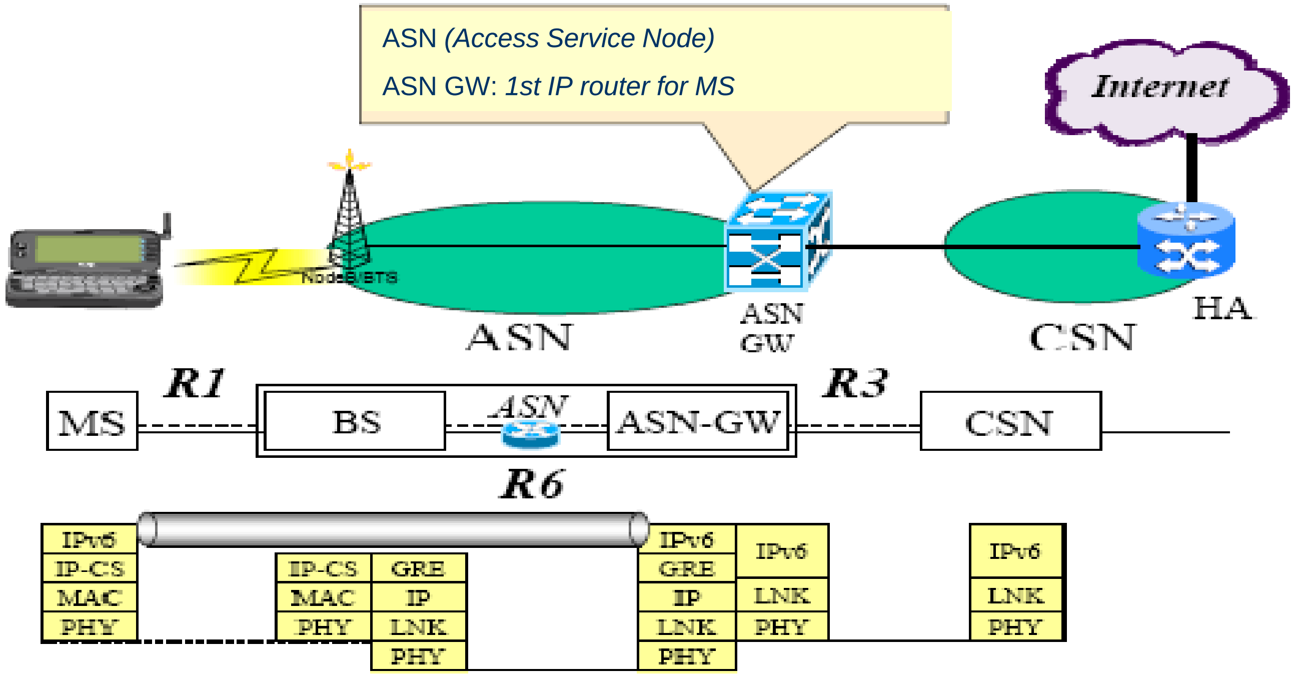
IP Transport Network Layer (TNL) (applies to WiMAX backhaul also)



- **IP TNL is standardized in WiMAX Forum to be used between BS and ASN GW**
- **For User Plane: L3 tunneling is currently specified in WIMAX Forum**
- **Services encapsulation over GRE for IPv4, IPv6, IPv4oEth, IPv6oEth**
- **For Control plane: traffic encapsulation is done over UDP/IP**

Mobile WiMAX
Reference architecture

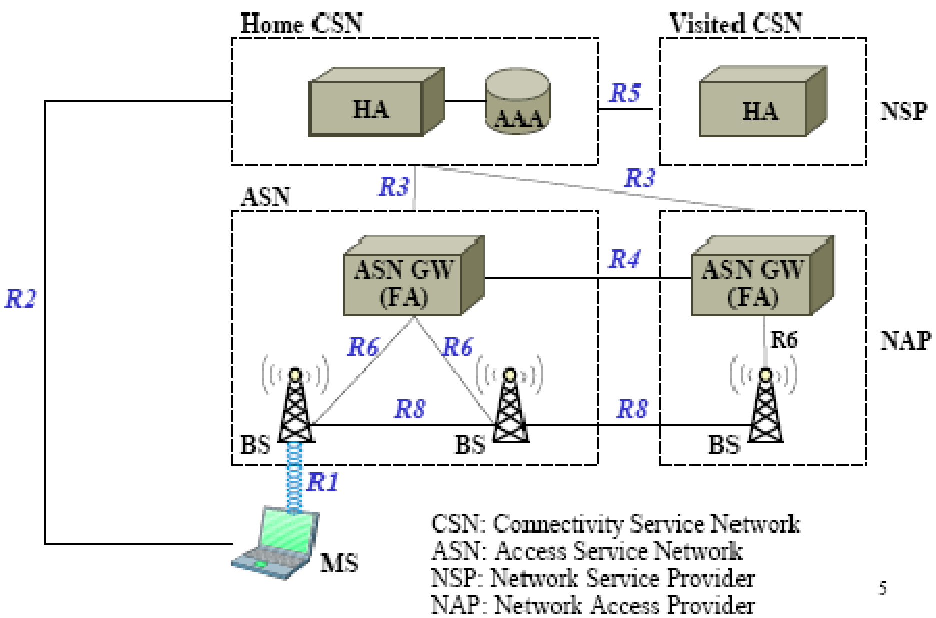


Table 1. Reference network model interfaces	
R1	Interface between the MS and the BS. Functionality: air interface
R2	Interface between the MS and the CSN. Functionality: AAA, IP host configuration, mobility management.
R3	Interface between the ASN and CSN. Functionality: AAA, policy enforcement, mobility management.
R4	Interface between ASNs. Functionality: mobility management.
R5	Interface between CSNs. Functionality: internetworking, roaming.
R6	Interface between BTS and ASN gateway. Functionality: IP tunnel management to establish and release MS connection.
R8	Interface between BTSs. Functionality: handoffs.

- **R6/R8/R2 interfaces have to be backhauled over PSN fixed networks**
- **Only IP connectivity is standardized in WiMAX Forum between BS and ASN GW at service transport level**
- **This WiMAX reference architecture is quite close to LTE architecture (flat and simplified architecture relying on IP protocol)**

IP/MPLS RAN Backhaul Networks: *Critical Success Factors*

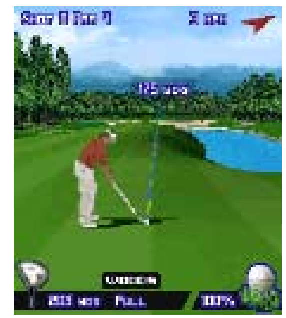
- **Carrier Grade IP/MPLS services**
  - **High Availability**
  - **Fast reconvergence**
- **Efficient End-to-End Management and OAM for rapid mass deployment**
- **Scalability to large numbers of cell sites**
- **Base Station synchronization**
  - **Carrier frequency accuracy of 50 PPB for GSM/W-CDMA**
  - **Need to preserve synchronization & timing with Carrier Ethernet transport**

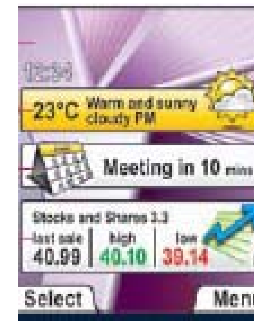
Focus from IP/MPLS Forum

- Rapid growth in mobile backhaul bandwidth demand
- Scaling the backhaul in TDM way is expensive
- Industry is shifting towards IP based networks
- IP/MPLS offers many benefits and has been deployed globally in mobile core. Similar drivers apply to backhaul.
- Standards for backhaul transport - leaning towards IP
- In recent years, IP/MPLS Forum has published implementation agreements to facilitate the migration of ATM and TDM to MPLS-based infrastructure
- **IP/MPLS Forum aims to complement the cost benefits of Ethernet with the proven track record of MPLS for building converged, reliable and QoS-aware mobile grade infrastructure.**

Opportunity for operators

- **Solving backhaul bottleneck**
  - Allowing operators to deploy high-bandwidth applications
- **Decouple bandwidth growth from transport cost**
  - Significantly Reduce transport OPEX while enabling high revenue services
- **Investment protection and simplification**
  - Leverage existing investments in 2G, while migrating towards 3G, 4G/Beyond
  - Converging technology specific backhaul networks to single multi-service packet infrastructure
- **Build with confidence**
  - Leverage proven benefits of MPLS from backbone to backhaul
  - Highly reliable, Worldwide deployments
  - Offer other services (i.e. L2/L3 VPN)





Related Standards Specifications and Work in Progress

IETF PWE3

Pseudowire Emulation Edge-to-Edge (PWE3) Architecture

- RFC 3985

An Architecture for Multi-Segment Pseudowire Emulation Edge-to-Edge

- draft-ietf-pwe3-ms-pw-arch-03.txt

ITU-T

- Recommendation G.8261 “Timing and Synchronization in Packet Networks”

IEEE

- IEEE draft standard 1588 v2 (Precision Clock Synchronization Protocol) – work in progress

Metro Ethernet Forum

- Mobile Backhaul Project Implementation Agreements – work in progress

For More Information. . .

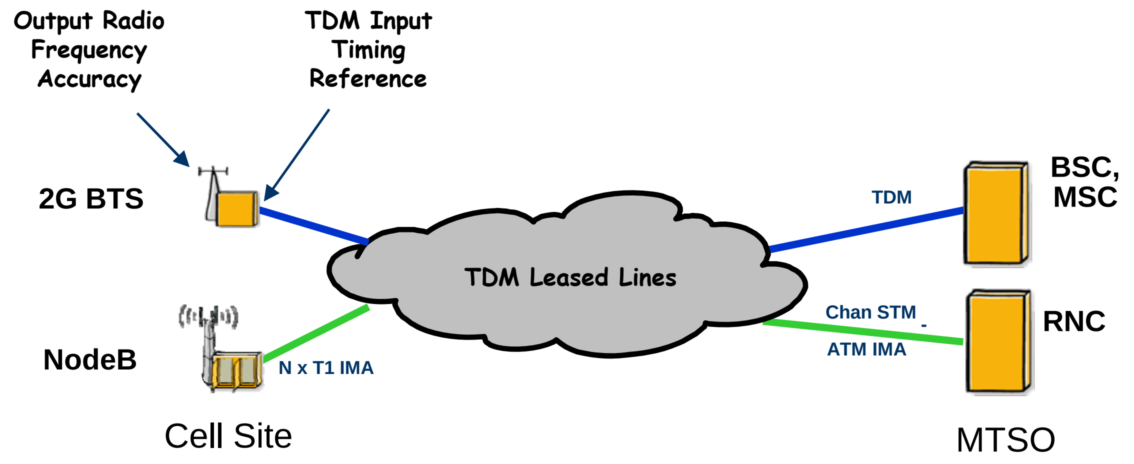
- http://www.ipmplsforum.org
- http://www.ietf.org
- http://www.itu.int
- http://www.mplsrc.com

Thank you **for attending the**

IP/MPLS in the Mobile Radio Access Network (RAN) Tutorial

Additional Information on timing and clock synchronization

Synchronization in Mobile Backhaul



Radio Frequency Requirements

Radio System	Frequency Accuracy	Time/Phase Accuracy
GSM	50 ppb	No requirement
UMTS (FDD mode)	50 ppb	No requirement
UMTS (TDD mode)	50 ppb	2.5 us
CDMA	50 ppb	10 us
WiMAX	8 ppm	(<5 us)

Radio System	Jitter/Wander
GSM	G.823/G.824
UMTS (FDD mode)	G.823/G.824
UMTS (TDD mode)	G.823/G.824
CDMA	G.823/G.824
WiMAX	G.823/G.824

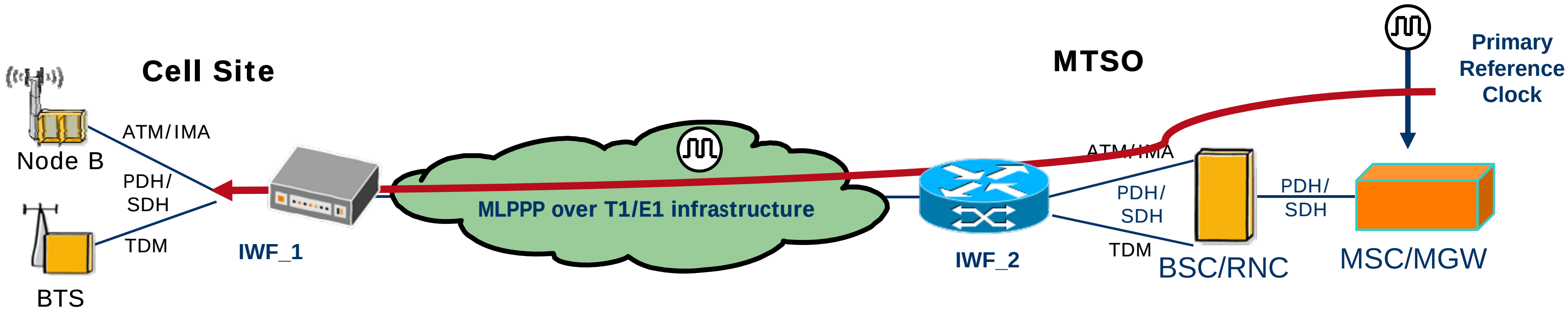
- NOTE: The radio frequency requirements are a specification for the air interface; not for the BTS-BSC interface. The utilization of a reference signal from the BTS-BSC interface for derivation of radio frequency accuracy will require filtering to remove short term inaccuracies > 50ppb.

Role of QoS & Resiliency in Support of Packet-based Timing Protocols

- The synchronization and timing requirements must continue to be met as backhaul networks evolve from PDH/SDH to packet-based technologies
- How well a backhaul network supports these requirements using packet-based timing protocols depends on its QoS and resiliency
- Inadequate QoS or resiliency can lead to impairments as represented by these metrics
  - Packet Transfer Delay
    - May cause a lag in response to changes in the master clock
    - Static delay is not usually a problem for recovery of clock frequency or phase
  - Packet Delay Variation (PDV)
    - Appears as change in frequency or phase of the recovered clock
    - Multiple causes, including queuing delays, routing changes, congestion, etc.
  - Extended Packet Loss (Network Outages)
    - May cause clock recovery process to go into “holdover” from lack of information

PDH/SDH Physical Layer Clock -- MLPPP Example

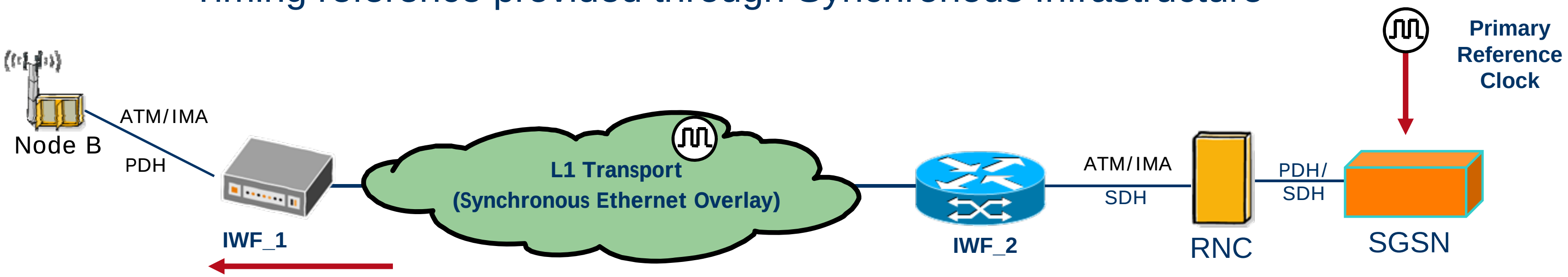
Timing distributed over Synchronous Infrastructure



- **MLPPP infrastructure uses synchronous T1/E1 facilities**

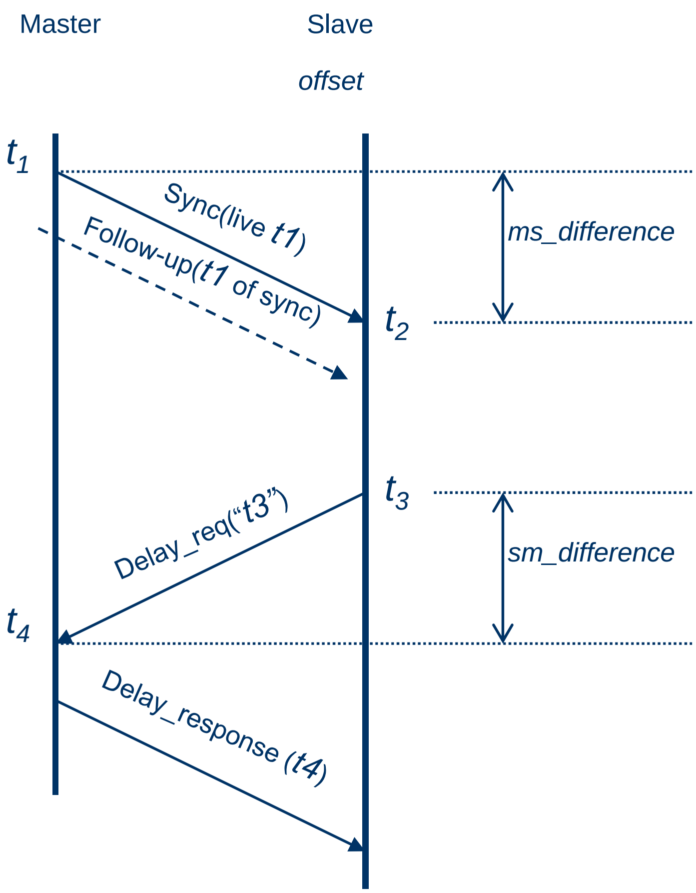
Physical Layer Clock -- Synchronous Ethernet

Timing reference provided through Synchronous Infrastructure



- **Very similar to using SONET or SDH to provide a synchronization reference**
- **Advantages:**
  - **Not affected by network traffic**
  - **Very good quality has been observed in initial testing (< 2ns Wander)**
- **Disadvantages:**
  - **Requires continuous path of Synchronous Ethernet capable links/nodes through network => cost concerns**

IEEE 1588v2 Packet Timing Protocol



Offset* = *slavetime* - *mastertime
ms_difference* = $t_2 - t_1$ = *offset* + *ms_delay
sm_difference* = $t_4 - t_3$ = -*offset* + *sm_delay

***Offset* = ((*ms_diferenence* – *sm_difference*) – (*ms_delay* – *sm_delay*))/2**

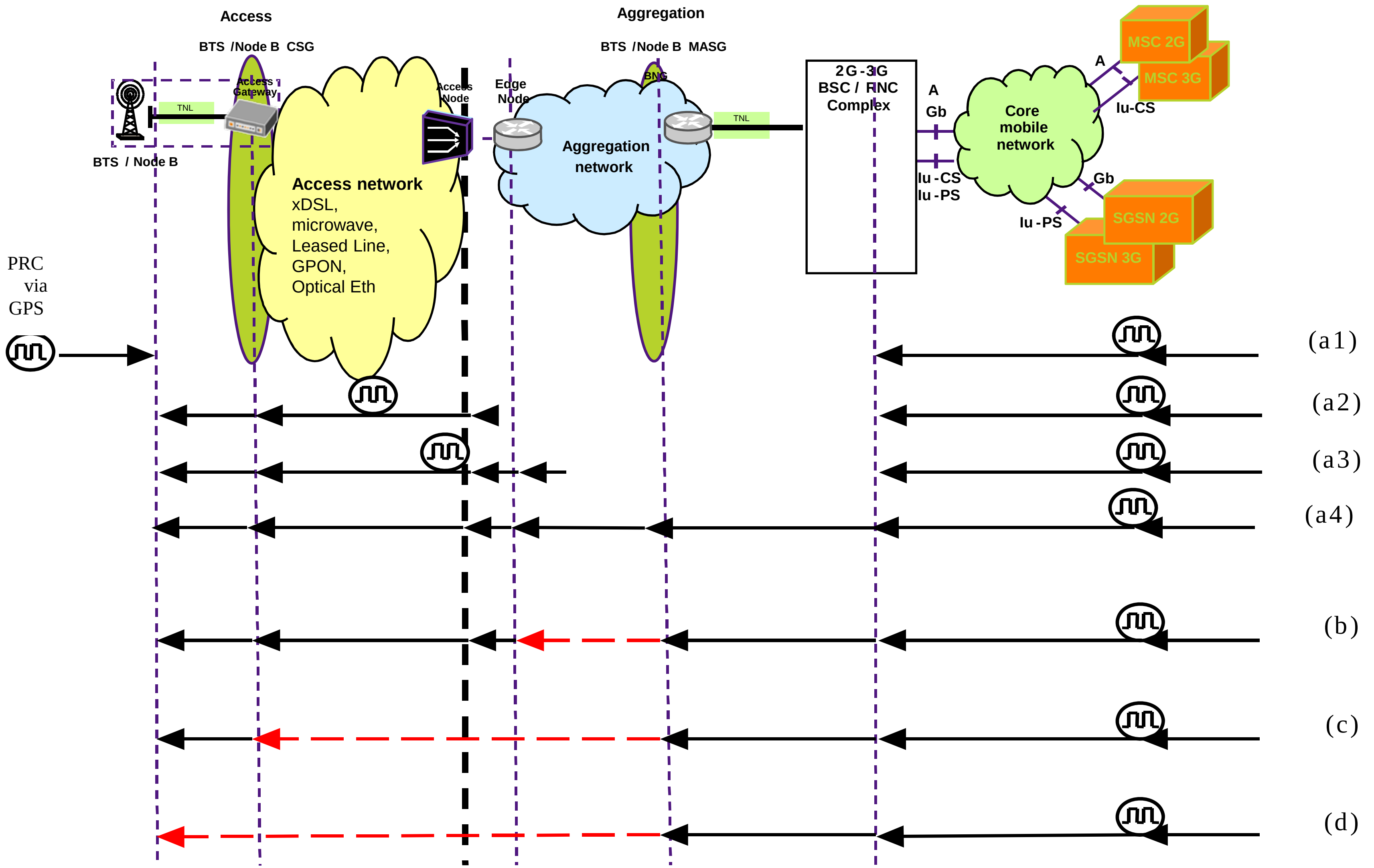
ms_delay* + *sm_delay* = *ms_difference* + *sm_difference

We can measure $t_1 - t_4$, so can measure *ms_difference* and *sm_difference*; but we can only calculate *offset* if we know relationship between *ms_delay* and *sm_delay.*
Assume *ms_delay* = *sm_delay*....

Then, *offset* = (*ms_difference* – *sm_difference*)/2 = $((t_2 - t_1) - (t_4 - t_3))/2$
And *one-way delay* = (*ms_difference* + *sm_difference*)/2 = $((t_2 - t_1) + (t_4 - t_3))/2$

=> Steer slave until t_2 (average) = t_1 + *one-way delay* (average)

Timing deployment scenarios



Deployment cases

- Deployment case (ax): All clocks are over physical layer, both the RNC and Node B have the same reference PRC clock.
- Deployment case (b): The aggregation network segment is running the clock over packet scenario. The Edge node would regenerate the physical clock and redistribute it over the access network.
- Deployment case (c): The Aggregation network segment and the access segment are running clock over packet . The access gateway would regenerate the physical clock and redistribute it to the Node-B.
- Deployment case (d): The Aggregation network segment and the access segment as well as the access gateway, are running clock over packet. The Node-B recovers the physical clock.

Timing Distribution Methods – Work in Progress

- Work on timing distribution exchanged by liaison with ITU-T Q13/15
  - Intended to align with the revised Recommendation G.8261
- Timing distribution approaches; work item focuses on latter case
  - Over a synchronous physical layer (e.g. PDH/SDH, SynchE)
  - Over a packet network, including MPLS (e.g. NTP, Clock PW)
- Timing distribution over packet networks to consider:
  - Quality of the Node B oscillator
  - Node B physical layer interface
  - Tolerance specification at the input to Node B
- Approaches under consideration
  - Use of a timing PW and SATOP
  - Differential timing technique
  - Adaptive timing technique