Unified MPLS Mobile Transport 2.0 Design Guide

Cisco Validated Design

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Unified MPLS Mobile Transport 2.0 Design Guide

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Preface

The huge growth in mobile data traffic is challenging legacy network infrastructure capabilities and forcing transformation of mobile transport networks. Until now, mobile backhaul networks have been composed of a mixture of many legacy technologies that are operationally complex and have reached the end of their useful life. The market inflection point for mobile backhaul is introduction of 4G/ LTE. The majority of deployments require concurrent legacy (2G/3G radio) backhaul support while gracefully introducing long term evolution (LTE) to the service mix, along with virtualization of the packet transport to deliver multiple services.

The Unified MPLS Mobile Transport (UMMT) System is a comprehensive RAN backhaul solution that forms the foundation for LTE backhaul, while integrating components necessary for continued support of legacy 2G GSM and existing 3G UMTS transport services. The UMMT System enables a comprehensive and flexible framework that integrates key technologies from Cisco's Unified MPLS suite of technologies to deliver a highly scalable and simple-to-operate MPLS-based RAN backhaul network.

This preface includes the following major topics:

- Document Version and System Release
- Document Organization
- Obtaining Documentation, Obtaining Support, and Security Guidelines
- Cisco Product Security Overview

Document Version and System Release

This is the UMMT System Release 2.0 DG.

Document Version

Table i-1 lists document version information.

Table i-1. Document Version

Document Version	Date	Notes
1	4/6/2012	Initial release.
2	4/30/2012	Updated software version table and software version for ME3800X.

System Release

UMMT System Release 2.0 covers Unified MPLS for Mobile Transport supporting LTE and the introduction of ASR 901.

Document Organization

The chapters in this document are described in Table i-2.

Table i-2. Document Organization

Chapter	Major Topics
Chapter 1, Introduction	Includes an executive summary of UMMT 2.0 and release notes.
Chapter 2, Next-Generation Mobile Transport	Provides an overview of the state of the mobile transport industry and characteristics of next-generation mobile transport.
Chapter 3, System Overview	Provides an overview of the UMMT 2.0 concept and transport architecture and mobile backhaul service models.
Chapter 4, System Architecture	Describes the UMMT 2.0 architectures: single area small network design with non-MPLS access, multi-area large network design with MPLS access, and inter-AS large network design with MPLS access.
Chapter 4.2, Service Models	Describes the UMMT 2.0 service models: L3 MPLS VPN service model for LTE and L2 MPLS VPN service model for 2G and 3G.
Chapter 5, Functional Components	Describes the UMMT 2.0 functional components: QoS, synchronization distribution, redundancy and high availability, and OAM and performance monitoring.
Chapter 6, Conclusion	Describes highlights and benefits summmary for UMMT 2.0.
Glossary	List of acronyms and initialisms used in this document.

Obtaining Documentation, Obtaining Support, and Security Guidelines

Specific information about UMMT can be obtained at the following locations:

- Cisco ASR 901 Series Aggregation Services Routers: http://www.cisco.com/en/US/products/ps12077/index.html
- Cisco ASR 903 Series Aggregation Services Routers: http://www.cisco.com/en/US/products/ps11610/index.html
- Cisco ME 3800X Series Carrier Ethernet Switch Routers: http://www.cisco.com/en/US/products/ps10965/index.html
- Cisco ASR 9000 Series Aggregation Services Routers: http://www.cisco.com/en/US/products/ps9853/index.html
- Cisco Carrier Routing System: http://www.cisco.com/en/US/products/ps5763/index.html

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CHAPTER 1

Introduction

This chapter includes the following major topics:

- Section 1.1 Executive Summary
- Section 1.2 Release Notes for UMMT System Release 2.0

1.1 Executive Summary

Infused with intelligence and select solutions for scalability, agile transport, security, and more, the Cisco® Unified MPLS for Mobile Transport System gives operators a proven architecture, platforms, and solutions to stay ahead of the curve for bandwidth demand and provide operational simplification, all at optimized cost points.

Cisco UMMT is a comprehensive RAN backhaul solution that forms the foundation for LTE service deployment while integrating components necessary to support legacy 2G and 3G transport services. It provides flexible cell site connectivity options, including integration of third-party microwave vendors. It supports both retail and wholesale backhaul options, and concurrent transport for residential and business services traffic over the same infrastructure.

Challenge

While voice calls and texting used to dominate the mobile network market, mobile multimedia devices such as tablet computers and smartphones are now ubiquitous, running a wide variety of bandwidth-intensive applications and creating unprecedented growth in mobile data traffic. To remain competitive, operators that supply transport for mobile traffic must continue to scale network throughput and performance, support legacy 2G/3G services and flexible any-to-any connectivity for LTE, and leverage fiber and microwave assets to the maximum extent possible.

The Cisco Visual Networking Index (VNI) Global Mobile Data Forecast 2011-2016 states that 2016 global mobile traffic will be 18 times greater than it was in 2010. Over 10 billion mobile devices will be in use by 2016, and sixty-six percent of mobile traffic will be video, with its high bandwidth and quality of service (QoS) demands. Aggregate traffic is expected to exceed 10 exabytes per month by 2016, an annual run rate of over 120 exabytes per year. This equates to roughly 30 billion DVDs or 839 quadrillion SMS text messages.

This huge growth is challenging legacy network infrastructure capabilities and forcing transformation of mobile network infrastructures. The mobile network is evolving to an all-IP network with greater cost efficiency in bandwidth scaling. New transport requirements, driven by the dramatic growth in data rates and new communication streams within the backhaul network, must be simultaneously accommodated. The key LTE interfaces that must be supported are X2 and S1:

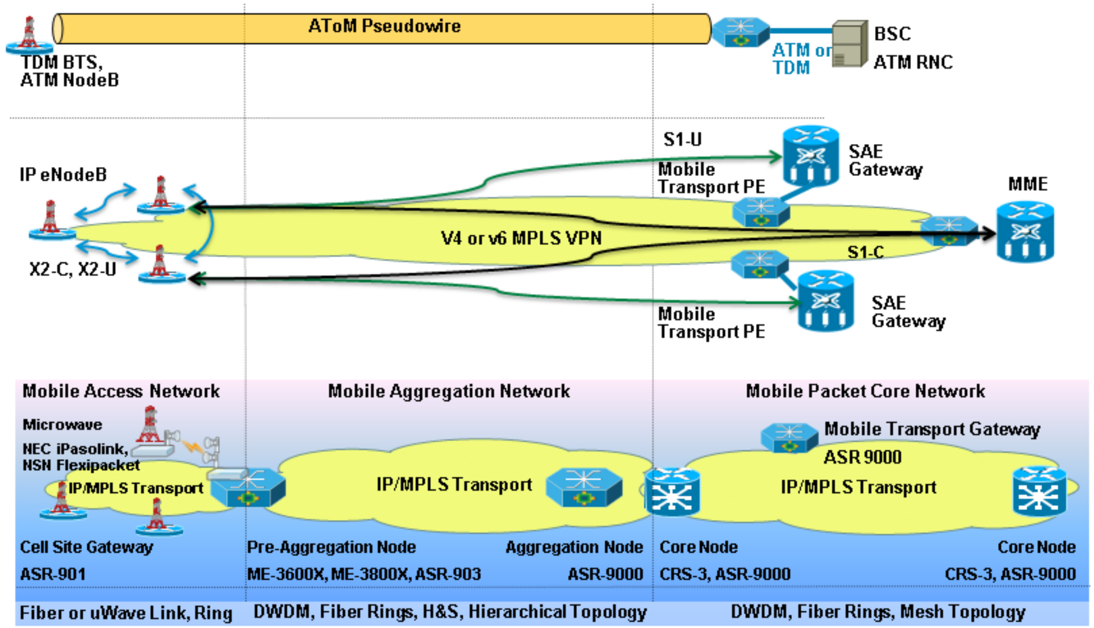
- The X2 interface requires a cell site-to-cell site communication path to support call handover for fast moving mobile devices, for which the centralized circuit paradigms of previous RAN architectures are ill suited.
- The S1 interface requires communication from the cell site to a centralized MME for user control.

To allow for growth in LTE adoption, users and cell site locations will need to be moved from heavily utilized gateways (e.g., mobility management entity (MME) and system architecture evolution (SAE)) to new, less centralized gateways. UMMT provides the capabilities for these changes to happen without re-architecting the underlying transport network.

Solution

UMMT provides reliable, scalable, high-density packet processing that addresses mass market adoption while reducing the operator's total cost of operation (TCO). It also handles the complexities of multiple access technologies, including seamless handover and mobility between access networks (2G, 3G, 4G LTE, and WiFi) to meet demands for convergence, product consolidation, and a common end user service experience.

Figure 1-1. Cisco Unified MPLS for Mobile Transport System



UMMT introduces key technologies from Cisco's Unified MPLS suite of technologies to deliver highly scalable and simple-to-operate MPLS-based IP RAN backhaul networks. For RAN backhaul of LTE services, operators are adopting MPLS over pure IP for two main reasons:

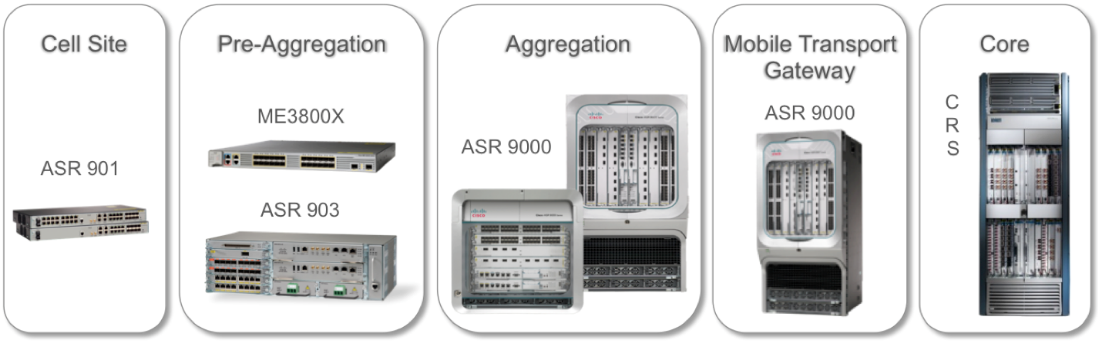
- Investment in packet-based networks delivers an economic solution to the exponential growth in packet traffic that needs transport. While the future lies with LTE, the present only offers 2G and 3G cell site connectivity. Support for ATM and TDM traffic inherent in legacy networks must exist in order to move traffic to the new higher-capacity LTE networks. The MPLS pseudowire is the industry choice for achieving this over a packet infrastructure.
- Layer 3 (L3) multi-protocol label switching (MPLS) VPNs in the RAN backhaul, which facilitate virtualization of the transport infrastructure, are becoming common in LTE designs. This is

useful when offering wholesale transport. It also leverages the RAN backhaul network for transport to other services for business and residential consumers.

Unified MPLS resolves legacy challenges such as scaling MPLS to support tens of thousands of end nodes, which provides the required MPLS functionality on cost-effective platforms, and the complexity of technologies like traffic engineering fast reroute (TE-FRR) to meet transport SLAs.

By addressing the scale, operational simplification, and cost of the MPLS platform, UMMT resolves the immediate need to deploy an architecture that is suitable for LTE deployment.

Figure 1-2. UMMT System Components



UMMT Highlights

- **Decoupling of Transport and Service layers**. Enables end-to-end MPLS transport for any service, at any scale. Optimal Service delivery to any location in the network unrestricted by physical topological boundaries.
- **Scaling of the MPLS infrastructure using RFC 3107 hierarchical LSPs**. RFC 3107 procedures define the use of Border Gateway Protocol (BGP) to distribute labels such that BGP can split up large routing domains to manageable sizes, yet still retain end-to-end connectivity.
- **Simplified provisioning of Mobile and Wireline services**. New service activation only requires end point configuration.
- **Highly-scaled MPLS VPNs support transport virtualization** that enables a single fiber infrastructure to be re-utilized to deliver transport to multiple entities, including mobile for retail and wholesale applications, residential, and business services.
- **TDM Circuit Support** Addition of time division multiplexing (TDM) transport over packet for the Global System for Mobile Communications (GSM) Abis interface.
- **Microwave Support** Full validation and deployment recommendations for Cisco's two main microwave partners: NEC (with their iPasolink product) and NSN (with their Flexipacket offering).
- **Synchronization Distribution** A comprehensive synchronization scheme is supported for both frequent and phase synchronization. Synchronous Ethernet is used in the core, aggregation and access domains where possible. Where SyncE may not be possible, based on the transmission medium, a hybrid mechanism is deployed converting SynchE to IEEE 1588v2 timing. IEEE 1588v2 Boundary Clock function in the aggregation to provide greater scalability.
- **QoS** UMMT leverages DiffServ QoS for core and aggregation, H-QoS for microwave access and customer-facing SLAs, and support for LTE QoS class identifier (QCIs) and wireline services, to deliver a comprehensive QoS design.

- **OAM and Performance Monitoring** Operation, Administration, and Maintenance (OAM) and Performance Management for Label-Switched Protocol (LSP) Transport, MPLS VPN, and Virtual Private Wire Service (VPWS) services are based on IP SLA, PW OAM, MPLS and MPLS OAM, and future Internet Engineering Task Force (IETF) MPLS PM enhancements.
- **LFA for FRR capabilities**. The required 50ms convergence time inherent in SONET/SDH operations used to be achieved in packet networks with MPLS TE-FRR. This has been successfully deployed in core networks, but not in access networks due to the complexity of additional required protocols and overall design. Loop-free alternate (LFA) delivers the same fast convergence for link or node failures without any new protocols or explicit configuration on a network device. Hub-and-spoke topologies are currently supported, with a later release extending LFA coverage to arbitrary topologies.

Until now, mobile network infrastructures have been composed of a mixture of many legacy technologies that have reached the end of their useful life. The UMMT system architecture provides the first integrated, tested, and validated mobile network architecture, meeting all the demands of legacy and highly scaled any-to-any connectivity for LTE networks.

UMMT Benefits

- **Flexible deployment options for multiple platforms** to optimally meet size and throughput requirements of differing networks.
- **High-performance solution**, utilizing the highest capacity Ethernet aggregation routers in the industry. The components of this system can be in service for decades to come.
- **Tested and validated reference architecture** that allows operators to leverage a pre-packaged framework for different traffic profiles and subscriber services.
- Promotes **significant capital savings** from various unique features such as pre-tested solutions, benchmarked performance levels, and robust interoperability, all of which are validated and pre-packaged for immediate deployment.
- Enables **accelerated time-to-market** based on a pre-validated, turnkey LTE RAN backhaul system.
- **Complementary system support**, with mobile video transport optimization integration; I-WLAN untrusted offload support on the same architecture; mobile packet core (MPC); and cost-optimized performance for Voice over LTE (VoLTE), plus additional services such as Rich Communication Suite (RCS).
- **Cisco's IP expertise is available to operators deploying UMMT through Cisco Services.** These solutions include physical tools, applications, and resources plus training and annual assessments designed to suggest improvements to the operator's network.

1.2 Release Notes

These release notes outline the hardware and software versions validated as part of the UMMT System effort and the key advancements of each system release.

UMMT 2.0

Release 2.0 of the Cisco UMMT system architecture continues to build upon the baseline established by release 1.0 by implementing the following improvements:

- Introduction of ASR 903 modular platform as a pre-aggregation node.
- Any Transport over MPLS (AToM): Complete TDM transport capabilities in access and aggregation domains with CESoPSN and SAToP TDM Circuit Emulation over Packet (CEoP) services on the ASR 903 and ASR 9000 platforms.

- 200Gbps/Slot line cards and new supervisor cards for the ASR 9000, which bring increased scalability, 100G Ethernet support, and synchronization enhancements with 1588 Boundary Clock support.
- BGP PIC Edge and core on ASR 9000 for labeled Unicast.
- Microwave partnerships with NEC and NSN.

Table 1-1. UMMT 2.0 Platforms and Software Versions

Architectural Role	Hardware	Software Revision
Core Node	ASR 9000 CRS-3	XR 4.2 XR 4.2
Aggregation Node	ASR 9000	XR 4.2
Pre-Aggregation Node	ASR 903 ME3800X	XE 3.5.1.S 15.1(2.0.47)EY0
Cell Site Gateway	ASR 901	15.1(2)SNH
Mobile Transport Gateway	ASR 9000	XR 4.2
Packet Microwave	NSN FlexiPacket	2.4
Hybrid Microwave	NEC iPASOLINK	2.02.29

UMMT 1.0

The first release of the Cisco UMMT System architecture formed the baseline for a highly-scalable and operationally-simplified system architecture to deliver mobile backhaul services:

- Introduction of RFC3107-compliant labeled BGP control plane in the access, aggregation, and core network domains.
- Introduction of hierarchical LSP functionality to provide abstraction between transport and service layers.
- MPLS L3VPN-based backhaul of S1 and X2 interfaces for LTE deployment.
- Simplified provisioning of mobile backhaul services enabled by BGP-based control plane. Only endpoint configuration needed for service enablement.
- Loop-Free Alternate (LFA) functionality provides fast reroute (FRR) capabilities in a greatly operationally-simplified manner.
- End-to-end OAM and PM functionality for mobile backhaul services and transport layer.

Table 1-2. UMMT 1.0 Platforms and Software Versions

Architectural Role	Hardware	Software Revision
Core Node	ASR 9000 CRS	IOS-XR 4.1.1 IOS-XR 4.1.1
Aggregation Node	ASR 9000	IOS-XR 4.1.1
Pre-Aggregation Node	ME3800X	IOS 15.1(2)EY1

Architectural Role	Hardware	Software Revision
Cell Site Gateway (CSG)	MWR2941 ASR 901	IOS 15.1(1)MR IOS 15.1(2)SNG
Mobile Transport Gateway (MTG)	ASR 9000	XR 4.1.1

CHAPTER 2

Requirements

This chapter includes the following major topics:

- Section 2.1 State of Mobile Transport Industry
- Section 2.2 Next-Generation Mobile Transport Characteristics

2.1 State of the Mobile Transport Industry

The shift from the dominance of mobile voice calls to mobile data has led to a fundamental change in the mobile service mix. As mobile standards evolved from 2G to 3G and now to 4G, mobile operators are under constant pressure to improve mobile backhaul speed, scale, and quality of service, while having the difficult task of controlling and reducing the cost per bit in the transport network. Legacy 2G and 3G transport is mostly synchronous digital hierarchy (SDH) based using dedicated T1/E1 circuits for GSM (TDM) and Universal Mobile Telecommunications System (UMTS) (ATM) backhaul. However, the rollout of mobile broadband standards such as High Speed Packet Access (HSPA) and Evolution Data Only Optimized (EV-DO) made it clear that the underlying SDH infrastructure could no longer cost effectively scale at the increased traffic volumes, and triggered the migration of mobile backhaul to packet networks. The debate between circuit versus packet transport has been laid to rest as packet transport is universally accepted as the best solution for next generation mobile transport. As a result, all new 3G rollout has been based on IP transport over Ethernet interfaces, and mobile operators are transitioning their backhaul infrastructure to packet networks.

Current industry solutions for RAN backhaul built on packet transport face the following issues:

Operational Complexity

Mobile standards have evolved over different transport technologies. While L3 packet transport has been predominant in the core and to a large extent in the aggregation domains of the network, the access network buildout has largely been based on Layer 2 (L2) transport. Consequently, industry solutions for RAN backhaul have been based on mixed packet transport technologies across the access, aggregation, and core layers of the network. These solutions typically involve a combination of L2 and L3 transport, with a L2 access and aggregation interfacing with a L3 core, or a L2 access interfacing with a L3 aggregation and core. Such architectures intrinsically couple the transport and service layers of the network and are consequently plagued with both control and management plane translations at the boundaries of these network domains:

- In mixed L2/L3 environments, increased complexity occurs in the control plane when MPLS RAN transport that uses pseudowire emulation (CESoPSN, SAToP, and ATM virtual channel and virtual path) for 2G/3G services is built over bridged infrastructures that rely solely on the L2 topology protection.

- Often interworking functions like multi-segment pseudowire (MSPW) stitching, VLAN to pseudowire (PW) XConnect, VLAN into VPLS VFI, spoke PW into H-VPLS VFI hub, or spoke PW into MPLS VPN virtual routing and forwarding (VRF) are required at the boundaries of these domains to provide the end-to-end services. These interworking entities are essentially touchpoints for the service that consume resources on the network device deployed at this boundary.
- These intermediate touchpoints introduce management complexity and require repeated provisioning as new services are added to the network.
- The intermediate touchpoints also complicate the operation and management of the service since they do not allow for simple end-to-end service monitoring and require separate L2 and L3 OAM technologies to be used in the respective segments of the service.

Short-Reach of Legacy RAN Backhaul

Existing industry solutions have been tailored to meet the immediate needs of 2G or 3G transport, which entails connectivity from the base transceiver station (BTS)/NodeB to the base station controller (BSC)/radio network controller (RNC). Therefore, the focus of backhaul thus far has been restricted to providing connectivity from the cell site to the controller located somewhere in the aggregation network, without considering implications to the MPC. While the limited reach of these backhaul designs suits the hierarchical nature of legacy 2G and 3G mobile standards, they have significant shortcomings for LTE deployments. The transition from a hierarchical 3G network architecture to a flat all-IP LTE/evolved packet core (EPC) network architecture has profound implications to the mobile transport network. LTE mandates reachability from the cell site all the way to the EPC gateways located deep in the core network. Extending the existing backhaul designs with interworking functions to provide reachability into the packet core will only introduce operational complexity and defeats the benefit that the flattened all-IP LTE/EPC architecture brings to mobile backhaul. These designs handicap the flexible placement of mobile gateways across the core network to address the gradual uptake in 4G scale as subscribers move from existing 2G and 3G services.

Lack of Consideration for Fixed Mobile Convergence

The biggest cost challenge facing MSPs today is the backhaul network. With circuit-to-packet migration being well under way, mobile operators are making huge investments in the rollout of packet-based networks. To this end, operators wanting to capitalize on their return on investment are looking to provide additional services on a converged network. In many cases, SPs are exploring the option of deploying fixed wireline services alongside 4G RAN backhaul in order to achieving fixed mobile convergence. The transport architecture plays a critical role in attaining this goal. However, existing industry solutions, which have been purpose built for legacy RAN backhaul with the transport architecture essentially following the circuit-switched paradigm of hub-and-spoke connectivity from cell sites to centrally located radio controllers, are not conducive to meeting the active convergence of packet transport in fixed mobile operations.

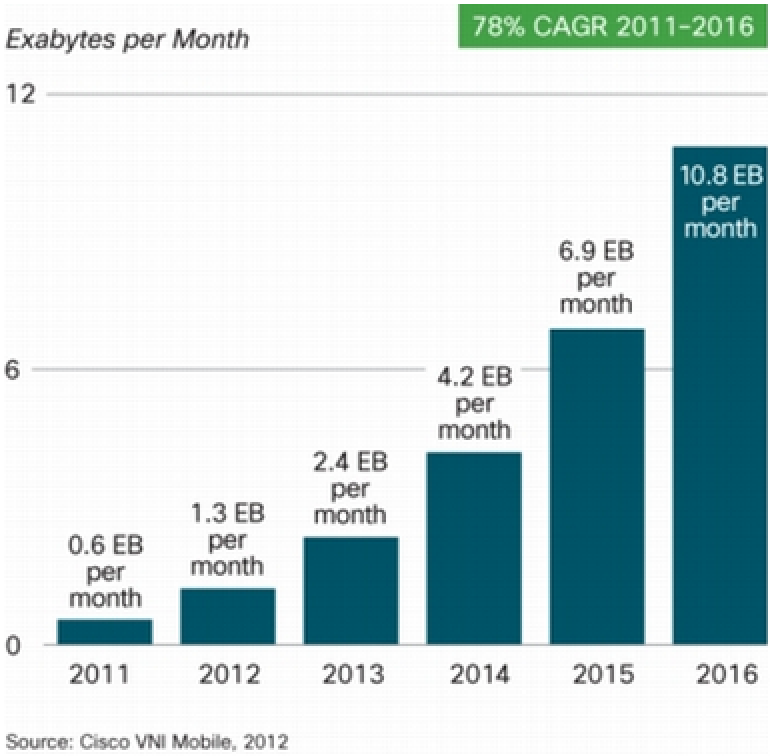
2.2 Next-Generation Mobile Transport Characteristics

The next-generation mobile backhaul infrastructure has the following characteristics:

High Capacity Requirements from Edge to Core

The mobile landscape is changing with consumer behavior. Powerful new mobile devices, increasing use of mobile Internet access, and a growing range of data-hungry applications for music, video, gaming, and social networking are driving huge increases in data traffic. The 2012 Cisco VNI states that global mobile data traffic grew 2.3-fold in 2011, more than doubling for the fourth year in a row. Global mobile data traffic in 2011 was over eight times greater than the total global Internet traffic in 2000, and mobile network connection speeds grew 66 percent, with a 4G connection generating 28 times more traffic on average than a non-4G connection. The VNI forecasts that mobile data traffic is set to increase 18-fold globally between 2011 and 2016. These exploding bandwidth requirements are driving high capacity requirements from the edge to core with typical rates of 100Mbps per eNodeB, 1Gbps access, 10Gbps aggregation, and future 100Gbps core networks.

Figure 2-1. Cisco VNI: Global Mobile Data Traffic, 2011 to 2016



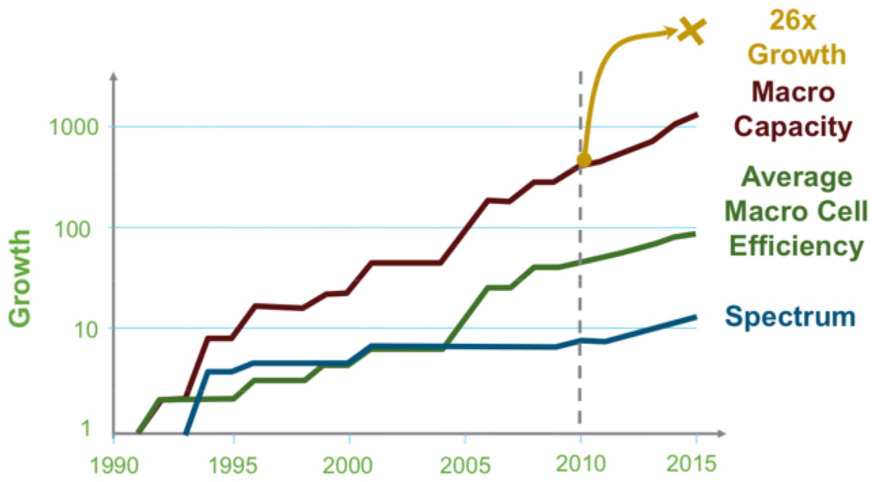
Exponential Increase in Scale Driven by LTE Deployments

LTE will drive ubiquitous mobile broadband with its quantum leap in uplink and downlink transmission speeds.

- In denser populations, the **increased data rates** delivered to each subscriber will force division of the cell capacity among fewer users. Because of this, cells must be much smaller than they are today.
- Another factor to consider is the **macro cell capacity**. The spectrum allotted to mobile networks has been increasing over the years, roughly doubling over a five year period. With advancements in radio technology, a corresponding increase in average macro cell efficiency has occurred over the same period. As a result, the macro cell capacity, which is a product of these two entities, will see a four-fold increase over a five year period. This increase, however, is nowhere close to the projected 26-fold increase in mobile data (as stated above), and will force mobile operators to deploy a small-cell network architecture.

These two factors will force operators to adopt small cell architectures, resulting in an exponential increase in cell sites deployed in the network. In large networks covering large geographies, the scale is expected to be in the order of several tens of thousands to a few hundred thousands of LTE eNodeBs and associated cell site gateways (CSG).

Figure 2-2. Macro Cell Capacity



Source: Agilent

Support for Multiple and Mixed Topologies

Many options exist for physical topologies in the RAN transport network, with hub-and-spoke and ring being the most prevalent. Capacity requirements driven by subscriber density, CAPEX of deploying fiber in large geographies, and physical link redundancy considerations could lead to a combination of fiber and microwave rings in access, fiber rings, and hub-and-spoke in aggregation and core networks, etc. The transport technology that implements the RAN backhaul must be independent of the physical topology, or combination thereof, used in various layers of the network, and must cost-effectively scale to accommodate the explosive increase in bandwidth requirements imposed by the mobile growth.

Seamless Interworking with the Mobile Packet Core

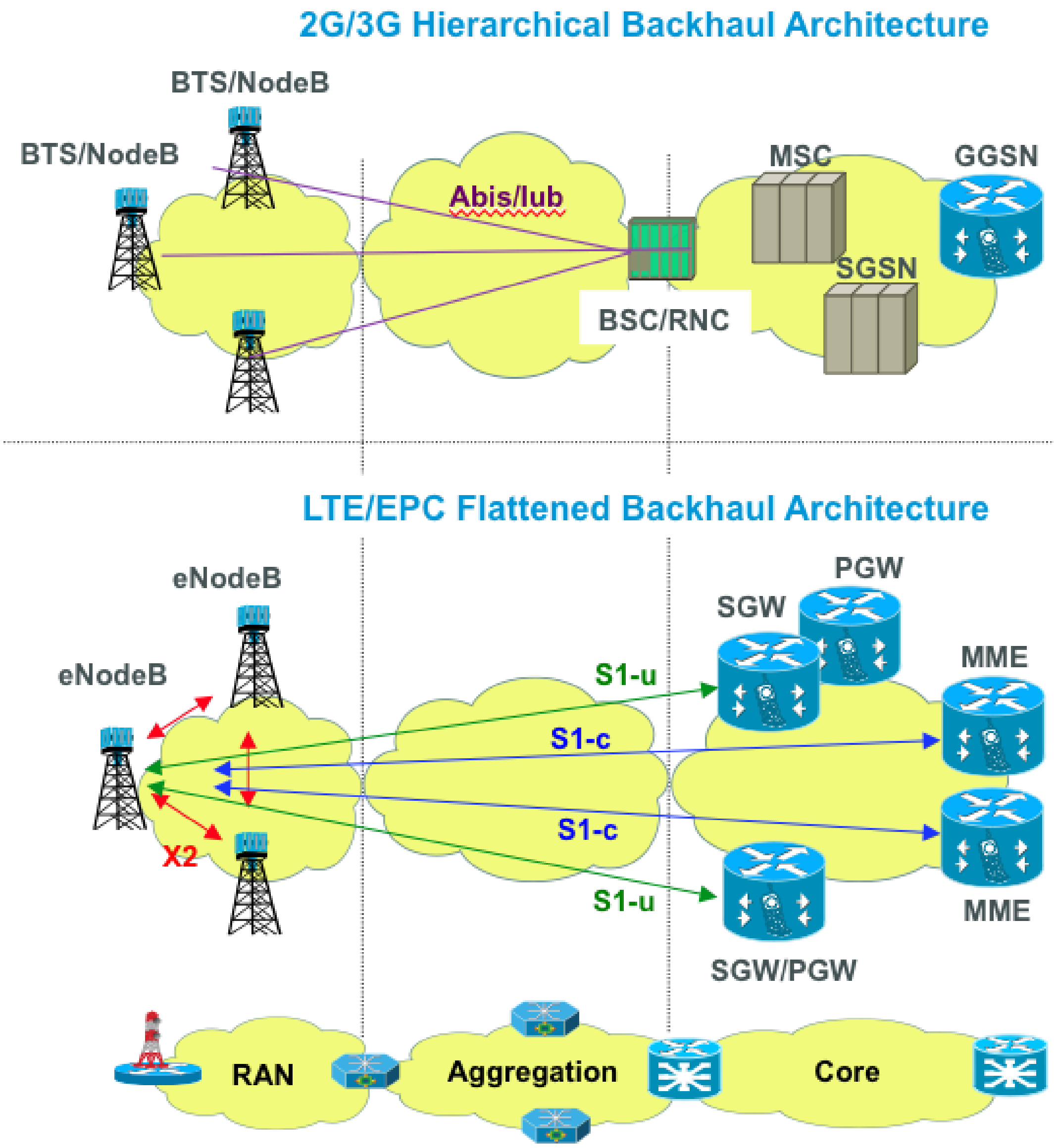
As mentioned in the previous section, the flattened all-IP LTE/EPC architecture is a significant departure from previous generations of mobile standards and should be an important consideration in designing the RAN backhaul for 4G mobile transport.

The 2G, 3G hierarchical architecture consists of a logical hub-and-spoke connectivity between BSC/RNC and the BTS/NodeBs. This hierarchical architecture lent itself naturally to the circuit-switched paradigm of having point-to-point connectivity between the cell sites and controllers. The reach of the RAN backhaul was also limited in that it extended from the radio access network to the local aggregation/distribution location where the controllers were situated.

In contrast, the flat LTE architecture does away with the hierarchy by getting rid of the intermediate controller like the BSC/RNC and lets the eNodeB communicate directly with the EPC gateways. It also does away with the point-to-point relationship of 2G, 3G architectures and imposes multipoint connectivity requirements at the cell site. This multipoint transport requirement from the cell site not only applies to the LTE X2 interface, which introduces direct communication between eNodeBs requiring any-to-any mesh network connectivity, but also applies to the LTE S1 interface, which requires a one-to-many relationship between the eNodeB and multiple EPC gateways. While the serving gateways (SGWs) may be deployed in a distributed manner closer to the aggregation network, the MMEs are usually fewer in number and centrally located in the core. This extends the reach of the RAN backhaul from the cell site deep into the core network.

Important consideration also needs to be given to SAE concepts like MME pooling and SGW pooling in the EPC that allow for geographic redundancy and load sharing. The RAN backhaul service model must provide for eNodeB association to multiple gateways in the pool and migration of eNodeB across pools without having to re-architect the underlying transport architecture.

Figure 2-3. RAN Backhaul Architecture



Transport of Multiple Services from All Locations

LTE has to co-exist with other services on a common network infrastructure that could include:

- Existing mobile services:
  - 3G UMTS IP/ATM
  - 2G GSM and SP WiFi in a mobile-only deployment
- A myriad of other services:
  - Residential broadband triple play

  - Metro Ethernet Forum (MEF) E-Line and E-LAN
  - L3VPN business services
  - RAN sharing, wireline wholesale in a converged mobile and wireline deployment

In these scenarios, the network has to not only support multiple services concurrently, but also support all these services across disparate endpoints. Typical examples are:

- L3 transport for LTE and Internet-High Speed Packet Access (I-HSPA) controller-free architectures: from RAN to SAE gateways in the core network.
- L3 transport for 3G UMTS/IP: from RAN to BSC in the aggregation network.
- L2 transport for 2G GSM and 3G UMTS/ATM: from RAN to RNC/BSC in the aggregation network.
- L2 transport for residential wireline: from access to broadband network gateways (BNG) in the aggregation network.
- L3/L2 transport for business wireline: from access to remote access networks across the core network.
- L2 transport for wireline wholesale: from access to retail wireline SP peering point.
- L3 transport for RAN sharing: from RAN to retail mobile SP peering point.

The transport technology used in the RAN backhaul and the network architecture must be carefully engineered to be scalable and flexible enough to meet the requirements of various services being transported across a multitude of locations in the network.

CHAPTER 3

System Overview

This chapter includes the following major topics:

- Section 3.1 Concept
- Section 3.2 Transport Models
- Section 3.3 Service Models

3.1 System Concept

UMMT provides the architectural baseline for creating a scalable, resilient, and manageable mobile backhaul infrastructure that is optimized to seamlessly interwork with the mobile packet core. The system is designed to concurrently support multiple generations (2G/3G/4G) of mobile services on a single converged network infrastructure. The system supports graceful introduction of LTE with existing 2G/3G services with support for pseudowire emulation (PWE) for 2G GSM and 3G UMTS/ATM transport, L2VPNs for 3G UMTS/IP, and L3VPNs for 3G UMTS/IP and 4G LTE transport. It supports essential features like network synchronization (physical layer and packet based), H-QoS, OAM, performance management, and fast convergence. It is optimized to cater to advanced 4G requirements like IPSec and authentication, direct eNodeB communication through the X2 interface, multicast for optimized video transport, virtualization for RAN sharing, capability of distributing the EPC gateways, and traffic offload.

The UMMT System meets the NGMN requirements for next-generation mobile backhaul, and innovates on the Broadband Forum TR-221 specification for MPLS in mobile backhaul networks by unifying the MPLS transport across the access, aggregation, and core domains. The architecture is also extensible to a converged mobile and wireline deployment and supports wireline residential, business, retail/wholesale L2VPNs and L3VPNs, and IP services.

The key aspects of the UMMT concept are described in this section.

Simplification of the End-to-End Mobile Transport and Service Architecture

A founding principle of UMMT is the simplification of the mobile backhaul architecture by eliminating the control and management plane translations that are inherent in legacy designs. As described in Section 2.1 State of the Mobile Transport Industry, traditional backhaul architectures relying on L2 transport are not optimized for 4G all-IP flat LTE architecture, and backhaul architectures built over mixed L2 and L3 transport are inherently complex to operate. The UMMT System enables a unified L3 MPLS/IP transport extending end-to-end from the mobile core all the way to the RAN access. It simplifies the control plane by providing seamless MPLS LSPs across access, pre-aggregation, aggregation/distribution, and core domains of the network. In doing so, a fundamental attribute of decoupling the transport and service layers of the network and eliminating intermediate touchpoints in the backhaul is achieved. By eliminating intermediate touchpoints, it simplifies the operation and management of the service. Service provisioning is restricted only at the edges of the network where it is required: namely at the CSGs in the access and the provider edge (PE) (hereby referred to as MTG) connecting the mobile gateways in the MPC. Simple carrier class operations with end-to-end OAM, performance monitoring of the GSM, UMTS, and LTE services are made possible.

Flexible Placement of L3 and L2 Transport Virtualization Functions for GSM, UMTS, and LTE

The hierarchical RAN backhaul architecture of 2G and 3G releases involved an intermediate agent like the BSC/RNC, which mostly resided at the aggregation/distribution layer of the transport network. This simplified the requirements on the transport in that it only required connectivity between the RAN access and aggregation network layers. In comparison, 4G LTE imposes many new requirements on the backhaul:

- Because of the any-to-any relationship between eNodeBs for the X2 interface and the one-to-many relationship between eNodeBs and EPC gateways (SGWs, MMEs) for the S1-u/c interface, the eNodeBs and associated CSGs in the RAN access need both local connectivity and direct connectivity to the EPC gateways in the mobile packet core.
- The stringent latency requirements of the X2 interface requires a logical mesh connectivity between CSGs that introduces the minimum amount of delay that is in the order of 30ms. The minimum delay is expected to reduce further to around 10ms for features such as collaborative multiple input multiple output (MIMO) in the future with 3GPP LTE Release 10 and beyond.
- The Evolved Universal Terrestrial Radio Access Network (E-UTRAN)/EPC architecture supports MME pooling and SGW pooling to enable geographic redundancy, capacity increase, load sharing, and signaling optimization. This requires the transport infrastructure to provide connectivity from eNodeBs in the RAN access to multiple MME and SGWs within these pools in the core network.
- The introduction of LTE into a existing 2G/3G network has to be graceful and the transition will take time. During this period, it is natural for a few centralized EPC gateways to be initially deployed and shared across different regions of the network. As capacity demands and subscriber densities increase, it is expected that new gateways will be added closer to the regions and subscribers will have to be migrated. While the migration across gateways within the packet core could be done seamlessly based on gateway pooling, it is imperative that the underlying transport infrastructure requires minimal to no provisioning changes to allow the migration.

In 2G and 3G releases, the hub-and-spoke connectivity requirement between the BSC/RNC and the BTS/NodeB makes L2 transport using Ethernet bridging with VLANs or P2P PWs with MPLS PWE3 appealing. In contrast, a L3 transport option is much better suited to meet the myriad of connectivity requirements of 4G LTE. The UMMT architecture provides both L2 and L3 MPLS VPN transport options that provide the necessary virtualization functions to support the coexistence of LTE S1-u/c, X2, interfaces with GSM Abis TDM, and UMTS IuB ATM backhaul. The decoupling of the transport and service layers of the network infrastructure and the seamless connectivity across network domains makes the system a natural fit for the flat all-IP LTE architecture by allowing for the flexible placement of 2G/3G/4G gateways in any location of the network to meet all the advance backhaul requirements listed above.

Deliver New Levels of Scale for MPLS Transport with RFC-3107 Hierarchical-Labeled BGP LSPs

As described in Section 2.2 Next-Generation Mobile Transport Characteristics, LTE deployments will introduce unprecedented levels of scale in terms of eNodeBs and associated network elements like CSGs into the network. While L2 and L3 MPLS VPNs are well suited to provide the required virtualization functions to transport 2G/3G/4G mobile services, LTE's requirement to have inter-domain connectivity from the RAN access all the way to the core network in order to reach the EPC gateways, however, presents challenges of scale to the transport infrastructure. This is because IP aggregation with route summarization usually performed between (access, aggregation, core) regions of the network does not work for MPLS as MPLS is not capable of aggregating Forwarding

Equivalency Class (FEC). In MPLS deployments, the FEC is typically the PE's /32 loopback IP address. Exposing the loopback addresses of all the nodes (10k -100k) across the network introduces two main challenges:

1. Large flat routing domains adversely affect the stability and convergence time of the IGP.
2. The sheer size of the routing and MPLS label information control plane and forwarding plane state will easily overwhelm the technical scaling limits on the smaller nodes (CSGs, pre-aggregation nodes) involved in the network.

Unified MPLS elegantly solves this problem with a divide-and-conquer strategy of isolating the access, aggregation, and core network layers into independent and isolated Interior Gateway Protocol (IGP) domains. Label Distribution Protocol (LDP) is used for setting up LSPs within these domains, and RFC-3107 BGP-labeled unicast is used for setting up LSPs across domains. This BGP-based inter-domain hierarchical LSP approach helps scale the network to hundreds of thousands of LTE cell sites without overwhelming any of the smaller nodes in the network. At the same time, the stability and fast convergence of the small isolated IGP domains corresponding to various network layers are maintained.

Facilitate Fixed-Mobile Convergence

The UMMT System addresses all of the needs of next-generation mobile backhaul while concurrently supporting transport legacy 2G and 3G mobile services. The concept of Unified MPLS, however, is not restricted to mobile transport. By decoupling the transport and service layers on the network, Unified MPLS enables end-to-end MPLS transport for any service, at any scale. The architecture is allows extensions for wireline residential, business, retail/wholesale L2 and L3 VPNs and IP services on the common network infrastructure supporting mobile backhaul.

3.2 Transport Models

The ubiquitous mobile broadband adoption driven by LTE will introduce unprecedented levels of scale in terms of eNodeBs and CSGs into the RAN backhaul network. This factor, combined with the flattened LTE/EPC architecture requiring connectivity from the RAN access all the way to the core network, introduces challenges in scaling the MPLS network. The endpoint identifier in MPLS is the PE's /32 loopback IP address, and since MPLS is is not capable of aggregating FEC, IP aggregation with route summarization cannot be performed between the access, aggregation, and core regions of the network. All network technologies meet a scale challenge at some point, and the solution is always some form of hierarchy to scale. The UMMT System uses this hierarchical approach to solve the scaling problem in MPLS-based LTE deployments.

Unified MPLS adopts a divide-and-conquer strategy where the core, aggregation, and access networks are partitioned in different MPLS/IP domains. The network segmentation between the core and aggregation domains could be based on a single AS multi-area design or inter-AS organization. Regardless of the type of segmentation, the unified MPLS transport concept involves partitioning the core, aggregation, and access layers of the network into isolated IGP/LDP domains. Partitioning these network layers into such independent and isolated IGP domains helps reduce the size of routing and forwarding tables on individual routers in these domains, which, in turn, leads to better stability and faster convergence. LDP is used for label distribution to build LSPs within each independent IGP domain. This enables a device inside an access, aggregation, or core domain to have reachability via intra-domain LDP LSPs to any other device in the same domain. Reachability across domains is achieved using RFC 3107 procedures whereby BGP-labeled unicast is used as an inter-domain label distribution protocol to build hierarchical LSPs across domains. This allows the link state database of the IGP in each isolated domain to remain as small as possible while all external reachability information is carried via BGP, which is designed to scale to the order of millions of routes. In single AS multi-area designs, interior Border Gateway Protocol (iBGP)-labeled unicast is used to build inter-domain LSPs, whereas in inter-AS designs, iBGP-labeled unicast is used to build inter-domain LSPs inside the AS and exterior Border Gateway Protocol (eBGP)-labeled unicast is used to extend the end-to-end LSP across the AS boundary. In both cases, the Unified MPLS transport across domains will use hierarchical LSPs that rely on a BGP-distributed label that is used to transit the isolated MPLS domains, and on a LDP-distributed label used within the AS to reach the inter-domain area border router (ABR) or autonomous system boundary router (ASBR) corresponding to the labeled BGP next hop.

The UMMT System integrates key technologies from Cisco's Unified MPLS suite of technologies to deliver a highly scalable and simple-to-operate MPLS-based RAN backhaul network. It enables a comprehensive and flexible transport framework structured around the most common layers in SP networks: the radio access network, the aggregation network, and the core network. The transport architecture structuring takes into consideration the type of access and the size of the network.

Access Type:

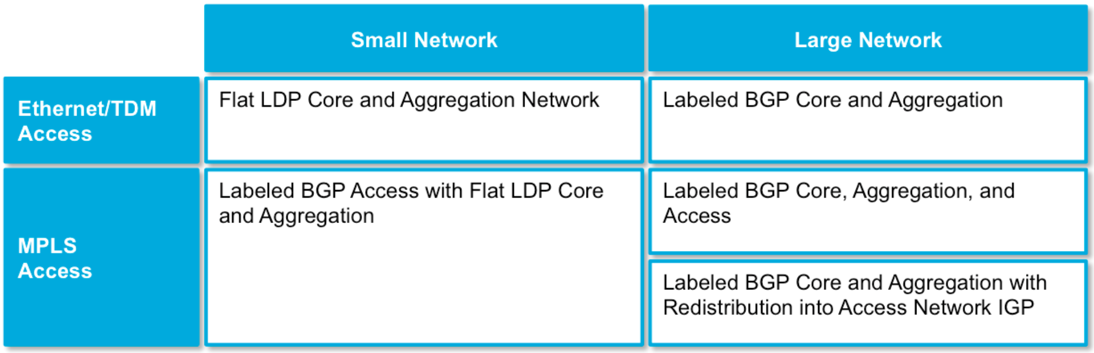
- MPLS Packet Access:
    - MPLS-based packet access covers point-to-point links, rings, and hierarchical topologies.
    - Applies to both fiber and newer Ethernet microwave-based access technologies with the MPLS access network enabled by the CSGs.
    - The services include both mobile and wireline services and can be enabled by the CSGs in the access network and the pre-aggregation or aggregation nodes in the aggregation network.
- IP/Ethernet/TDM Access:
    - Includes native IP or Ethernet links in point-to-point or ring topologies over fiber and newer Ethernet microwave-based access.
    - Covers point-to-point TDM+Ethernet links over hybrid microwave access.
    - The MPLS services are enabled by the aggregation network and includes GSM Abis, ATM IuB, IP IuB, and IP S1/X2 interfaces aggregated in MPLS pre-aggregation or aggregation nodes.

Network Size:

- Small Network:
    - Applies to network infrastructures in small geographies where the core and aggregation network layers are integrated in a single domain.
    - The single IGP/LDP domain includes less than 1000 core and aggregation nodes.
- Large Network:
    - Applies to network infrastructures built over large geographies.
    - The core and aggregation network layers have have hierarchical physical topologies that enable IGP/LDP segmentation.

This transport architecture structuring based on access type and network size leads to five architecture models that fit various customer deployments and operator preferences as shown in Figure 3-1, and described in the sections below.

Figure 3-1. UMMT Transport Models

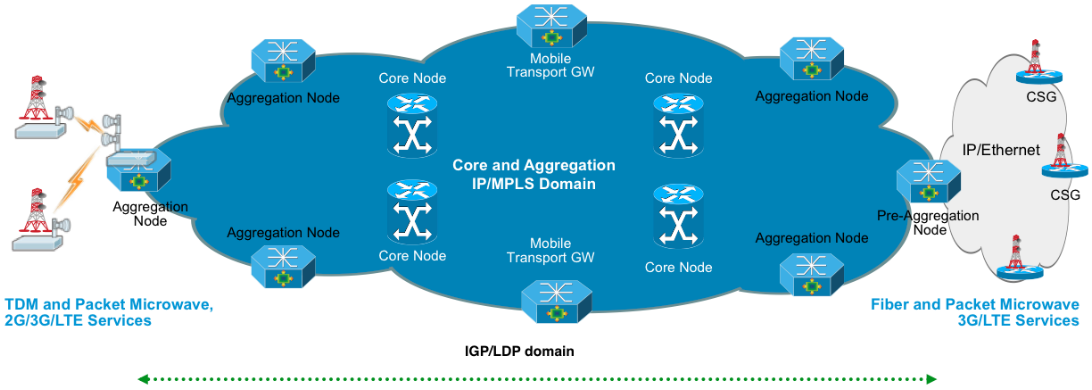


	Small Network	Large Network
Ethernet/TDM Access	Flat LDP Core and Aggregation Network	Labeled BGP Core and Aggregation
MPLS Access	Labeled BGP Access with Flat LDP Core and Aggregation	Labeled BGP Core, Aggregation, and Access Labeled BGP Core and Aggregation with Redistribution into Access Network IGP

3.2.1 Flat LDP Core and Aggregation

This architecture model applies to small geographies where core and aggregation networks may not have distinct physical topologies, are integrated under common operations and network segmentation is not required for availability reasons. It assumes an non-MPLS IP/Ethernet or TDM access being aggregated in a small scale network.

Figure 3-2. Flat LDP Core and Aggregation

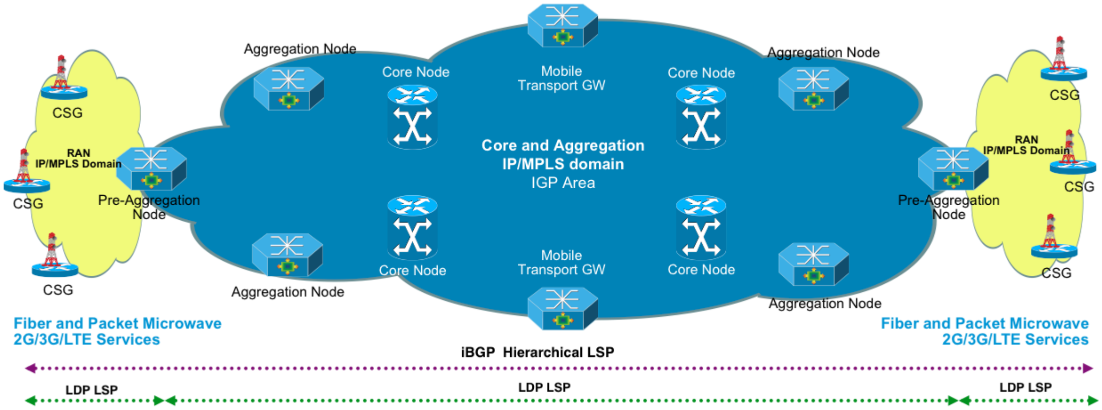


The small scale aggregation network is assumed to be comprised of core and aggregation nodes that are integrated in a single IGP/LDP domain consisting of less than 1000 nodes. Since no segmentation between network layers exists, a flat LDP LSP provides end-to-end reachability across the network. All mobile (and wireline) services are enabled by the aggregation nodes. The mobile access is based on TDM and packet microwave links aggregated in aggregation nodes that provide TDM/ATM/Ethernet VPWS and MPLS VPN transport.

3.2.2 Labeled BGP Access with Flat LDP Core and Aggregation

This architecture model applies to small geographies. It assumes an MPLS-enabled access network with fiber and packet microwave links being aggregated in a small scale network.

Figure 3-3. Labeled BGP Access with Flat LDP Core and Aggregation



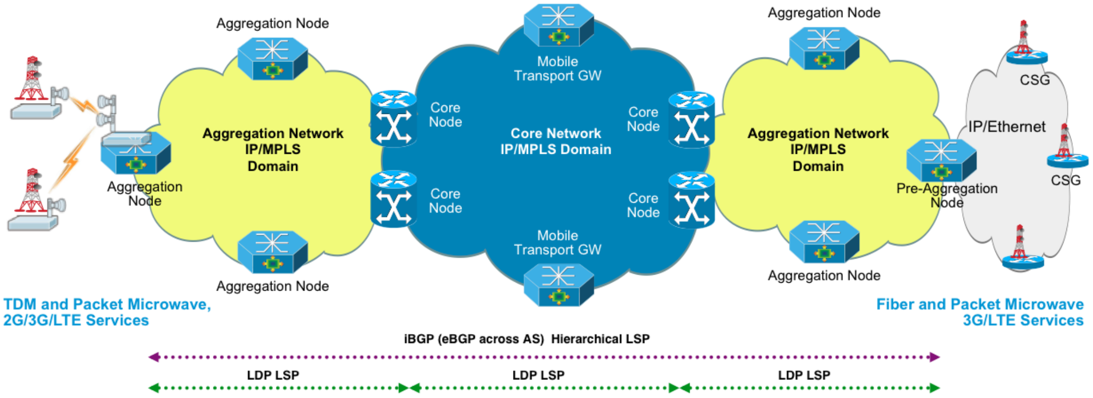
The small scale aggregation network is assumed to be comprised of core and aggregation nodes that are integrated in a single IGP/LDP domain consisting of less than 1000 nodes. The RAN access network is comprised of a separate IGP domain. The separation can be enabled by making the access network part of a different IGP area from the aggregation and core nodes, or by running a different IGP process on the pre-aggregation nodes corresponding to the aggregation/core and RAN access networks. LDP is use to build intra-area LSP within each segmented domain. The aggregation/core and RAN access networks are integrated with labeled BGP LSPs, with the pre-aggregation nodes acting as ABRs performing BGP next-hop-self (NHS) function to extend the iBGP hierarchical LSP across the two domains. The mobile 2G/3G/LTE (and wireline) services can be enabled by the CSGs in the access as well as the pre-aggregation/aggregation nodes.

BGP community-based egress filtering is performed towards the RAN access at the pre-aggregation node ABRs so that the CSGs only learn required remote destinations and all unwanted prefixes are dropped so as to keep their BGP tabels small and prevent unnecessary updates.

3.2.3 Labeled BGP Core and Aggregation

This architecture model applies to networks deployed in medium to large geographies. It assumes a non-MPLS IP/Ethernet or TDM access being aggregated in a relatively large scale network.

Figure 3-4. Labeled BGP Core and Aggregation



The network infrastructure is organized by segmenting the core and aggregation networks into independent IGP/LDP domains. The segmentation between the core and aggregation domains could be based on a single AS multi-area design or an inter-AS organization. In the single AS multi-area option, the separation can be enabled by making the aggregation network part of a different IGP area from the core network, or by running a different IGP process on the core ABR nodes corresponding to the aggregation and core networks. The mobile RAN access is based on native IP or Ethernet links in point-to-point or ring topologies over fiber and newer Ethernet microwave-based access, or point-to-point TDM+Ethernet links over hybrid microwave.

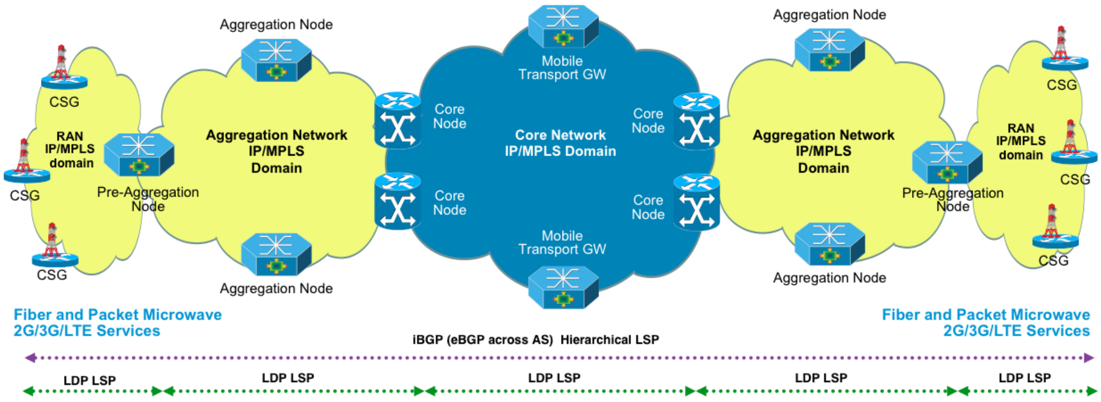
All mobile (and wireline) services are enabled by the aggregation nodes. LDP is used to build intra-area LSP within each segmented domain. The aggregation and core networks are integrated with labeled BGP LSPs. In the single AS multi-area option, the core ABRs perform BGP NHS function to extend the iBGP hierarchical LSP across the aggregation and core domains. When the core and aggregation networks are organized in different autonomous systems, iBGP is used to build the hierarchical LSP from the pre-aggregation node to the ASBRs and eBGP is used to extend the end-to-end LSP across the AS boundary.

BGP community-based egress filtering is performed towards the aggregation networks at the core ABRs so that the pre-aggregation and aggregation nodes only learn required remote destinations and all unwanted prefixes are dropped. This helps reduce the size of BGP tables on these nodes and also prevents unnecessary updates.

3.2.4 Labeled BGP Core, Aggregation, and Access

This architecture model applies to networks deployed in large geographies. It assumes an MPLS-enabled access network with fiber and packet microwave links being aggregated in a large scale network.

Figure 3-5. Labeled BGP Core, Aggregation, and Access



The network infrastructure is organized by segmenting the core, aggregation, and access networks into independent IGP/LDP domains. The segmentation between the core, aggregation, and access domains could be based on a single AS multi-area design or an inter-AS organization. In the single AS multi-area option, the separation between core and aggregation networks can be enabled by making the aggregation network part of a different IGP area from the core network, or by running a different IGP process on the core ABR nodes corresponding to the aggregation and core networks. The separation between aggregation and access networks is enabled by running a different IGP process on the pre-aggregation nodes corresponding to the aggregation and RAN access networks. In the inter-AS option, while the core and aggregation networks are in different autonomous systems, the separation between aggregation and access networks is enabled by making the access network part of a different IGP area from the aggregation network, or by running a different IGP process on the pre-aggregation nodes corresponding to the aggregation and RAN access networks.

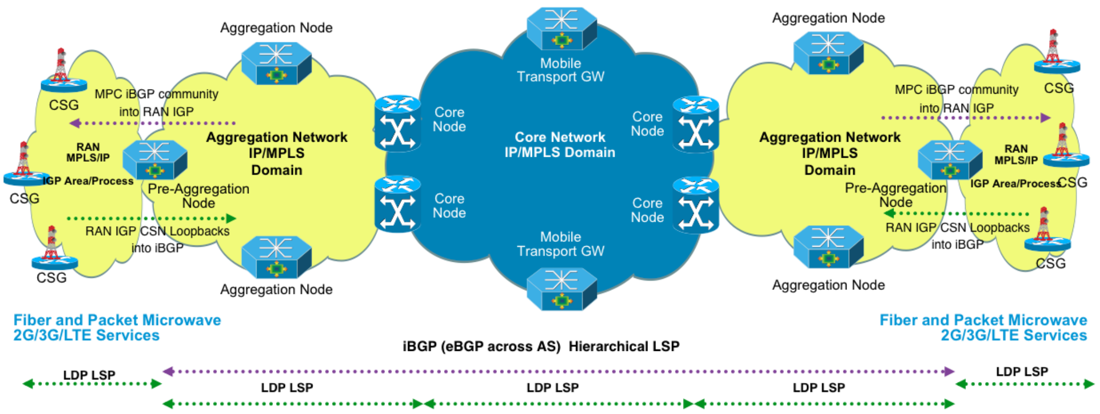
The mobile 2G/3G/LTE (and wireline) services can be enabled by the CSGs in the access as well as the pre-aggregation/aggregation nodes. LDP is use to build intra-area LSP within each segmented domain. The access, aggregation, and core networks are integrated with labeled BGP LSPs. In the single AS multi-area option, the pre-aggregation nodes and core ABRs act as ABRs for their corresponding domains and extend the iBGP hierarchical LSP across the access, aggregation, and core domains. When the core and aggregation networks are organized in different autonomous systems, the pre-aggregation nodes act as ABRs performing BGP NHS function to extend the iBGP hierarchical LSP across the access and aggregation domains. At the ASBRs, eBGP is used to extend the end-to-end LSP across the AS boundary.

BGP community-based egress filtering is performed towards the aggregation networks at the core ABRs, and towards the RAN access at the pre-aggregation node ABRs so that the corresponding nodes in each domain only learn required remote destinations and all unwanted prefixes are dropped. This helps reduce the size of BGP tables on these nodes and also prevents unnecessary updates.

3.2.5 Labeled BGP Core and Aggregation with Redistribution into Access Network IGP

This architecture model applies to networks deployed in large geographies. It assumes an MPLS-enabled access network with fiber and packet microwave links being aggregated in a large scale network.

Figure 3-6. Labeled BGP Core and Aggregation with Redistribution into Access Network IGP



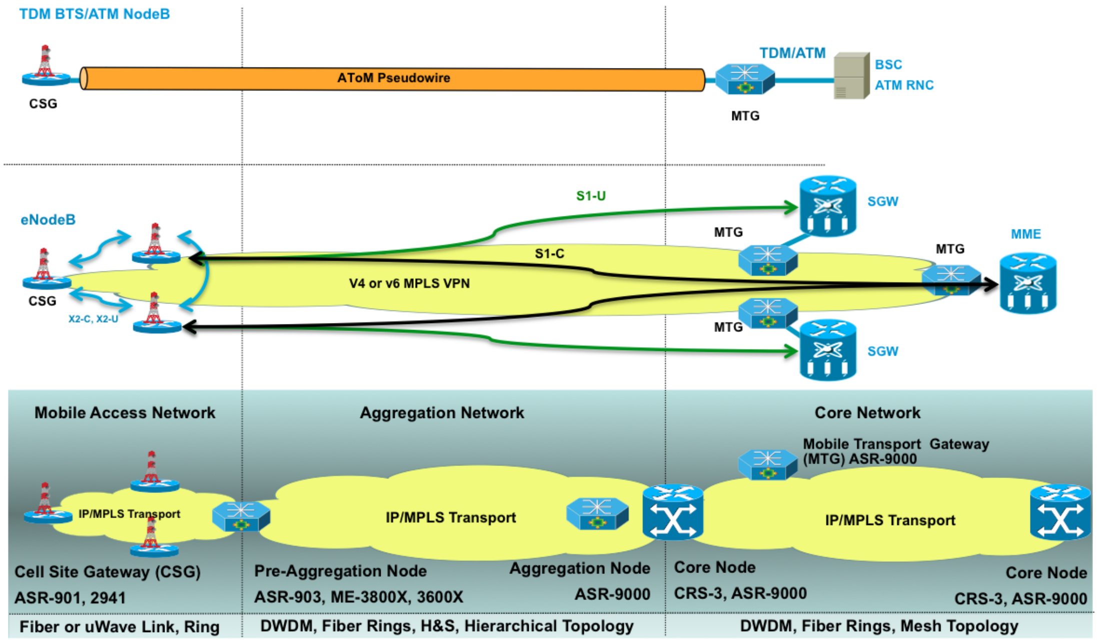
The network infrastructure organization in this architecture model is the same as the one described in Section 3.2.4 Labeled BGP Core, Aggregation, and Access, with options for both Single AS Multi-Area and Inter-AS designs. The service options in this model are also the same with support for mobile 2G/3G/LTE (and wireline) services that can be enabled by the CSGs in the access as well as the pre-aggregation/aggregation nodes. This model differs from aforementioned one in that the hierarchical-labeled BGP LSP spans only the core and aggregation networks and does not extend to the RAN access. Instead of using BGP for inter-domain label distribution in the RAN, the end-to-end unified MPLS LSP is extended into the RAN access using LDP with redistribution. The IGP scale in the RAN access is kept small by selective redistribution of required remote prefixes from iBGP based on communities.

3.3 Service Models

The fundamental goal of the UMMT System is the simplification of the end-to-end mobile transport and service architecture. It achieves this goal by decoupling the transport and service layers of the network, thereby allowing these two distinct entities to be provisioned and managed independently. As described in Section 3.2 Transport Architecture Models, Unified MPLS Transport seamlessly interconnects the access, aggregation, and core MPLS domains of the network infrastructure with hierarchical LSPs at the transport layer. Once this unified MPLS transport is established (a task that only needs to be undertaken once), a multitude of services can be deployed on top it. These services can span any location in the network without restricting topological boundaries.

The decoupling of the transport and service layers makes it possible for the service architecture or service delivery model for any given service to be provisioned, managed, and changed independently, without having to touch the transport layer. It eliminates the unwanted complexity of having to provision and manage intermediate touchpoints like the pre-aggregation, aggregation, and core ABRs for service delivery, requiring service provisioning only at the service endpoints.

Figure 3-7. Mobile Backhaul Services



The UMMT System is a comprehensive RAN backhaul solution that provides the foundation for LTE, legacy 2G GSM, and existing 3G UMTS transport services.

The system proposes a highly-scaled MPLS L3VPN-based service model to meet the immediate needs of LTE transport and accelerate its deployment. The MPLS VPN model provides the required transport virtualization for the graceful introduction of LTE into a existing 2G/3G network, and also satisfies future requirements of RAN sharing in a wholesale scenario. It is well suited to satisfy the mesh connectivity and stringent latency requirements of the LTE X2 interface. Simple MPLS VPN route-target import/export mechanisms can be used to enable:

- Multipoint connectivity within the local RAN access for intra-RAN-access X2 handoff.
- Multipoint connectivity with adjacent RAN access regions for inter-RAN-access region X2 handoff.

- Multipoint connectivity with EPC gateways (SGWs, MMEs) in the MPC for the S1-u/c interface.
- Multipoint connectivity with more than one MME and SGW for MME and SGW pooling scenarios.

The MPLS VPN-based service model allows for eNodeBs and associated CSGs to be added to the RAN at any location in the network, EPC gateways can be added in the MPC and have instant connectivity to each other without additional configuration overhead. It allows seamless migration of eNodeBs initially mapped to centralized EPC gateways to more distributed ones to accommodate capacity and scale demands, without having to re-provision the transport infrastructure. Section 4.2.1 L3 MPLS VPN Service Model for LTE covers these aspects in detail.

Service virtualization with MPLS-based L2 and L3 VPNs also allows legacy 2G GSM and existing 3G UMTS services to co-exist with LTE on the same transport infrastructure. The system supports MSPs with GSM and ATM-based UMTS deployments wishing to remove, reduce, or cap investments in SONET/SDH and ATM transport infrastructure by using MPLS-based Circuit Emulation over Packet (CEoP) services.

For the MSPs that want to reduce SONET/SDH infrastructure used for GSM, UMMT enables PWE3-based transport of emulated TDM circuits. Structured circuit emulation is achieved with Circuit Emulation Service over Packet Switched Network (CESoPSN), and unstructured emulation is achieved with Structure-Agnostic Transport over Packet (SAToP). E1/T1 circuits from BTS equipment connected to the CSG or to the pre-aggregation node (PAN) are transported to MTG, where they are bundled into channelized STM1/OC-3 interfaces for handoff to the BSC. Section 4.2.2 L2 MPLS VPN Service Model for 2G and 3G covers these aspects in detail.

The next system release will cover ATM transport for mobile service providers (MSP) that want to reduce their ATM infrastructure used for ATM-based UMTS with ATM VC (AAL0 or AAL5) or VP (AAL0) PWE3-based transport. ATM E1/T1 or IMA interfaces from NodeB equipment connected to the CSG or PAN can be transported to the MTG, where they are bundled into STM1 ATM interfaces for handoff to the RNC. Cell packing may be used to optimize the bandwidth used for this transport.

For the above service models, the system supports physical layer synchronization of frequency based on SyncE, or packet-based synchronization of frequency and phase based on 1588 Precision Time Protocol (PTP), as described in Section 5.2 Synchronization Distribution.

CHAPTER 4

System Architecture

This chapter includes the following major topics:

- Section 4.1 Transport Architecture
- Section 4.2 Service Models
- Section 4.3 Inter-Domain Hierarchical LSPs
- Section 4.4 Transport and Service Control Plane
- Section 4.5 Prefix Filtering
- Section 4.6 Scale Considerations

4.1 Transport Architecture

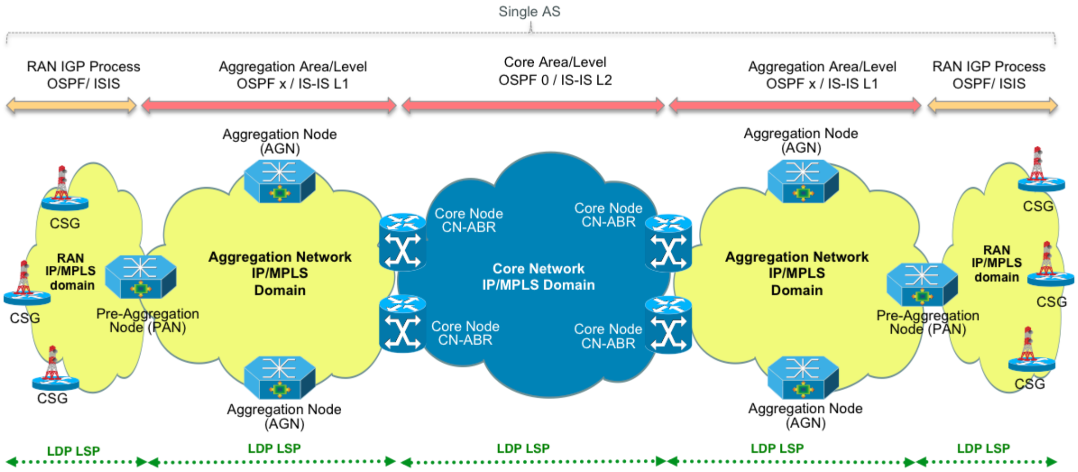
This section includes the following topics:

- Section 4.1.1 Large Network, Multi-Area IGP Design with IP/MPLS Access
- Section 4.1.2 Large Network, Inter-AS Design with IP/MPLS Access
- Section 4.1.3 Large Network, Multi-Area IGP Design with non_IP/MPLS Access
- Section 4.1.4 Large Network, Inter-AS Design with non_IP/MPLS Access
- Section 4.1.5 Small Network, Single-Area IGP Design with non_IP/MPLS Access

4.1.1 Large Network, Multi-Area IGP Design with IP/MPLS Access

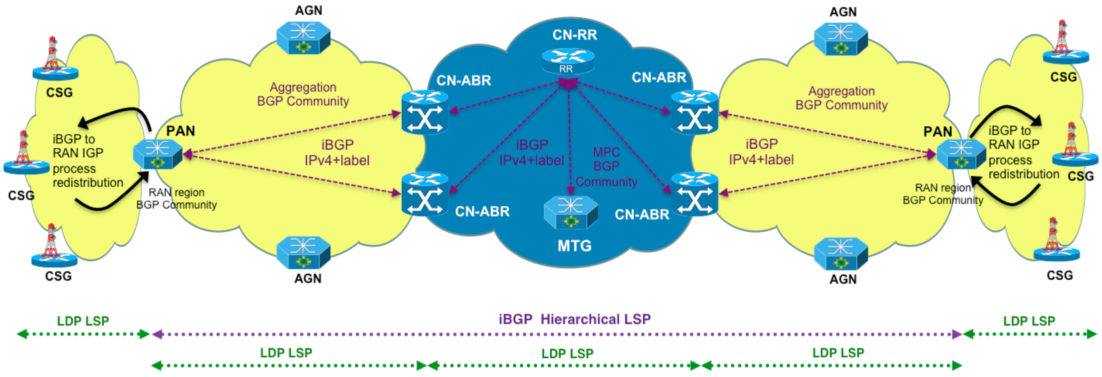
This section details the system architecture for the transport model described in Section 3.2.5 Labeled BGP Core and Aggregation with Redistribution into Access Network IGP. It assumes that the network organization between the core and aggregation domains is based on a single autonomous system, multi-area IGP design. This model follows the approach of enabling a Unified MPLS LSP using hierarchical-labeled BGP LSPs across the core and aggregation network with extension to the access based on labeled BGP redistribution into the access network IGP.

Figure 4-1. Multi-Area IGP/LDP Domain Organization



From an multi-area IGP organization perspective, the core network is either an intermediate system to intermediate system (IS-IS) Level 2 or an open shortest path first (OSPF) backbone area. The aggregation domains, in turn, are IS-IS Level 1 or OSPF non-backbone areas. No redistribution occurs between the core and aggregation IGP levels/areas, thereby containing the route scale within each domain. The MPLS/IP mobile access networks subtending from aggregation or pre-aggregation nodes are based on a different IGP process, restricting their scale to the level of the local RAN. Partitioning these network layers into such independent and isolated IGP domains helps reduce the size of routing and forwarding tables on individual routers in these domains, which, in turn, leads to better stability and faster convergence within each of these domains. LDP is used for label distribution to build intra-domain LSPs within each independent access, aggregation, and core IGP domain.

Figure 4-2. Inter-Domain Transport with Hierarchical LSPs



RFC 3107 procedures based on iBGP IPv4 unicast+label are used as an inter-domain LDP to build hierarchical LSPs across domains. All nodes in the core and aggregation network that require inter-domain LSPs act as labeled BGP PEs and run iBGP-labeled unicast peering with designated route reflectors (RRs) depending on their location in the network.

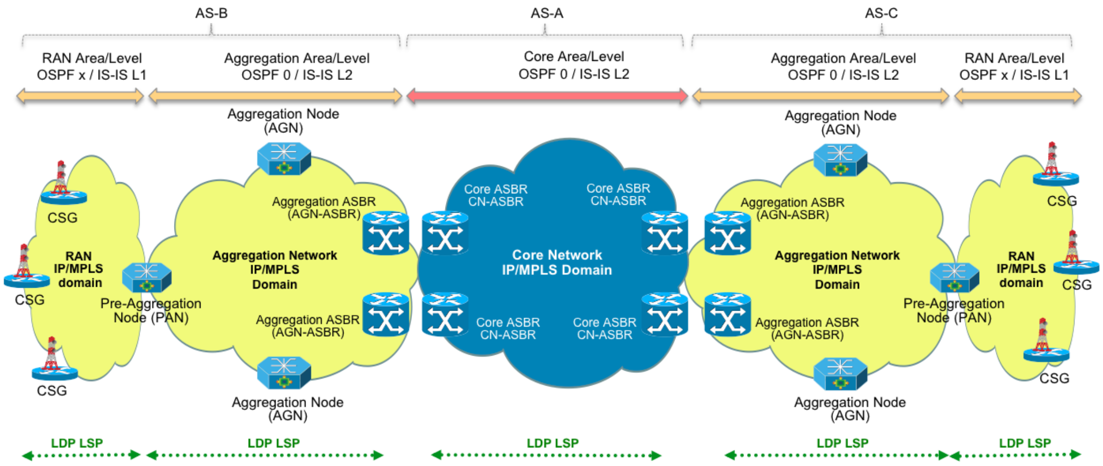
- The core PoP nodes are labeled BGP ABRs (CN-ABR) between the aggregation and core areas, and act as inline route reflectors (RR) for their local aggregation area-labeled BGP PEs. The CN-ABRs peer with other CN-ABRs using iBGP-labeled unicast in either a full mesh configuration or using centralized RRs over the core network. The centralized RR deployment option is shown in Figure 4-2 above.

- The MTGs residing in the core network are labeled BGP PEs and peer either directly with the closest CN-ABR RRs, in the case of a CN-ABR full-mesh configuration, or with the centralized RRs, depending on the deployment setting. The MTGs advertise their loopbacks into BGP-labeled unicast with a common BGP community representing the MPC. They learn all the labeled BGP prefixes and have reachability across the entire network down to the MPLS/IP RAN access.
- All aggregation nodes and PANs in aggregation networks that require inter-domain LSPs to either reach nodes in another remote aggregation network, or that need to cross the core network to reach the MTGs, act as labeled BGP PEs, and peer with their local CN-ABR RRs. These aggregation nodes advertise their loopbacks into BGP-labeled unicast with a common BGP community that represents the aggregation community. The local CN-ABR RRs may perform BGP egress filtering towards their aggregation clients based on aggregation and MPC-marked BGP communities to drop unwanted remote RAN loopbacks and contain the labeled BGP scale on the aggregation nodes.
- Since redistribution of routes between the core and aggregation IGP levels/areas is prevented in order to keep the routing domains isolated, the CN-ABRs have to insert themselves into the data path to enable inter-domain LSPs. The CN-ABRs acting as inline RRs do this by reflecting the labeled BGP prefixes with NHS symmetrically towards the PANs in their local aggregation network, and MTGs and remote CN-ABRs in the core network.
- The inter-domain LSPs are extended to the MPLS/IP RAN access with a controlled redistribution based on IGP tags and BGP communities. Each mobile access network subtending from a pair of pre-aggregation nodes is based on a different IGP process. At the pre-aggregation nodes, the inter-domain core and aggregation LSPs are extended to the RAN access by redistributing between iBGP and RAN IGP. In one direction, the RAN access node loopbacks (filtered based on IGP tags) are redistributed into iBGP-labeled unicast and tagged with RAN access BGP community that is unique to that RAN access region. In the other direction, the MPC prefixes (filtered based on MPC-marked BGP communities) are redistributed into the RAN access IGP process. The MPC prefixes consisting of MTG loopbacks are limited in number and help contain the low scale in the RAN IGP. The MTGs in the core network, on the other hand, are capable of handling large scale and will learn all iBGP-labeled unicast prefixes.

4.1.2 Large Network, Inter-AS Design with IP/MPLS Access

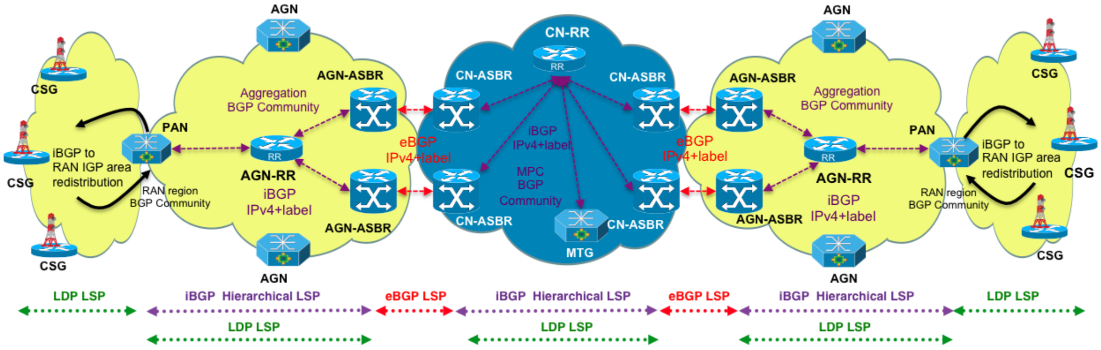
This section details the system architecture for the transport model described in Section 3.2.5 Labeled BGP Core and Aggregation with Redistribution into Access Network IGP. It assumes that the core and aggregation networks are organized as different autonomous systems. This model follows the approach of enabling a Unified MPLS LSP using hierarchical-labeled BGP LSPs based on iBGP-labeled unicast within each AS, eBGP-labeled unicast used to extend the LSP across AS boundaries, and extension to the access based on labeled BGP redistribution into the access network IGP.

Figure 4-3. Inter-AS IGP/LDP Domain Organization



The core and aggregation networks are segmented into different autonomous systems. Within each aggregation domain, the aggregation and access networks are segmented into different IGP areas or levels, where the aggregation network is either an IS-IS Level 2 or an OSPF backbone area, and subtending access networks are IS-IS Level 1 or OSPF non-backbone areas. No redistribution occurs between the aggregation and access IGP levels/areas, thereby containing the route scale within each domain. Partitioning these network layers into such independent and isolated IGP domains helps reduce the size of routing and forwarding tables on individual routers in these domains, which, in turn, leads to better stability and faster convergence within each of these domains. LDP is used for label distribution to build intra-domain LSPs within each independent access, aggregation, and core IGP domain.

Figure 4-4. Inter-Domain Transport with Hierarchical LSPs



RFC 3107 procedures based on iBGP IPv4 unicast+label are used as an inter-domain LDP to build hierarchical LSPs across domains. All nodes in the core and aggregation network that require inter-domain LSPs act as labeled BGP PEs and run iBGP-labeled unicast peering with designated RRs, depending on their location in the network.

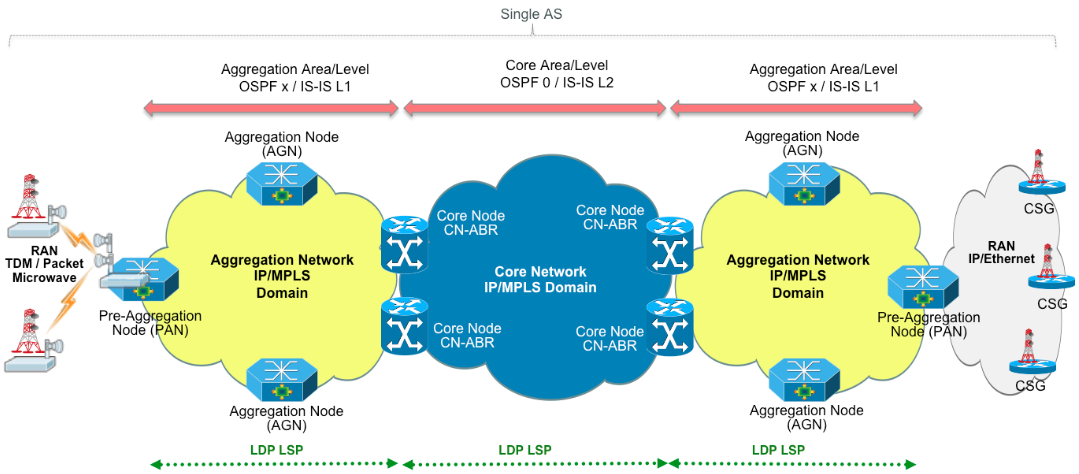
- The MTGs residing in the core network are labeled BGP PEs and peer with iBGP-labeled unicast sessions with the centralized core route reflector (CN-RR). The MTGs advertise their loopbacks into BGP-labeled unicast with a common BGP community representing the mobile packet core. They learn all the labeled BGP prefixes and have reachability across the entire network down to the MPLS/IP RAN access.

- The core PoP nodes act as labeled BGP autonomous system boundary routers (CN-ASBR) in the core AS. They peer with iBGP labeled unicast sessions with the CN-RR within the core AS, and peer with eBGP-labeled unicast sessions with the neighboring aggregation ASBRs. The CN-ASBRs insert themselves into the data path to enable inter-domain LSPs by setting next-hop-self on all BGP updates towards their local CN-RRs and neighboring aggregation ASBRs.
- The aggregation PoP nodes act as labeled BGP AGN-ASBRs in the aggregation AS. They peer with iBGP-labeled unicast sessions with the centralized aggregation route reflector (AGN-RR) within the aggregation AS, and peer with eBGP-labeled unicast sessions to the CN-ASBR in the neighboring AS. The AGN-ASBRs insert themselves into the data path to enable inter-domain LSPs by setting next-hop-self on all BGP updates towards their local AGN-RRs and neighboring core ASBRs.
- All PANs in the aggregation networks that require inter-domain LSPs to either reach nodes in another remote aggregation network, or that need to cross the core network to reach the MTGs, act as labeled BGP PEs, and peer with iBGP-labeled unicast sessions to the local AGN-RR. The PANs advertise their loopbacks into BGP-labeled unicast with a common BGP community that represents the aggregation community. They learn labeled BGP prefixes marked with the aggregation BGP community and the MPC BGP community.
- The inter-domain LSPs are extended to the MPLS/IP RAN access with a controlled redistribution based on IGP tags and BGP communities. At the PANs, the inter-domain core and aggregation LSPs are extended to the RAN access by redistributing between iBGP and RAN IGP level/area. In one direction, the RAN access node loopbacks (filtered based on IGP tags) are redistributed into iBGP-labeled unicast and tagged with RAN access BGP community that is unique to that RAN access region. In the other direction, the MPC prefixes (filtered based on MPC-marked BGP communities) are redistributed into the RAN access IGP level/area. The MPC prefixes consisting of MTG loopbacks are limited in number and help contain the low scale in the RAN IGP level/area. The MTGs in the core network, on the other hand, are capable of handling large scale and will learn all iBGP-labeled unicast prefixes.

4.1.3 Large Network, Multi-Area IGP Design with non-IP/MPLS Access

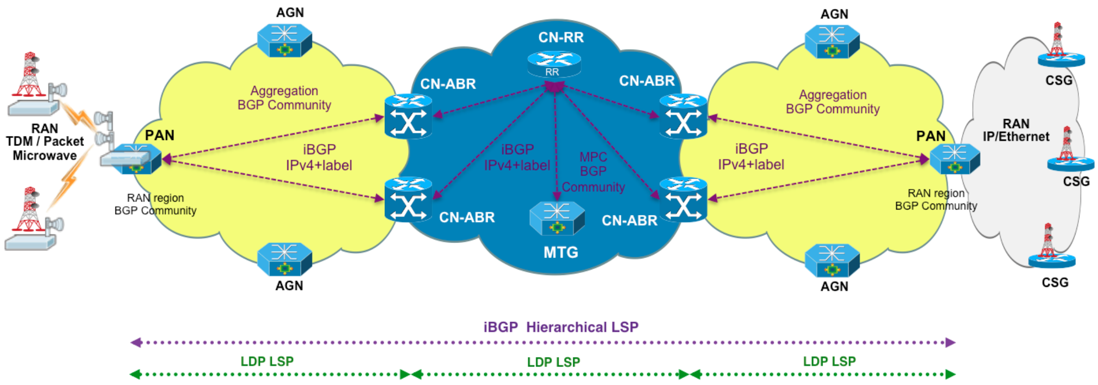
This section details the system architecture for the transport model described in Section 3.2.3 Labeled BGP Core and Aggregation. It assumes that the network organization between the core and aggregation domains is based on a single autonomous system, multi-area IGP design. It assumes a non-MPLS IP/Ethernet or TDM access where all mobile and potentially wireline services are enabled by the aggregation nodes.

Figure 4-5. Multi-Area IGP/LDP Domain Organization



From an multi-area IGP organization perspective, the core network is either an intermediate system to intermediate system (IS-IS) Level 2 or an open shortest path first (OSPF) backbone area. The aggregation domains, in turn, are IS-IS Level 1 or OSPF non-backbone areas. No redistribution occurs between the core and aggregation IGP levels/areas. This isolation helps reduce the size of routing and forwarding tables on individual routers in these domains, which, in turn, leads to better stability and faster convergence. LDP is used for label distribution to build intra-domain LSPs within each independent aggregation and core IGP domain. The access network is based on native IP or Ethernet links over fiber or packet microwave integrated in point-to-point or ring topologies, or based on TDM +Ethernet links over hybrid microwave with point-to-point connectivity.

Figure 4-6. Inter-Domain Transport with Hierarchical LSPs



RFC 3107 procedures based on iBGP IPv4 unicast+label are used as an inter-domain LDP to build hierarchical LSPs across domains. All nodes in the core and aggregation network that require inter-domain LSPs act as labeled BGP PEs and run iBGP-labeled unicast peering with designated route reflectors (RRs) depending on their location in the network.

- The core PoP nodes are labeled BGP ABRs (CN-ABR) between the aggregation and core areas, and act as inline route reflectors (RR) for their local aggregation area-labeled BGP PEs. The CN-ABRs peer with other CN-ABRs using iBGP-labeled unicast in either a full mesh configuration or using centralized RRs over the core network. The centralized RR deployment option is shown in Figure 4-6 above.

- The MTGs residing in the core network are labeled BGP PEs and peer either directly with the closest CN-ABR RRs, in the case of a CN-ABR full-mesh configuration, or with the centralized RRs, depending on the deployment setting. The MTGs advertise their loopbacks into BGP-labeled unicast with a common BGP community representing the MPC. They learn all the labeled BGP prefixes and have reachability across the entire network.
- All aggregation nodes and PANs in aggregation networks that require inter-domain LSPs to either reach nodes in another remote aggregation network, or that need to cross the core network to reach the MTGs, act as labeled BGP PEs, and peer with their local CN-ABR RRs. These aggregation nodes advertise their loopbacks into BGP-labeled unicast with a common BGP community that represents the aggregation community. The local CN-ABR RRs may perform BGP egress filtering towards their aggregation clients based on aggregation and MPC-marked BGP communities to drop unwanted remote RAN loopbacks and contain the labeled BGP scale on the aggregation nodes.
- Since redistribution of routes between the core and aggregation IGP levels/areas is prevented in order to keep the routing domains isolated, the CN-ABRs have to insert themselves into the data path to enable inter-domain LSPs. The CN-ABRs acting as inline RRs do this by reflecting the labeled BGP prefixes with NHS symmetrically towards the PANs in their local aggregation network, and MTGs and remote CN-ABRs in the core network.

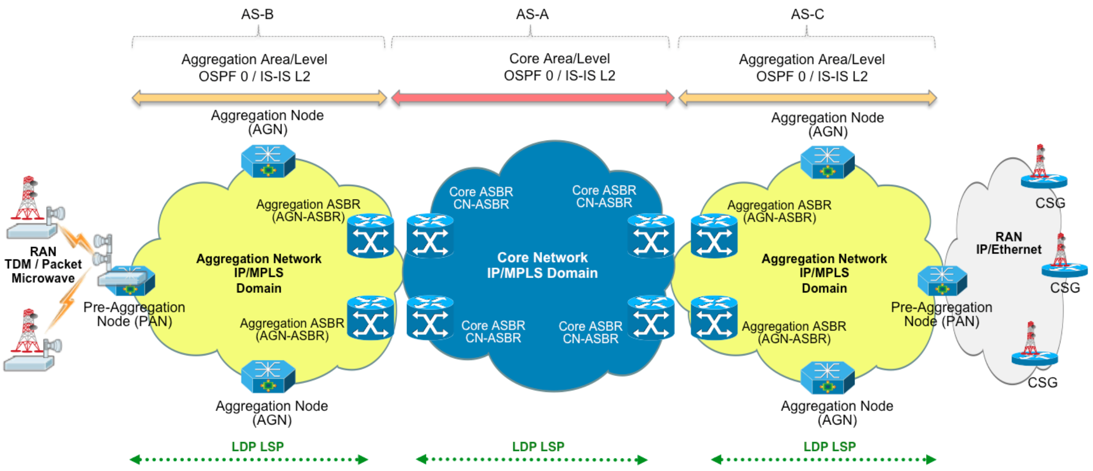
All MPLS services are enabled by the PANs in the aggregation network. These include:

- GSM Abis, ATM IuB, IP IuB, and IP S1/X2 interfaces for 2G/3G/LTE services for RAN access domains with point-to-point connectivity over TDM or hybrid (TDM+Packet) microwave
- IP IuB, and IP S1/X2 interfaces for 3G/LTE services for RAN access domains with point-to-point or ring topologies over fiber or packet microwave.

4.1.4 Large Network, Inter-AS Design with non-IP/MPLS Access

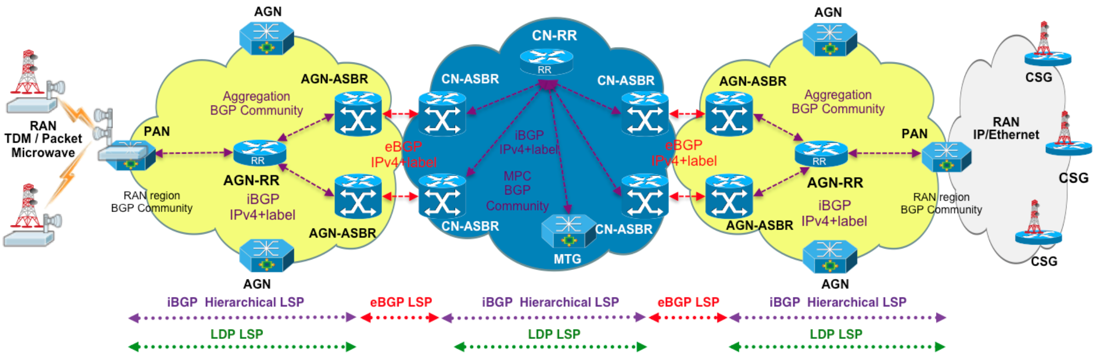
This section details the system architecture for transport model described in Section 3.2.3 Labeled BGP Core and Aggregation. It assumes that the core and aggregation networks are organized as different autonomous systems. It assumes a non-MPLS IP/Ethernet or TDM access where all mobile and potentially wireline services are enabled by the aggregation nodes.

Figure 4-7. Inter-AS IGP/LDP Domain Organization



This model follows the approach of enabling a Unified MPLS LSP using hierarchical-labeled BGP LSPs based on iBGP-labeled unicast within each AS, eBGP-labeled unicast used to extend the LSP across AS boundaries. The core and aggregation networks are segmented into different autonomous systems. LDP is used for label distribution to build intra-domain LSPs within each independent aggregation and core IGP domain. The access network is based on native IP or Ethernet links over fiber or packet microwave integrated in point-to-point or ring topologies, or based on TDM+Ethernet links over hybrid microwave with point-to-point connectivity.

Figure 4-8. Inter-Domain Transport with Hierarchical LSPs



RFC 3107 procedures based on iBGP IPv4 unicast+label are used as an inter-domain LDP to build hierarchical LSPs across domains. All nodes in the core and aggregation network that require inter-domain LSPs act as labeled BGP PEs and run iBGP-labeled unicast peering with designated RRs, depending on their location in the network.

- The MTGs residing in the core network are labeled BGP PEs and peer with iBGP-labeled unicast sessions with the centralized core route reflector (CN-RR). The MTGs advertise their loopbacks into BGP-labeled unicast with a common BGP community representing the MPC. They learn all the labeled BGP prefixes and have reachability across the entire network down to the MPLS/IP RAN access.
- The core PoP nodes act as labeled BGP autonomous system boundary routers (CN-ASBR) in the core AS. They peer with iBGP-labeled unicast sessions with the CN-RR within the core AS, and peer with eBGP-labeled unicast sessions with the neighboring aggregation ASBRs. The CN-ASBRs insert themselves into the data path to enable inter-domain LSPs by setting NHS on all BGP updates towards their local CN-RRs and neighboring aggregation ASBRs.
- The aggregation PoP nodes act as labeled BGP AGN-ASBRs in the aggregation AS. They peer with iBGP-labeled unicast sessions with the centralized aggregation route reflector (AGN-RR) within the aggregation AS, and peer with eBGP-labeled unicast sessions to the CN-ASBR in the neighboring AS. The AGN-ASBRs insert themselves into the data path to enable inter-domain LSPs by setting NHS on all BGP updates towards their local AGN-RRs and neighboring core ASBRs.
- All PANs in the aggregation networks that require inter-domain LSPs to either reach nodes in another remote aggregation network, or that need to cross the core network to reach the MTGs, act as labeled BGP PEs, and peer with iBGP-labeled unicast sessions to the local AGN-RR. The PANs advertise their loopbacks into BGP-labeled unicast with a common BGP community that represents the aggregation community. They learn labeled BGP prefixes marked with the aggregation BGP community and the MPC BGP community.

All MPLS services are enabled by the PANs in the aggregation network. These include:

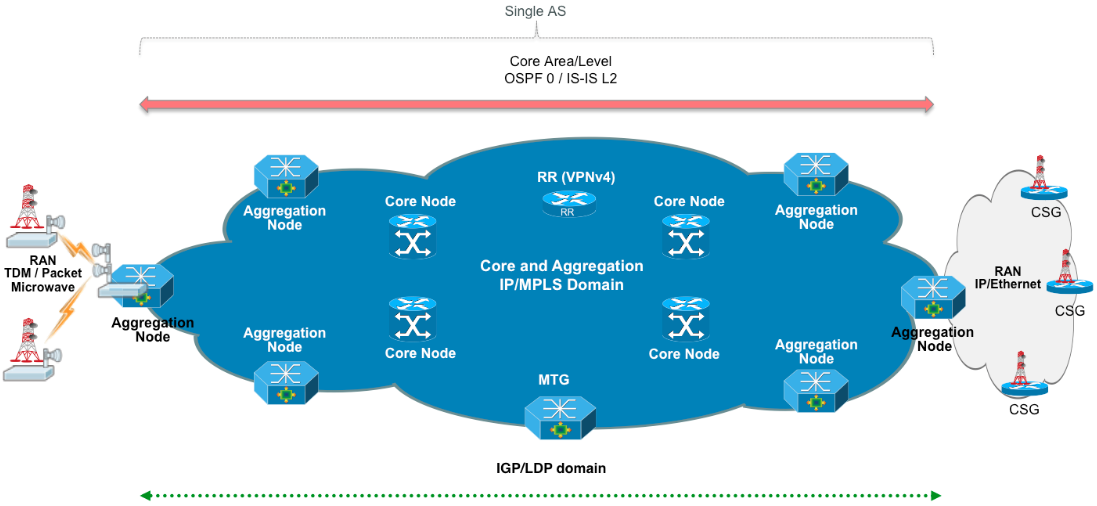
- GSM Abis, ATM IuB, IP IuB, and IP S1/X2 interfaces for 2G/3G/LTE services for RAN access domains with point-to-point connectivity over TDM or hybrid (TDM+Packet) microwave

- IP IuB, and IP S1/X2 interfaces for 3G/LTE services for RAN access domains with point-to-point or ring topologies over fiber or packet microwave.

4.1.5 Small Network, Single-Area IGP Design with non-IP/MPLS Access

This section details the system architecture for the transport model described in Section 3.2.1 Flat LDP Core and Aggregation.

Figure 4-9. Single-Area IGP with Flat LDP Core and Aggregation



This model assumes that the core and aggregation networks form a single IGP/LDP domain consisting of less than 1000 nodes. Since no segmentation between network layers exists, a flat LDP LSP provides end-to-end reachability across the network. The mobile access is based on TDM and packet microwave links aggregated in aggregation nodes that provide TDM/ATM/Ethernet VPWS and MPLS VPN transport.

All MPLS services are enabled by the Aggregation Nodes. These include:

- GSM Abis, ATM IuB, IP IuB, and IP S1/X2 interfaces for 2G/3G/LTE services for RAN access domains with point-to-point connectivity over TDM or hybrid (TDM+Packet) microwave
- IP IuB, and IP S1/X2 interfaces for 3G/LTE services for RAN access domains with point-to-point or ring topologies over fiber or packet microwave.

4.2 Service Architecture

The UMMT System design provides transport for both legacy and current mobile services. To accomplish this on a single network, MPLS service virtualization is employed, which provides emulated circuit services via L2VPN for 2G and 3G services and L3VPN services for IP-enabled 3G and 4G/LTE services. Both service models are outlined in this section.

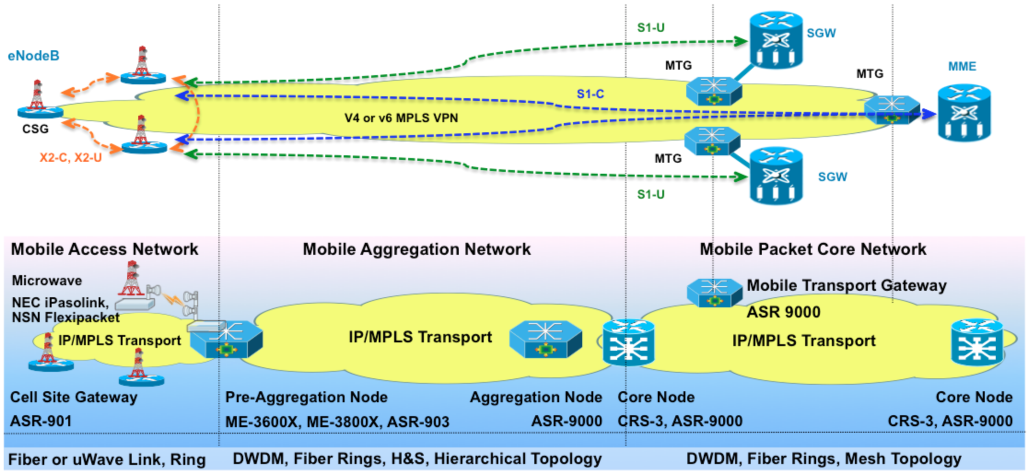
This section includes the following major topics:

- Section 4.2.1 L3 MPLS VPN Service Model for LTE
- Section 4.2.2 L2 MPLS VPN Service Model for 2G and 3G

4.2.1 L3 MPLS VPN Service Model for LTE

The UMMT supports MSPs that are introducing 3G UMTS/IP and 4G LTE-based next generation mobile access in order to scale their mobile subscribers and optimize their network infrastructure cost for the mobile broadband growth. To this end, the system proposes a highly scaled MPLS VPN-based service model to meet the immediate needs of LTE and accelerate its deployment.

Figure 4-10. LTE Backhaul Service



The mobile RAN includes cell sites with eNodeBs that are connected either:

- directly in a point-to-point fashion to the pre-aggregaton nodes utilizing Ethernet fiber or microwave OR
- through CSGs connected in ring topologies using MPLS/IP packet transport over Ethernet fiber or microwave transmission.

The cell sites in the RAN access are collected in a MPLS/IP pre-aggregation/aggregation network that may be comprised of a physical hub-and-spoke or ring connectivity that interfaces with the MPLS/IP core network that hosts the EPC gateways.

From the E-UTRAN backhaul perspective, the most important LTE/SAE reference points are the X2 and S1 interfaces. The eNodeBs are interconnected with each other via the X2 interface, and towards the EPC via the S1 interface.

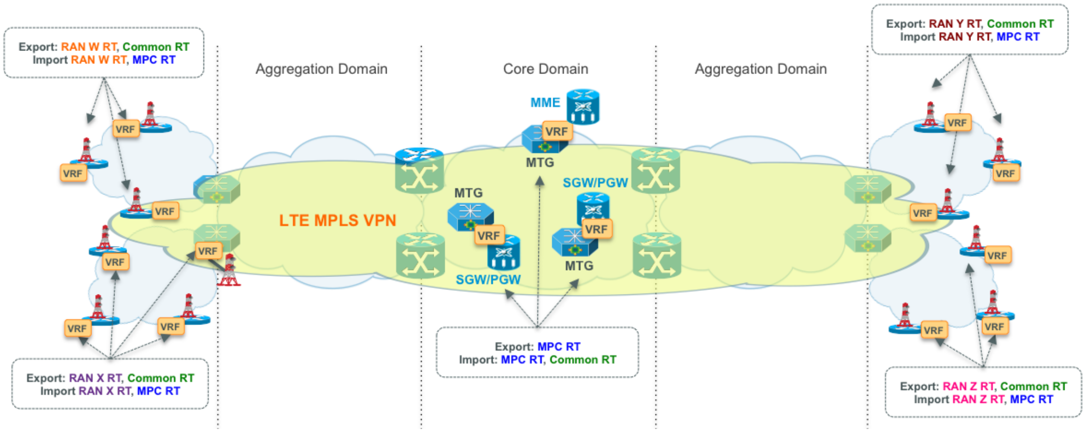
- The **S1-c** or **S1-MME** interface is the reference point for the control plane between E-UTRAN and MME. The S1-MME interface is based on the S1 Application Protocol (S1AP) and is transported over the Stream Control Transmission Protocol (SCTP). The EPC architecture supports MME pooling to enable geographic redundancy, capacity increase, and load sharing. This requires the eNodeB to connect to multiple MMEs. The L3 MPLS VPN service model defined by UMMT allows eNodeBs in the RAN access to be connected to multiple MMEs that may be distributed across regions of the core network for geographic redundancy.
- The **S1-u** interface is the reference point between E-UTRAN and SGW for the per-bearer user plane tunneling and inter-eNodeB path switching during handover. The application protocol used on this interface is GTPv1-U, transported over User Datagram Protocol (UDP). SGW locations affect u-plane latency, and the best practice for LTE is to place S/PGWs in regions closer to the aggregation networks that they serve so that the latency budget of the eNodeBs to which they connect is not compromised. The EPC architecture supports SGW pooling to enable load balancing, resiliency, and signaling optimization by reducing the handovers. This requires the

eNodeB to connect to multiple SGWs. The L3 MPLS VPN service model allows eNodeBs in the RAN access to be connected to multiple SGWs, which include ones in the core close to the local aggregation network and SGWs that are part of the pool serving neighboring core PoPs.

- The **X2** interface comprised of the X1-c and X2-u reference points for control and bearer plane provides direct connectivity between eNodeBs. It is used to hand over a User Equipment (UE) from a source eNodeB to a target eNodeB during the inter-eNodeBs handover process. For the initial phase of LTE, the traffic passed over this interface is mostly control plane related to signaling during handover. This interface is also used to carry bearer traffic for a short period (<100ms) between the eNodeBs during handovers. The stringent latency requirements of the X2 interface requires that the mesh connectivity between CSGs introduces a minimum amount of delay that is in the order of 30ms. The L3 MPLS VPN service model provides shortest path connectivity between eNodeBs so as to not introduce unnecessary latency.
- During initial deployments in regions with low uptake and smaller subscriber scale, MME and SGW/PGW pooling can be used to reuse mobile gateways serving neighboring core PoPs. Gradually, as capacity demands and subscriber scale increases, newer gateways can be added closer to the region. L3 MPLS VPN service model for LTE backhaul that is defined by the UMMT System allows migrations to newer gateways to take place without any re-provisioning of the service model or re-architecting of the underlying transport network required.
- With the distribution of the new spectrum made available for 3G and 4G services, many new SPs have entered the mobility space. These new entrants would like to monetize the spectrum they have acquired, but lack the national infrastructure coverage owned by the incumbents. LTE E-UTRAN-sharing architecture allows different core network operators to connect to a shared radio access network. The sharing of cell site infrastructure could be based on:
  - A shared eNodeB: shared backhaul model where different operators are presented on different VLANs by the eNodeB to the CSG, OR
  - A different eNodeB: shared backhaul model where the foreign operator's eNodeB is connected on a different interface to the CSG.

Regardless of the shared model, the UMMT System provides per-mobile SP-based L3 MPLS VPNs that are able to identify, isolate, and provide secure backhaul for different operator traffic over a single converged network.

Figure 4-11. L3 MPLS VPN Service Model



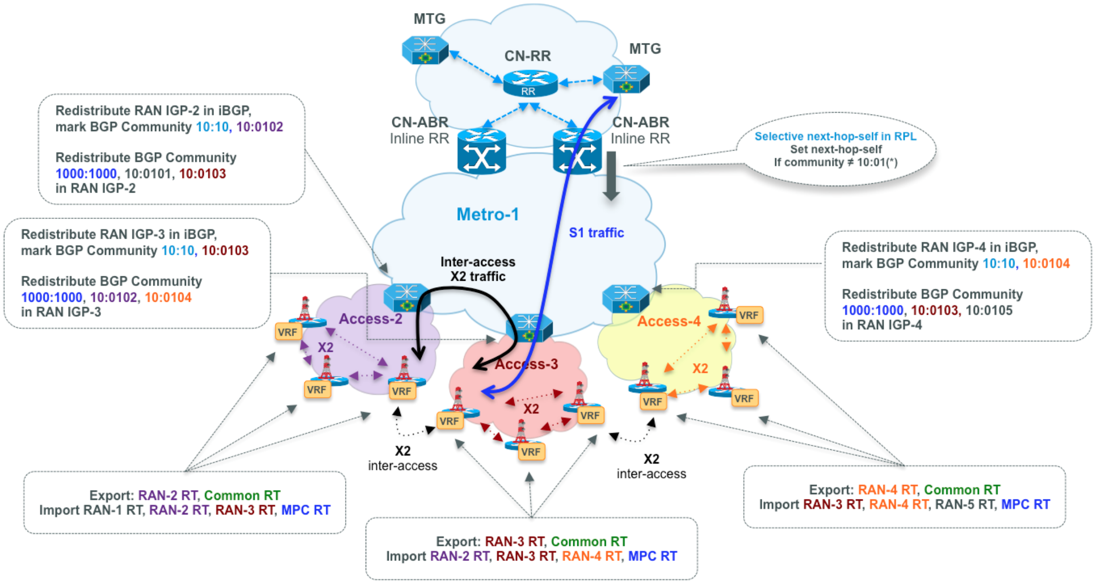
The UMMT System proposes a simple and efficient L3 service model that addresses the LTE backhaul requirements addressed above. The L3 service model is built over a unified MPLS transport with a common highly-scaled MPLS VPN that covers LTE S1 interfaces from all CSGs across the network and a LTE X2 interface per RAN access region. The single MPLS VPN per operator is built across the network with VRFs on the MTGs connecting the EPC gateways (SGW, MME) in the MPC, down to the RAN access with VRFs on the CSGs connecting the eNodeBs. Prefix filtering across the VPN is done using simple MP-BGP Route Target (RT) import and export statements on the CSGs and MTGs.

- A unique RT denoted as **Common RT** in Figure 4-11 is assigned to the LTE backhaul MPLS VPN. It is either imported or exported at various locations or the VPN, depending on the role of node implementing the VRF.
- A unique RT denoted by **MPC RT** in Figure 4-11 is assigned to the MTGs in the MPC.
- Each RAN access region in the network is assigned a unique RT. These RTs are denoted as **RAN X, RAN Y, and RAN Z RTs** in Figure 4-11.

In every RAN access region, all CSGs import the *MPC RT* and the *RAN x RT*. The CSGs export the *Common RT* and the *RAN x RT*. Here *x* denotes the unique RT assigned to that RAN access region. With this importing and exporting of RTs, the route scale in the VRF of the CSGs is kept to a minimum since VPNv4 prefixes corresponding to CSGs in other RAN access regions – either in the local aggregation domain, or RAN access regions in remote aggregation domain across the core – are not learnt. The CSGs have reachability to every MTG and the corresponding EPC gateways (SGW, MME) that they connect anywhere in the MPC. They also have shortest path mesh connectivity among themselves for the X2 interface.

In the MPC, the MTGs import the *MPC RT* and the *Common RT*. They export only the *MPC RT*. With this importing and exporting of RTs, the MTGs have connectivity to all other gateways in the MPC, as well as connectivity to the CSGs in the RAN access regions across the entire network. The MTGs are capable of handling large scale and learn all VPNv4 prefixes in the LTE VPN.

Figure 4-12. Inter-Access X2 Connectivity



In some cases, depending on the spread of the macro cell footprint, it might be desirable to provide X2 interfaces between CSGs located in neighboring RAN access regions. This connectivity can easily be accomplished using the BGP community-based coloring of prefixes used in unified MPLS transport. As described in Section 4.1 Transport Architecture, all PANs in the network advertise the CSG loopbacks of their local RAN access regions into BGP-labeled unicast marked with a common BGP community that represents the RAN community and a BGP community that is unique to that

RAN access region. At the PANs, the loopback addresses of CSGs from adjacent RAN access regions can be identified based on this coloring scheme and redistributed from iBGP into the local RAN IGP to establish labeled BGP hierarchical LSPs across neighboring regions. At the service level, any CSG in a RAN access domain that needs to establish inter-access X2 connectivity will import its neighboring CSG access region RT in addition to its own RT in the LTE MPLS VPN as shown in Figure 4-12 above.

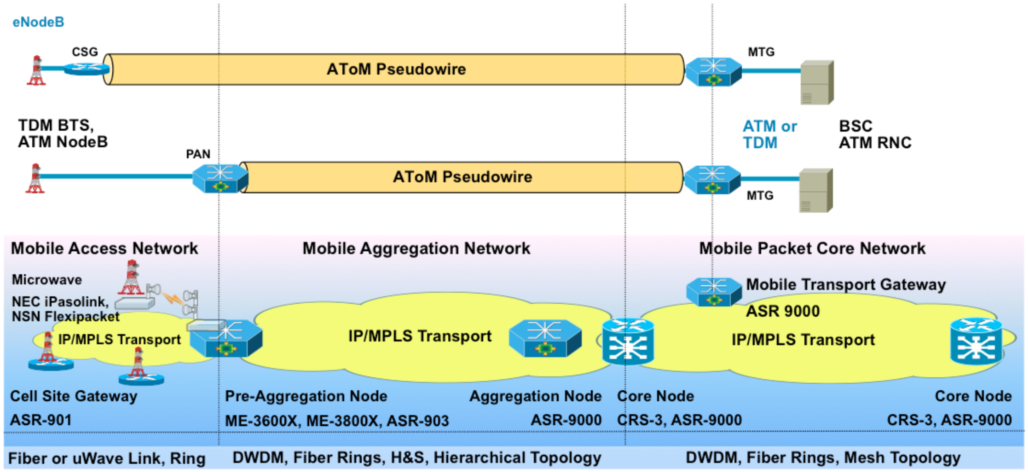
The CN-ABR inline-RR applies selective NHS function using Route Policy in the egress direction towards its local PAN neighbor group in order to provide shortest-path connectivity for the X2 interface between CSGs across neighboring RAN access regions. The Routing Policy Language (RPL) logic involves changing the next-hop towards the PANs for only those prefixes that do not match the local RAN access regions based on a simple regular expression matching BGP communities. This allows for the CN-ABR to change the BGP next-hop and insert itself in the data path for all prefixes that originate in the core corresponding to the S1 interface, while keeping the next-hop set by the PANs unchanged for all prefixes from local RAN regions. With this, the inter-access X2 traffic flows across adjacent access regions another along the shortest path interconnecting the two PANs without having to loop through the inline-RR CN-ABR node.

4.2.2 L2 MPLS VPN Service Model for 2G and 3G

UMMT 2.0 also supports MSPs with GSM. ATM-based UMTS deployments may remove, reduce, or cap investments in SONET/SDH and ATM transport infrastructure by using MPLS-based CEoP services.

- For the MSPs that want to reduce SONET/SDH infrastructure used for GSM, UMMT enables PWE3-based transport of emulated TDM circuits. Structured circuit emulation is achieved with CESoPSN, and unstructured emulation is achieved with SAToP. E1/T1 circuits from BTS equipment connected to the CSG or to the PAN are transported to MTG, where they are bundled into channelized STM1/OC-3 interfaces for handoff to the BSC. The synchronization is delivered from the BSC via TDM links, or from a Primary Reference Clock (PRC), across the core, aggregation, and access domains via SyncE, or via 1588 across domains where SyncE is not supported.
- For the MSPs that want to reduce their ATM infrastructure used for ATM-based UMTS, UMMT enables ATM VC (AAL0 or AAL5) or VP (AAL0) PWE3-based transport. ATM E1/T1 or IMA interfaces from NodeB equipment connected to the CSG or PAN are transported to the MTG, where they are bundled into STM1 ATM interfaces for handoff to the RNC. Cell packing may be used to optimize the bandwidth used for this transport. The synchronization is delivered from the RNC via ATM links, or from a PRC, across the core, aggregation, and access domains via SyncE, or via 1588 across domains where SyncE is not supported.

Figure 4-13. ATM/TDM Transport Services



- For the mature mobile operator, their GSM (2G) deployments will consist of cell sites that don't require a full E1/T1 for support. In such cell sites, a fractional E1/T1 is used. The operator can deploy these cell sites in a daisy chain fashion (i.e., down a highway) or aggregate them at the BSC location. To save in the CAPEX investment on the number of channelized STM-1/OC-3 ports required on the BSC, the operator will utilize a digital XConnect to merge multiple fractional E1/T1 links into a full E1/T1. This reduces the number of T1/E1s needed on the BSC, which results in fewer channelized STM-1/OC-3 ports being needed. Deploying CESoPSN PWs from the CSG to the RAN distribution node supports these fractional T1/E1s and the aggregation of them at the BSC site. In this type of deployment, the default behavior of CESoPSN for alarm sync needs to be changed. Typically, if a T1/E1 on the access nodes goes down, the PWs will forward the AIS alarm through the PW to the distribution node and then propagate the alarm indication ignal (AIS) alarm to the BSC by taking the T1/E1 down. In this multiplexed scenario, TS alarming must be enabled on a CESoPSN PW to only propagate the AIS alarm on the affected time slots, thus not affecting the other time slots (e.g., cell sites) on the same T1/E1.

The same BGP-based control plane and label distribution implemented for the L3VPN services is also used for circuit emulation services. For hub-and-spoke access topologies, BFD-protected static routes can be used to eliminate the need for an IGP at the cell site. The CSGs utilize MPLS/IP routing in this system release when deployed in a physical ring topology. TDM and ATM PWE3 can be overlaid in either deployment model.

The CSGs, PAN, aggregation nodes, and MTGs enforce the contracted ATM CoS SLA, and mark the ATM and TDM PWE3 traffic with the corresponding PHB inside the access, aggregation, and core Differentiated Services (DiffServ) domains. The MTG enables multi-router automatic protection switching (MR-APS) (or single-router automatic protection switching (SR-APS)) redundancy for the BSC or RNC interface.

4.3 Inter-Domain Hierarchical LSPs

The UMMT System uses hierarchical LSPs for inter-domain transport. The hierarchical LSP is based on a BGP-distributed label that is used to transit the isolated MPLS domains, and a LDP-distributed label that is used intra-domain to reach the labeled BGP next hop. This section describes the different hierarchical LSPs that apply to various transport architecture options and their corresponding service models.

This section includes the following topics:

- Section 4.3.1 Inter-Domain LSPs for Multi-Area IGP Designs
- Section 4.3.2 Inter-Domain LSPs for Inter-AS Designs

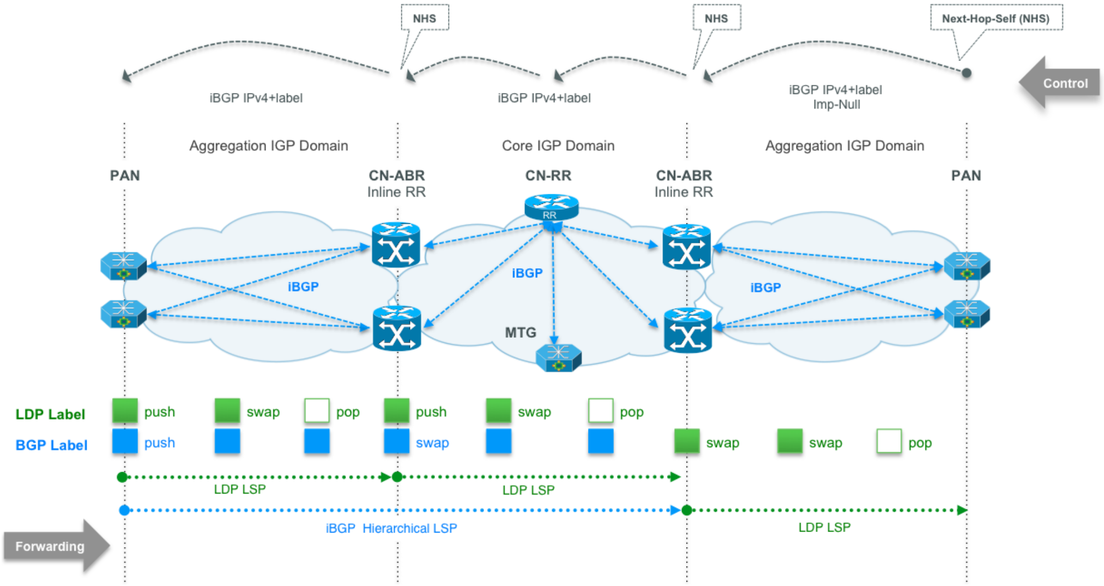
4.3.1 Inter-Domain LSPs for Multi-Area IGP Designs

This section describes inter-domain hierarchical LSPs that apply to Single AS Multi-Area IGP designs where the core and aggregation networks are part of the same autonomous system, but segmented into isolated IGP areas.

Hierarchical LSPs between Remote Aggregation Nodes

This scenario applies to inter-domain LSPs between the loopback addresses of remote PANs connected across the core network. It is relevent to wireline L2/L3 MPLS VPN business services deployed between remote PANs across the core network, that use the /32 loopback address of the remote PEs as the endpoint identifier for the t-LDP or MP-iBGP sessions. The PANs are labeled BGP PEs and advertise their loopback using labeled IPv4 unicast address family (AFI/SAFI=1/4).

Figure 4-14. Hierarchical LSPs between Remote Aggregation Nodes



The remote PANs learn each other's loopbacks through BGP-labeled unicast. For traffic flowing between the two PANs as shown in Figure 4-14, the following sequence occurs:

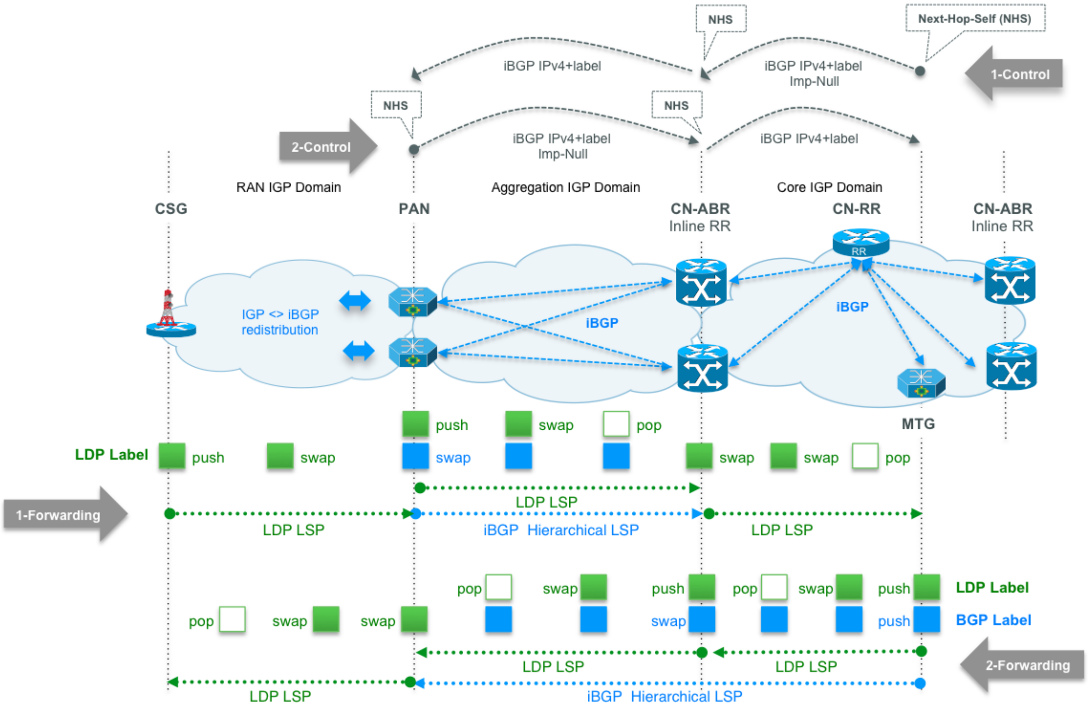
1. The downstream PAN pushes the BGP label corresponding to the remote prefix, and then pushes the LDP label that is used to reach the local core ABR (CN-ABR) that is the labeled BGP next hop.
2. The aggregation nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a penultimate hop popping (PHP) before handing to the local CN-ABR.
3. The local CN-ABR will swap the BGP-based inter-domain LSP label, and push the LDP label used to reach the remote CN-ABR that is the labeled BGP next hop.
4. The core nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a PHP before handing off to the remote CN-ABR.

5. Since the remote CN-ABR has reachability to the destination PAN via IGP, it will swap the BGP label with an LDP label corresponding to the upstream PAN intra-domain LDP LSP.

Hierarchical LSPs between Cell Site Gateways and Mobile Transport Gateways

This scenario applies to inter-domain LSPs between the loopback addresses of CSGs in the RAN and the MTGs in the core network. It is relevant to 4G LTE and 3G UMTS/IP services deployed using MPLS L3 VPNs or 2G GSM and 3G UMTS/ATM services deployed using MPLS L2 VPNs that use the /32 loopback address of the remote PEs as the endpoint identifier for the t-LDP or MP-iBGP sessions. The MTGs are labeled BGP PEs and advertise their loopback using labeled IPv4 unicast address family (AFI/SAFI=1/4). The CSGs do not run labeled BGP, but have connectivity to the MPC via the redistribution between RAN IGP and BGP-labeled unicast done at the local PANs, which are the labeled BGP PEs.

Figure 4-15. Hierarchical LSPs between CSGs and MTGs



The CSG in the RAN access learns the loopback address address of the MTG through the BGP-labeled unicast to RAN IGP redistribution done at the PAN. For traffic flowing between the CSG in the RAN and the MTG in the MPC, as shown in Figure 4-15, the following sequence occurs:

1. The downstream CSG will push the LDP label used to reach the PAN that redistributed the labeled BGP prefix into the RAN IGP.
2. The CSGs that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label towards the PAN.
3. The PAN will first swap the LDP label with the BGP label corresponding to the remote prefix, and then push the LDP label used to reach the local CN-ABR that is the labeled BGP next hop.
4. The aggregation nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a PHP before handing off to the local CN-ABR.

5. Since the local CN-ABR has reachability to the MTG via the core IGP, it will swap the BGP label with an LDP label corresponding to the upstream MTG intra-domain core LDP LSP.

The MTG in the MPC learns the loopback address of the remote RAN CSG through BGP labeled unicast. For traffic flowing between the MTG and the CSG in the RAN as shown in Figure 4-15, the following sequence occurs:

1. The downstream MTG node will first push the BGP label corresponding to the remote prefix, and then push the LDP label that is used to reach the CN-ABR that is the labeled BGP next hop.
2. The core nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a PHP before handing to the CN-ABR.
3. The CN-ABR will swap the BGP label corresponding to the remote prefix, and then push the LDP label used to reach the PAN that is the labeled BGP next hop.
4. The aggregation nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a PHP before handing off to the PAN connecting the RAN.
5. The PAN will swap the locally-assigned BGP label and forward to the upstream CSG using the local RAN intra-domain LDP-based LSP label.

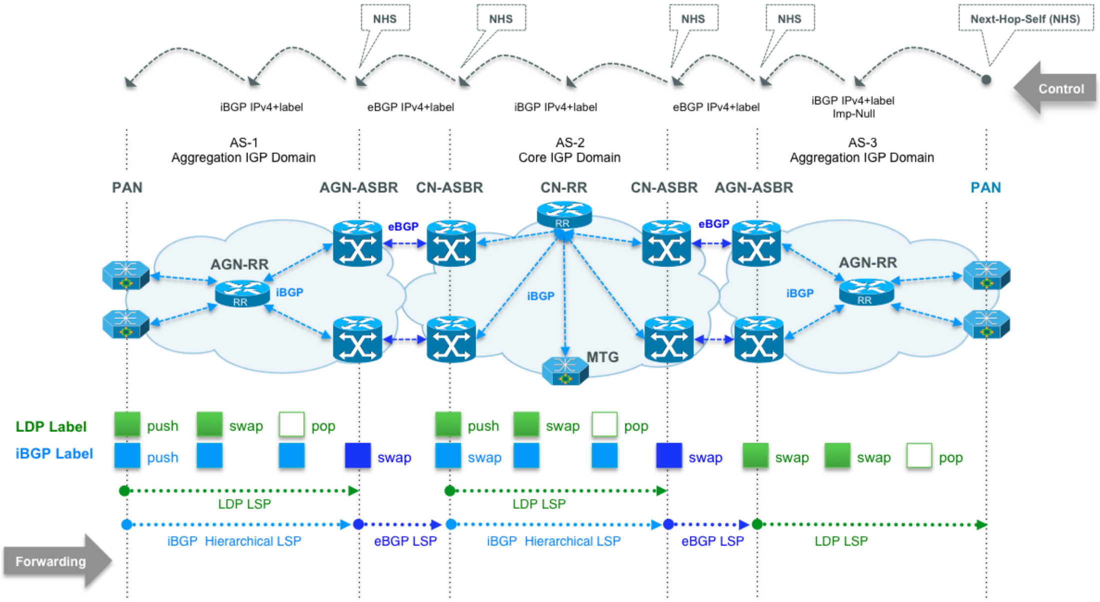
4.3.2 Inter-Domain LSPs for Inter-AS Designs

This section describes inter-domain hierarchical LSPs that apply to inter-AS designs where the core and aggregation networks are segmented into different autonomous systems.

Hierarchical LSPs between Remote Aggregation Nodes

This scenario applies to inter-domain LSPs between the loopback addresses of remote PANs connected across the core network. It is relevent to wireline L2/L3 MPLS VPN business services deployed between remote PANs across the core network that use the /32 loopback address of the remote PEs as the endpoint identifier for the t-LDP or MP-iBGP sessions. The PANs are labeled BGP PEs and advertise their loopback using labeled IPv4 unicast address family (AFI/SAFI=1/4).

Figure 4-16. Hierarchical LSPs between Remote Aggregation Nodes



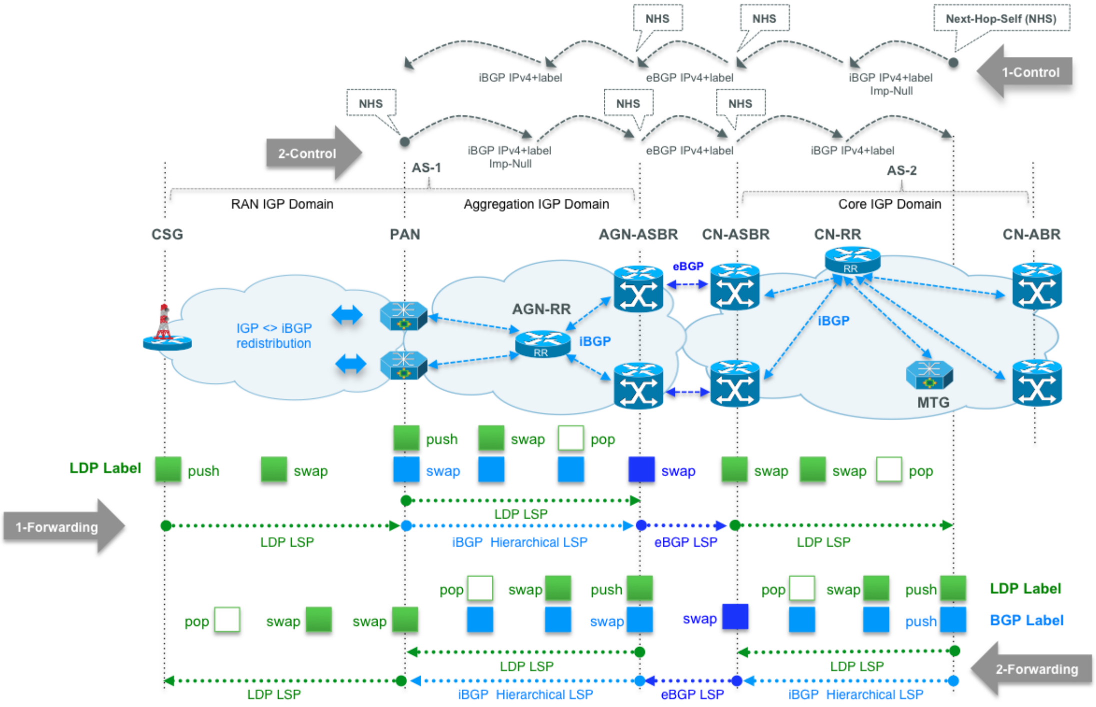
The remote PANs learn each other's loopbacks through BGP-labeled unicast. iBGP-labeled unicast is used to build the inter-domain hierarchical LSP inside each autonomous systems, and eBGP-labeled unicast is used to extend the LSP across the AS boundary. For traffic flowing between the two PANs as shown in Figure 4-16, the following sequence occurs:

1. The downstream PAN pushes the iBGP label corresponding to the remote prefix, and then pushes the LDP label that is used to reach the local AGN-ASBR that is the labeled BGP next hop.
2. The aggregation nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a PHP before handing to the local AGN-ASBR.
3. The local AGN-ASBR will swap the iBGP-based inter-domain LSP label with the eBGP label assigned by the neighboring CN-ASBR
4. The CN-ASBR will swap the eBGP label with the iBGP inter-domain LSP label, and then push the LDP label that i used to reach the remote CN-ASBR that is the labeled BGP next hop.
5. The core nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a PHP before handing off to the remote CN-ASBR.
6. The remote CN-ASBR will swap the iBGP-based inter-domain LSP label with the eBGP label assigned by the neighboring aggregation domain AGN-ASBR.
7. Since the remote AGN-ASBR has reachability to the destination PAN via IGP, it will swap the eBGP label with an LDP label corresponding to the upstream PAN intra-domain LDP LSP.

Hierarchical LSPs between Cell Site Gateways and Mobile Transport Gateways

This scenario applies to inter-domain LSPs between the loopback addresses of CSGs in the RAN and the MTGs in the core network. It is relevant to 4G LTE and 3G UMTS/IP services deployed using MPLS L3 VPNs or 2G GSM and 3G UMTS/ATM services deployed using MPLS L2 VPNs that use the /32 loopback address of the remote PEs as the endpoint identifier for the t-LDP or MP-iBGP sessions. The MTGs are labeled BGP PEs and advertise their loopback using labeled IPv4 unicast address family (AFI/SAFI=1/4). The CSGs do not run labeled BGP, but have connectivity to the MPC via the redistribution between RAN IGP and BGP-labeled unicast done at the local PANs, which are the labeled BGP PEs.

Figure 4-17 Hierarchical LSPs between CSGs and MTGs



The CSG in the RAN access learns the loopback address address of the MTG through the BGP-labeled unicast to RAN IGP redistribution done at the local PAN. For traffic flowing between the CSG in the RAN and the MTG in the MPC, as shown in Figure 4-17, the following sequence occurs:

1. The downstream CSG will push the LDP label used to reach the PAN that redistributed the labeled iBGP prefix into the RAN IGP.
2. The CSGs that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label towards the PAN.
3. The PAN will first swap the LDP label with the iBGP label corresponding to the remote prefix, and then push the LDP label used to reach the AGN-ASBR that is the labeled BGP next hop.
4. The aggregation nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a PHP before handing off to the local AGN-ASBR.
5. The local AGN-ASBR will swap the iBGP-based inter-domain LSP label with the eBGP label assigned by the neighboring CN-ASBR.
6. Since the CN-ASBR has reachability to the MTG via the core IGP, it will swap the eBGP label with an LDP label corresponding to the upstream MTG intra-domain core LDP LSP.

The MTG in the MPC learns the loopback address of the remote RAN CSG through BGP-labeled unicast. For traffic flowing between the MTG and the CSG in the RAN as shown in Figure 4-17, the following sequence occurs:

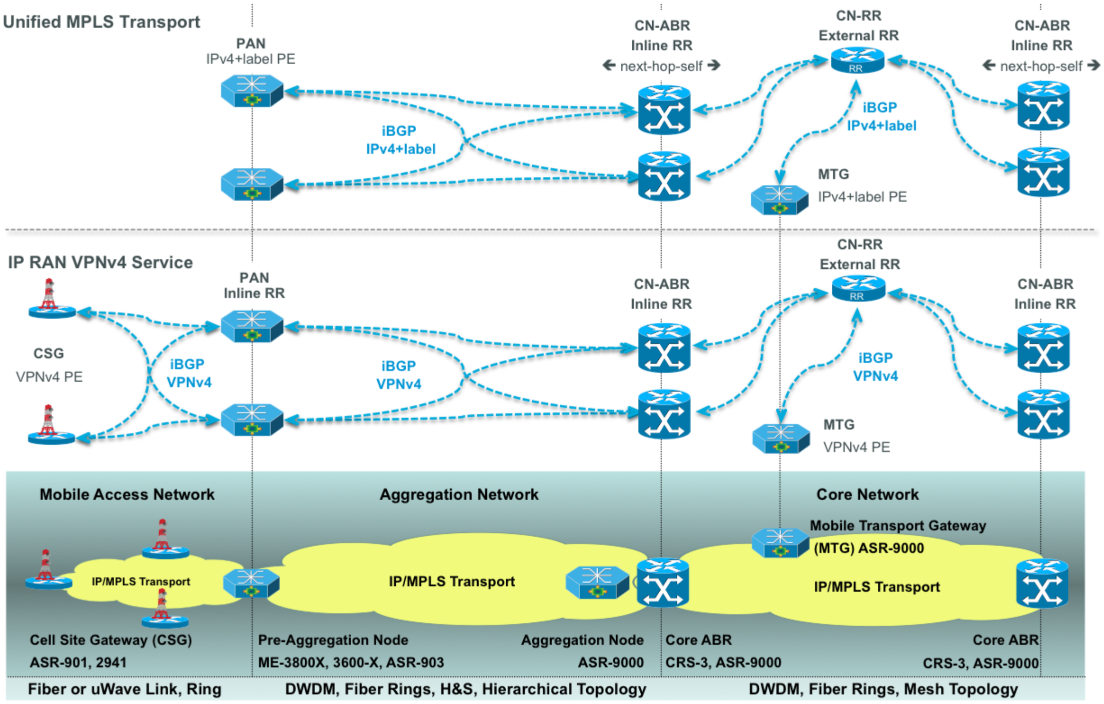
1. The downstream MTG node will first push the iBGP label corresponding to the remote prefix, and then push the LDP label that is used to reach the CN-ASBR that is the labeled BGP next hop.
2. The core nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a PHP before handing to the CN-ASBR.

3. The CN-ASBR will swap the iBGP-based inter-domain LSP label with the eBGP label assigned by the neighboring aggregation domain AGN-ASBR.
4. The AGN-ASBR will swap the eBGP label with the iBGP inter-domain LSP label corresponding to the remote prefix, and then push the LDP label that is used to reach the PAN that is the labeled BGP next hop.
5. The aggregation nodes that transit the inter-domain LSP will swap the intra-domain LDP-based LSP label, performing a PHP before handing off to the PAN connecting the RAN.
6. The PAN will swap the locally-assigned BGP label and forward to the upstream CSG using the local RAN intra-domain LDP-based LSP label.

4.4 Transport and Service Control Plane

The UMMT System proposes a hierarchical Route Reflector (RR) design for setting up the Unified MPLS transport and LTE MPLS VPN service BGP control plane. The hierarchical RR approach is used to reduce the number of iBGP peering sessions on the RRs across different domains of the backhaul network. The PANs and core ABRs are used as inline RRs for both the transport and service layers, which eliminates the need for standalone RRs in those domains of the network. At the top level of the hierarchy, the core MPLS ABR RRs can either peer in a full mesh configuration across the core, or peer as RR clients to a centralized standalone RR in the core network. In deployments with only a few PoPs, a full-mesh configuration at the top ABR level would suffice.

Figure 4-18. Transport and Service Control Plane for Multi-Area IGP Organization



BGP Control Plane for Unified MPLS transport with Multi-Area IGP Organization

The Core ABRs (CN-ABR) are inline RRs for the MP-iBGP IPv4-labeled unicast address-family:

- They form iBGP session neighbor groups towards the local aggregation network to serve the PAN RR clients that are the labeled BGP PEs implementing the intra-domain iBGP hierarchical LSPs.

- They either form neighbor groups towards other non-client ABRs in the core if a full-mesh configuration is used, or form neighbor groups towards higher level CN-RRs in the core network if the external configuration is used at the top level of the hierarchy as shown in Figure 4-18.
- If the full mesh option is used, the CN-ABRs also act as RRs serving the closest MTG RR clients in the core network that are labeled BGP PEs implementing the intra-domain iBGP hierarchical LSPs.

BGP Control Plane for LTE Service with Multi-Area IGP Organization

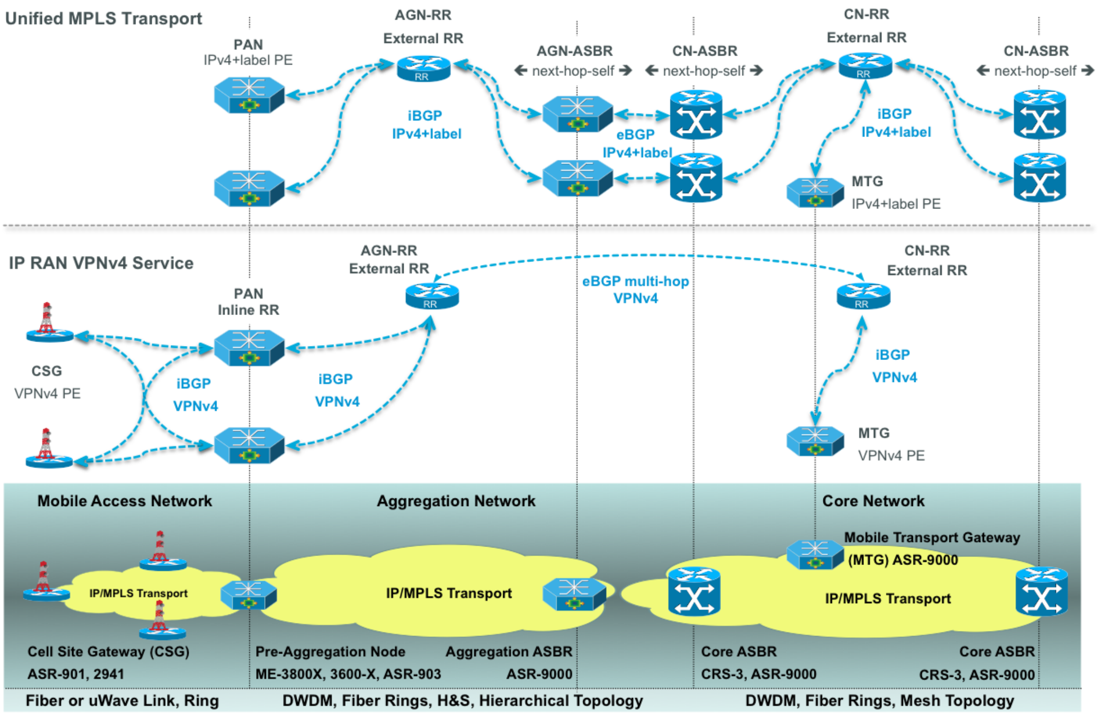
For the LTE MPLS VPN service, the PANs are inline RRs for the MP-iBGP VPNv4 address-family:

- They form iBGP session neighbor groups towards the local RAN access network to serve the CSG RR-clients that are the PEs implementing the LTE MPLS VPN.
- They also form iBGP session neighbor groups towards the local CN-ABR inline RRs.

The CN-ABRs are inline RRs for the MP-iBGP VPNv4 address-family and form the next level of the RR hierarchy:

- They form iBGP session neighbor groups towards the local aggregation network to serve the PAN RR clients.
- They either form neighbor groups towards other non-client CN-ABRs in the core if a full-mesh configuration is used, or form neighbor groups towards higher level CN-RRs in the core network if the external configuration is used at the top level of the hierarchy as shown in Figure 4-18 above.
- If the full-mesh option is used, the core ABR RRs also form neighbor groups for the closest MTG RR clients in the core network that are the PEs implementing the LTE MPLS VPN.

Figure 4-19. Transport and Service Control Plane for Inter-AS Organization



BGP Control Plane for Unified MPLS transport with Inter-AS Organization

The CN-RRs are external RRs for the MP-iBGP IPv4-labeled unicast address-family in the core network:

- They form iBGP session neighbor groups towards the MTG and CN-ASBR RR clients in the core network.
- The MTGs are labeled BGP PEs that advertise their loopbacks in iBGP-labeled unicast to the CN-RRs.
- The CN-ASBRs enable the intra-domain LSPs by setting NHS while exchanging labeled unicast prefixes between the eBGP session to the neighboring aggregation network AGN-ASBR and the core network CN-RR.

The AGN-RRs are external RRs for the MP-iBGP IPv4-labeled unicast address-family in the aggregation network:

- They form iBGP session neighbor groups towards the AGN-ASBR and PAN RR clients in the aggregation network.
- The PANs are labeled BGP PEs that advertise their loopbacks, and CGS loopbacks redistributed from the local RAN IGP in iBGP-labeled unicast to the AGN-RRs.
- The AGN-ASBRs enable the intra-domain LSPs by setting NHS while exchanging labeled unicast prefixes between the eBGP session to the core network CN-ASBR and the local aggregation network AGN-RR.

BGP Control Plane for LTE Service with Inter-AS Organization

For the LTE MPLS VPN service, the PANs are inline RRs for the MP-iBGP VPNv4 address-family:

- They form iBGP session neighbor groups towards the local RAN access network to serve the CSG RR-clients that are the PEs implementing the LTE MPLS VPN.
- They also form iBGP session neighbor groups towards the local aggregation network AGN-RR external RRs.

The AGN-RRs are external RRs for the MP-iBGP VPNv4 address-family in the aggregation network and form the next level of the RR hierarchy:

- They form iBGP session neighbor groups towards the local aggregation network to serve the PAN RR clients.
- They enable the LTE VPN service with a eBGP multi-hop session towards the CN-RR in the core network to exchange VPNv4 prefixes over the inter-domain transport LSP.

The CN-RRs are external RRs for the MP-iBGP VPNv4 address-family in the core network and form the next level of the RR hierarchy:

- They form iBGP session neighbor groups in the core network to serve the MTG RR clients that are the PEs implementing the LTE MPLS VPN.
- They enable the LTE VPN service with a eBGP multi-hop session towards the AGN-RRs in the neighboring aggregation network autonomous systems to exchange VPNv4 prefixes over the inter-domain transport LSP.

4.5 Prefix Filtering

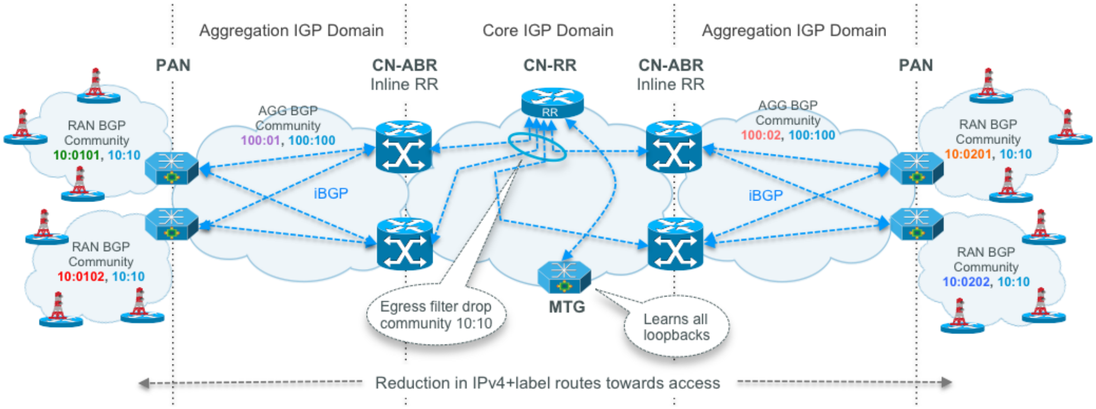
While the hierarchical RR approach described in Section 4.4 Transport and Service Control Plane helps reduce the number of BGP sessions multi-fold when compared to using a centralized RR, the number of routes held in the RRs remains the same. In large LTE deployments involving several tens of thousands of eNodeBs and associate CSGs, a few steps can be taken to ensure that the CSGs and

PANs in the network are not overloaded with huge numbers of IPv4+label and VPNv4 routes from remote RAN access regions.

Constraining IPv4 Routes from Remote RAN Access Regions

In terms of inter-domain reachability, the CSGs in RAN access need to reach the MTGs in the core network, whereas the PANs may need to reach remote aggregation domains across the core for wireline services. The number of CSGs is several magnitudes larger than the number of PANs in the network, and so it may be desirable to filter the RAN access prefixes in remote aggregation networks where they are not needed.

Figure 4-20. ***BGP-Community based Coloring of Transport Prefixes***



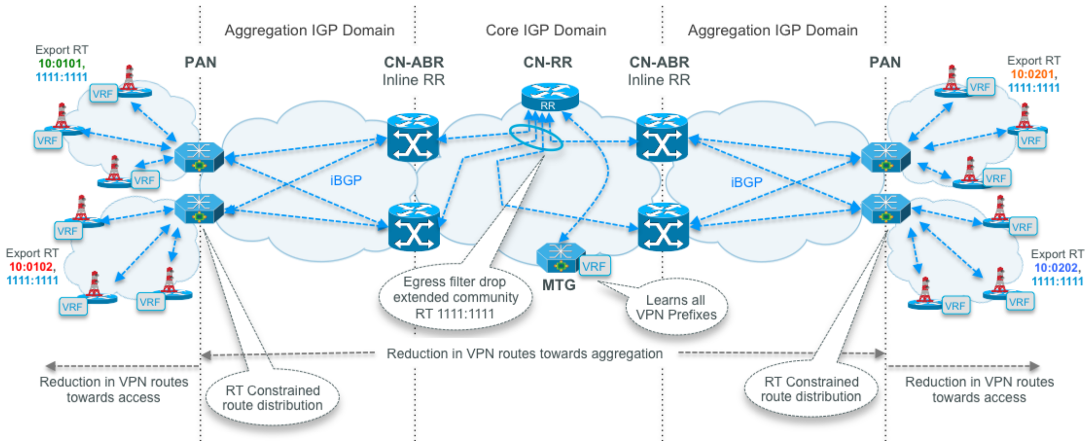
As described in Section 4.1 Transport Architecture, all PANs in the network advertise their loopbacks into BGP-labeled unicast with a common BGP community that represents the aggregation community and a unique BGP community that represents the aggregation location. In addition, the CSG loopbacks that are redistributed from the RAN access IGP into BGP-labeled unicast at the PANs are marked with a common BGP community that represents the RAN community and a BGP community that is unique to that RAN access region. Based on this BGP community-based coloring scheme, simple BGP community-based egress filtering can be performed at the top level RRs to constrain the IPv4-labeled-unicast route scale towards the access regions:

- If a external RR is used in the core network as show in Figure 4-20, then an egress filter is applied towards the neighbor group corresponding to the CN-ABR or CN-ASBR clients so that RAN prefixes from one aggregation domain are not propagated into other domains.
- If a full-mesh configuration is used between CN-ABRs, then this egress filter is applied at each CN-ABR towards the neighbor group corresponding to its local aggregation domain PANs to drop remote aggregation domain RAN prefixes.

Constraining VPNv4 Routes from Remote RAN Access Regions

BGP extended-community based egress filtering based on the RTs used for the LTE MPLS VPN can be performed at the top level RRs to constrain the VPN route scale towards the aggregation domains. As per the RT import/export schema defined in Section 4.2.1 L3 MPLS VPN Service Model for LTE, the filtering logic would involve dropping the common RT-extended BGP communities in the egress direction towards neighboring aggregation domains where they not needed.

Figure 4-21. BGP Extended Community-based Coloring of Service Prefixes



- For Single AS Multi-Area IGP designs, if a external CN-RR is used in the core network as show in Figure 4-21, then an egress filter is applied towards the neighbor group corresponding to the CN-ABRs so that VPN prefixes with common RT assigned the LTE VPN service are dropped.
- For Single AS Multi-Area IGP designs involving full-mesh peering between CN-ABRs, a egress filter is applied at the CN-ABRs towards the neighbor group corresponding to the PANs such that VPN prefixes with common RT assigned the LTE VPN service that do not match the local aggregation domain RTs are dropped.
- For Inter-AS designs, an egress filter is applied at the CN-RR towards the neighboring aggregation domain AGN-RRs so that VPN prefixes with common RT assigned the LTE VPN service are dropped.

Within each aggregation domain, the PANs can implement RT Constrained Route Distribution (RFC 4684) towards the CSG VPNv4 clients. With this feature, the CSGs will send RT constraint Network Layer Reachability Information (NLRI) to the local PAN inline RRs corresponding to the *MPC RT* and *RAN x RT* import statements (as denoted in Figure 4-21) configured for the LTE VPN. The PAN inline-RR function RR will translate the NLRI into a dynamic outbound route filter that only permits MP-iBGP updates matching these RTs towards the local CSG RR-clients. This would result in the CSG receiving only a limited number of VPNv4 prefixes corresponding to the MTG for the S1 interface and the neighboring local eNodeB prefixes for the X2 interface.

4.6 Scale Considerations

This section describes the route scale and the control plane scaling aspects involved in setting up the unified MPLS transport across the network domains.

As an example, we consider a large scale LTE deployment following the Single AS Multi Area design described in Section 4.1.1 Large Network, Multi-Area IGP Design with MPLS Access involving 60,000 CSGs across 25 PoPs in a SP network. In the core network, we consider around fifteen EPC S/PGW locations and five EPC MME locations, with each location connected to a pair of redundant MTGs. This leads a total of forty MTGs for transport connectivity from the core to the CSGs in the RAN access domain. If we consider that each RAN access domain is comprised of twenty CSGs connected in physical ring topologies of five nodes each to the pre-aggregation network, and (for the purpose of illustration) we assume an even distribution of RAN backhaul nodes across the twenty-five PoPs, we end up with the network sizing shown in Table 4-1.

Table 4-1. Network Sizing

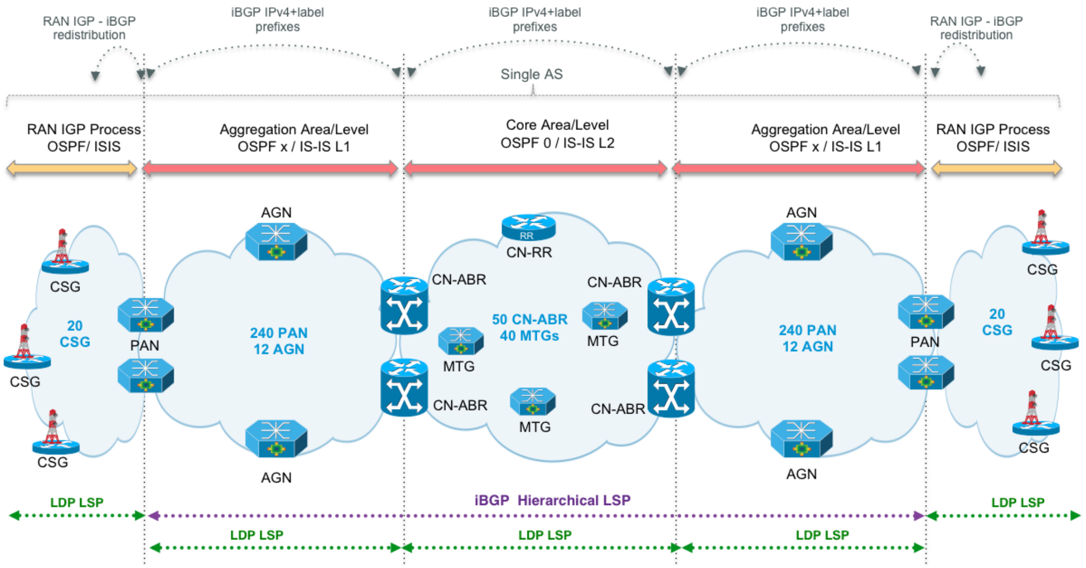
Node	Access Domain	Aggregation Domain	Network Wide
CSGs	20	2,400	60,000
PANs	2	240	6,000
AGNs	NA	12	300
CN-ABRs	NA	2	50
MTGs	NA	NA	40

Route Scale

RAN backhaul for LTE requires connectivity between the CSGs in the RAN access and the MTGs in the core network. In an MPLS environment, since route summarization of PE's /32 loopback IP address cannot be performed, a flat IGP/LDP network design would imply that the core network would have to learn all the 60,000 loopback addresses corresponding to the CSGs deployed across the entire network. While this level route of scale in a IGP domain may be technically feasible, it is an order of magnitude higher than typical deployments and would present huge challenges in IGP convergence when a topology change event is encountered.

The UMMT System architecture provides a scalable solution to this problem by adopting a divide-and-conquer approach of isolating the access, aggregation, and core network layers into independent and isolated IGP/LDP domains. While LDP is used to set up intra-domain LSPs, the isolated IGP domains are connected to form a unified MPLS network in a hierarchical fashion by using RFC 3107 procedures based on iBGP to exchange loopback addresses and MPLS label bindings for transport LSPs across the entire MPLS network. This approach prevents the flooding of unnecessary routing and label binding information into domains or parts of the network that do not need them. This allows scaling the network to hundreds of thousands of LTE cell sites without overwhelming any of the smaller nodes like CGS in the network. Since the route scale in each independent IGP domain is kept to a minimum, and all remote prefixes are learnt via BGP, each domain can easily achieve sub-second IGP fast convergence.

Figure 4-22. *UMMT Hierarchical Network*



If we consider a hierarchical network design as shown in Figure 4-22, we end up with a route scale across various domains of the unified MPLS transport network as depicted in Table 4-2.

Table 4-2. *Route Scale*

Node	Routes in Core-Agg IGP Process	Routes in RAN IGP Process	iBGP IPv4-Labeled Routes
CSGs	NA	87	NA
PAN	~ 504	47	5,821
AGN	~ 504	NA	NA
CN-ABR	~ 742	NA	66,040
MTG	~ 240	NA	66,000

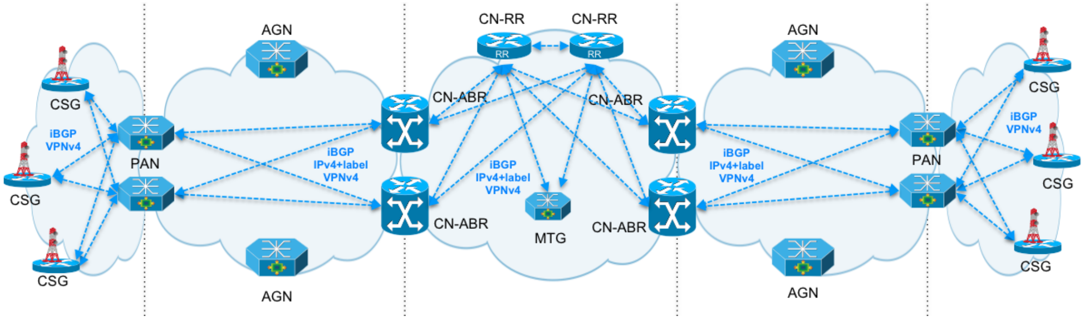
Note

- On CSGs, the 87 IGP routes correspond to 20 local RAN access CSG loopbacks + 25 links in RAN access network + 2 local PANs + 40 MTG loopbacks from the MPC.
- On PANs:
  - The 504 IGP routes in Core-AGG IGP process correspond to 240 local PANs + 12 local AGNs + 2 local CN-ABRs + around 250 links in the aggregation network, depending on physical topology.
  - The 47 IGP routes in the RAN IGP process correspond to 20 local RAN access CSG loopbacks + 25 links in the RAN access network + 2 local loopback addresses in RAN IGP.
  - The 5,821 iBGP IPv4-labeled routes correspond to 20 locally-redistributed RAN access CSG loopbacks + 1 own loopback + 5760 remote PAN loopbacks + 40 MTG loopbacks from the core network.
- On AGNs, the 504 IGP routes correspond to 240 local PANs + 12 local AGNs + 2 local CN-ABRs + around 250 links in aggregation network, depending on physical topology.
- On CN-ABRs:
  - The 742 IGP routes correspond to 240 local PANs + 12 local AGNs + around 250 links in the aggregation network, depending on physical topology, + 50 CN-ABRs + 40 MTG nodes + around 150 links in core network, depending on physical topology.
  - The 66,040 iBGP IPv4-labeled routes correspond to 60,000 CSG loopbacks + 6000 PAN loopbacks + 40 MTG loopbacks.
- On MTGs:
  - The 240 IGP routes correspond to 50 core ABRs + 40 MTG nodes + around 150 links in the core network, depending on physical topology.
  - The 66,000 iBGP IPv4-labeled routes correspond to 60,000 CSG loopbacks + 6000 PAN.

Control Plane Scale

As described in Section 4.4 Transport and Service Control Plane, the UMMT System uses a hierarchical RR design with inline RR functionality on the CN-ABRs and PANs to greatly reduce the number of iBGP peering sessions across different domains of the backhaul network.

Figure 4-23. UMMT Hierarchical RR Topology



For the example network sizing shown in Table 4-1, if we consider the peering organization illustrated in Figure 4-23, we have the following BGP session scale on different elements in the network (see Table 4-3).

Table 4-3. BGP Session Scale

Node	Address-Family	Client iBGP Sessions	RR iBGP Sessions	Non-Client iBGP Sessions	Total iBGP Sessions
CSG	VPNv4	NA	2	NA	2
PAN	IPv4+label, VPNv4	20	2	NA	22
CN-ABR	IPv4+label, VPNv4	240	2	NA	242
MTG	IPv4+label, VPNv4	NA	2	NA	2
CN-RR	IPv4+label, VPNv4	90	NA	1	91

Note

- CSRs in each RAN access domain peer with their two redundant local PAN inline-RRs.
- PANs in each aggregation domain peer with their CSG clients and with their two redundant local CN-ABR inline-RRs.
- MTGs in the core domain connecting regional EPC GWs peer with the redundant external CN-RRs.
- CN-ABRs peer with their PAN clients and with the redundant external CN-RRs in the core domain.

CHAPTER 5

Functional Components

The base transport design, control plane, data plane, and service model aspects of UMMT 2.0 have been covered to this point. This chapter looks at the other aspects required for delivering and operating a comprehensive mobile backhaul system architecture.

This chapter includes the following major topics:

5.1 Quality of Service

The UMMT System applies the IETF DiffServ Architecture (RFC 2475) across all network layers, utilizing classification mechanisms like MPLS EXP, IP DSCP, IEEE 802.1p, and ATM CoS for implementing the DiffServ per hop behaviors (PHB) in use.

In a transport network, congestion can occur anywhere. However, congestion is more likely where statistical estimates of peak demand are conservative (i.e., under-provisioned), which happens more often on the design of access and aggregation bandwidth links. Congestion due to instantaneous ingress bandwidth to a node exceeding egress bandwidth (assuming the node can process all ingress bandwidth) therefore requires all nodes to be able to implement DiffServ scheduling functions. The result is that the under-provisioning is unfairly distributed between the services transported. This redistribution with DiffServ can result in over-provisioning for higher quality services (like VoIP and Video) and differing levels of under-provisioning for other services. This is inline with the functional requirements defined by standards bodies, such as the NGMN and Broadband Forum TR-221 specification for mobile backhaul.

Each network layer defines an administrative boundary, where traffic remarking may be required in order to correlate the PHBs between different administrative domains. A critical administrative and trust boundary is required for enforcing subscriber SLAs. Subscriber SLAs are enforced with sound capacity management techniques and functions, such as policing/shaping, marking, and hierarchical scheduling mechanisms. This administrative boundary is implemented by the CSG, NodeB equipment, or radio controllers, depending on the service model, for traffic received (upstream) from the subscribers and by the core nodes for traffic sent (downstream) to the subscribers.

Figure 5-1 and Figure 5-2 present visual representations of the QoS model for the upstream and downstream directions. In most administrative domains in the UMMT System, a flat QoS policy with a single-level scheduler and shaper is sufficient for the required DiffServ functionality, as all links are capable of line rate transmission. The exception is in the case of microwave links in the access, where the connection to the equipment on either end of the link is GbE, but the wireless portion of the link is only capable of sub-gigabit speeds (typically 400Mbps sustained). In this case, the PAN interface facing the microwave access implements a H-QoS policy with a parent shaper equal to the sustained microwave link speed required for proper DiffServ functionality. If the microwave systems support DiffServ QoS and are able to synchronize the QoS classes used by the CSGs in the access to provide EF and AF guarantees, then flat QoS policies on the transit CSG NNIs are sufficient. On the other hand, if the microwave systems do not support DiffServ QoS, or are unable to synchronize the QoS classes used by the CSGs, the CSGs have to implement H-QoS policy with a parent shaper equal to the sustained microwave link speed on their network-to-network interface (NNI), as shown in the following figures.

Figure 5-1. UMMT System Upstream QoS Model

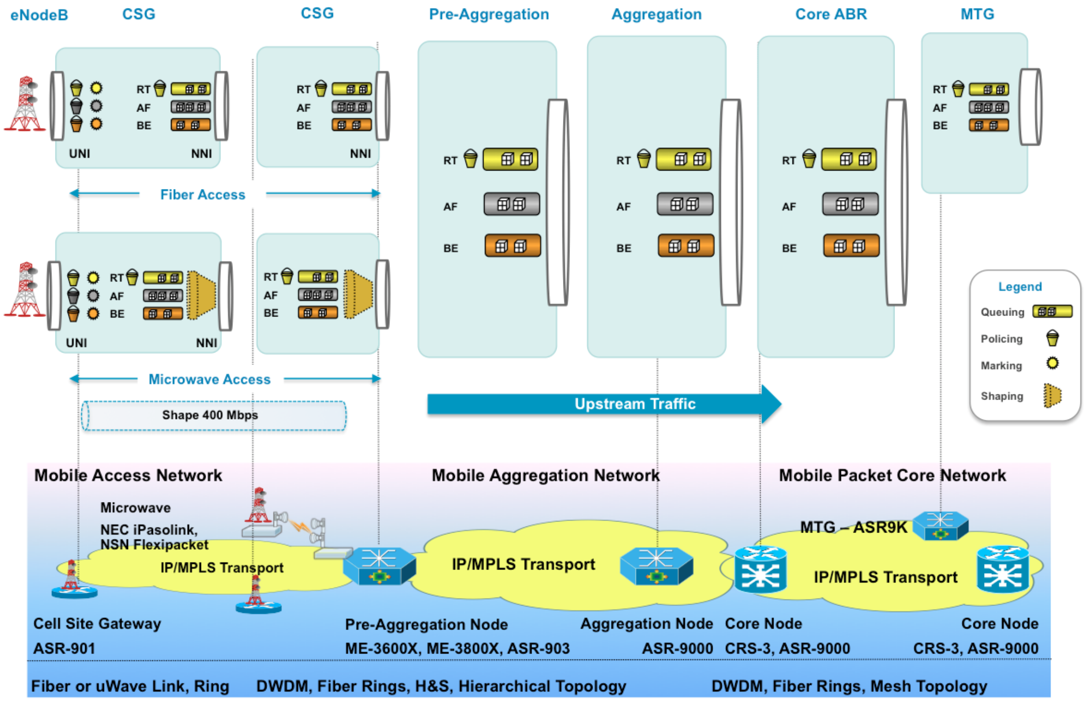
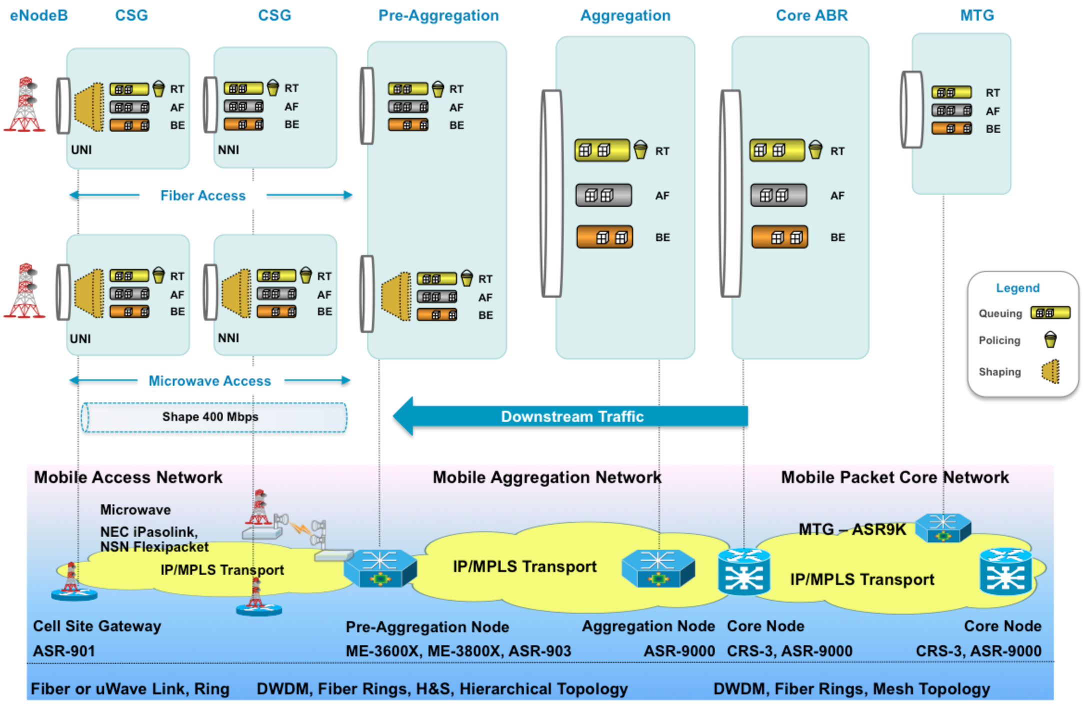


Figure 5-2. UMMT System Downstream QoS Model



DiffServ QoS Domain

The traffic classification, marking, and DiffServ PHB behaviors considered in the system architecture, which are described in Figure 5-3, are targeted to fit the deployment of mobile services.

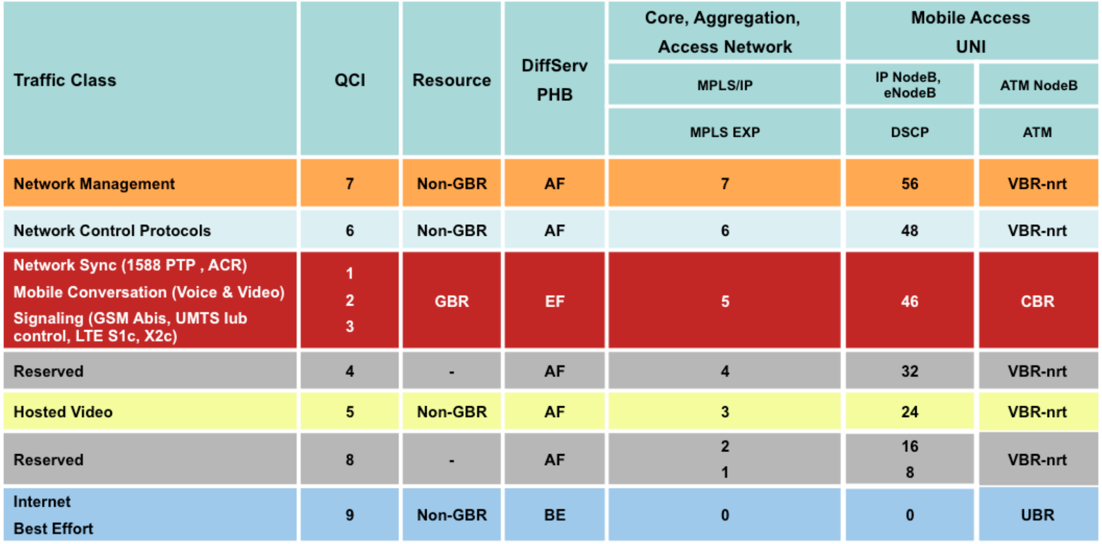
PTP synchronization, GSM Abis, UMTS Iub control plane and voice user plane, LTE S1c, X2c, and the LTE GBR user plane are classified in a traffic class that requires an expedited forwarding (EF) PHB, as described in RFC 3246. This class will be serviced with a priority queue due to the stringent latency and delay variation requirements these services have. The EF PHB defines a scheduling behavior that guarantees an upper limit on per hop delay variation that can be caused by packets from non-EF services.

UMTS IuB user plane that needs guaranteed bandwidth and the LTE MBR user plane are classified in traffic classes that use the advanced forwarding (AF) PHB behavior as described in RFC 2597. The AF PHB guarantees a certain amount of bandwidth to an AF class while guaranteeing a certain limit of latency.

IuB and LTE S1 and X2 best effort (BE) traffic will use the BE PHB behavior.

The system includes additional AF traffic classes, used for network control protocols and network management traffic that will be serviced in the aggregation network by a weighted queue.

Figure 5-3. UMMT System DiffServ QoS Domain



Traffic Class	QCI	Resource	DiffServ PHB	Core, Aggregation, Access Network	Mobile Access UNI	
				MPLS/IP	IP NodeB, eNodeB	ATM NodeB
				MPLS EXP	DSCP	ATM
Network Management	7	Non-GBR	AF	7	56	VBR-nrt
Network Control Protocols	6	Non-GBR	AF	6	48	VBR-nrt
Network Sync (1588 PTP , ACR) Mobile Conversation (Voice & Video) Signaling (GSM Abis, UMTS Iub control, LTE S1c, X2c)	1 2 3	GBR	EF	5	46	CBR
Reserved	4	-	AF	4	32	VBR-nrt
Hosted Video	5	Non-GBR	AF	3	24	VBR-nrt
Reserved	8	-	AF	2 1	16 8	VBR-nrt
Internet Best Effort	9	Non-GBR	BE	0	0	UBR

The core network traffic marking is based on MPLS EXP. The core network may use different traffic marking and simplified PHB behaviors, or may be transporting services in addition to mobile backhaul, therefore requiring traffic remarking in between the aggregation and core networks. The aggregation and access network traffic marking is based on MPLS EXP. Access UNI markings may be based on DSCP for MPLSoGRE transport, MPLS EXP for MPLS transport, 802.1P CoS for Ethernet-bridged transport, and ATM CoS for ATM UNI support.

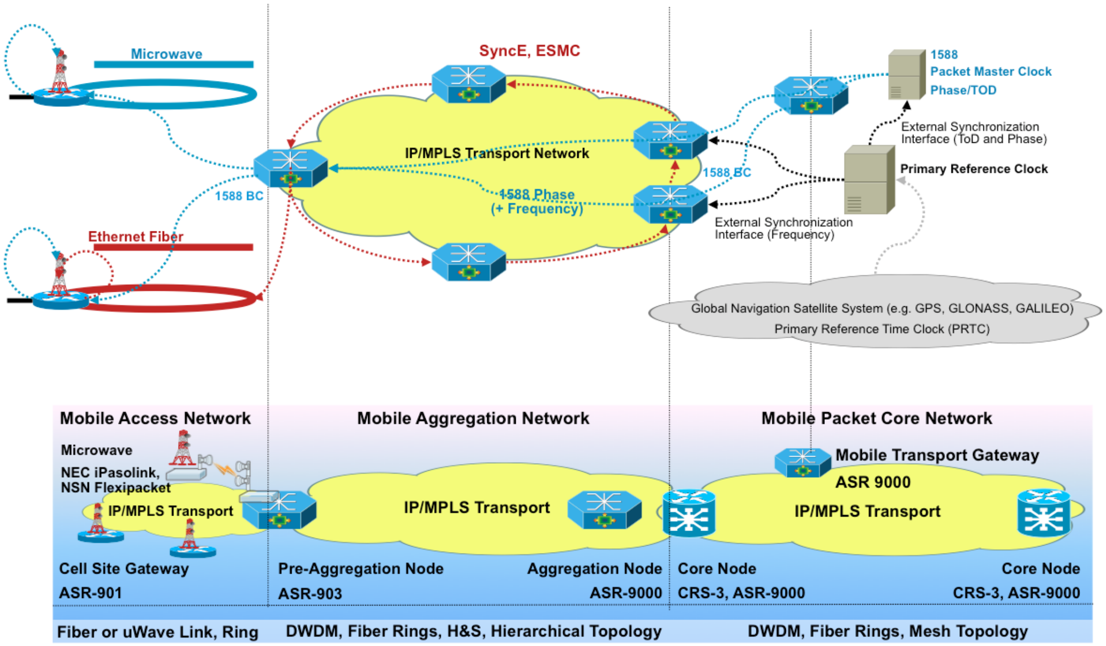
5.2 Synchronization Distribution

Synchronization distribution for both frequency and phase is a fundamental functional component of the access and aggregation areas of the UMMT System. The primary target for the current system release is to provide frequency synchronization using the Ethernet physical layer (SyncE) and phase synchronization using IEEE 1588-2008 PTP. SyncE operates on a link-by-link basis and will provide a high quality frequency reference equal to SONET and SDH networks. SyncE supports an Ethernet Synchronization Monitoring Channel (ESMC), which provides a communications channel for transmitting Synchronization Status Message (SSM) quality levels over SyncE-enabled links. This allows the SyncE node to derive timing from the most reliable source and detect timing loops, which is essential for deployment of SyncE in ring topologies.

Because not all links on the network may be SyncE-capable or have synchronization distribution at the physical layer, IEEE 1588 packet-based mechanism may also be used for frequency distribution. 1588-based synchronization distribution is overlaid across the entire system infrastructure; third-party master and third-party IP-NodeB client equipment are considered outside the scope of the system. The mechanism is standards based and provides frequency and phase distribution, relying on unicast or multicast packet-based transport. As with any packet-based mechanism, IEEE 1588 PTP traffic is subject to packet loss, packet delay, and packet delay variation. To minimize the effects of these factors and meet the requirements for synchronization delivery utilizing IEEE 1588, EF PHB treatment across the network is required.

Figure 5-4 illustrates how synchronization distribution is achieved for mobile RAN services over both fiber and microwave access networks in the UMMT architecture.

Figure 5-4. Synchronization Distribution



The timing source for the mobile backhaul network is the PRC, which sources timing via a Global Navigational Satellite System receiver or other Primary Reference Time Clock (PRTC). This PRC then distributes frequency and phase synchronization via Building Integrated Timing Supply (BITS) interfaces to the aggregation nodes, and if required by the architecture, the 1588 Primary Master Clock (PMC). From this point, three models of synchronization distribution are supported:

1. For mobile services that only require frequency synchronization, where all network nodes support SynchE, then frequency is carried to the NodeB via SyncE. The ESMC provides transport of synchronization messages between nodes, and SSM prevent timing loops in Ethernet ring topologies.
2. For mobile services that require synchronization over an infrastructure which does not support SyncE, 1588v2 PTP is then utilized for all synchronization distribution. The PMC generates 1588v2 PTP streams for each NodeB, and are passed into the transport MPLS VPN at the regional MTG, which ensures that the PTP streams do not traverse more than 20 network hops en route to the NodeB.
3. For mobile services that require frequency and phase and/or Time of Day (ToD) synchronization, IEEE 1588v2 PTP is used in conjunction with SyncE to provide a hybrid synchronization solution, where SyncE still provides frequency distribution, and 1588v2 is used for phase and/or ToD distribution. Again, the 1588v2 PTP streams are carried in the transport MPLS VPN from the regional MTG to the NodeBs.

In general, a packet-based timing mechanism such as 1588v2 PTP has strict packet delay variation requirements, which limits the number of hops over which the recovered timing from the source is still valid. This current release of the system architecture has a 1588 PTP stream generated from the PMC for each NodeB, and thus the number of PTP streams the PMC can generate dictates the number of NodeBs which may synchronize to it. Also, even with strict priority queuing of the PTP streams, it is generally not acceptable to have greater than 20 hops from the PMC to the NodeB, thus placing an upper limit on the distance between the PMC and the NodeB.

Scalability and reliability of 1588v2 in the UMMT System can be enhanced by enabling Boundary Clock (BC) functionality in the aggregation and/or PANs. Implementing BC functionality in these nodes serves two purposes:

1. Increases scaling of 1588v2 phase/frequency distribution, by replicating a single stream from the PMC to multiple destinations, thus reducing the number of PTP streams needed from the PMC.
2. Improves the phase stability of 1588v2, by re-synchronizing the PTP from SyncE or another frequency source, thus increasing the number of hops and distance supported between the PMC and NodeB.

Boundary Clock functionality is currently being evaluated, but official support of 1588 BC will come in a future release of the UMMT System.

5.3 Redundancy and High Availability

The UMMT System seeks to provide a highly resilient and robust network architecture to provide rapid recovery from any link or node failure within the transport network. By implementing various mechanisms at the network and service levels, this resilient design is achieved. The mechanisms described in this section are applicable to both single AS as well as multiple AS models.

The UMMT System implements the following baseline transport mechanisms for improving network availability:

- For intra-domain LSPs, fast IGP/BFD convergence is utilized for unicast MPLS/IP traffic in both hub-and-spoke and ring topologies. Also integrated are BFD rapid failure detection and IS-IS/OSPF extensions for incremental SPF and LSA/SPF throttling (XR defaults should be applied to IOS devices). A future system phase will implement extended Loop-Free Alternate Fast ReRoute (LFA FRR) for even faster reconvergence with operational simplicity.
- For inter-domain LSPs, network reconvergence is accomplished via BGP recalculation when a failure event is encountered. A future system phase will implement BGP Prefix Independent Convergence (PIC) throughout the system to allow for deterministic network reconvergence regardless of the number of BGP prefixes, through the pre-calculation of backup paths for every prefix.

The MPLS VPN services providing the backhaul of mobile traffic between the CSG and MTG implement the following mechanisms for improving network availability:

- For UNI connections at the CSG to the eNodeB, static routes to the MTG are utilized in the eNodeB.
- For UNI connections to the MPC from the MTG, fast IGP convergence with BFD keep-alive checks are utilized.
- For the MPLS VPN transport between the CSG and MTG, network convergence is handled by BGP VPNv4 recalculation. A future system phase will implement BGP PIC throughout the system to allow for deterministic network reconvergence regardless of the number of BGP prefixes through the pre-calculation of backup paths for every prefix.

In order to protect critical synchronization functions, the following mechanisms are implemented within the UMMT System for synchronization distribution:

- For SyncE frequency synchronization, the ESMC is used to pass frequency quality between nodes. In ring topologies, SSMs allow nodes within the ring to avoid timing loops, and to switch from one side of the ring to another if a network failure is encountered within the ring.
- For frequency, phase, and ToD synchronization via 1588 PTP, active and standby streams from two different PRCs are received at each 1588 Slave. If the active stream becomes unavailable,

then the backup stream can be utilized. As 1588 is a packet-based protocol, L2 or IGP resiliency mechanisms will prevent loops within a ring topology.

5.4 OAM and Performance Monitoring

The UMMT System defines an operations, administration, and maintenance (OAM) subsystem that is broadly classified into two categories: Service OAM and Transport OAM. Service OAM and Transport OAM rely on the same set of protocols to provide end-to-end OAM capabilities, including fault and performance management, but fulfill different functions.

Service OAM is a service-oriented mechanism that operates and manages the end-to-end services carried across the network. It is provisioned only at the touch points associated with the end-to-end service, and is primarily used for monitoring the liveliness and performance management of the service. Service OAM ensures services are up and functional and that the SLA is being met. When services are affected due to network events, it provides the mechanisms to detect, verify, and isolate the network faults. The following protocols are the building blocks of Service OAM:

- ATM Service OAM:
  - F4/F5 VC/VP ATM OAM
- Ethernet Service OAM and PM:
  - 802.1ag Connectivity Fault Management (CFM)
  - MEF Ethernet Local Management Interface (E-LMI)
  - ITU-T Y.1731: OAM/PM for Ethernet-based networks
  - Cisco IP SLA PM based on CFM
- MPLS VPWS Service OAM and PM:
  - Virtual Circuit Connectivity Verification (VCCV) PW OAM: PW Ping, BFD failure detection
  - Cisco IP SLA PM based on CFM
  - Future releases of the UMMT architecture will support PW OAM-based PM
- MPLS VPLS Service OAM and PM:
  - VCCV PW OAM: PW Ping, BFD failure detection
  - Cisco IP SLA PM based on CFM
- IP/MPLS VPN Services OAM and PM:
  - IP and VRF ping and trace route
  - BFD single and multi-hop failure detection
  - Cisco IP SLA PM

Transport OAM is a network-oriented mechanism that operates and manages the network infrastructure. It is ubiquitous in the network elements that make up the network infrastructure, and it is primarily used for monitoring liveliness and performance management of the transport mechanism on which the services are carried. The primary purpose of Transport OAM is to know the state of the transport entities (MPLS LSP, and Ethernet VLAN). It monitors the transport entities to ensure that they are up and functional and performing as expected, and provides the mechanisms to detect, verify, and isolate the faults during negative network events. The following protocols are the building blocks of Transport OAM:

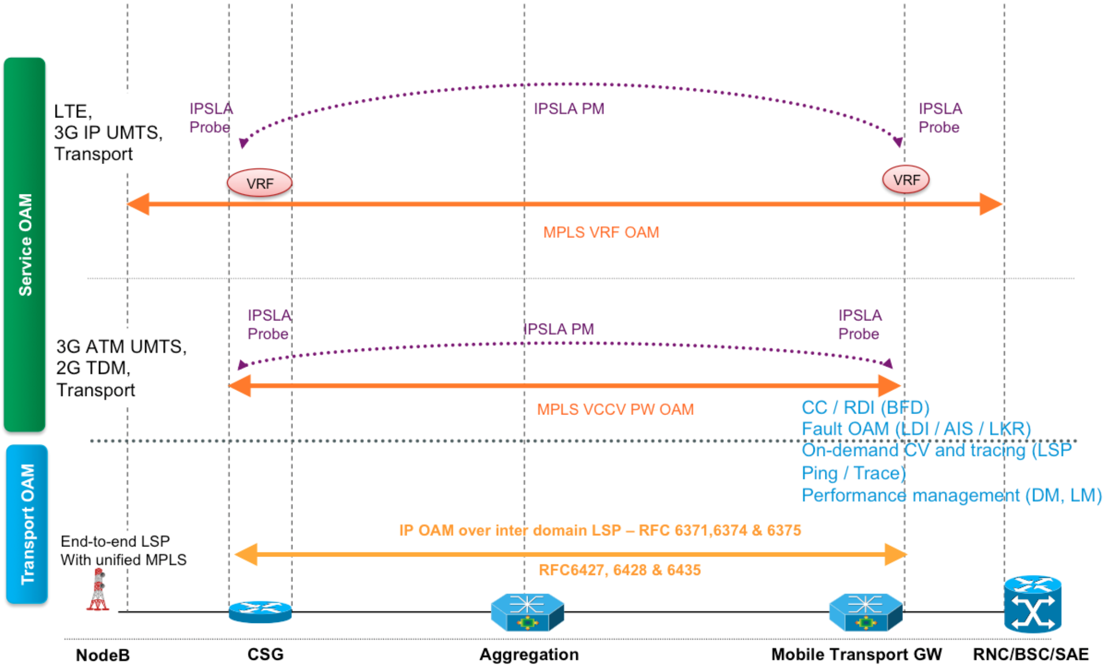
- Ethernet Transport OAM and PM:

  - IEEE 802.3ah: Ethernet Link OAM (EFM OAM)
  - 802.1ag CFM
  - ITU-T Y.1731: OAM/PM for Ethernet-based networks
  - Cisco IP SLA PM based on CFM
- IP/MPLS Transport OAM and PM:
  - BFD single and multi-hop failure detection
  - IP and MPLS LSP ping and traceroute
  - Cisco IP SLA PM
  - Future releases of the UMMT architecture will support G-ACh-based OAM and PM for MPLS LSPs

OAM Implementation in the UMMT System

The UMMT System, due to the nature of the mobile backhaul services supported, only utilizes a subset of these protocols to provide the required Service and Transport OAM and PM functionality. The details of the required mechanism are highlighted in Figure 5-5.

Figure 5-5. OAM Protocol Positioning



CHAPTER 6

Conclusion

As illustrated and explained in depth in this design guide, the Cisco UMMT System 2.0 gives operators a proven architecture, platforms, and solutions to stay ahead of the curve for bandwidth demand and provide operational simplification, all at optimized cost points. The UMMT System is a comprehensive RAN backhaul solution that supports LTE, 3G, and 2G service deployment. It provides flexible cell site connectivity options, including integration of third-party microwave vendors. It supports both retail and wholesale backhaul options, and concurrent transport for residential and business services traffic over the same infrastructure.

UMMT 2.0 builds upon the foundation delivered by UMMT 1.0, which introduced key technologies from Cisco's Unified MPLS suite of technologies to deliver highly scalable and simple-to-operate MPLS-based IP RAN backhaul networks. Unified MPLS resolves legacy challenges such as scaling MPLS to support tens of thousands of end nodes, which provides the required MPLS functionality on cost-effective platforms and without the complexity of technologies like TE-FRR to meet transport SLAs. By addressing the scale, operational simplification, and cost of the MPLS platform, UMMT 2.0 provides a comprehensive solution to the mobile operator seeking an immediately deployable architecture suitable for LTE deployment.

UMMT 2.0 Highlights

To recap, here are the highlights of the second release of the UMMT System:

- Full validation and deployment recommendations for Cisco's two main microwave partners: NEC (with their iPasolink product) and NSN (with their Flexipacket offering).
- Addition of TDM transport over packet for the GSM Abis interface.
- Addition of the ASR903 platform to provide a cost-effective and redundant pre-aggregation solution supporting legacy interfaces.
- Introduction of the IEEE 1588v2 boundary clock function in the aggregation to provide greater scalability.
- QoS: UMMT leverages DiffServ QoS for core and aggregation, H-QoS for microwave access and customer-facing SLAs, and support for LTE QCIs and wireline services, to deliver a comprehensive QoS design.
- Synchronization Distribution: SynchE is used in the core, aggregation, and access domains where possible. Where SyncE may not be possible, based on the transmission medium, a hybrid mechanism is deployed converting SynchE to 1588 timing.
- OAM and Performance Monitoring: OAM and performance management for LSP transport, MPLS VPN, and VPWS services are based on IP SLA, PW OAM, MPLS and MPLS OAM, and future IETF MPLS PM enhancements.

Until now, mobile network infrastructures have been composed of a mixture of many legacy technologies that have reached the end of their useful life. UMMT 2.0 continues to advance the UMMT 1.0 baseline that provided the first integrated, tested, and validated mobile network architecture, to meet all the demands of legacy and highly scaled any-to-any connectivity for LTE networks.

UMMT 2.0 Benefits Summary

- Flexible deployment options for multiple platforms to optimally meet size and throughput requirements of differing networks.
- High-performance solution, utilizing the highest capacity Ethernet aggregation routers in the industry. The components of this system can be in service for decades to come.
- Tested and validated reference architecture that allows operators to leverage a pre-packaged framework for different traffic profiles and subscriber services.
- Promotes significant capital savings from various unique features such as pre-tested solutions, benchmarked performance levels, and robust interoperability, all of which are validated and pre-packaged for immediate deployment.
- Enables accelerated time-to-market based on a pre-validated, turnkey LTE RAN backhaul system.
- Complementary system support, with mobile video transport optimization integration; I-WLAN untrusted offload support on the same architecture; mobile packet core (MPC); and cost-optimized performance for VoLTE, plus additional services such as Rich Communication Suite (RCS).
- Cisco's IP expertise is available to operators deploying UMMT 2.0 through Cisco Services. These solutions include physical tools, applications, and resources plus training and annual assessments designed to suggest improvements to the operator's network.

CISCO

GLOSSARY

A

ABR	area border router
AF	assured forwarding
AIS	alarm indication signal
ASBR	autonomous system border router
ATM	asynchronous transfer mode

B

BC	boundary clock
BGP	Border Gateway Protocol (RFC 4271)
BITS	Building Integrated Timing Supply
BNG	Broadband Network Gateway
BSC	base station controller (GSM)
BTS	base transceiver station

C

CEoPS	Circuit Emulation over Packet (Cisco)
CESoPSN	Circuit Emulation over Packet Switching Network
CFM	Connectivity Fault Management (IEEE 802.1ag)
CN-ABR	core node Area Border Router
CN-ASBR	core node Autonomous System Border Router
CSG	cell site gateway

D

DiffServ	Differentiated Services

E

eBGP	External Border Gateway Protocol
EF	expedited forwarding
E-LMI	Ethernet Local Management Interface
EPC	Evolved Packet Core
ESMC	Ethernet Synchronization Monitoring Channel
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EV-DO	Evolution Data Only Optimized

F

FEC	Forwarding Equivalency Class

G

GSM	Global System for Mobile Communications

H

H-QoS	Hierarchical QoS
HSPA	High-Speed Packet Access

I

iBGP	Internal Border Gateway Protocol
IGP	Interior Gateway Protocol
I-HSPA	Internet-High Speed Packet Access

IS-IS	intermediate system to intermediate system

L

LDP	Label Distribution Protocol (MPLS)
LFA-FRR	Loop-Free Alternate Free Reroute
LSP	Label-Switched Path
LTE	Long Term Evolution (3G)

M

MEF	Metro Ethernet Forum
MIMO	multiple input multiple output
MME	Mobility Management Entity
MPC	Mobile Packet Core
MPLS	Multiprotocol Label Switching
MSP	mobile service provider
MSPW	multi-segment pseudowire
MTG	mobile transport gateway

N

NHS	next hop self
NLRI	Network Layer Reachability Information
NNI	network-to-network interface

O

OAM	Operation, Administration, and Maintenance
OSPF	Open Shortest Path First

P

PAN	pre-aggregation node
PE	provider edge
PGW	packet data network gateway
PHB	per hop behavior
PHP	Penultimate Hop Popping
PIC	Prefix Independent Convergence
PMC	Packet Master Clock
PRC	Primary Reference Clock
PRTC	Primary Reference Time Clock
PRS	Primary Reference Source
PTP	Precision Time Protocol
PW	pseudowire
PWE	Pseudowire Emulation

Q

QCI	QoS class identifier
QoS	quality of service

R

RCS	Rich Communication Suite
RNC	radio network controller (UMTS)
RR	Route Reflector
RT	Route Target

S

S1AP	S1 Application Protocol
SAE	System Architecture Evolution
SAToP	Structure-Agnostic Transport over Packet
SCTP	Stream Control Transmission Protocol (RFC 2960)
SDH	Synchronous Digital Hierarchy
SGW	Serving Gateway (LTE)
SONET	Synchronous Optical Networking
SR-APS	Single-Router Automatic Protection Switching
SSM	synchronization status message
SSU	synchronization supply unit

T

TCO	total cost of ownership
TDM	time division multiplexing
TE-FRR	Traffic Engineering Fast ReRoute
ToD	Time of Day

U

UDP	User Datagram Protocol
UMMT	Unified MPLS Mobile Transport
UMTS	Universal Mobile Telecommunications System

V

VCCV	Virtual Circuit Connectivity Verification

VNI	Cisco Visual Networking Index
VoLTE	Voice over LTE
VPWS	virtual private wireline service
VRF	virtual routing and forwarding