BANDWIDTH PROVISIONING ARCHITECTURE IN BACKHAUL

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***Abstract*— the Metro Ethernet Forum has defined a set of Ethernet Virtual Connection services that are adopted to provide scalable Ethernet transport for mobile backhaul. However, these services usually address single cell site backhaul per UNI handoff, not considering statistical multiplexing gain at a hub site which aggregates backhaul traffics of multiple cell sites backhaul pipe. This paper proposed an efficient carrier Ethernet bandwidth provisioning architecture for mobile backhaul with cellular cluster. A statistical estimation scheme has been developed for deriving a safe overbooking factor at a given User-Network-Interface. Then an efficient QinQ transport architecture was proposed to support bandwidth sharing in cellular cluster with overbooked backhaul bandwidth in carrier Ethernet. Experimental data analysis have showed that our new schemes can benefit mobile operators in resource utilization efficiency, carrier Ethernet cost saving and backhaul performance.**

Keywords- Mobile backhaul, overbooking, Carrier Ethernet, UNI handoff, CIR, SLA

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I. INTRODUCTION

The Metro Ethernet Forum (MEF) [9] has defined Ethernet virtual Connection (EVC) services with performance requirements, as a transport association between two or more user-network-interfaces (UNI) [2][9]. There are three types of EVC service including E-Line, E-LAN and E-Tree services, which represent a point-to-point (P2P), multipoint-to-multipoint (MP2MP), and rooted multipoint-to-multipoint EVC service, respectively. Due to simplicity and reliability, P2P EVC services are adopted by most mobile operators to connect their cellular sites to mobile core networks. A carrier Ethernet vendor is responsible to provide such a P2P EVC connectivity following the bandwidth profile and performance requirements defined in a Service Level agreement (SLA) [2][3] between the carrier vendor and the mobile operator.

Compared to single cell site backhaul that is directly connected with carrier Ethernet cable or fiber, mobile operators normally develop their own wireless radio links, such as microwave [4], to connect multiple cell sites nearby, and deliver aggregated backhaul traffic to a hub site which handoff to carrier Ethernet network at UNI. In order to support different backhaul bandwidth requirements for each cell site in cluster, carrier vendors normally assign each mobile cell site an individual EVC circuit with a distinct VLAN ID and Committed Information Rate (CIR), and then implement parallel multiple EVC handoff over a same UNI at the hub site.

However, since all EVC circuits are assigned with fixed CIR values, they cannot take advantages of statistical multiplexing gain at UNI handoff and have no way sharing idle bandwidth among EVCs [1]. Therefore, the overall resource utilization of an UNI is low and mobile operators overpay carrier vendors for unused bandwidth. Authors in [5, 6] proposed delay based methods to decide the minimum transport capacity for which all traffic delay requirements are met. However, multimedia services have different performance requirements and optimal delay performance may result in low bandwidth utilization too [7]. A piecewise linear approach was proposed in [7] to achieve balance between network performance and bandwidth saving. Authors proposed a selective overbooking scheme based on trunk size and usage profile. However, due to different service types and traffic distributions in cell sites, peak bandwidth utilizations at hub site may differ even UNI bandwidth or cluster sizes are same, which means overbooking factors at different hub UNIs may differ from each other, instead of linearly following CIR. A capacity planning scheme for LTE backhaul networks has been proposed in [8] where an overbooking factor calculation method based on traffic forecast, multiplexing gain and peak throughput. However, the overbooking factor is derived from estimation on 50 user peak throughput model, without considering real cellular traffic distributions.

The contributions of this paper are follows: First, we developed a statistical estimation method for overbooking factor, based on UNI peak utilization data, cellular traffic distributions, and statistical service outage performance. Then we designed efficient carrier Ethernet architectures to help bypass CIR binding in EVC and implement mobile backhaul bandwidth sharing among a cellular cluster. Specifically, a mobile operator can adopt an Ethernet VLAN tunneling to complete backhaul transport in its cellular cluster, while using a single EVC pipe in carrier Ethernet for bandwidth overbooking. Experimental networking data and results showed that the proposed schemes can benefit mobile operators in resource utilization efficiency and backhaul cost saving.

This paper is organized as follows: in section II, we present the UNI capacity estimation and overbooking derivation methods. Then we describe an efficient Carrier Ethernet architecture for implementing UNI overbooking with carrier Ethernet. Network performance data are shown in section IV with analysis. Finally, we conclude this paper with a brief summary.

II. Overbooking Estimation

Consider a microwave cluster containing total K cell sites and traffic intensity of a cell site i, X_i, the aggregated traffic intensity at UNI, Y_{uni}, is represented as,

$$Y_{uni} = A_{uni} \cdot \sum_{i=1}^{K} X_i \tag{1}$$

where A_{uni} is the statistical multiplexing gain value at the UNI.

Assume backhaul traffic intensities of cell sites are independent, and there are two major traffic patterns: the Poisson based model and self-similar model [7]. The Poisson-based traffic model has been intensively used to represent cellular voice connections, while the self-similar model is used to represent data services with burst throughputs. We further assume there are M types of voice services, and N types of self-similar services. We adopt an ON-OFF source model [10-12] to analyze the peak throughput of a voice connection, where the ON and OFF states represent the active and silent conditions of the voice connection, respectively. Both ON and OFF state intervals are assumed to be exponentially distributed, and R_j is a constant packet generation rate of voice class j in the ON state. Due to packet burst characteristics and CIR throttle on backhaul capacity, the throughput ξ_j of self-similar service class j follows truncated Pareto distribution with following probability distribution function [5] shown below:

$$f(\xi_j) = \frac{\alpha_j E_j^{\alpha_j} \xi_j^{-\alpha_j - 1}}{1 - (E_j / H_j)^{\alpha_j}} \tag{2}$$

where α_j denotes shape parameter, E_j denotes the minimal traffic rate, and H_j denotes the maximum traffic rate of service class j. Then the aggregated throughput ξ_{uni} at the UNI is denoted as,

$$\xi_{uni} = \sum_{i=1}^{K}\sum_{j=1}^{M}\sum_{k=0}^{l_{i,j}} \xi_p(i,j,k) + \sum_{i=1}^{K}\sum_{j=M+1}^{M+N}\sum_{k=0}^{l_{i,j}} \xi_s(i,j,k)$$
$$\leqslant \sum_{i=1}^{K}\sum_{j=1}^{M} l_{i,j} R(j) + \sum_{i=1}^{K}\sum_{j=M+1}^{M+N}\sum_{k=0}^{l_{i,j}} \xi_s(i,j,k) \tag{3}$$

where $\xi_p(i,j,k)$ represents the throughput of connection k of Poisson-based service type j in cell i, $\xi_s(i,j,k)$ represents throughput of connection k of self-similar service type j in cell i, and $l_{i,j}$ represents total connection number of class j in cell i.

From the equation (3), the peak aggregation throughput at UNI is determined by the sum of self-similar traffics following truncated Pareto distribution function, which can be approximated as a Gaussian distribution [5][7], with mean value μ_{peak}, and standard deviation σ_{peak}, which can be derived from peak throughputs at the UNI. When an overbooking ratio O_{uni} is applied at UNI bandwidth which equal to $\sum_{i=1}^{N} CIR(i)$, it is expected to achieve low bandwidth outage probability, i.e., the probability of the case that overbooked bandwidth cannot transport aggregated peak throughput is smaller than or equal to a threshold service outage ratio ε, $0 < \varepsilon < 1$. Then we can get,

$$P(\xi_{uni} \le O_{uni} \cdot \sum_{i=1}^{N} CIR(i)) \ge \varepsilon \tag{4}$$

When equality holds in (4), the overbooking ratio O_{uni} is minimized, and the overbooked UNI bandwidth can be minimized. Since ξ_{uni} follows normal distribution, then the following relationship is satisfied,

$$O_{uni} = \frac{\sigma_{peak} \cdot Q^{-1}(\varepsilon) + \mu_{peak}}{\sum_{i=1}^{N} CIR(i)} \tag{5}$$

where $Q^{-1}(x)$ is the inverse function of normal distribution $Q(x)$, and $Q(x) = \frac{1}{2\pi}\int_x^{\infty} e^{-\frac{s^2}{2}} ds$. Applying O_{uni} on existing UNI bandwidth, we get the overbooked UNI bandwidth for the whole cluster as,

$$B_o = O_{uni} \cdot \sum_{i=1}^{N} CIR(i) \tag{6}$$

III. Effient Uni Handoff Architecture

The generic mobile backhaul architecture is shown in Figure 2, in which an EVC is provisioned between two Provider Edge devices (PEs) in a carrier Ethernet network. All backhaul Ethernet frame is marked with a predefined VLAN tag which is associated with the EVC circuit and help UNI handoff between the PE and Customer Edge (CE) device in mobile network. The UNI bandwidth is defined in SLA as a fixed value. The architecture has been used to define Service Level Agreement content and performance requirements, in which CIR binds with EVC circuit, and

UNI only contains one EVC. Therefore, the UNI bandwidth equal to EVC CIR value.

A. *Generic Mobile Backhaul Architecture for single site*

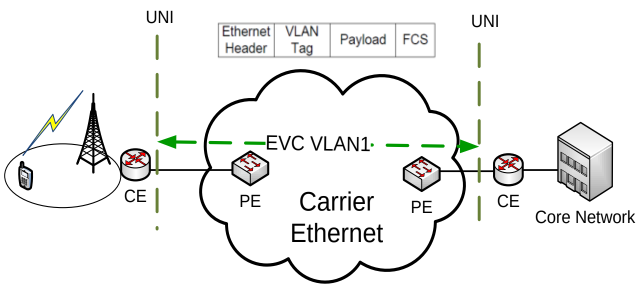

Figure 2. Generic Carrier Backhaul Architecture

B. *Multiple EVC Bundling Architecture*

For microwave backhaul, there are multiple cell sites in which backhaul traffic from recipient sites aggregates at hub site, and multiple EVC circuits provisioned in carrier Ethernet network for each site, as shown in Figure 2. Similar to the generic carrier backhaul architecture, each EVC circuit is marked with a predefined VLAN tag and bind with CIR bandwidth defined in SLA. Although all circuits go through same UNI, they cannot share all the UNI bandwidth due to different circuit ID and SLA CIR binding isolation.

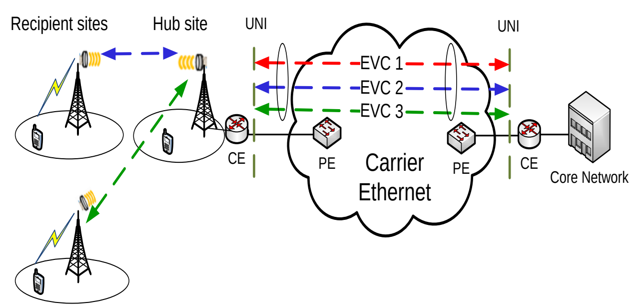

Figure 3. Multiple EVC Bundling Architecture

Since current MEF E-line service does not support overbooking at UNI with parallel EVC circuits, we need to improve the carrier Ethernet transport architecture to implement bandwidth sharing inside the cellular cluster. Considering a CE device at a UNI is a layer 2 switch, we proposed tunneling based UNI handoff architectures to implement the above goal.

C. *Q-in-Q Tunneling Architecture*

In scenarios that the CE at UNI only supports Layer 2 VLAN switching, a mobile operator can order a single EVC pipe with its contracted carrier vendor for mobile backhaul of a target cell cluster. The EVC pipe is implemented with IEEE 802.1ad stacked VLAN bridging technology (Q-in-Q tunneling) [2], in which the Ethernet carrier configures and delivers P2P mobile backhaul traffic between two PEs based on outer VLAN service tag (S-tag) in carrier Ethernet frames. After the carrier PE handoffs traffic to associated CE in mobile network, the CE implement switching based on inner customer VLAN tag (c-tag) for frame delivery to the destination recipient cell, as shown in Figure 4.

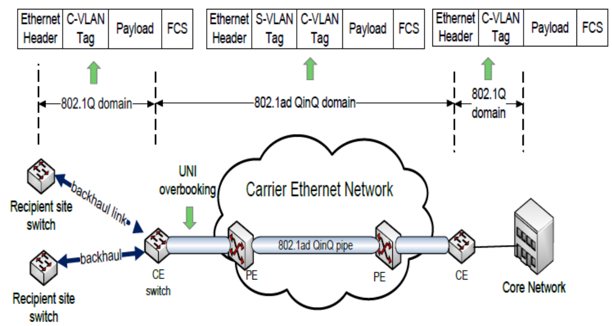

Figure 4. Q-in-Q Tunneling Carrier Backhaul Architecture

The EVC capacity is determined by the overbooked UNI bandwidth defined in equation (7). The mobile operator predefines and encapsulates a VLAN ID associated with one of their destination cell sites with inner customer-tag (C-tag) without necessarily notifying the carrier vendor CIR value of each cell site, and only contract with the vendor with the CIR value of ordered EVC circuit, which tunnel backhaul traffic between MSO and the hub site. The tunneling backhaul scheme goes as follows: any backhaul Ethernet frame generated in MSO or in a cellular cluster is attached with a C-tag VLAN ID which works as an ID marker of the backhaul of a destination cell site. When aggregated backhaul frames arrive at CE devices at UNI, the CE attaches S-tag VLAN ID in each frame as an indicator of the pre-specified carrier Ethernet EVC circuit, and handoffs the Q-in-Q frame to carrier Ethernet network. When the PE device in the carrier network receives the frame, it checks S-tag VLAN ID in the frame and finds out the associated carrier EVC circuit for delivery. Once a CE on the other side of the EVC circuit receives Q-in-Q frame from its associated PE, it detaches the outer S-tag, checks the inner VLAN ID in C-tag for destination site, and delivers the frame to next hop that follows same layer 2 switching scheme based on VLAN ID until it reaches the destination cell site.

D. *Advantage of Tunneling Architecture*

Advantages of our proposed architecture: the UNI is implemented as a backhaul aggregation pipe, instead of a group of parallel EVC circuits. And the UNI bandwidth profile is determined by the multiplication product value of the derived overbooking ratio and the sum of CIR values of all cell sites in the cluster. Therefore, the statistical multiplexing gain is used for bandwidth sharing among the cell site cluster, and no more dependency on carrier EVC provisioning. The mobile operator can adjust bandwidth profile more easily based on cluster size and the peak utilization at the UNI. The scalability of mobile backhaul also get improved because it is not necessary for the mobile operator to request additional EVC circuits for newly added cell sites in the cluster. Furthermore, carrier vendors reduce the complexity in networking configurations and EVC maintenance, through a single EVC circuit provisioning for whole cellular cluster.

IV. Performance Evaluation

In this section, we evaluate the overbooking ratio selection with several production microwave clusters in a national cellular network. For proprietary information protection, we neglect locations and names of the selected clusters and only show related performance data, as shown in table 1.

TABLE I. Network Utilization and Overbooking ratio

Cluster	C1	C2	C3	C4	C5
K	2	3	3	4	4
$\sum_{i=1}^{K} CIR(i)$	100	150	150	200	200
T_{peak}	40.7	33.1	76.3	21.9	80.0
O_{uni}	40.11%	23.76%	52.62%	10.85%	44.43%
B_{uni}	60	50	100	30	110

For each cluster, the service outage threshold ε is set as 0.001%, and maximum allowable utilization η in equation (7) is set as 0.8. μ_{peak} and σ_{peak} of each UNI are calculated through daily peak UNI throughput data over one year. The peak throughput with 99% confidence interval based on estimation is denoted as T_{peak}. Compared to a linear piecewise relationship between UNI bandwidth and overbooking ratio in [7], we found that peak UNI backhaul throughputs of clusters are different to each other and not strictly follows a monotonically non-increasing relationship with total CIR values of a cell cluster. This demonstrates that traffic intensity and statistical multiplexing gains of clusters are different from each other, even they have same CIR values or cluster size. So it is more appropriate to adopt our statistical estimation method for cluster based overbooking estimation, rather than using the linear piecewise based scheme which derived overbooking ratio only based on UNI CIR value.

V. Conclusion

This paper proposes an efficient overbooking framework for mobile backhaul. We first develop a statistical estimation method to derive a safe overbooking factor for a given UNI. Then a novel QinQ transport architecture is proposed to help cellular cluster backhauls with overbooked UNI bandwidth in carrier Ethernet. Experimental networking data analysis show that our new schemes can benefit mobile operators in resource utilization efficiency and carrier Ethernet cost saving.

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