Abstract—Transition from 2G to 3G and the evolution of 3G radio technologies have dramatically increased bandwidth delivery to the end user and at the same time shifted the bandwidth bottleneck from the radio segment to the cellular backhaul network. Solutions addressing the challenges of the cellular backhaul network must economically balance backhaul capacity expansion with its utilization during 2G to 3G transition and within various 3G evolution phases. 2G and 3G use different backhaul transmission technologies, from TDM to ATM to IP. To minimize CAPEX and OPEX of the cellular backhaul, mobile operators have been seeking a unified 2G/3G backhaul solution that is technology-agnostic and addresses cellular backhaul evolution phases while maximizing the reuse of the existing 2G backhaul infrastructure. Cellular backhaul switching (CBS) is a sub-class of multi-service switching (MSS), designed to address cellular backhaul evolution needs. A converged backhaul by CBS technology is the solution of choice for economically managing backhaul network expenses during 2G to 3G migration while reusing the 2G backhaul infrastructure.

Index Terms—CBS (cellular backhaul switching), Cellular Backhaul (transmission infrastructure connecting cellular base stations to their controllers).

INTRODUCTION

By the end of 2005, approximately 1.8 million cellular base stations (BTSs) were expected to be deployed globally, projected to reach approximately 4 million by 2009. Each BTS requires dedicated backhaul transmission, which traditionally consists of multiple circuit-switched T1 or E1 links. According to Philip Marshall of the Yankee Group, "Today the lion’s share of T1 and E1 base-station backhaul is supported by leased-line circuits provided by wireline service providers. Leased-line infrastructure represents between 6 percent and 12 percent of a typical service provider’s operational expenditures. Globally this accounts for $22 billion in operational expenditures for wireless service providers.”

3G deployed as an overlay to an operating 2G network significantly increases the number of backhaul lines. Backhaul inefficiencies related to fragmented, under-utilized backhaul lines are becoming noticeable and expensive. A re-evaluation of the cellular backhaul utilization approach is in order in light of capacity limitations of microwave networks and the growing expense of leased lines. Migration to 3G services increases the connectivity requirements per site and adds on sites. The cumulative effect produces an explosion of expenses, particularly costly during the introduction phase of 3G, when under-utilized infrastructures fail to balance the operational cost. This is the period when sharing 3G backhaul needs with 2G backhaul infrastructure can keep 3G expenses down.

The real challenge lies in evolving 2G backhaul networks to provide the backhaul capacity required by 3G while reusing the investment in the 2G backhaul infrastructure. This paper focuses on the CBS technology and the device that enables it, the cellular backhaul switch. CBS interworks with all standard cellular backhaul technologies: TDM, ATM, and IP across PDH, SDH, and Ethernet infrastructure. The converged backhaul is based on standard E1/T1 bundling approaches (IMA for ATM or virtual concatenation for Ethernet over PDH) or Ethernet interfaces, and uses standard ATM or Ethernet framing and switching as required by the underlying transport infrastructure.

I. RADIO ACCESS NETWORKS – BACKHAUL CHALLENGES

In today’s radio access networks (RAN), E1s or T1s are the links of choice. E1/T1 traffic from the cell sites is aggregated by cross-connect switches and backhauled to the site of the corresponding controllers (BSC/RNC). From there the traffic is forwarded to the Mobile Switching Center (MSC), primarily over SDH or SONET rings.

2G GSM backhaul networks consist of a combination of Base Transceiver Stations (BTS), Base Station Controllers (BSC), and Mobile Switching Centers (MSC). The transport technology is TDM over T1/E1 interfaces carrying frames of digital compressed voice over circuit switched fractional channels allocated for the duration of the connection.

When 2G was first deployed, voice was the primary service, backhauled from BTS to MSC across channelized TDM networks using PDH and SDH technology.
3G introduced a packet-based approach, initially implemented using the ATM-infrastructure. However, 3G is specified to be packet-infrastructure agnostic and hence will evolve into IP/Ethernet as deemed appropriate. In the initial 3G release the packet network is based on ATM. ATM backhaul is usually implemented over bundles of E1s/T1s (IMA groups). Future deployment of the backhaul network will be based on IP/MPLS/Ethernet technologies. Ethernet over PDH is an example of an approved standard. Several chip vendors provide implementation that enables reuse of the existing "channelized" infrastructure during transition to Ethernet with link bundling by means of standard virtual concatenation.

The challenging aspect of the 3G network is traffic unpredictability and its implications for network planning and dimensioning. The practical approach to 3G backhaul is to start with a single or a pair of E1/T1 connections and increase backhaul capacity based on utilization reports. As simple as it is, the addition of an overlaid 3G network (as shown above) across the same transmission infrastructure is not optimal from CAPEX and OPEX perspectives.

Statistical multiplexing of both 2G and 3G traffic over shared facility links enabling a converged backhaul is by far a more efficient way to introduce 3G in a cost-controlled manner.

The standard approach to 2G-3G convergence is to select the prevailing 3G backhaul technology (ATM or Ethernet) and merge 2G (TDM) traffic into it by circuit emulation (CES) or PseudoWireEmulation (PWE). This approach accounts poorly for transmission infrastructure already in place, which is predominantly based on E1/T1 lines. The following figure shows the non-optimal gain resulting from the use of CES/PWE3. Two cases are studied, with 3G:2G link ratios of 1:1 and 3:1. In both cases the gain of statistical multiplexing of 3G traffic is estimated at 3:1 and the consequence of CES/PWE packetization at an additional capacity requirement of 15%. The resulting size of the converged backhaul pipe is shown on the right side of each diagram.

Although 2G-3G consolidation resulted in a noticeable gain, it is clear that convergence of 2G into the shared ATM pipe by means of CES caused several negative side effects:
1) Capacity requirements for 2G traffic increased.
2) Capacity consumed by 2G cannot be reused when 2G traffic is low. This is the essence of CES and/or PWE: the entire link is emulated regardless of its momentary utilization.
3) 3G requires dedicated capacity.
Note that most existing MSSs could enhance 2G gains by grooming preconfigured 2G timeslots before performing CES/PWE3. But the ultimate result is that CES capacity is preallocated and cannot be used for statistical multiplexing purposes. The outcome is the same with both CES and PWE: 2G and 3G are not statistically multiplexed, resulting in an overlaid network.

Circuit emulation of 2G links over ATM or IP is viable but not optimal, resulting in an emulation tax that increases the number of links required to match the current level of service.

II. CELLULAR BACKHAUL SWITCHING

Mobile operators seek ways to preserve the CAPEX on 2G infrastructure while acquiring equipment to handle the 3G backhaul traffic, expected to evolve from ATM to all-IP transport. Lessons learned from early 3G deployments attest to the cost-efficiency of the following steps:

1) Reduce the capacity consumed by 2G backhaul traffic.
2) Statistically multiplex 2G with 3G backhaul traffic to optimally carry it across existing infrastructures. Use the finest possible granularity for maximum statistical gain.
3) Provide real-time dynamic bandwidth allocation for 2G and 3G traffic over the full capacity of the converged backhaul network.
4) Support QoS for all 2G and 3G traffic to ensure network resource allocation based on operator-defined priorities.

Let’s assume that cellular backhaul switching (CBS) accomplishes all this and provides 2.5:1 statistical gain for 2G traffic by eliminating idle and inefficient parts and statistically multiplexing the significant cellular traffic. Let’s assume further that a CBS using AAL2 for the adaptation of the significant GSM traffic to Variable Bit Rate (VBR) flow, and the resulting ATM/AAL2 “tax” reduces statistical gain to 2:1. The above chart now looks as follows.

3G:2G ratio of 1:1

<table>
<thead>
<tr>
<th>CBS/ATM</th>
<th>3G: 21xE1s</th>
<th>Stat-Mux</th>
<th>3G: 7xE1s</th>
<th>Stat-Mux</th>
<th>3G: 18 E1s</th>
</tr>
</thead>
<tbody>
<tr>
<td>2G: 21xE1s</td>
<td>42 E1s</td>
<td>2G Opt and AAL2</td>
<td>11xE1s</td>
<td>2G Opt and AAL2</td>
<td>15 E1s</td>
</tr>
<tr>
<td>30 UMTS</td>
<td>40</td>
<td>Stat-Mux</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 GSM</td>
<td></td>
<td>Stat-Mux</td>
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</table>

More important than the overall reduction of E1 connectivity in the converged pipe is the flexibility to allow 3G traffic to burst to full pipe capacity during the hours when traditional 2G traffic drops down. Comparing CBS and CES/PWE:

- CBS adds an additional 1/3 reduction over the one provided by CES/PWE.
- CBS enables true statistical multiplexing of 2G and 3G backhaul, unlike CES/PWE.

III. CELLULAR BACKHAUL SWITCH

The cellular backhaul switch is a derivative of the MSS class of devices. It is a special-purpose MSS for the cellular backhaul infrastructure. In addition to interworking and flexibility features found in MSSs, it contains cellular-traffic switching engines that enhance overall backhaul network performance and improve service delivery while cutting network expenses.

The main features of cellular traffic switching technology are:

- Increased network efficiency and effective capacity through elimination of idle and inefficient parts and statistical multiplexing of 2G and 3G traffic.
- Maximized network flexibility by real-time dynamic bandwidth allocation to all 2G and 3G services.
- QoS support for 2G and 3G traffic to ensure network resource allocation based on operator-defined priorities.
- Optimally converged 2G and 3G traffic onto a unified backhaul network that maximizes the service delivery capabilities of the available backhaul infrastructure.

The following figure illustrates the role of CBS as a “switch”:

- At the BSC site the cellular backhaul switch optimizes and statistically multiplexes traffic that is dropped from the ring by the corresponding ADM to the domain containing sites A, B and C.
- The cellular backhaul switch at site C processes traffic addressed to the site but also switches traffic to sites A and B.
- Customers at all sites gain from shared statistical multiplexing provided by the ADM site C pipe.

To summarize:

- The cellular backhaul switch is a MSS with a cellular-traffic-switching engine that enhance overall backhaul network performance.
The cellular backhaul switch enables CBS to maximize backhaul network performance and service delivery capability of the existing infrastructure.

IV. CONCLUSION

CBS implemented in a cellular backhaul switch is the solution to the backhaul challenges facing mobile operators during migration from 2G to 3G. In the initial phases of transition to 3G, CBS provides the required coverage without the mobile operator incurring the cost of an underutilized 3G backhaul. While ramping up 3G usage, the mobile operator incrementally adds links to the backhaul pipe based on their utilization reports, taking advantage of the existing infrastructure and statistically multiplexing 2G and 3G traffic across the shared pipe. Statistical self-adjustment of the combined backhaul capacity enables operators to balance peak-rate 3G services with 2G voice services to maximize mobile service delivery over the existing backhaul infrastructure.

CBS is poised to become the prevailing technology for the evolving cellular backhaul networks. CBS provides seamless end-to-end networking that balances the statistical multiplexing and traffic prioritization of the next generation of networks with the OAM capabilities of traditional transport networks.

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V. REFERENCES