Case Study for Unified Backhaul Performance Optimization

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Abstract— **In an attempt to optimize network performance of delivered 2G and 3G services and reduce operating costs, today's mobile operators are searching for aggregation and concentration alternatives for the backhaul network. This paper explores a solution that would provide improved traffic aggregation at the regional hub sites in order to optimize traffic backhauling to the network core.**

Index Terms— **Backhaul network, 2G/3G integration, Cellular traffic switching, HSDPA; RNC; HSUPA**

I. Introduction

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 [1]. 2G and 3G use different backhaul transmission technologies, from TDM to ATM to IP. To minimize CAPEX (Capital expenditures) and OPEX (Operating expenditures) 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.

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.

As commercial high-speed downlink packet access (HSDPA) networks appear around the world, most public discussion has focused on the promise of end-user downlink speeds of up to 14 Mbit/s - and the services that such data rates could enable [2]. However, little consideration has been given to how significant increases in data traffic will be transported on the backhaul link between the W-CDMA base station and the first network node. Mobile broadband services based on HSDPA could require up to 15 times more backhaul transmission capacity than current mobile services. If mobile broadband is to live up to its promise, it is imperative that mobile operators prepare their transmission networks to cater for this increased load.

II. Backhaul Crunch

HSDPA enables more users to be served within each radio carrier frequency. The technology also reduces round-trip delay over the air interface, improving the end-user experience for interactive services such as web browsing. Figure 1 shows a typical mobile backhaul network showing last and second-mile connection and an optical ring connection to the radio-network controller (RNC). Although HSDPA can be rolled out with minimal impact on the transport network, the move towards true mobile broadband means that each 3G base station is likely to require 20 Mbit/s or more of dynamic transmission capacity [3]. This in turn could require a "second mile" network with links in the 100 Mbit/s range. This is much higher than existing networks, which typically employ 2-4 Mbit/s links to base stations. High-Speed Uplink Packet Access (HSUPA) is another data access protocol for mobile phone networks with extremely high upload speeds up to 5.4 Mbit/s [4]. Similar to HSDPA, HSUPA is considered 3.75G. HSUPA is expected to use an uplink enhanced dedicated channel (E-DCH) on which it will employ link adaptation methods similar to those employed by HSDPA, namely: shorter Transmission Time Interval enabling faster link adaptation and HARQ (hybrid ARQ) with incremental redundancy making retransmissions more effective [5] .

The backhaul is the terrestrial network connecting the cell sites with the mobile switching centre (MSC) at the

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core network [6]. This network is based on SONET/SDH rings on the upper part of the network. A tree topology in the lower part of the network distributes traffic to the cell sites. Cellular backhaul traffic can be carried hundreds of kilometers across multiple hops of copper, microwave, satellite, or fibre-optic infrastructure. Because cellular traffic is compressed, the overall traffic in the backhaul network is relatively low. A typical 2G base station service with an average population of around 1000 subscribers requires a connection of a few megabits per second, which can be accommodated by several E1/T1 lines.

To implement and operate their backhaul networks, operators either lease capacity from fixed-line operators or own the network themselves [7]. The most common self-owned infrastructure technology is the microwave link. This is relatively inexpensive to install but may be limited in its ability to support the increased capacity needs of new cellular technologies.

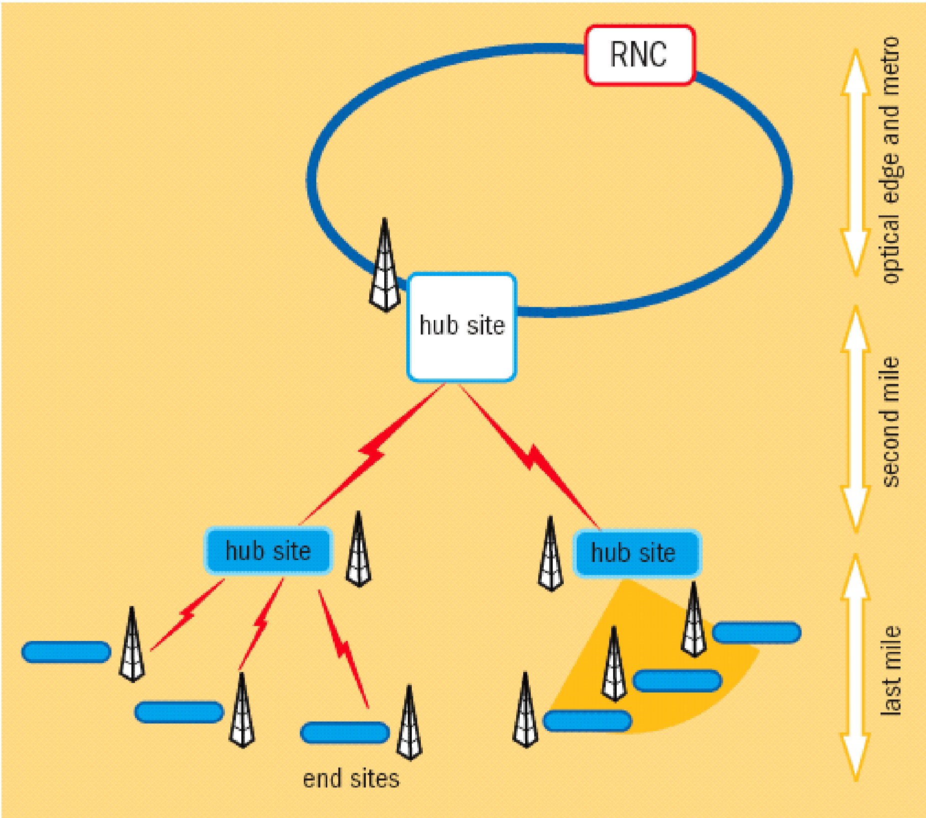

Figure 1. Initial Mobile Backhaul Network

A backhaul network also includes aggregation and switching functions. These are deployed at several levels in the aggregation sites and hubs that concentrate traffic moving from lower to upper levels of the network. Traditional 2G networks employ a time-division multiplex (TDM) backhaul network in which aggregation is performed by TDM access cross connects. However, in more recently deployed 3G backhaul networks, traffic is concentrated by packet switching that is based on asynchronous transfer mode and Internet protocol (ATM/IP) technologies.

III. Design Concerns

Initial deployments of 3G equipment have been collocated with existing 2G infrastructure. Most 3G base stations are deployed at the same sites as their 2G counterparts and the same hub and core sites are used for 2G and 3G backhaul equipment [8]. The 3G ATM backhaul network is overlaid on the existing TDM network. The 3G radio network controller (RNC) is deployed only at core sites. There are no remote RNCs resembling the remote base-station controllers (BSCs) that are used in 2G networks. As a result 3G backhaul lines tend to be longer than their 2G counterparts.

The initial phase aggregation in 3G networks usually includes ATM switches, which are deployed alongside the RNC at core sites. These switches groom the ATM E1 to STM1 and reduce capital expenditure associated with RNC interfaces [9].

As 3G traffic grows, new micro- and picocells will be added to the network and more backhaul connectivity will be required at each 3G cell site. More packet-based aggregation will also be added to the backhaul network to improve traffic flow and to reduce transmission costs. Upgrading the backhaul network to meet these requirements will be expensive.

The relationships between capacity and cost in operator-owned microwave networks are more complicated. Most microwave networks are running at full capacity - especially microwave rings - and the only viable alternative for expansion are fibre-optic connections, which are costly to install. In busy urban areas with high subscriber densities, fibre may be the only alternative [10]. However, in suburban and rural areas, and over long distances, the costs associated with fibre would be prohibitive.

IV. Scope

It is clear that there is no single solution to the backhaul challenges facing 3G operators. Instead, an operator must combine increases in infrastructure capacity with traffic-flow improvements enabled by the deployment of switching solutions at aggregation sites.

Backhaul capacity can be boosted by more leased capacity, upgrades to microwave technologies, and adding fibre links where microwave technologies have been exhausted [11]. A switching technology must also be introduced in the backhaul network to improve traffic flow and maximize the network performance of the backhaul infrastructure. To be successful, a backhaul switching solution should increase the efficiency and effective capacity of the network to achieve improved service delivery at reduced network costs.

The switching system must improve flexibility to ensure that the network can accommodate changes in traffic type and allow the rapid introduction of new services. Quality of service (QoS) support for all cellular technologies - 2G, 3G and beyond - should be delivered by the switching system via the real-time allocation of scarce backhaul network resources according to operator-defined priorities.

Finally, a switching system should converge all generations of cellular traffic into a unified backhaul network to utilize the infrastructure efficiently for all services and to reduce costs related to the operation of multiple overlaid networks.

These guidelines can be put into practice by implementing two switching layers. The first layer is the traditional multi service switching (MSS) of TDM/ATM/IP, which occurs in layers 2-3 of the network. The second is application-layer switching, which occurs in network layers 4-7 and switches the cellular voice, data and signalling frames. The integration of application-layer switching with traditional TDM/ATM/IP switching improves network performance by maximizing network efficiency, providing full network flexibility, and enabling real-time network resource allocation based on support of QoS for multi-generational voice, data and signalling traffic.

V. Improved Solution

In order to deliver both 2G and 3G services, the operator decided to deploy an aggregation solution that reduced transmission expenses and opened up bottlenecks in the microwave links. This scenario is illustrated in Figure 2, which is based on a packet-based aggregation solution of a standard ATM MSS (multi service switching). On the input side there are six fractional E1 lines, utilizing 115 time slots to carry 2G GSM traffic from eight base stations. Another six E1s carry 3G UMTS traffic from six base stations. The six fractional GSM E1s are groomed and a circuit emulation service (CES) is used to concentrate the traffic such that 4.5 E1s will suffice. The six UMTS (Universal Mobile Telecommunication System) lines are concentrated into 2.5 E1s. As a result seven E1s are required to connect the hub site to the core network, which is a significant reduction from the original 12.

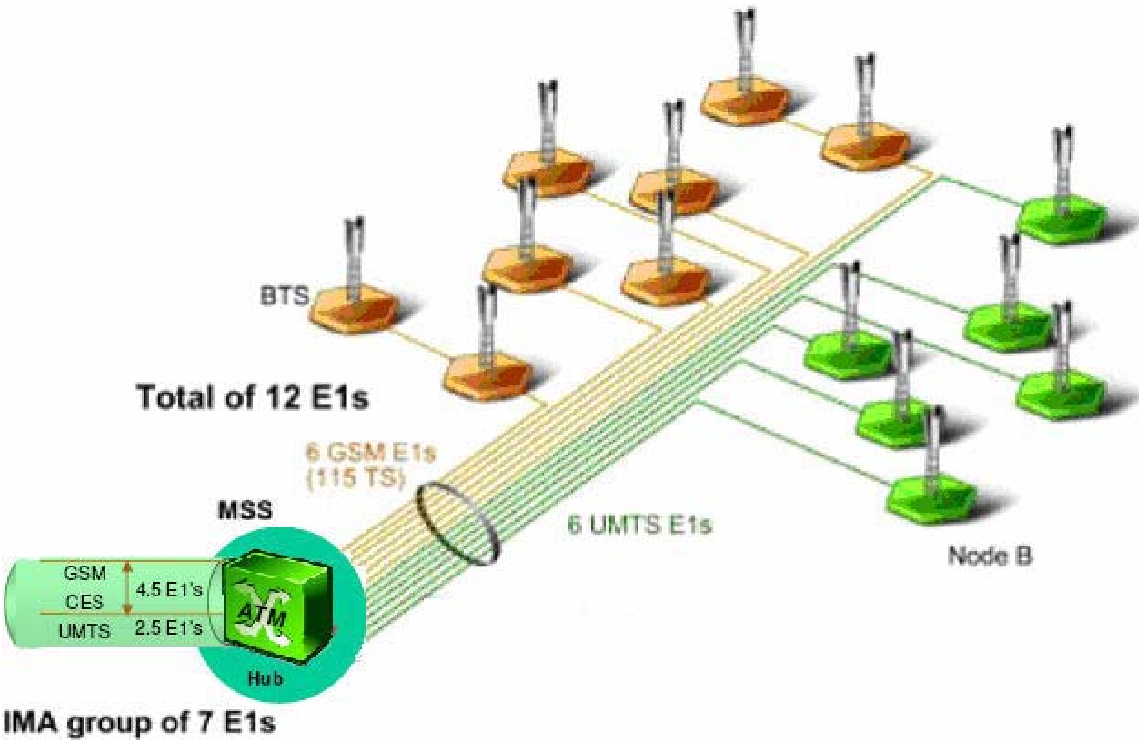

Figure 2. Standard ATM MSS Deployment

This solution, which is based on a standard ATM MSS, provides the benefits of statistical multiplexing of UMTS traffic and time slot grooming of GSM traffic, and enables the mixing of all traffic on one IMA group with static partitioning between GSM and UMTS. However, network efficiency and flexibility are compromised due to the fixed bandwidth allocation for 2G\3G traffic.

Standard ATM MSS architecture is limited by the fact that the output comprises dedicated GSM and UMTS channels. These are entirely separate networks that cannot be shared using a dynamic allocation process. In other words, if at any given moment there is barely any GSM traffic but there is an overload demand for UMTS services, the empty GSM channel cannot be used for UMTS traffic and vice-versa. Standard MSS can almost halve the backhaul requirements of a 2G/3G network. However, separate pipes are required for 2G and 3G traffic, which can lead to inefficiencies

The need to further improve network performance while cutting down network expenses compelled the operator to seek alternative solutions. At this point, we have proposed much higher network performance by adding application-level switching to the standard MSS. Cellular traffic switching terminates the transmission protocol to switch on the cellular frame level. This eliminates idling and protocol inefficiencies, performs statistical multiplexing of all 2G and 3G traffic, and provides full flexibility for sharing network resources according to actual 2G and 3G traffic demands.

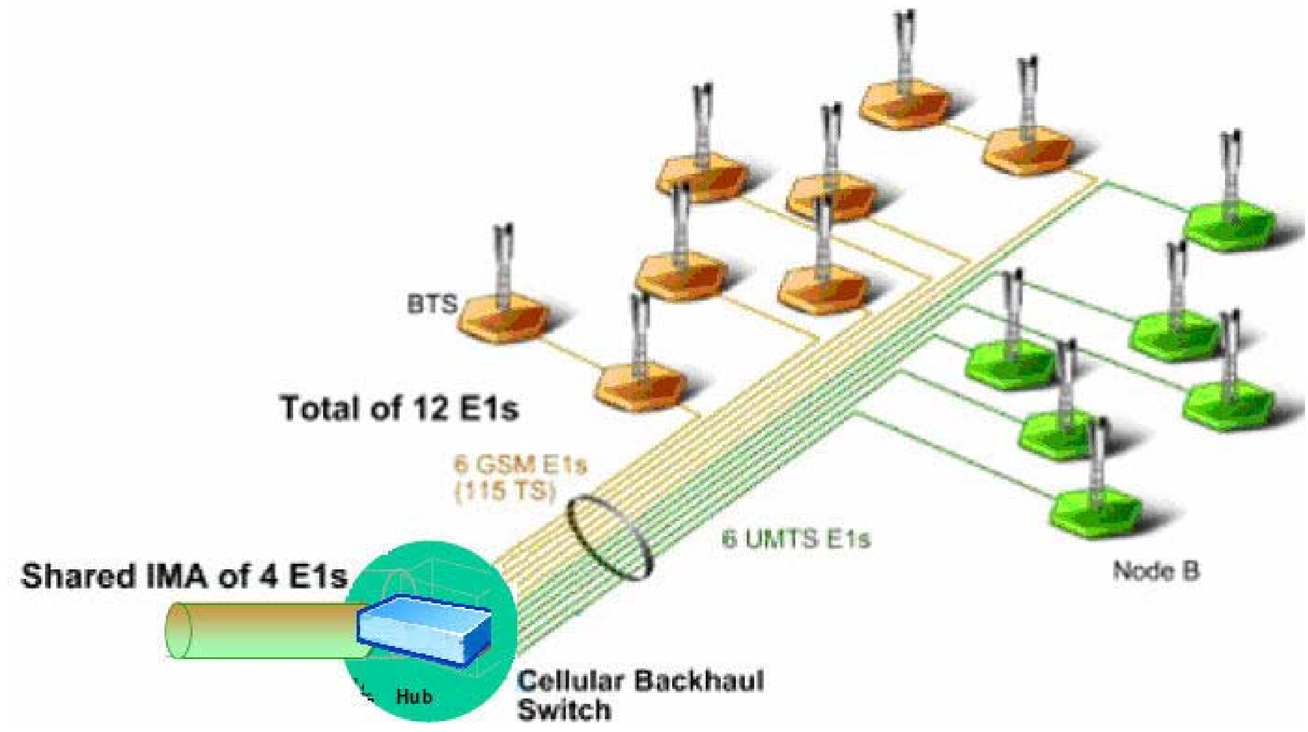

Figure 3. Improved Solution for Backhaul Optimization

An equally important benefit of cellular traffic switching is its ability to distinguish between voice, data and signalling frames, which are all forwarded in a single unified pipe. This allows QoS to be implemented based on the classification of the cellular voice, data and signalling traffic.

After classification and optimization, the cellular frames are adapted into the network protocol of choice - ATM, Ethernet or multiprotocol label switching (MPLS) - to achieve the complete integration of 2G and 3G technologies.

Figure 3 shows how cellular traffic switching can be applied to scenario in figure 2. The E1 lines have been further reduced to four from the initial 12. In addition, the network is entirely and dynamically shared between GSM and UMTS traffic.

VI. Case Study

The backhaul part of initial mobile network segment. shown in Figure 4, is based on a mixture of microwave links with 8 leased lines, resulting in network (comprised of all similar segments) that is complex, expensive and difficult to maintain.

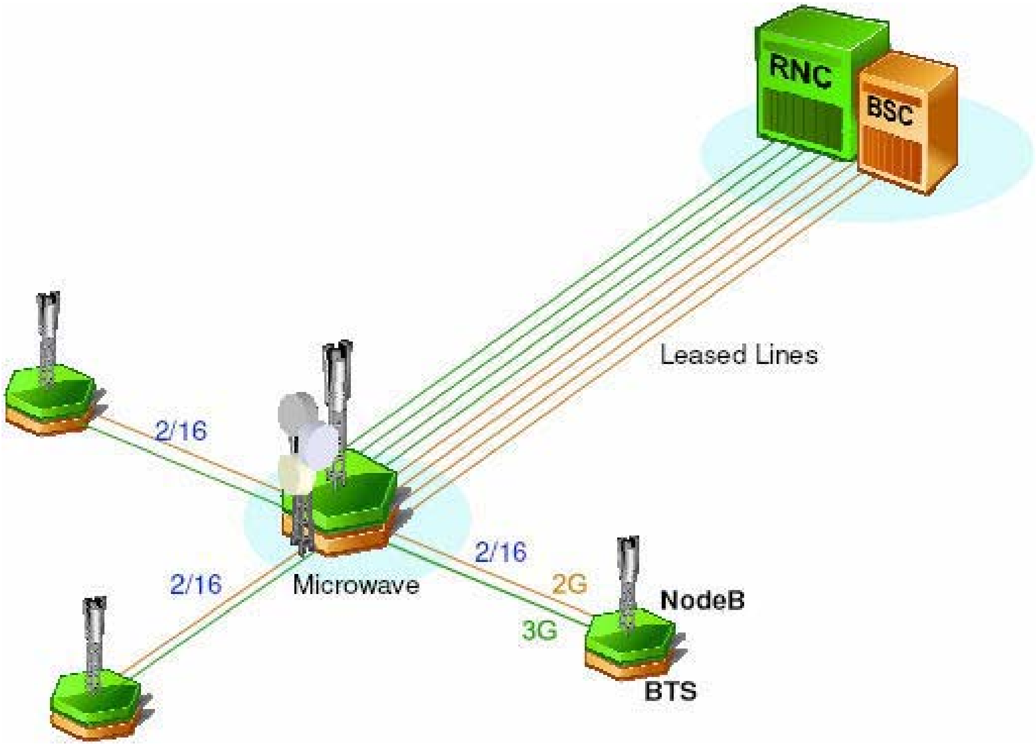

Figure 4. 2G/3G Network Segment of Initial Network

To cope with the fast expansion of initial multisegment network, traffic flow optimization became crucial. Moreover, the existing equipment and network configuration were insufficient to sustain the expected growth and forecasted evolution of the network in terms of the coverage and the services that were to be provided. To optimize the traffic flow and to support the network's future growth, the cellular backhaul switches have been deployed (Figure 5).

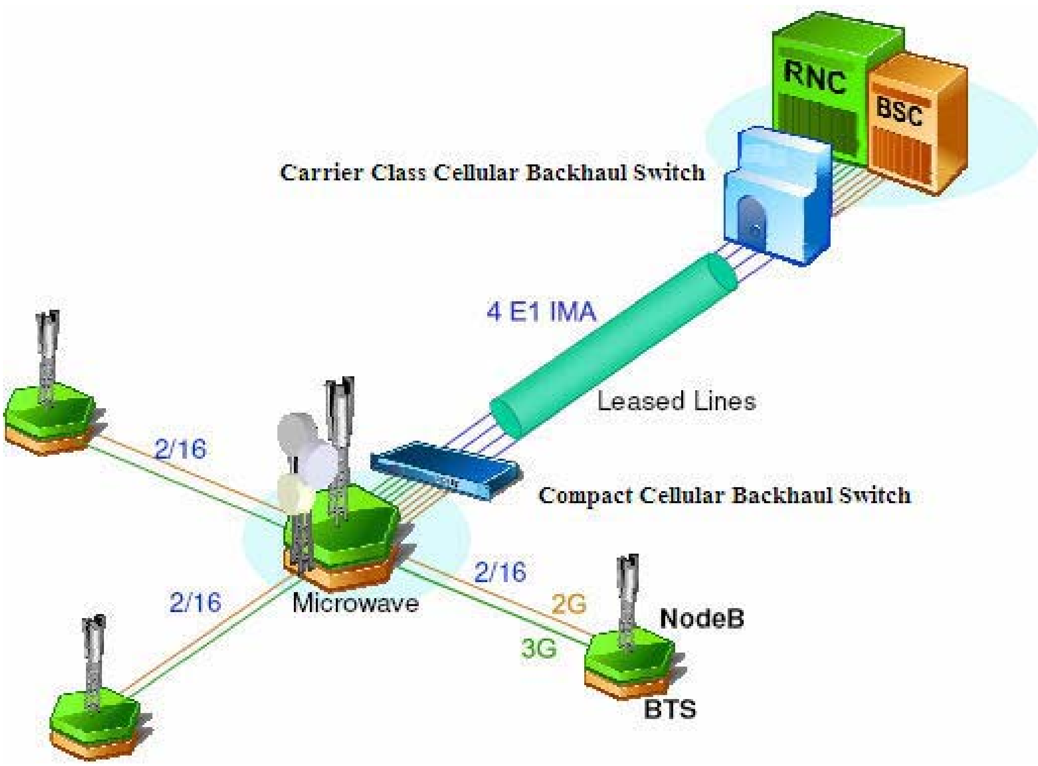

Figure 5. 2G/3G Optimized Backhaul

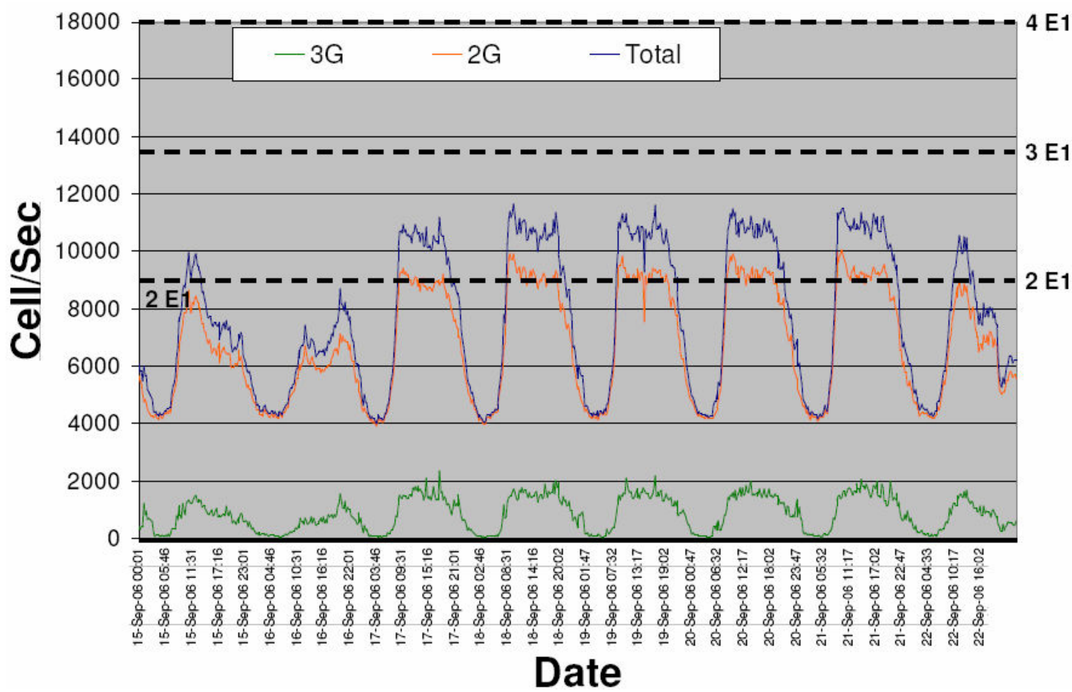

Figure 6. Converged 2G and 3G Downlink Traffic Statistics

Figure 6 shows a downlink traffic statistics during a field trial usage of converged 2G and 3G services (Incoming signal: 4x 2G E1 and 4x 3G E1; Outgoing signal: 4E1 IMA group of converged 2G and 3G traffic). As a result of cellular backhaul switches deployment, the network became more efficient and easier to manage. Scalability and future expansion were made easy since deployed switches can carry additional traffic in the current network configuration and can accommodate network expansion with additional E1 links. Hence, the operator has the flexibility to expand his customer base as well as to introduce new HSDPA services for his customers at his own pace, while preserving his investment in the network (Figure 7).

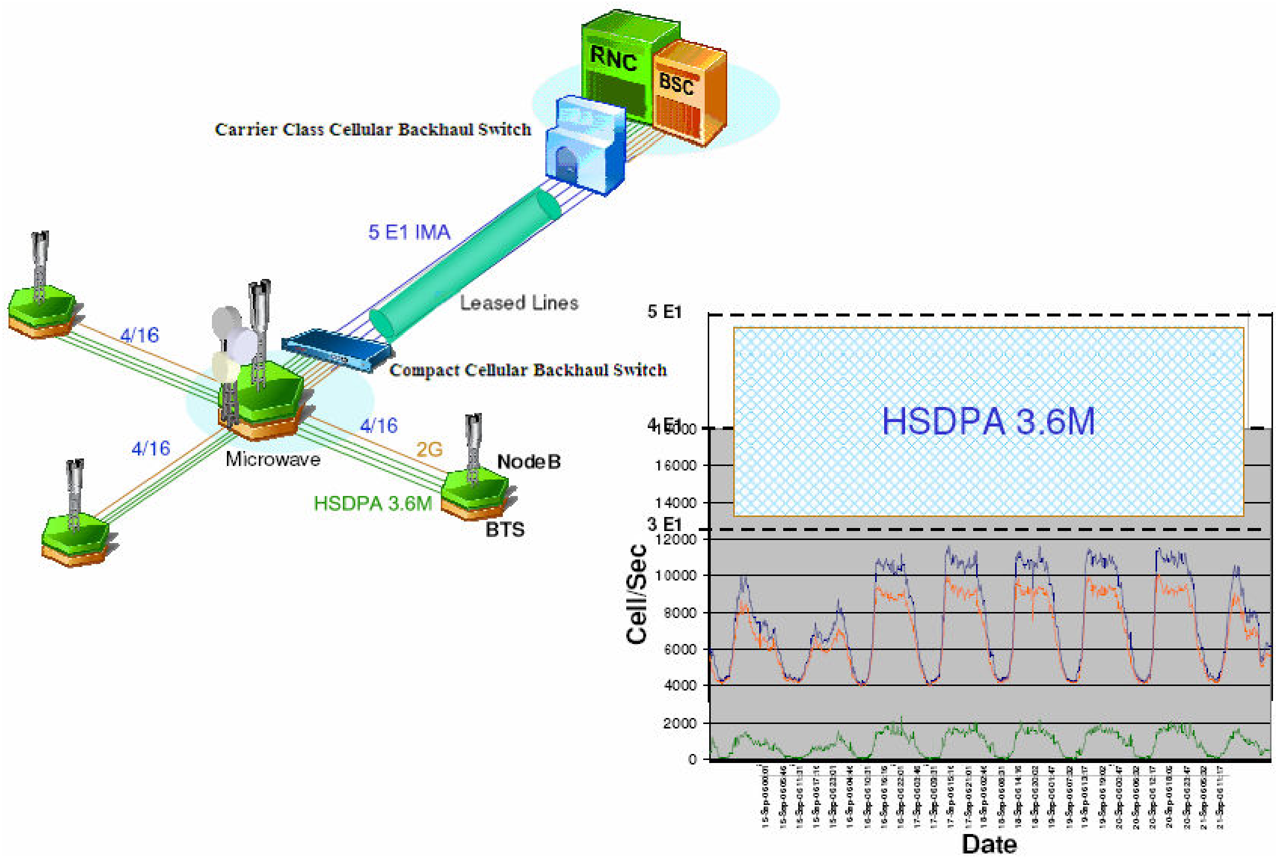

Figure 7. Rolling-Out of HSDPA 3.6Mbit/sec

In summary, the improved solution provides:

- Elimination of idle parts of GSM and UMTS traffic and adaptation of the actual information to Variable Bit Rate (VBR) traffic flows
- Statistical multiplexing of actual 2G and 3G traffic, obtaining maximal statistical gain for maximum network efficiency
- Real-time dynamic bandwidth allocation for all 2G and 3G services
- QoS support for all 2G and 3G voice, data and signaling traffic.

VII. Conclusion

Described implementation of a cellular backhaul switching technology can cut backhaul requirements by a factor of three and can also dynamically optimize the resources dedicated to 2G and 3G. Cellular traffic switching offers the flexibility to deliver the best possible performance in any congested situation by automatically negotiating the QoS trade-offs to deliver optimal performance of essential services and maintain network integrity under any circumstances. Switching can also play a vital role in the upgrading of aging backhaul networks to support the high traffic levels that 3G and 3.5G wireless technology will generate.

CBS implemented in a cellular backhaul switch is the solution to the backhaul challenges facing mobile operators during migration from 2G to 3G. CBS provides seamless end-to-end networking that balances the statistical multiplexing and traffic prioritization of the next generation of networks with the Operation, Administration, and Maintenance (OAM) capabilities of traditional transport networks.

New cellular technologies will pave the way for new broadband mobile services, such as Mobile TV and Voice over IP [12, 13] by delivering DSL-like data rates to the end user [14]. Further in the future, emerging technologies such as Radio Access Network Long Term Evolution (RAN LTE) or Evolution/Super 3G are expected to provide individual users with data rates in the 30-100 Mbit/s range by the end of the decade.

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