A Cost Effective and Optimum Backhaul Network Solutions in 3G Network

Ibikunle, F.A., MNSE, IEEE
Covenant University, Ota, Ogun-state, Nigeria
E-mail: faibikunle2@yahoo.co.uk

Abstract

With the rollout of 3G networks and introduction of new data intensive applications, expenses incurred by operators on their backhaul network will increase and form a major component of the cost of network operations. Backhaul refers to the transmission of traffic between cell sites (base stations e.g. BTS/ Node B) and the core of the cellular network (e.g. BSC/RNC and MSC). Traditionally these backhaul connections use a variety of TDM interfaces and the TDM based backhaul network architecture used till date are not optimal for carrying large volumes of packet voice and data services from both a cost and performance perspective. The typical approach towards designing backhaul networks has been to apply emerging technologies to squeeze more out from the network. Leveraging technology to deliver more is an absolute necessity but is akin to throwing more bandwidth for meeting increasing traffic. This meets the requirements of additional capacities but does not address key issues around cost and performance. This paper provides a study and approach in designing optimal backhaul networks while leveraging technologies in a 3G and broadband wireless networks.

1. Introduction

In a cellular network, the traffic from a base station to the base station controller and further to the Mobile Switching center is carried on the backhaul network. There is no standard that specifies how a backhaul network should be defined and implemented to optimally carry this traffic. At the same time, backhaul networks constitute a significant component of the overall operational expenses incurred by cellular operator. The advent of 3G, broadband wireless technologies and the introduction of new data intense application increases the traffic carried on the backhaul network, further increasing the costs that backhaul networks contribute to overall operational expense in a network. Further, these applications require that the backhaul network be dimensioned in a manner that they support ringent quality of service requirements. The typical approach towards designing backhaul networks has been to apply emerging technologies to squeeze more out from the network. Leveraging technology to deliver more is an absolute necessity but is akin to throwing more bandwidth for meeting increasing traffic. This meets the requirements of additional capacities but does not address key issues around cost and performance.

The paper provides a study and addresses the importance of backhaul optimization, the challenges in doing so, the technology options available as a result of convergence and provides various approaches to designing and building a cost effective and optimal backhaul network solution while leveraging technologies in a 3G and broadband wireless networks.

2. Importance of backhaul networks

Globally, the mobile voice traffic Minute of Usage (MOU) continues to grow healthily. However, intense competition among mobile carriers to increase uptake of new customers in the lower income tier markets is resulting in price erosion from voice services, with lowered revenue per user. Thus, globally, ARPU from voice service is steadily declining. A slow but steady growth in the mobile data market is globally observed (which includes SMS, MMS, Mobile Multimedia & Internet, etc). The mobile traffic pattern is shifting from a pure voice only traffic in the early 90s to a mix of voice and low speed data in the late 90s; and finally towards high speed and mega high-speed data in the 2000s. UMTS/HSDPA technologies are capable of delivering 2Mbps and beyond and are required for successful delivery of Multimedia applications. These applications are bandwidth hungry and also require stringent QoS to be implemented. Figure 1 below shows potential demand for applications and the bandwidth needed to deliver these. Applications like video conferencing, streaming and interactive gaming need high bandwidths and proper QoS mechanisms.

According to survey, service providers typically spend half or more of their revenue on operational expenditures. It is estimated that operators spend some 34% or more of this operational expenditure on transmission networks to backhaul traffic. Traditionally, backhaul transmission was not a major area of focus or a cost driver for a cellular operator. The introduction of newer packet data applications is causing the backhaul network to be expanded continuously to cater for the increased packet data traffic. Also, QoS requirements are forcing the service providers to dimension the backhaul transport network to meet the peak data demands. The spending on backhaul networks is increasing exponentially and a study found that backhaul costs constitute more of the cost of service for the four licensed wireless carriers in Nigeria. Backhaul networks for GSM/CDMA are designed primarily to provide extensive voice coverage using narrowband TDM Backhaul. Packet data was virtually non-existent a few years back.

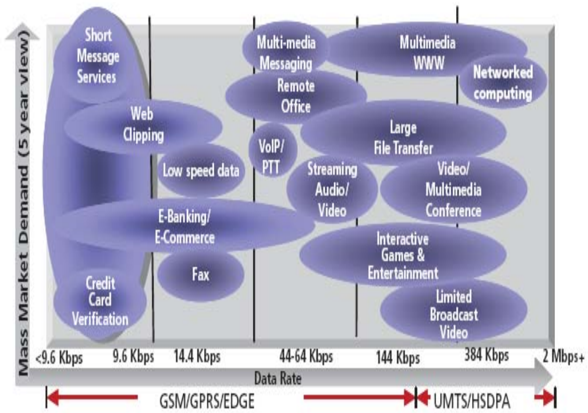

Figure 1. High Speed Wireless Multimedia Applications

The weakness of TDM-based backhaul solution is exposed when they need to cater for the growing traffic due to packet data services.

Table 1 below shows the heavy demand placed on the backhaul network as a result of various data applications. For example, video streaming or video calls generates large volumes of bursty and delay sensitive traffic. Intensive usages pattern like file transfer or interactive gaming make the conventional network dimension assumptions out of synch with reality. This is further complicated by new services that require QoS support like Multimedia Broadcast Multicast service (MBMS) based Mobile TV services being planned in future release of 3GPP. These trends are adversely impacting the financial performance of cellular operators.

Table 1. Requirements for Data Applications

	BW Required (bps)	Session Time (secs)	Connection Time	Messages per Session	Bytes per session	CoS
Video Streaming	22,954	30	100%	n.a.	86,080	Streaming
Audio Streaming	6,991	60	100%	n.a.	52,431	
Interactive Gaming	20,200	300	50%	n.a.	378,750	Interactive
PTT	20,200	60	50%	n.a.	75,750	Interactive
Location Services	8,000	n.a	n.a	2	20,000	Interactive
IMMM	7,752	n.a	n.a	3	29,070	Interactive
PTTE	20,200	60	50%	n.a.	75,750	Conversational
Video Telephony	42,400	60	100%	n.a.	318,000	Conversational
Rich Voice	27,952	60	100%	n.a.	209,640	Conversational

Service Model

While the overall subscribers, MOU's and ARPU from data services are seeing an increasing trend, voice ARPU is steadily decreasing. The backhaul expense being incurred to carry the growing subscribers and data related traffic is significantly increasing. The ARPU from data services is just not adequate enough to offset the decline of voice ARPU. Operators thus need to focus on other areas to lower their operational expenses and expand margins. With 30-40% of spending taking place in the backhaul network, operators are looking at this area to save costs and improve margins.

3. Limitations of current backhaul networks

Backhaul refers to the transmission of traffic between cell sites (base stations e.g. BTS/ Node B) and the core of the cellular network (e.g. BSC/RNC and MSC). Traditionally these backhaul connections use a variety of TDM interfaces, for example channelized E1 interfaces for data and Voice traffic carried over leased lines, PDH Microwave as well as SDH Microwave, and/or Optical (SDH) interfaces.

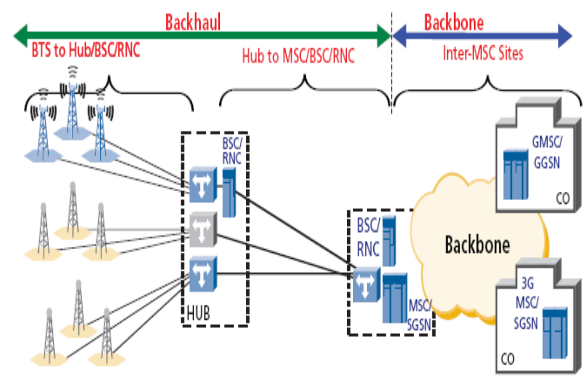

Figure 2. Backhaul/Backbone definition

TDM based backhaul network architecture used till date are not optimal for carrying large volumes of packet voice and data services from both a cost and performance perspective. The key limitations of current backhaul technologies are:

First, GSM used a fixed radio transceiver time slot allocation method to backhaul traffic using E1 links. For example, for a BTS with eight TRX, each TRX occupies two timeslots. Typically, each timeslot is further provisioned for four Enhance Full Rate (EFR) encoding sub-timeslots. Additional timeslots allocated are: one timeslot for each TRX signaling, one timeslot for link synchronization/ alignment, two or more timeslots for BTS Operation-Administration and Maintenance (OA&M) control and signaling message. The rest of the timeslot are unutilized. Thus, there are timeslots within the E1 structure that are not fully allocated. As the number of TRX's increases, more E1s are added to support these TRX timeslots, and the unallocated and unutilized time slots within these E1's increases. The actual utilization of timeslots could be low for a prolonged duration. When a new BTS is deployed, it could take several weeks or months or even years before the available capacity on the backhaul circuit is properly utilized. Also, fixed timeslot design leads to inefficiencies in utilizing capacity on the backhaul E1 links. During periods of high traffic, the number of TRX on E1 links may not be sufficient to handle the additional traffic. This means unless the operator adds more E1 links, there will be a trade-off on performance and revenue. Even during an active call, it is known that both calling and called parties seldom talk simultaneously. However, the full capacity of each channel is required for the full duration of the call, even when either or both party are silent.

Second, data traffic is bursty in nature and current backhaul technologies designed to carry voice traffic are inefficient in carrying packet bursts. This leads to operators having to make more bandwidth available in the backhaul network for peak hour traffic leading to increased expenditure. Non-availability of adequate bandwidths leads to poor throughput and deterioration in performance, especially for delay sensitive applications (VoIP, Video Conferencing). During low data traffic periods, these backhaul resources are not fully utilized. During a data transmission session, the data is not transmitted continuously. Over period of the active data session, there will be on-time (where data bursts are transmitted) and off-time (where data is being queued, waiting for transmission).

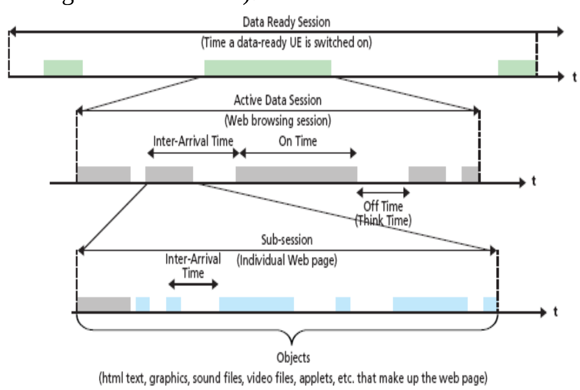

Figure 3. Data Session for Web Browsing

This means the backhaul link is not being fully utilized and more packets could be packed into the backhaul links. The introduction of UMTs further complicates the utilization of backhaul resources and leads to further increase in backhaul capacities and related costs. UMTS data rates increase peak to mean ratio as UMTS applications are expected to be highly bursty in nature. Provisioning the backhaul network for peak data throughput is a very expensive proposition.

Third, TDM-based backhaul networks are inconvenient to operate and manage. For example, while provisioning a new E1 for a new Node B/BTS or while removing a base station/NodeB TRX, the mobile carrier needs to coordinate this closely with the E1 provider. The provisioning needs to go through formal processes and testing, causing a long provisioning time. Provisioning times of order of 4-12 weeks are not uncommon in the market. Further, at times depending on the provisioning need, system and process in place, an entire link may be required to be brought down in order to insert a new TRX.

Fourth, mobile carriers may not know the exact status of their backhaul links on a real time basis as leased line providers offer limited monitoring and control. Industry feedback suggests that 20-50% of network outages are attributable to failures in the backhaul due to lack of monitor and control capabilities of the mobile service provider, the majority of these being in the point-to-point links between nodes. Conventional backhaul technologies do not differentiate between various multimedia traffics like video streaming, video conferencing, VoIP, or simple file transfer. The transmission links are unable to provide the required QoS for traffic differentiation and prioritization of 3G applications. There is simply no definition of QoS mechanisms and support required for delivering these services.

4. Challenges in backhaul network in 3G

Operators are keenly looking at various options to overcome the limitations of current backhaul technologies. The approach normally adopted is to choose from emerging technologies, conduct field technology trials, and use business models to ensure the identified solution(s) delivers better financial returns when compared to other viable solutions. The challenge with optimizing backhaul networks is that identifying the optimal solution requires evaluating numerous permutations and combinations of technologies, placements and aggregation points. There are countless architecture options available to designing an backhaul solution and determining the best option for given network environment will yield the optimal network solution.

a. Ensuring best architecture option for the backhaul network. Each network environment is unique. Operators adopt different strategies in evolving and migrating their GSM networks to UMTS/HSDPA. The options available to an operator in each market are varied, with some markets consist of monopolies to other markets being fully liberalized to the extent of even offering packet based transmission facilities on lease. The availability of spectrum, target coverage area- urban or rural, terrain and building vectors, availability/ cost of leased lines, operating costs like rental and maintenance, influence the choice of technologies and design of the backhaul network. The mobile carrier needs sift through all these factors in arriving at the optimal network design. Key considerations that weigh in are:

- Should 2G/2.5G/3G voice & data traffic from cell sites be aggregated?
- Where should an aggregation hub be introduced? What is impact of aggregating traffic on performance?

- Where is the optimal location for aggregation hubs? How to re-home Cells to BSC/RNC; BSC/RNC to MSC/SGSN?
- Is it economical to lease or to build a backhaul network? If leased line tariff are falling or if these are based on distance, would these be attractive as opposed to building a network?
- Does one backhaul architecture model fits all cell sites or multiple backhaul models are required?

b. Leveraging new technologies. There are several promising technologies available today claiming excellent cost and spectral efficiencies. It is a daunting task to evaluate and determine the most suitable technology(s) from these emerging backhaul solutions like – WiMax, WiFi-Mesh, Point to Multipoint, IP Wireless, Ethernet, cable and DSL etc. There are several technical factors that need to be evaluated including benefits from aggregations & multiplexing, overbooking factor to be used for GSM, UMTS, HSDPA networks, delivering end to end QoS on the network, overall network reliability and ease of maintenance. It is not feasible to conduct a technology trial across all these technologies yet key questions need to be answered before migrating from legacy backhaul solutions.

- Where and how do emerging technologies fit in a given network environment?
- What are the pros and cons of using a particular technology for delivering a high performance end-to-end network?
- What is the financial impact and risks associated with each of these technologies?

c. Investment protection. Mobile Carriers use various wireline and wireless infrastructures to carry their backhaul traffic in a GSM network. This TDM infrastructure is not suitable for carrying packet data traffic and for UMTS/HSDPA deployments. Usually, the infrastructure has not reached end of life and yet the operators are forced to replace this infrastructure. Operators also need to introduce new backhaul capacities to cater for the new Node B/BTS being introduced as part of their UMTS/HSDPA deployment. Protecting investments made in existing infrastructure and identifying and introducing newer technology(s) at appropriate phases to meet the overall performance requirements of a combined 2G & 3G network is a key challenge. There are technologies/products available today which offer statistical multiplexing gains and offer features like voice inactivity detection, silence suppression that could be introduced to modify existing legacy networks and prepare them for 3G traffic. A key metric that is useful is cost per megabyte incurred to carry the backhaul traffic. An ideal backhaul network design would protect existing investment in infrastructure by leveraging new technology developments like multiplexers, aggregators and introducing new backhaul solutions to provide additional capacity & quality needed for new node B deployments while lowering the total cost of ownership and meeting performance requirements. The design considerations also need to cover issues relating to redundancy, path protection, network management across both new and existing infrastructures.

4.2. Capitalizing on the benefits of convergence

With the onset of new convergence technologies, there are new products available to design effective backhaul networks. The Table below summarizes some of the key technologies and their key features. These technologies are as follow.

4.2.1. Multi-Services aggregation gateways(MSAG). Multi-service aggregation gateways are capable of supporting multiple types of interface including IP, ATM, Optical, Gigabit Ethernet (GE), TDM E1/T1 as well as voice. They offer low latency, which is critical for backhaul networks. MSAG have a high scalability with typical switching capacity from just 600Mbps to 9.6Gbps. It works with both land based as well as wireless networks; with the ability of mapping traffic with the required QoS. MSAG's provide built-in DS0 grooming, aggregation, ATM over-subscription, as well as GSM frame idle channel removal/ silence suppression to take advantage of capacity gain and to realize OPEX savings. MSAG has been implemented by service providers globally and is a proven solution.

4.2.2. IP Mux: An IP Mux aggregates multiple IP ports or TDM E1/T1s; packetizing the data using Pseudowire Emulation Edge-to-Edge technology (PWE3). IPMux's key feature is its ability to work with any carrier grade IP capable network such as a Metro Ethernet network or a Wireless broadband IP networks to backhaul the packetized data to the cellular core network, where it will be converted back to its original format. IPMux has a low latency, however it does not examine the GSM frames to remove any silence/idle frames.

4.2.3. Point-to-Multipoint (P2MP) microwave. A wireless backhaul P2MP Microwave systems such as works in 3.5, 10.5 and 26 GHz spectrums with adaptive modulation (QPSK, 16QAM and 64QAM); with QPSK for increased range and 64QAM for increased throughput capability. These solutions can carry ATM, E1/T1, VLAN, and IP traffics (including SIP based VoIP). They work in both Line of Sight (LOS) and non-Line of Sight (NLOS) environments. An integrated backhaul system greatly simplifies the OAM of cellular backhaul, especially when the service providers have an aggressive UMTS roll out schedule.

4.2.4. WiMax. WiMax though capable, is not really optimized for cellular backhaul. The costs associated with WiMax (e.g. spectrum and roll out cost) make it a viable solution for high volume mobile DSL type data/Internet subscriptions rather than for backhaul application. WiMax is not seen as a viable solution to compete with mature, proven and price competitive microwave solutions. WiMax is also not seen as better option to new solution like P2MP microwave which is purposed-built. Cellular (especially HSDPA/ HSUPA) backhaul needs to meet stringent delays requirement that WiMax may not be able to meet.

4.2.5. LMDS. Local Multi-Distribution System (LMDS) operates mostly in the high 24 to 30GHz frequency bands, and has a range of up to 5km depending on spectrum, terrain, fading and other RF parameters. It is most suitable for short range, wide area, and very high capacity requirement environment. Similar to other wireless backhaul system, it consists of a Base Station Hub and multiple CPEs that are connected to cellular BTS/ NodeBs. In terms of network design, special attention is required since millimeter waves at high frequencies can be very susceptible to high rain fading.

5. Approach to building backhaul solutions

Having stated the importance of backhaul optimization, challenges in doing so and technology options available as a result of Network convergence, this section provides different approach to building optimal backhaul solutions in a 3G wireless network. They are:

5.1. Periodic review of backhaul network. The increase in mobile users has been rapid worldwide and operator's efforts are focused on ensuring there is enough capacity in all parts of the cellular network to meet subscriber growth. There is little to zero focus on overall cost/ performance of the backhaul network. Backhaul network needs to be reviewed and optimized periodically, below are some key questions to determine if the network is due for optimization:

- Significant performance issues including customer churn attributable to backhaul network
- Past review of backhaul network done some months or years back
- Periodic increase in backhaul capacities
- Rollout of new features that requires high bandwidth

The benefits of optimizing the network periodically outweigh the costs tremendously and provide multi-year savings in millions of Naira/Dollars.

5.2. Decompose the backhaul network. The backhaul network is not just one network but connects different parts of a cellular network. The backhaul network can thus further be subdivided into following networks:

- Backhaul network connecting the Radio Access Network (RAN) to the core of the network
- Backbone network providing connectivity within the core
- PSTN/PDN connectivity providing connectivity to PSTN/Internet through various POP's

Each of the above networks needs to be analyzed separately as the technology options available to optimize these networks are different.

5.3. Technology futuristic approach. There are several technologies available and newer ones emerging; each of these are likely to show substantial savings. The usual practice adopted is to use simple ROI plug-ins and focus on the performance of a particular technology. Adopting a technology agnostic view by considering technology to be an enabler and evaluating the financial impact of the underlying technology helps in designing effective backhaul solutions.

5.4. Recursive Processes. A tool based and recursive process supported by sound subject matter experts is required to analyze the countless architecture options, their pros and cons, performances and financial impact for each architecture option. The methodology use for optimizing present network mode of operations looks into the:

- Cell sites, node capacities, homing patterns
- Switching, multiplexing, cross-connectors with cost, capacity, feature specification
- Cost, capacity, traffic demand for all applications
- Architectural preferences & constraints
- Financial preferences-depreciation, cost of capital

The recommended design from various options will then form the next mode of operation that may now include: Optimal network design with network architecture, maps; homing of cell sites, interconnection; and total network cost, risk, sensitivity analysis, and discounted cash flows.

6. Conclusion

With the rollout of 3G services, current TDM backhaul solutions will prove to be costly for service providers. There are unique challenges that need to be addressed in designing an effective backhaul network solution. New technologies generate savings over traditional backhaul networks but need to be evaluated and incorporated as part of overall backhaul solution. Backhaul contributes to a significant part of overall operational expense, service providers need to adopt innovative approaches to controlling their backhaul expense.

References

[I] Mooi choo, Design and performance of 3G wireless networks and wireless LANs, Springer, USA. 2006

[2] WiMax Forum (2004), Can WiMax Address your Applications?

[3] Steve Reckley, Wireless Networking Technology, Newnes, UK 2007.

[4] Deepak Pareek The business of WiMax, John Wiley, 2006.

Table 2. Convergence technologies and their key features

	Multi-Services Gateways	IP Mux	P2MP Microwave	WiMAX as backhaul	LMDS
	(e.g. Lucent PSAX)	(e.g. RAD IP Mux)	(e.g. Cambridge VectaStar)	(e.g. Alvarion WiMax)	(e.g. Alcatel LMDS)
Roundtrip Delay Latency	Packetization Latency is ~4-5ms round trip	Packetization Latency is ~2ms round trip	Packetization Latency ~5-10ms round trip	Packetization Latency ~15-20 ms round trip	Packetization Latency ~15ms round trip
Coverage range	Not Applicable	Not Applicable	up to 15km depending on spectrum, terrain, fading and other RF parameters	up to 15km depending on spectrum, terrain, fadings and other RF parameters	up to 5km depending on spectrum, terrain, fadings and other RF parameters
Throughput Capacity	Switching capacity 600Mbs to 9.6 Gbps	Ipmux-16 up to 16 E1/T1 over PSDN	Up to 60Mbps@14Mhz channel, 64QAM modulation	14Mbps @ 5MHz channel	Up to 40Mbps per channel, D-QPSK modulation
Spectrum requirement	Not Applicable	Not Applicable	1.75-14MHz per channel, FDD	1.25 - 20MHz per channel, FDD	14-36 MHz per channel, FDD
LOS	Not Applicable	Not Applicable	LOS and Near LOS	LOS and Near LOS	LOS only
Aggregation & Statistical Multiplexing	yes	yes, working in conjunction with Metro Ethernet Access network	yes	yes	yes
E1/T1 Grooming & Optimization including GSM frame Silence Suppression, etc	yes	DSO grooming, no GSM frame silence suppression	yes	No	No
QoS Support	ATM QoS	ToS, VLAN tag IEEE802.1p&Q	ATM QoS	WiMax CoS	No
Supported Traffic types	IP, ATM, STM-1, E1/T1, voice	IP, VLAN, E1/T1, voice	IP, ATM, E1/T1, VoIP	IP, E1/T1, VoIP	ATM, E1/T1, STM-1
Scalability	yes	yes	yes	yes	yes
OPEX Savings	yes	yes	yes	yes	yes
Path Protection/ Redundancy	Configurable	Configurable	Full path redundancy	No	No
EMS to NMS integration & Ease of OAM	yes	possible	yes	yes	yes
Remarks		Pseudowire Emulation Edge to Edge (PWE3)		Half Duplex FDD at CPE, or TDD	special attention since millimeter waves at high frequencies are very much affected by rain fading