Small Cells and the Evolution of Backhaul Assurance

Mobile-network bandwidth demands continue to increase with no end in sight, driven by the proliferation of newer mobile devices such as smartphones and tablets. With powerful processors and operating systems, mobile applications require considerable network resources. In recent years, the Google Android™ operating system has further accelerated new product introductions from a variety of device manufacturers, resulting in a quadrupling of processor speeds. Averaging hundreds of thousands of new activations per day, Android and other powerful mobile platforms such as the Apple iOS and Windows have fostered an environment enabling the rapid introduction of new, interactive, video-based applications. Emerging machine-to-machine requirements, including sensor networks and connected car platforms, will add further traffic load to today's mobile networks.

Evolution to the latest mobile-network technologies such as LTE is required to help keep pace with this growth. LTE, with its IP-based architecture and higher spectral capacity promises to help operators reduce mobile-service delivery costs. However, the existing mobile-network footprint is based on low data rates and intermittent voice services; the initial focus was on coverage rather than capacity. Mobile-operator strategies favored erecting large macrocell towers to get the broadest radio-frequency (RF) footprint possible to cover the largest number of subscribers possible. However, these strategies no longer work. If a single cell site has to serve 1000 subscribers (333 subscribers per sector), supporting existing mobile data services is impossible, not to mention emerging services.

For example, an LTE network using 10 MHz radio channels with a spectral efficiency of 1.5 bps/Hz will deliver sector throughput of 15 Mbps – 15 Mbps to be shared by all subscribers. Fewer than twenty iPhone FaceTime users will saturate today's typical cell-site capacity. As defined by the 3GPP specification[1], the optimal LTE sector size is 5 km (3 miles) and the number of subscribers is 200 or fewer. It is clear that smart-device proliferation and the increasing number of connected devices are breaking existing network architectures.

As a result, a tremendous number of new antennas will be needed to meet the coverage and performance needs of mobile networks. While continuing to grow, the traditional macrocell deployment model is neither economical nor practical. Since 2010, the mobile industry has witnessed tremendous innovation from the equipment supplier community, including faster, smaller, energy-efficient, and

1. www.3gpp.org/About-3GPP

highly-integrated systems-on-chips, has enabled very compact form factors. The result is a new generation of fully-integrated, compact indoor and outdoor mobile base stations. These include LTE eNodeBs which are small, energy efficient, cost effective, and are more easily deployed closer to subscribers in dense urban environments: they are mounted on utility poles, building faces, and other street furniture. Not only does this new generation of outdoor small cells complement the macrocell network by in-filling coverage gaps, they serve the important role of maximizing spectral resources. By moving RF sources closer to subscribers, thereby reducing the number of subscribers sharing the same spectrum, the subscriber/density ratio is reduced, resulting in higher average mobile capacities per subscriber.

Backhaul Network Challenges—Carrier Ethernet to the Rescue

Backhaul performance has always been critical for end-to-end mobile-network performance. Key metrics such as throughput, latency, and jitter are obviously important. However, whereas these metrics were also important with macrocells, backhaul performance was often more deterministic. In the past, the backhaul service, while based on IP/Ethernet, was delivered over what was, effectively, a private line with guaranteed throughput and performance similar to time-division multiplexing (TDM) circuits such as E1/T1. Traffic patterns were also more deterministic—all traffic originated at the macrocell and was transported back to a central location such as a mobile switching center (MSC) where its performance could be relatively easily assessed. Backhaul-bandwidth upgrades were performed on a more predictive basis—for earlier-generation mobile services, the backhaul network could be more or less set and forgotten.

As the price competitiveness of newer-generation mobile base stations improves, corresponding price pressure is placed on backhaul. For instance, assume backhaul network costs account for 20–30% of overall service delivery costs. Because of technology enhancements, as well as basic supply and demand principles which drive down the cost of mobile base stations, backhaul network costs must improve accordingly. More cost-effective backhaul approaches include shifting from private-line delivered services to more affordable, shared IP/Ethernet-based solutions. These solutions support more class-of-service options, more granular bandwidth and pricing, and additional traffic management options including committed information rates, committed burst rates, excess information rates, and random early discards. This added flexibility allows additional service tiers and pricing, as well as more efficient use of network infrastructure, resulting in improved service delivery costs.

Carrier Ethernet has grown to become a dominant technology in service-provider networks. Driving this growth is the demand from business customers for scalable services, higher bandwidth, and lower costs. Carrier Ethernet has evolved to provide reliability and availability, evolving from best-effort technology found in local area networks to support network-fault and performance monitoring. Service providers require a comprehensive set of operations administration and maintenance (OAM) tools. IEEE 802.1ag and ITU-T Y.1731 standards define these service OAM tools that follow the service path and monitor the entire Ethernet service from end-to-end. With service OAM, service providers can receive and offer service level agreement (SLA) assurances and reduce operating costs associated with manual network fault monitoring, truck rolls, and labor-intensive performance measurements.

This paper will focus on the challenges of mobile-backhaul services as they transition from TDM to Ethernet/IP and from private lines to shared, switched-packet networks, while supporting the additional challenges that small cells introduce. The paper will also introduce a new approach, based on microprobe technology, which can dramatically simplify and improve the performance of mobile-backhaul networks.

Fundamentals of Service OAM

A number of common OAM standards have evolved including "IEEE 802.1ag Connectivity Fault Management – Service OAM (SOAM) or CFM," and "ITU-T Y.1731 OAM Functions and Mechanisms for Ethernet-based Networks," commonly referred to as performance monitoring (PM). These evolving standards have enabled Ethernet/IP to become the foundational technologies for mobile backhaul by introducing methodologies for service testing and service delineation, namely maintenance associations (MA) and maintenance points. MAs are the physical network paths that reside in each domain. Maintenance domains abstract Ethernet services into different levels, making it simpler to delineate the responsibilities or different stakeholders, such as mobile network operators from backhaul service providers. The white paper[2] footnoted below is recommended reading and provides a background on many of the common OAM standards used in mobile-backhaul applications:

2. Ethernet OAM Test Applications, Reza Vaez-Ghaemi, Ph.D, 2012.

Mobile-Backhaul Network Architectures

For macrocell deployments, mobile operators typically deploy a cell-site router (CSR) at the mobile base station which serves to aggregate and encapsulate traffic originating from the base station, and which also serves as a remote performance endpoint.

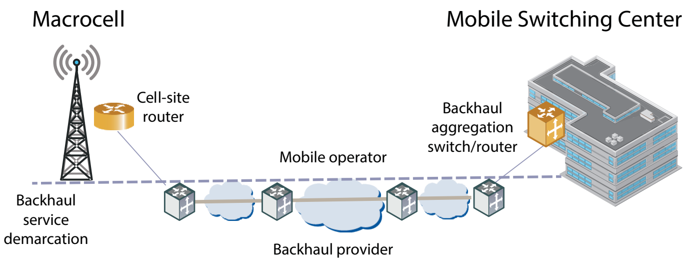


Figure 1. Macrocell mobile-backhaul reference network

As some CSRs support various OAM standards, they can be effectively used by the mobile service provider as part of the service-activation and performance-monitoring process.

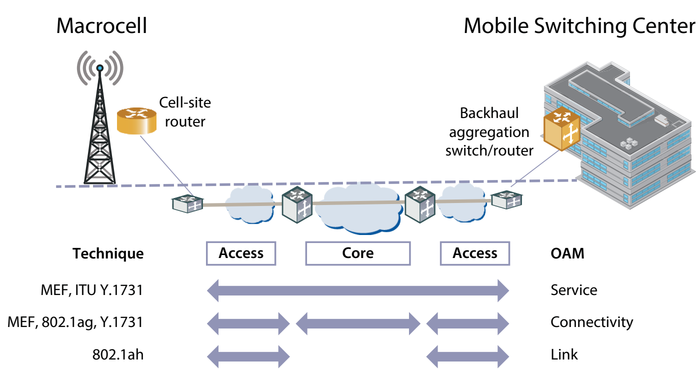


Figure 2. OAM applications

Unfortunately, the OAM software capabilities needed to automate backhaul service activation and to test ongoing service performance are often not available from the network devices themselves. Inconsistent vendor implementations result in undesirable service-provider challenges and consequences.

Table 1: Mobile-backhaul service-provider challenges

	Challenges	Consequences
Inconsistency	· Multi-vendor environments come with challenges and OAM inconsistencies	· Inconsistent services · Inefficient processes
Cost	· Strong and rapid service growth doesn't allow for simplifying processes	· High operational costs · High equipment costs associated with premise equipment
Complexity	· Ongoing setup, maintenance, and testing challenges · Activation testing and trouble-shooting across net-works are not repeatable	· Poor network performance · Inconsistent customer experiences

Because of these non-existent, inconsistent, or performance-impacting side effects, operators often deploy dedicated probes or devices in the backhaul network to act as OAM performance test points. The most common example is the use of Ethernet access devices (EADs), otherwise known as network interface devices (NIDs). These are typically deployed adjunct to the CSR. NIDs are often owned and managed by the mobile network operator and used to provide the demarcation point where the service is handed off to the backhaul-network provider. NIDs are typically configured as maintenance end points (MEPs) to enable service OAM functions.

While many NIDs support more advanced networking capabilities, one reason for their recent market surge is a consequence of the mobile-network expansion and their use as performance-management end points. The leading suppliers of these types of devices support the necessary test OAM features including, but not limited to, ITU.1731 and IEEE 802.1ag. The drawback with using NIDs for backhaul service activation and performance management is that they introduce another managed device into the network, increasing cost and complexity. NIDs also require valuable space and power, which is becoming increasingly scarce as mobile networks adopt small cells.

Small Cells Introduce Added Complexity

Small cells introduce additional end points, deeper in the network and closer to subscribers, and for which backhaul networks need to be activated, monitored, optimized, and assured. Current service-activation methodologies developed for the macrocell network now need to scale to support the needs of small-cell backhaul; however, the processes themselves must become even more automated. It is no longer economically practical for operators to simply deploy field technicians to perform tests and validate backhaul-network performance. In addition, there is a resulting need by mobile operators to audit the ongoing performance of backhaul services to ensure performance guarantees are met not only initially, but throughout the service lifecycle as backhaul-network demands evolve. This is both to ensure optimal network performance and to seek remuneration from backhaul providers in the event of SLA violations.

Small-cell backhaul introduces additional layers of aggregation in the backhaul network, creating hub-and-spoke topologies, often resulting in performance-visibility network blindspots. Traffic is backhauled from outdoor small cells (spokes) to an aggregation point (a hub, often located at an existing macrocell) where it is combined with backhaul traffic from other spokes, aggregated, and backhauled to another aggregation point typically at a mobile switching center (MSC) or mobile core. Blindspots impact the ability to segment, monitor, and test services between the aggregation point (at the MSC/core) and the hub, and between the hub and the spokes. Blindspots result when the hub networking equipment, typically a CSR, does not support standard OAM and MIP capabilities. In addition, with the introduction of LTE and its all-IP architecture, IP/MPLS backhaul is the preferred backhaul technology. As MPLS label switch paths (LSPs) are tunneled through hub networking equipment, blindspots are again introduced. If the mobile operator wishes to configure a single backhaul virtual connection from one CSR to the central aggregation point, the backhaul traffic is tunneled through the hub CSR.

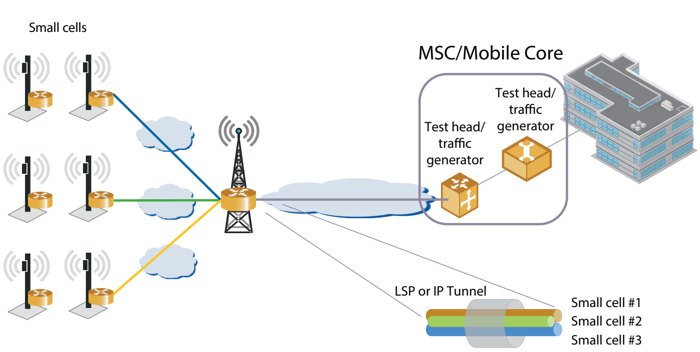


Figure 3. Small-cell backhaul hub-and-spoke topology

While testing can be initiated from the MSC/core to the spoke, because traffic is tunneled through the hub device (for instance in a MPLS/VPLS tunnel), often visibility into spoke backhaul performance is lost when traffic is aggregated through hub CSRs. Furthermore, the operator is left without the ability to segment the network to isolate the sources of performance-impacting issues.

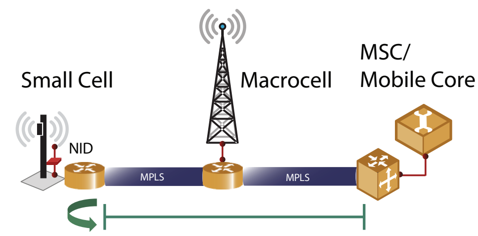


Figure 4. Network segmentation is lost at hub location

Mobile operators are left with few choices other than to change the network topology and/or deploy more external instrumentation such as NIDs. These workarounds increase the time, complexity, and cost to activate and monitor backhaul services. For instance, the mobile operator must manually segment the network, execute multiple service-activation and performance-monitoring tests, and manually correlate the results from these multiple tests. Furthermore, often the operator loses the fine-grain performance visibility required such as one-way latency measurements. As latency, and latency deviation, are the most critical parameters affecting services like voice and other real-time applications, isolating the sources of latency impairments in order to optimize backhaul-network performance is vital.

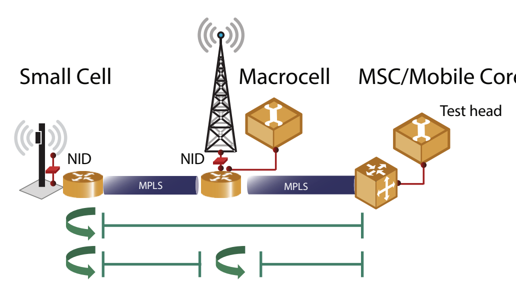


Figure 5. Manual segmentation increases time, cost, and complexity

LTE introduces additional unique challenges such as increased signaling traffic, some of which is never backhauled to the network core and is therefore not visible to centralized monitoring probes. Specifically, the LTE X2 interface, which is an inter-base station (eNodeB in LTE) signaling protocol for call handover, is typically routed back at the hub CSR. It never reaches a core probing point where signaling performance can be analyzed.

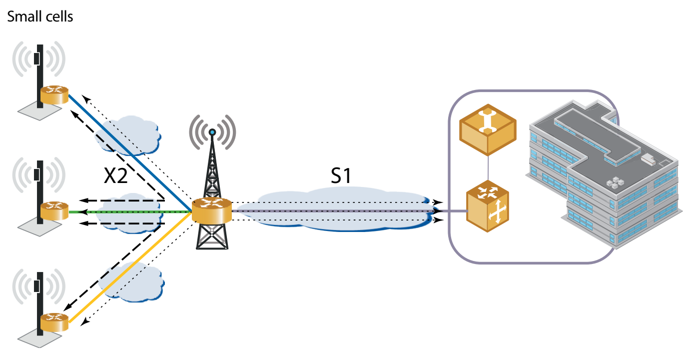


Figure 6. LTE introduces additional signaling complexity

Microprobes Address the Unique Needs of Small-Cell Backhaul Networks

Again, small cells introduce additional end points, deeper in the network closer to subscribers, for which backhaul networks need to be activated, monitored, optimized, and assured. Current service-activation and performance-monitoring methodologies simply do not scale. While mobile service providers try to reuse as much of their existing methods and procedures as possible, these were typically developed for macrocell backhaul, and the dependency on external probes (NIDs) is impractical and uneconomical. A new approach using microprobes, which leverage technology embedded into Gigabit Ethernet small form factor pluggable (SFP) transceivers, provides a compelling option which uniquely addresses small-cell backhaul assurance challenges.

Figure 7. SFP-based microprobe

Transceiver-based microprobes deploy into existing network equipment such as cell-site routers and mobile base stations. This accelerates service-activation times by enabling a uniform and standard set of capabilities regardless of network-element type or manufacturer. Microprobes consume no additional space or power and are thus ideally suited for cost-sensitive, constrained small-cell backhaul environments. Compared to conventional NID-based approaches, using microprobes can provide significant economic advantages. As an example, comparing the deployment costs of using NIDs to using microprobes for backhaul service activation and performance monitoring of a 10,000 small-cell network shows considerable financial advantages.

	NID-Based Deployments	**Microprobe-Based Deployments**
Planning cost	$500	$200
Installation cost	$300	$50
Hardware cost	$700	$275
Software cost	$350	$350
Annual Operating cost per end point	*$310*	*$50*
Annual cost related to truck rolls	*$465*	*N/A*
Total cost per end point	***$2,625***	***$925***
Yearly operating cost for 10,000 end points	**$7.75M**	**$500K**

As some microprobes may provide standard OAM capabilities, such as 802.1ag and Y.1731, they can be compelling options in mobile-backhaul networks, providing MEP capability.

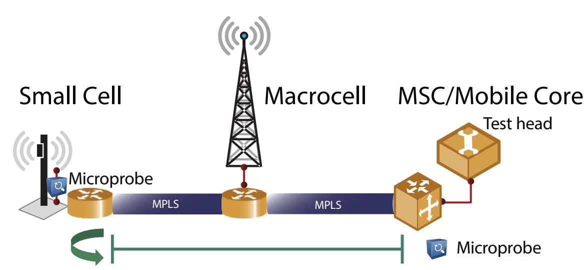


Figure 8. Microprobe acting as a MEP

Additionally, some more-advanced microprobes also support content-inspection capabilities. As a result, they can be strategically deployed in hub-CSR equipment and complement microprobes which provide OAM capabilities alone. With the ability to look into the IP transport tunnel or LSP, microprobes unlock blindspots to monitor service performance within the tunnel/LSP. Effectively providing a virtual MIP, one which functions in Layer 2 carrier Ethernet or Layer 3 IP/MPLS networks, lets a mobile service provider easily monitor backhaul-network performance segment-by-segment, obtain one-way latency measurements, and rapidly isolate faults or sources of performance-affecting issues.

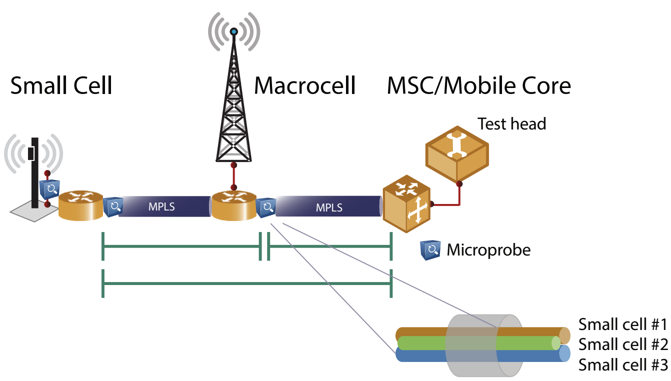
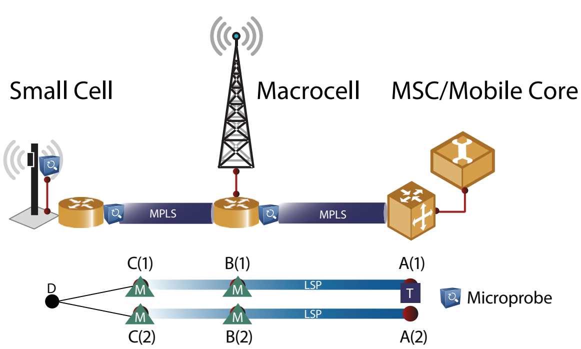


Figure 9. Microprobes deployed along the full service delivery path



Segment	Measurement		
	Frame Loss	Frame Delay	Frame Delay Variation
A(1) → B(1)	✓	✓	✓
B(1) → C(1)	✓	✓	✓
A(1) → C(1)	✓ (One way)	✓ (One way)	✓ (One way)
C(2) → B(2)	✓	✓	✓
B(2) → A(2)	✓	✓	✓
C(2) → A(2)	✓	✓	✓
A(1) → A(2)	✓ (Round trip)	✓ (Round trip)	✓ (Round trip)

Figure 10. Microprobes provide segment-by-segment one-way latency measurements

Again, because some microprobes provide content and packet inspection, they can be used to overcome LTE X2 signaling performance blindspots resulting at the hub location. Microprobes can be used to better understand backhaul-network utilization and packet capture without requiring the additional cost and performance penalties of deploying SPAN, RSPAN, or ERSPAN capabilities on the networking equipment itself.

A switch port analyzer (SPAN) is a tool supported on some switches for monitoring traffic. It is often used for debugging network problems by analyzing traffic on ports or VLANs. Local SPAN ports copy or mirror traffic received and/or sent on source ports (or source VLANs) on a single device to a destination port for analysis. The source and destination are always on the same switch or router. Remote SPAN (RSPAN) allows monitored traffic to traverse a Layer 2 network and provides the ability to capture and analyze traffic on two different switches that are part of a single Layer 2 domain. Encapsulated remote SPAN (ERSPAN) allows remote monitoring of traffic across a Layer 3 or IP network and uses generic routing encapsulation (GRE) for captured traffic, allowing it to be extended across Layer 3 domains.

Some microprobes provide selective filtering, metrics, and bandwidth-control capabilities. As a result, they can be used continuously and permanently for simultaneous network-wide monitoring. They can also provide instant, on-demand remote troubleshooting without adversely impacting network-device processing or link bandwidth. At the same time, microprobes can continuously measure one-way latency and jitter in each direction to and from networking elements. While monitoring and troubleshooting LTE signaling is important, these microprobes can be part of a holistic customer-experience management instrumentation strategy, supplying key performance indicators from throughout networks. This helps operators better understand the end-to-end performance of applications such as video and voice.

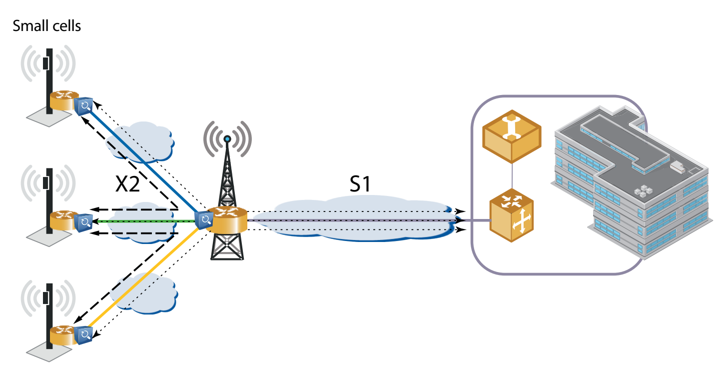


Figure 11. Microprobes simultaneously used for signaling monitoring and packet capture

LTE and Small Cells Drive the Need for New Backhaul Assurance Solutions

Small-cell market growth is being driven by operators seeking to enhance saturated macrocellular networks that are currently struggling to maintain an acceptable mobile broadband experience for subscribers. The global small-cell market is predicted to grow rapidly, with approximately three million small cells shipping by 2016. Presently, nearly 70% of global SPs have either begun small-cell and all-IP backhaul development or have plans to do so in the near future[3].

Mobile-backhaul network performance is crucial to maintaining mobile service quality. The explosive growth of end points created by small cells drives the need for new approaches for backhaul service activation, monitoring, troubleshooting, and optimization. Microprobe technology, together with centralized test systems and software applications, can help accelerate backhaul-network service activation and dramatically reduce the costs to monitor and maintain these networks.

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