MARKET INSIGHT

FROST & SULLIVAN

Satellite Backhaul of 3G and LTE Radio Access Networks

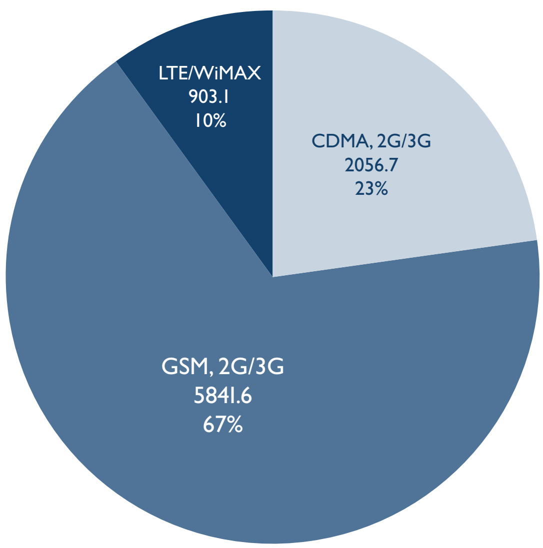
INTRODUCTION

Advancements in wireless network and device technologies, coupled with the proliferation of sophisticated mobile applications, have had a profound effect on the way people communicate today. The evolution from basic features phones to smartphones has been nothing short of phenomenal, and robust mobile services have become a part of the fundamental way that people function in their day-to-day lives. New services such as free or low-cost streaming media services, social networking, and location-based services (LBS) are quickly becoming "essential" and a necessary component for every cellular carrier to support. In fact, Frost & Sullivan research indicates the average smartphone user is rapidly approaching 2 gigabytes (GB) of cellular data usage every month. As the "information era" continues to mature, never before has mobile innovation offered so much to so many in so short a time. But as with all technology advancements, new challenges inevitably emerge.

More specifically, as consumers have become increasingly attached to their mobile devices, any interruption in service usage is unacceptable in today's connected world. The growing expectation for more bandwidth and ubiquitous service is a challenge for cellular service operators. The reality is that although perceived connectivity is high due to cellular network evolution in densely populated areas, many more remote locations still have low to no connectivity and subpar service. However, the opportunity to address this challenge is bright with carriers recognizing the benefits of adopting satellite backhaul technology to reach previously cost- or resource-prohibitive locations with modern cellular technology. As the world continues to expect more from cellular technology, satellite backhaul solutions will grow as a necessary component for enabling a true, high-performance global communication network.

Frost & Sullivan anticipates that 3G technologies will continue to account for the vast majority of radio access network (RAN) deployments, as depicted in the graph below:

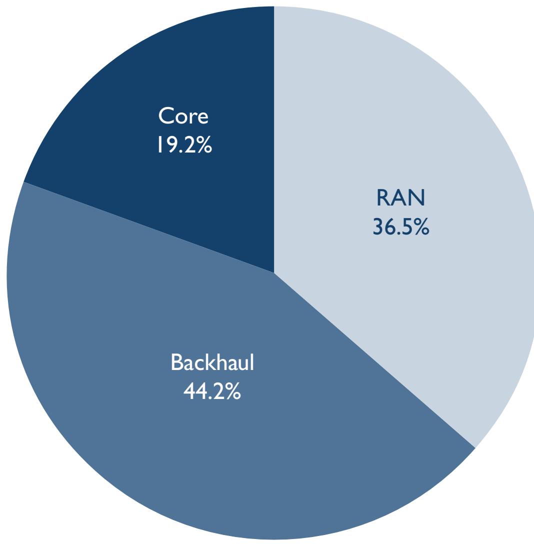
Figure 1: Technology Forecast Cellular Connectivity Market- Global 2016
(Units are in Millions of Connections)



Source: Frost & Sullivan

At the inception of cellular RAN, clear voice communication was the key application. Since then other applications have emerged (e.g., Short Message Service (SMS), instant messaging, Internet access, and video streaming), leading to far greater demand for bandwidth on RANs. Backhaul, a means of connecting NodeB or eNodeB to the core network, is a key component of the wireless network with as much as 44.2% of the network operating cost associated with backhaul. See chart below.

Figure 2: 3G Cell Tower Pricing Breakout Cellular Connectivity Market - Global, 2013



Source: Frost & Sullivan

RAN costs account for 36.5% of the average mobile operator's network operating expenses.

Among the key items driving backhaul costs are:

- Ever-increasing traffic capacity requirements in the access networks;
- End-user requirements for prompt access to rapidly expanding content;
- Convergence of cellular and Wi-Fi access networks; and
- Performance monitoring and network service-level agreement (SLA) guarantees.

Several technology options exist for backhaul of RAN (e.g., fiber, microwave, and satellite). Of these options, only satellite technology is suitable from either a cost or practicality standpoint for use in deploying wireless access networks in hard-to-serve areas such as rural communities, oil rigs, airplanes, etc.

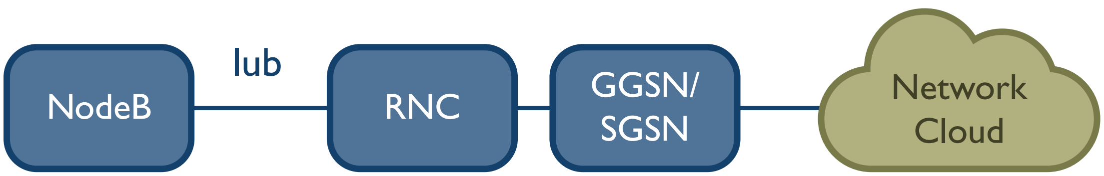
There is a common misconception that RAN backhauled over satellite will not support an acceptable user experience for real-time applications such as voice, gaming, and video conferencing due to the round-trip signal delay and variation, otherwise referred to as latency and jitter, respectively.

This white paper debunks the misconception and examines the real issues regarding the backhaul of RAN over satellite. As a case in point, for several years Hughes has provided successful satellite backhaul solutions for 2G and earlier cellular standards that are based on a T1/E1 TDM interface over satellite, using mediation devices to improve bandwidth efficiency and/or for interface conversion from TDM to IP. However, due to the rapid adoption of packetized IP interface for the backhaul of 3G/LTE traffic, this white paper will focus on the most widely deployed applicable interfaces, namely: the 3GPP logical interface between 3G NodeB or HNB to the core, referred to as Iub and Iuh, respectively, and S1, the interface between LTE eNodeB and Evolved Packet Core (EPC).

3G/LTE RAN OVERVIEW

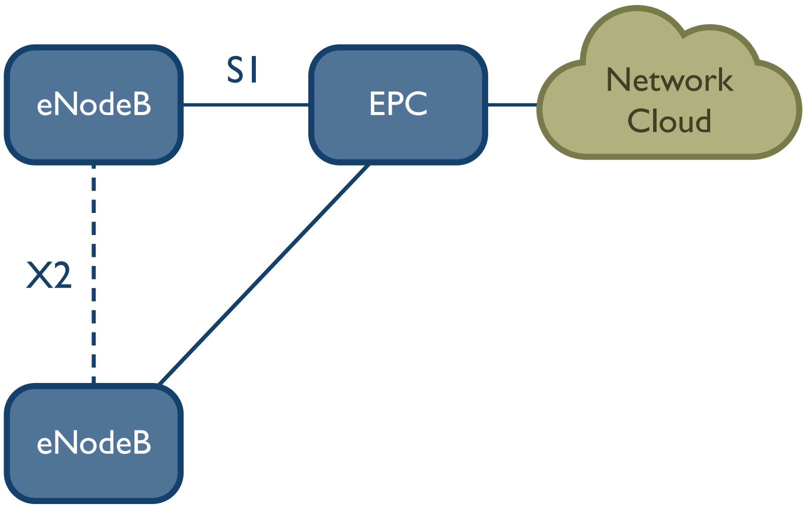
Third Generation (3G) is a cellular standard initially specified by the International Mobile Telecommunications-2000 (IMT-2000) that supports wireless applications such as voice telephony, mobile Internet access, fixed wireless Internet access, video calls, and mobile TV with a rate of about 200 Kbit/second. Two of the standards classified as 3G are Wideband Code Division Multiple Access (W-CDMA), which is used in most of the world. In Asia, it is known as Time Division Synchronous Code Division Multiple Access (TD-SCDMA).

A typical 3G network configuration is shown below.



Long-Term Evolution (LTE) is a global standard for wireless communication developed by the 3GPP (3rd Generation Partnership Project) starting with Release 8 for delivering voice telephony, mobile Internet access, fixed wireless Internet access, video calls, and mobile TV at a rate of about 300 Mbit/s. Evolved Universal Terrestrial Radio Access (E-UTRA) is the air interface of LTE with OFDMA for the downlink and SC-FDMA for the uplink, which supports both FDD and TDD communication systems, as well as half-duplex FDD with the same radio access technology. The key advantage of the LTE standard is its very flat IP structure and low data transfer latencies.

A typical LTE network configuration is shown below.



The table below shows both 3G and LTE technology specifications at a high level.

	3G		4G/LTE		
	WCDMA (UMTS)	**HSPA HSDPA/ HSUPA**	**HSPA+**	**LTE**	**LTE Advanced (IMT Advanced)**
Max downlink speed bps	384 kbps	14 Mbps	28 Mbps	100 Mbps	1G
Max uplink speed bps	128 kbps	5.7 Mbps	11Mbps	50 Mbps	500 Mbps
Latency RTT approx.	150 ms	100 ms	50 ms (max)	~10 ms	Less than 5 ms
3GPP releases	Rel 99/4	Rel 5/6	Rel 7	Rel 8	Rel 10
Approx years of initial rollout	2003/4	2005/6 HSDPA 2007/8 HSUPA	2008/9	2009/10	
Access methodology	CDMA	CDMA	CDMA	OFDMA/SC-FDMA	OFDMA/SC-FDMA

Source: Radio Electronics

With respect to backhaul of the above RAN technologies, attention should be paid to the downlink and uplink throughputs and the latency for each standard. These will be discussed in detail later in the white paper as they pertain to satellite backhaul considerations.

RAN ARCHITECTURE EVOLUTION

Over the years, RAN architecture and its associated technology have evolved from macro base stations with very tall towers meant to provide service to the largest possible area, to Small Cells, which can be the size of a small laptop and meant to provide coverage for varying areas such as in residential, enterprise, urban or rural environments.

Today, the most commonly discussed architecture is **Small Cells**. Small Cells are classified by the size of RF coverage area served and by their embedded intelligence. Regardless of the size of the area served, each Small Cell can support any and all of the RAN standards indicated above (3G or 4G/LTE) with both voice and data services. Small Cells are classified by the size of coverage area from smallest to largest. Below is the typical range covered by the different types of Small Cells.

	Coverage
Femtocell	Less than 10 yards (10m)
Picocell	Less than 218 yards (218m)
Microcell	Less than 1.2 miles (1.9km)
Macrocell	Up to 22 miles (35km)

The Small Cells approach was adopted to:

- Boost network capacity;
- Provide better cellular coverage;
- Enhance overall end-user experience; and
- Lower overall cost of RAN infrastructure.

Cloud RAN is another architecture being introduced to solve the problem of large bandwidth requirements in areas with much simultaneous access. Unlike Small Cells, Cloud RAN takes a centralized approach that supports very high capacity sites, such as offered by LTE Advance.

Heterogeneous Network (HetNet) has complex interoperation among macrocell, Small Cell and, in some cases, Wi-Fi network elements, collectively resulting in seamless coverage and with handoff capabilities between different network elements and technologies. This interoperation between cell types and technologies is meant to enhance the overall end-user experience. Satellite solutions for HetNets have been successfully proven to backhaul 3G, LTE, and Wi-Fi technologies, all of which may be found in a given deployment.

SATELLITE BACKHAUL

Satellite backhaul is rapidly growing as a solution for filling in the gaps of a cellular mobile network. As carriers around the world continue to expand their networks and get closer to 100% points of presence (POP) coverage, the need to connect remote and difficult locations increases significantly, and the limitations of fiber or other terrestrial solutions such as microwave are already apparent.

Frost & Sullivan anticipates satellite will be the technology of choice for bridging these coverage gaps for the foreseeable future.

There are two main satellite backhaul access techniques–Time Division Multiplexing/Time Division Multiple Access (TDM/TDMA) and Single Channel per Carrier (SCPC).

- o TDM/TDMA – Outroutes employ a statistical multiplexing scheme compliant with DVB-S2 for sharing information among multiple remote terminals, while inroutes use a demand-assigned, multi-frequency Time Division Multiple Access (TDMA) approach to allow remotes to transmit to the hub.

- o SCPC – This uses dedicated frequencies to transmit and receive information to a single remote terminal.

With TDM/TDMA, remote NodeB or eNodeBs sites share the same satellite capacity for their traffic; the capacity is dynamically assigned as needed to each site.

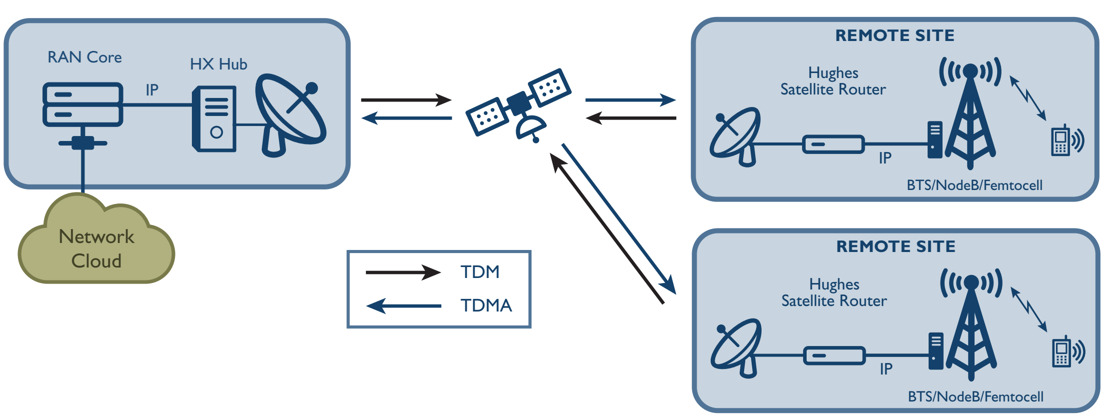
In a dispersed, multi-site network, busy hour traffic occurs at different times at different site locations. This is very suitable for dynamic sharing of the same satellite capacity, a key attribute of a TDM/TDMA system. This is in contrast to SCPC solutions, where the capacity is allocated or variable on a per-site basis only.

Hughes offers a full range of satellite-based RAN backhaul solutions that have been specifically designed for mobile operators to enable rapid and cost-effective service expansion into rural or hard-to-serve markets. These solutions provide high-quality links while optimizing space segment resource utilization by coupling the appropriate satellite technology with intelligent traffic optimization.

In addition, the time to implement a satellite backhaul connection is quite short. Once the satellite terminal is installed, the service can begin immediately. Satellite also offers a significantly lower capital expenditure versus the cost of establishing (installing) and maintaining a terrestrial backhaul system using fiber or microwave (with multiple hops) in hard-to-reach or rural areas.

The Hughes HX System satellite backhaul solution supports both star and mesh configurations.

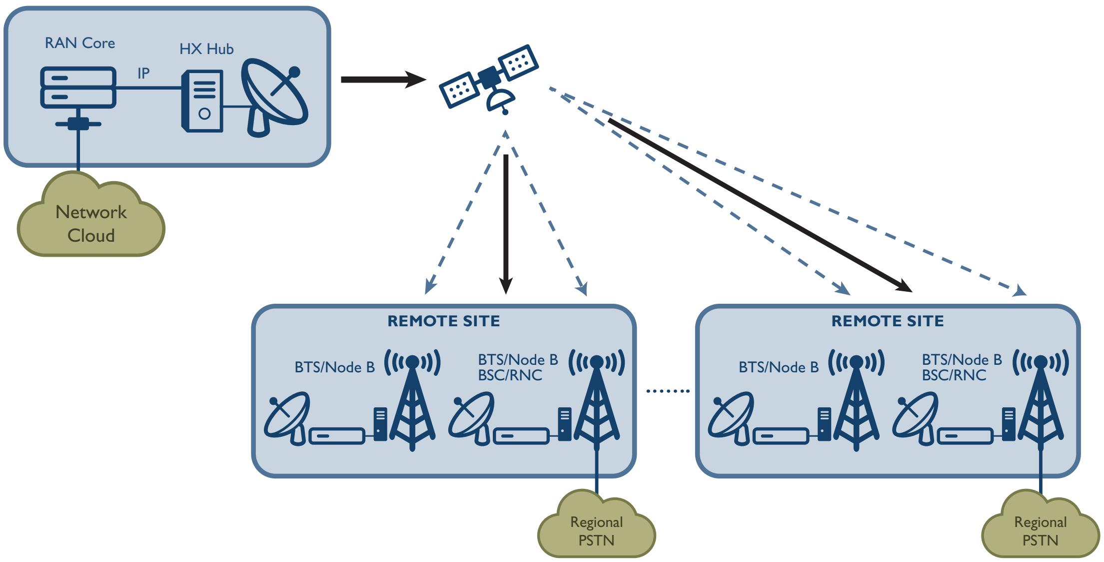
Star Architecture of Hughes Satellite Cellular Backhaul Solution



In the star configuration, the hub receives traffic from the RAN core and transmits over the TDM outroute to the remote terminal serving a designated NodeB or eNodeB. The NodeB or eNodeB communicates back to the RAN core through the HX remote terminal using TDMA channels.

In the mesh configuration shown below, connections for traffic from NodeB or eNodeB to the core do not need to be routed through a central hub. This is very suitable for IP connectivity and RAN deployments with a distributed core.

Mesh Architecture of Hughes Satellite Cellular Backhaul Solution



SATELLITE BACKHAUL CONSIDERATIONS

Key considerations in the backhaul of 3G or 4G/LTE over satellite are summarized below.

Capacity

This is the amount of space segment in Mbps required to backhaul each site to the core network to provide an acceptable end-user experience. As RAN technologies evolve, the required download and upload speeds per user continuously increase; hence, the overall throughput speed in Mbps required to backhaul a site increases. For small, rural GSM sites supporting just voice and a low rate of data, the backhaul speed can be in the order of 256 Kbps download and 128 Kbps upload; for 3G/LTE, the required backhaul speed starts from about 2 Mbps download and 1 Mbps upload. In fact, for a meaningful user experience, 3G/LTE sites require speeds from 10 Mbps download to 2 Mbps upload and above.

To address the space segment requirement for a backhaul application or general content access needs, the satellite industry has been implementing advanced technology processes in existing technologies, as shown below, to increase space segment efficiency. In addition, the industry is investing in new-generation, high-throughput satellites (HTS). Hughes leads the industry in delivering the highest space segment-efficient solutions and HTS.

Security

To maintain the security and the integrity of the 3G/LTE network, most operators prefer to pass the backhaul traffic end-to-end via an IPsec tunnel. While this approach surely increases the level of security of the network, it introduces more overhead bandwidth to the different traffic types–voice, signaling, control, and video–for backhaul over satellite. The Hughes satellite backhaul solution supports both approaches–backhaul traffic encapsulated in an IPsec tunnel or not.

Latency

This is the time period that information travels from one point to another in a network, measured either one way or round-trip time (RTT). As can be seen from the RAN technology evolution, maximum latency has been lowered with every new standard. This is because lower latency increases the efficiency and performance of the network by achieving a higher data throughput and delivering better real-time voice and video applications.

In the case of geosynchronous satellites, there is always a minimum latency of about 500ms RTT due to the distance the signals travel in space. Most RAN vendors have configured their RAN solutions to operate over satellite backhaul with a latency of 700 to 900ms RTT, which includes end-to-end traffic processing delays. It should be noted that while lower latencies are shown in the specifications that RAN vendors typically use, a distributed software approach accommodates the satellite delays. Hughes is able to deliver a lower latency that ultimately leads to a better end-user experience for real-time applications for RAN sites that are backhauled over satellite.

Jitter

Variation in latency, measured as jitter–which can be due to congestion or loading on the network–significantly affects network stability, causing a more damaging effect than latency alone. Hughes has delivered a solution that is well within the requirements of most RAN vendors, typically less than 20ms jitter for sites backhauled over satellite.

Packet Loss

Packet loss is the number of packets that do not reach their destination due to transmission error, network congestion, etc. Measured in percentages, typically less than .1 percent is required for a good functional RAN backhaul. This is primarily a network engineering issue, but it is critical to the performance of RAN sites backhauled over satellite.

Synchronization

In a RAN system, the NodeB and eNodeBs need to operate at the same clock rates with the RNC or core network. If not, slips occur and degrade system performance. The chart below shows the different synchronization methodologies.

	GNSS	NTP	IEEE 1588v2 (PTP)	SyncE	Sniffing
Frequency					
Phase					
Transport	Physical	Layer 3	Layer 2 & 3	Physical	Physical
Use Cases	North American Femtocells, Any 3G/LTE Small Cell	3G UMTS Femtocells & Enterprise	Enterprise and Urban Small Cells	Urban Small Cells	Residential and standalone Enterprise
Limitations	Possible poor indoor signal reception	Packet delay variations in wireline broadband	Packet delay variation in backhaul	Must be end-to-end SyncE throughout	Reception from nearby cell towers

Source: ThinkSmallCell

HUGHES SATELLITE BACKHAUL SOLUTION

The Hughes HX System is an innovative IP broadband satellite system comprised of a Hub and Remote Terminal that is highly bandwidth-efficient and supports several features specifically suited for backhaul applications. The HX system supports Ka, Ku, C, and X bands.

HX Bandwidth Efficiency Features:

Outbound

- DVB-S2 -The world's most successful satellite air interface is approved by TIA, ETSI, and ITU.
- Adaptive Coding and Modulation (ACM) -This allows the system to dynamically vary the modulation and coding of the forward channel for each transmission, leading to a more robust system and 30% bandwidth gain over a DVB-S system.
- Generic Stream Encapsulation (GSE) - Hughes's implementation of GSE reduces encapsulation overhead and provides improvement in bandwidth efficiency of ~4 to 14%, depending on the distribution of user IP packet sizes.
- Scheduling Bypass and Real-Time Fast Track - Together these features reduce the latency and jitter on the outroute by not queuing real-time traffic.

Inbound

- Adaptive Coding - Similar to ACM on the forward channel, adaptive coding on the return channel enables a remote terminal to dynamically adjust its transmissions to handle fade conditions. Selecting the most efficient coding rate for the transmission to be received leads to 20% increased throughput, as extra rain margin is not configured.
- Adaptive Low-Density Parity Check (LDPC) - LDPC on the return channel enables Hughes to achieve a 12% increase in bandwidth efficiency over existing Turbo Coded return channel systems.

- Just in Time (JIT) TDMA Burst Forming - This ensures that data packets are transmitted at the earliest possible opportunity, and thus reduces the Real-Time Transport Protocol (RTP) latency in the inroute.
- Jitter Buffer (JB) - An integrated jitter buffer feature enables an operator to configure the desired jitter performance. In mesh, JB allows the system to reduce jitter for traffic sent between mesh peers, while in star JB reduces the packet jitter in the inroute direction.

Other benefits

- Very low latency RTT of ~600ms and Jitter of ~20ms one way enhance efficient delivery of real-time sensitive traffic such as voice, video and increased data throughput
- Simple and economical network expansion:
  - o Add more channels without any remote hardware change
  - o Remote equipment competitively priced
  - o Full functionality for RAN backhaul included in the standard HX Gateway
- High-speed inroutes up to 9.6 Mbps
- Strong QoS features enabling easy prioritization and transmission of critical traffic
- Mesh connectivity with HX Mesh Gateway (GW) stations enabling cost-effective, single-hop connections for RNC/Core to NodeB or eNodeB traffic
- End-to-end network management and support for higher network management connectivity
- Transparent to cellular traffic – Supports GSM (2, 3 and 4G/LTE protocols), CDMA, and WiMax standards
- Works with all major cellular equipment RAN vendors
- Overall, lowers total cost of ownership for sites backhauled over satellite

SATELLITE VALUE PROPOSITION

The expansion of communications networks to remote locations can quickly result in the need for alternative technologies to traditional fiber expansion due to adverse conditions. These conditions typically require the use of satellite or microwave technology to span large distances. However, cost of satellite access is independent of location, whereas the cost-effectiveness of microwave towers is directly linked to the distance needed to travel and subsequent number of hops necessary. The longer the distance, the less appealing microwave is and the more attractive satellite becomes.

Currently, both satellite backhaul and microwave backhaul installations can cost as little as $25,000 or less for a single installation. However the microwave installation can only maintain this low cost within a 30-mile range where line of sight (LOS) is achievable. With rough terrain and long distances requiring three or more hops, costs can quickly exceed $100,000 and add complexity to the deployment and operation of the solution. Thus, microwave often has the same limitations as fiber when reaching remote locations, as the deployment quickly multiplies in price and complexity.

Due to this, satellite remains the most cost-effective solution for connecting locations that are remote and would require multiple microwave installations to serve the location. Satellite has no geographical limitation and can serve any location where fiber and microwave become costly and cumbersome to deploy.

CONCLUSION

The Hughes HX System, based on the DVB-S2 standard, incorporates a host of unique backhaul-related features to enhance cellular backhaul, including Just in Time (JIT), Jitter Buffer, Scheduling Bypass, and Real-Time Fast Track. Together, these features enable the HX Systems' fast packet processing design to reduce round-trip latency to approximately 600ms and one-way jitter to 20 ms, resulting in superior voice quality and very efficient data throughput–essential for real-time applications.

The Hughes HX satellite backhaul solution has been proven to successfully backhaul Small Cells of various sizes (femto, pico, and macrocells) from major RAN manufacturers covering different technologies and standards. Using star and mesh configurations, Hughes has successfully certified and commercially deployed several thousand remote base stations, NodeB, and eNodeB sites, supporting 2G, 3G, and LTE voice and data services based on infrastructure from the market's leading vendors, including Ericsson, Huawei, Nokia Siemens Networks, Alcatel-Lucent, ZTE, Altobridge, and Lemko.

With the aggressive expansion and evolution of cellular technology and services–and the pressure on wireless carriers to connect even the most remote users–satellite technology is rapidly becoming recognized as a viable and cost-effective alternative to fiber for backhaul. Not surprisingly, this has resulted in an estimated compound annual growth rate (CAGR) of approximately 5% for the satellite backhaul market between 2012 and 2017. Perceptions of low performance, inefficient use of bandwidth, jitter, latency, high cost, and complex integration have traditionally been the most common inhibitors to satellite technology adoption–all of which have been addressed by Hughes in its advanced HX satellite backhaul solution. As carriers continue to look for alternative means to connect difficult and remote locations without sacrificing the performance of traditional fiber technology, the Hughes HX backhaul solution presents a particularly compelling value proposition. Currently, Hughes is unrivaled in its ability to support both voice and data services over satellite technology at the highest possible quality of service and end-user experience. Frost & Sullivan believes Hughes is well-positioned to fill the rapidly growing needs of cellular network providers as they continue to expand and enhance their respective networks.

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