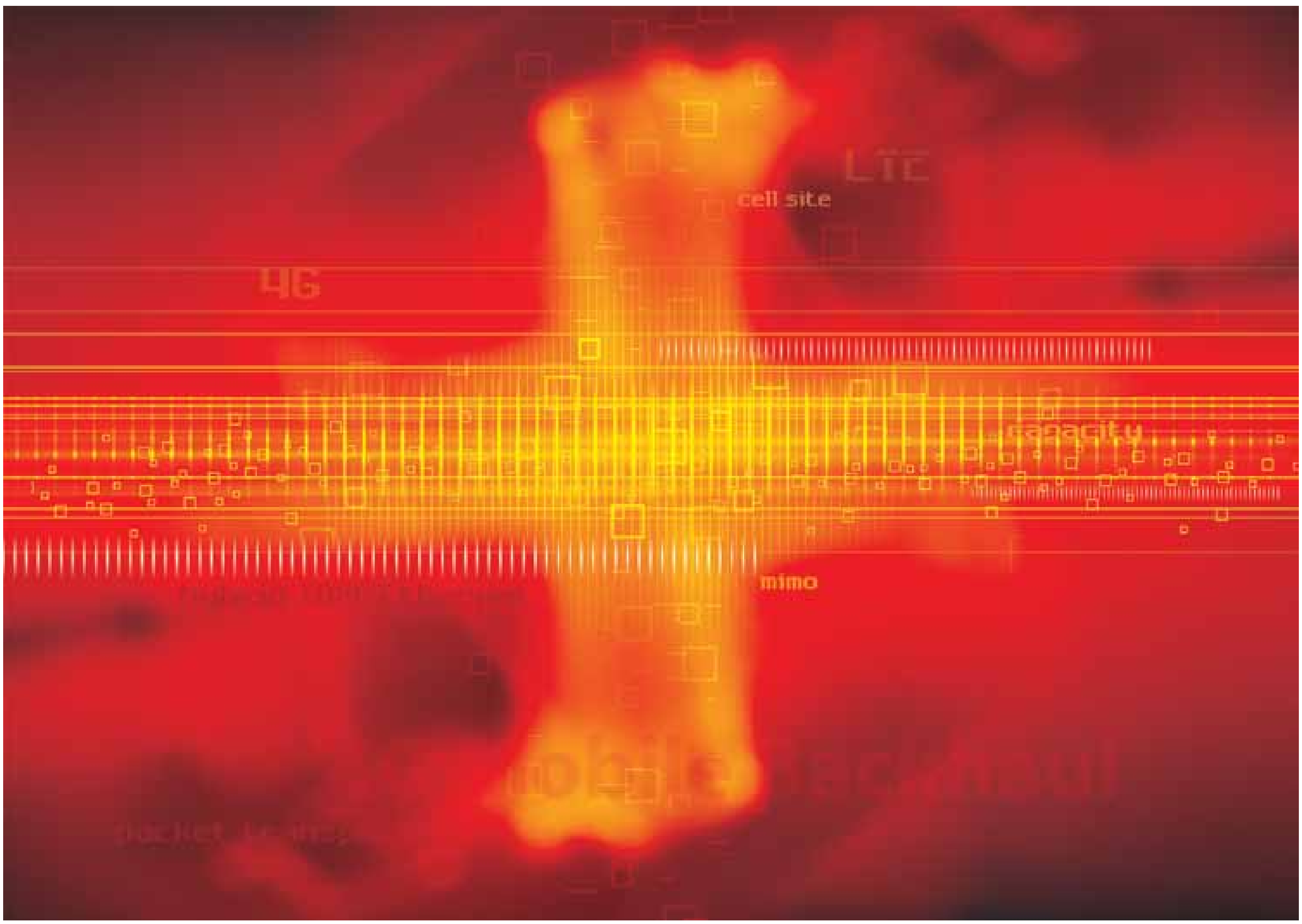
FUJITSU

# 4G Impacts to Mobile Backhaul



## Introduction

With the introduction of 4G systems, wireless networks are evolving to next-generation packet architectures capable of supporting enhanced broadband connections. Simple text messaging and slow email downloads are being replaced by high-speed connections that support true mobile office applications, real time video, streaming music, and other rich multimedia applications. 4G wireless networks will approach the broadband speeds and user experience now provided by traditional DSL and cable modem wireline service.

From the wireless operator's perspective, 4G systems are vastly more efficient at using valuable wireless spectrum. These spectral efficiency improvements support new high-speed services, as well as larger numbers of users.

The additional speeds and capacity provided by 4G wireless networks put additional strains on mobile backhaul networks and the carriers providing these backhaul services. Not only are the transport requirements much higher, but there is also a fundamental shift from TDM transport in 2G and 3G networks to packet transport in 4G networks. Understanding the impact of 4G on mobile backhaul transport is critical to deploying efficient, cost-effective transport solutions that meet wireless carrier expectations for performance, reliability and cost.

Unfortunately, there has been a great deal of hype and misinformation in the industry regarding 4G bandwidths and their impact on networks. Separating fact from fiction with regards to mobile backhaul requires an understanding of three fundamental areas:

- Network architecture
- Spectral efficiency and capacity
- Native TDM and native Ethernet transport

A thorough understanding of these issues ensures operators choose the right technology, network and architecture to implement a successful wireless backhaul business.

## LTE Architectural Benefits

Key objectives of 4G LTE networks are to support higher data rates, improve spectral efficiency, reduce network latency, support flexible channel bandwidths, and simplify or flatten the network by utilizing an all-packet (Ethernet/IP) architecture. In a GSM network, whether 2G or 3G, radios (Node B) at the cell site provide the radio air interface for each cell. A Radio Network Controller (RNC) provides control over multiple cell sites and radio transceivers, supporting call handoffs and resource allocation. The RNCs are connected to both a TDM voice switch and a packet gateway located at the MSC, as shown in Figure 1.

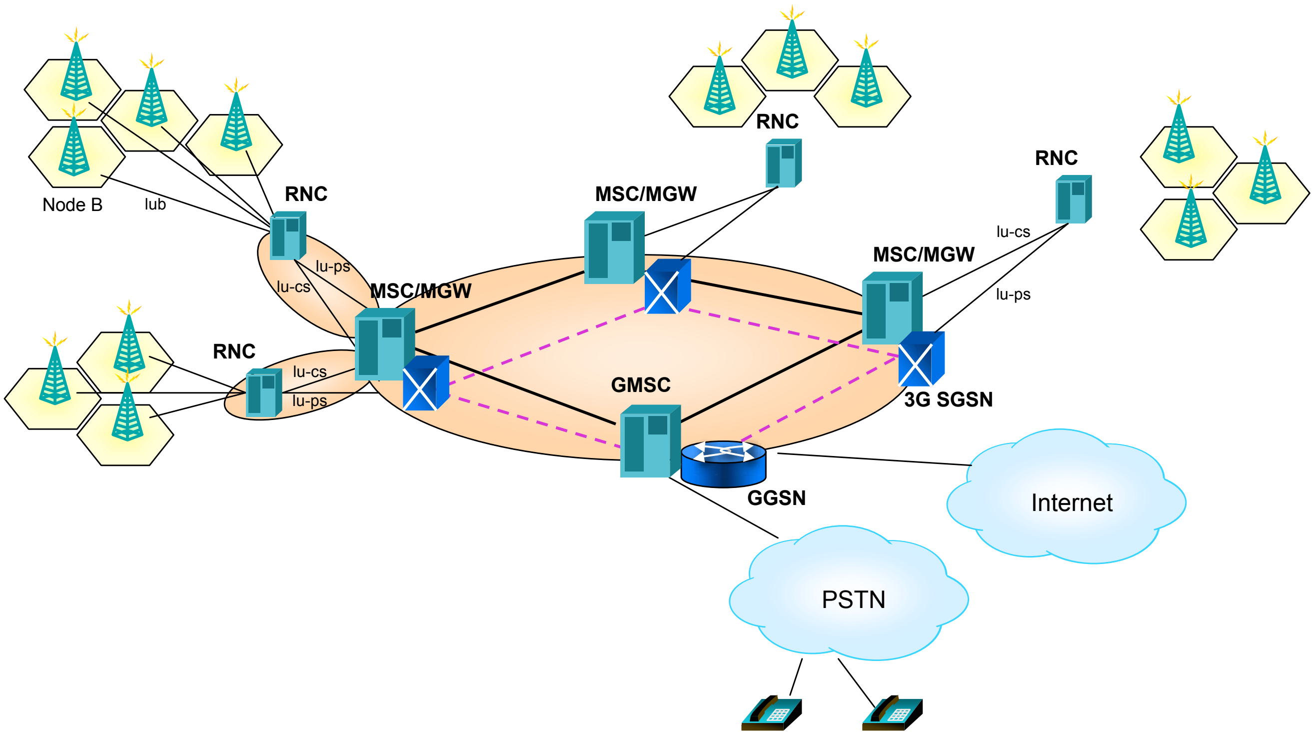



**Figure 1: A Typical 3G Network**

The wireless industry defined each functional element in the network, as well as a set of standard interfaces for interconnecting each of these devices. While their functions are similar, the 3GPP wireless standards body adopted slightly different names for the functional nodes and logical interfaces for GSM 2G and UMTS 3G networks. Although updated in recent years to include Ethernet, historically the 2G/3G wireless standards were based on T1 TDM physical interfaces for interconnection between these devices. Given the wide availability of T1 copper, fiber, and microwave services, this was a very logical choice for the physical layer. This traditional reliance on T1 physical interfaces has, up to this point, driven mobile backhaul transport requirements.

LTE systems are based on entirely new packet-based architecture, including the use of Ethernet physical interfaces for interconnection between the various functional elements. Another objective of the LTE standards was to flatten and simplify the network architecture. This resulted in pushing more intelligence into the radios (eNodeB) and elimination of the radio controllers as a separate device. In effect, the radio controller function has been distributed into each eNodeB radio. The resultant network, as shown in Figure 2, is indeed much simpler and flatter, with far fewer functional devices.

From a mobile backhaul perspective, the major changes are the higher capacities required by LTE cell sites, as well as the use of native Ethernet as the physical interface for connection and transport of these services back to the MSC. Given that most cell sites will continue to support GSM 2G and UMTS 3G networks for many years, the addition of LTE means backhaul transport carriers need to implement systems that can support both native T1 TDM services and Ethernet services.

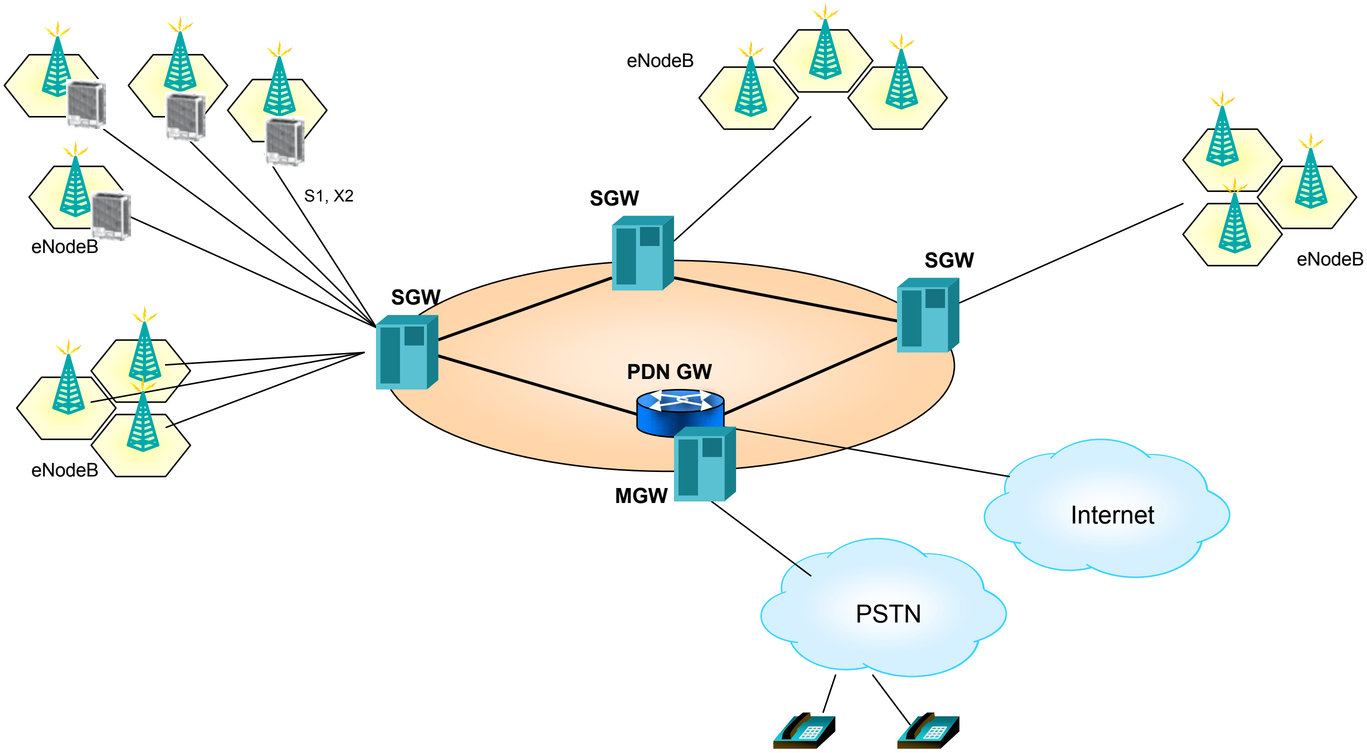



**Figure 2: A Typical LTE Network**

## Spectral Efficiency: Making Optimal Use of Bandwidth

LTE wireless networks offer vastly more bandwidth than traditional GSM 2G and UMTS 3G networks. While these enhanced speeds are very impressive, there has been a great deal of hype within the industry on the theoretical performance as compared to the more typical or realistic bandwidths that will be needed at LTE cell sites. As an example, Fujitsu has achieved an impressive 288 Mbps data rate in LTE demonstrations of a single radio. Without diminishing this technical feat, it should be noted that it was achieved by using a wide amount of spectrum (20 MHz) and by incorporating MIMO antennas. MIMO has the effect of increasing the capacity of a system by two to four times compared to systems using a single transmit and single receive antenna. The vast majority of LTE deployments in North America will rely on 5 or 10 MHz channel sizes per direction (Tx/Rx).

The amount of bandwidth on a wireless network is ultimately constrained by two factors: the spectral efficiency of the wireless interface and the amount of licensed spectrum a carrier owns. Spectral efficiency is a fancy way of saying how much information can be transmitted over a given radio channel (i.e., Hz). Spectral efficiency is measured as the amount of data (bps) that can be transmitted for every Hz of spectrum; the higher the number (bps/Hz) the better. Newer technologies, such as LTE, use advanced modulation schemes (OFDM) that support higher spectral efficiencies and higher data rates than 2G and 3G wireless networks.

Spectral efficiency decreases with the distance from the cell tower, due to lower received power and higher noise levels. To accommodate for users at varying distances within a cell sector, wireless networks adjust their modulation scheme for each user. Those closest to the tower, with the highest received power, operate with the most advanced modulation technique resulting in the highest data rates. Further away from the tower, simpler modulation techniques are utilized which result in lower spectral efficiencies and slower data rates.

Wireless operators spend billions of dollars on their spectrum licenses from the FCC, making their licensed spectrum highly valuable assets. The higher spectral efficiencies of LTE allow them to use these assets more efficiently, supporting more users and with higher speed services, resulting in higher revenues for a given amount of spectrum.

The amount of licensed spectrum a carrier owns and can operate at a cell site is determined by the amount of spectrum purchased through an FCC auction. Spectrum has typically been allocated in 5 MHz or 10 MHz channel sizes or "blocks." Spectrum is usually auctioned as paired blocks, with a separate 5 MHz block for the downlink channel and a separate 5 MHz block for the uplink channel.

The maximum amount of bandwidth required at a cell site is simply the amount of licensed spectrum (i.e., channel size) owned by the wireless operator, multiplied by the spectral efficiency of the air interface. As an example, the table in Figure 3 illustrates typical cell site bandwidths required by the following four scenarios:

- GSM 2G voice 1.2 MHz
- GSM/EDGE 2.75G 3.5 MHz
- UMTS/HSPDA 3G 5.0 MHz
- LTE 4G 5.0 MHz

**Wireless Capacity Requirements**

| | Voice Spectrum (MHz) | Data Spectrum (MHz) | Voice Spectral Efficiency (bit/s/Hz) | Data Efficiency (bit/s/Hz) | # Sectors | Traffic Eng % Peak | Total Bandwidth (Mbps) | # T1s |
|---|---|---|---|---|---|---|---|---|
| GSM 2G | 1.2 | | 0.52 | | 3 | 70% | 1.3 | 1 |
| GSM / Edge 2.75G | 1.2 | 2.3 | 0.52 | 1 | 3 | 70% | 6.1 | 4 |
| HSDPA 3G | | 5 | 0 | 2 | 3 | 70% | 21.0 | 14 |
| **LTE 4G** | | **5** | **0** | **3.8** | **3** | 70% | **39.9** | **n/a** |
| **LTE 4G** | | **10** | **0** | **3.8** | **3** | 70% | **79.8** | **n/a** |

**Figure 3: Table of Wireless Capacity Requirements**

For a fully populated, three-sector LTE cell site, the backhaul bandwidth requirements will be approximately 40 Mbps. As LTE systems are deployed in 2010 and 2011, their initial bandwidth requirements will likely be only 20 Mbps until a large population of 4G handsets and users within a given area is achieved.

The first LTE 4G value shown in Figure 3 is based on 5 MHz channel blocks, a very common size in the wireless industry. However, some wireless carriers own 10 MHz blocks, effectively doubling the potential capacity. In addition, MIMO antennas can be used to boost LTE speeds. MIMO is a technique that uses multiple transmit and multiple receive antennas on both the LTE radio, as well as on end user devices (handsets, PC cards). A 4x4 MIMO configuration would provide four separate transmit and four receive antennas. These multiple antennas create additional "paths" that can be used to transmit additional information over the same spectrum. As mentioned previously, Fujitsu has demonstrated 288 Mbps over a single radio sector using 4x4 MIMO and 20 MHz spectrum.

The higher capacities driven by larger channel sizes and MIMO antennas is somewhat balanced by the fact that not all users in a sector operate at peak spectral efficiency. Spectral efficiency is a function of the modulation scheme used on the air interface. The more advanced the modulation scheme, the higher the spectral efficiency and the higher the bandwidth (bps). However, these advanced modulation techniques can only be used in relatively high-power, low-noise conditions, typically found close to the cell tower. As users move further away from the tower, power levels decrease and noise levels increase. Wireless networks adapt to users at various distances by automatically adjusting their modulation scheme for each user. Those close to the tower operate at the highest data rates and those furthest from the tower utilize less complex modulation schemes that support lower data rates, as shown in Figure 4.

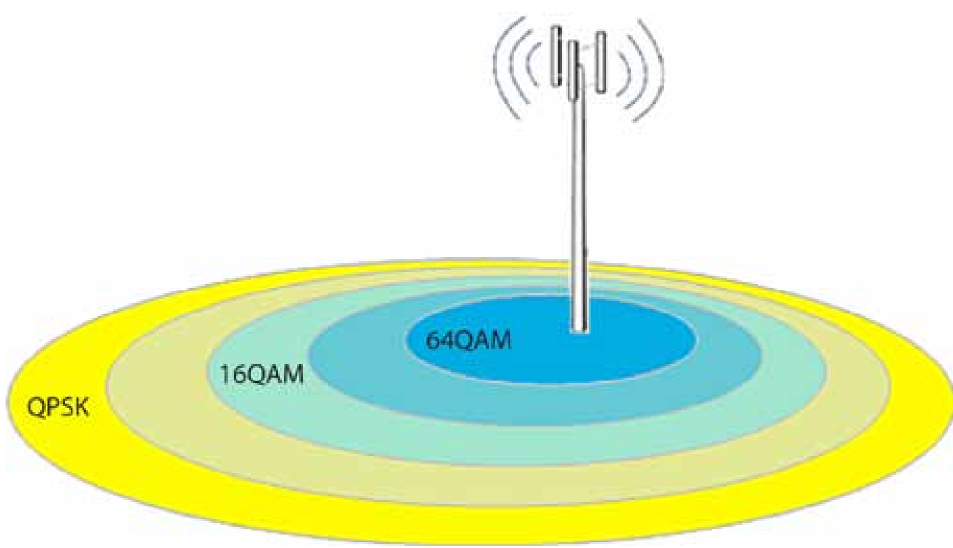



**Figure 4: Adaptive Modulation**

## Legacy TDM Revenue

While there is tremendous industry interest and excitement in 4G LTE services and deployments, it's important not to lose sight of the fact that there are approximately 190,000 cell sites in the U.S., most with T1 TDM base stations requiring T1 TDM backhaul. GSM 2G and UMTS 3G standards specified the use of T1 physical interfaces for interconnecting the cell sites to base station controllers and then onto MSCs. This large, installed base of 2G/3G wireless systems will remain in the network for many, many years, resulting in a continued need to provide T1 mobile backhaul transport.

As 4G LTE systems are deployed alongside existing 2G/3G systems, there will be a need to transport both T1 TDM and Ethernet services for mobile backhaul. Several large wireless carriers have specified performance metrics that require their T1 TDM services to be carried in native TDM format (see Figure 5), as opposed to T1 Circuit Emulation Service (CES). It is important to understand why carriers continue relying on native T1 TDM transport and the issues surrounding T1 CES. This fundamental issue is critical in designing and implementing optimal backhaul architectures, so that networks that can easily transition to Ethernet services as 4G LTE systems are deployed.

| Parameter | Wireless Carrier RFP | MEF Spec | SONET |
|---|---|---|---|
| Delay | < 5 ms | < 25 ms | < 100 us |
| Jitter | < 1 ms | < 10 ms | < 3.2 us |
| Availability | 99.999%<br>< 5.3 min/yr | 99.95%<br>< 263 min/yr | 99.999%<br>< 5.3 min/yr |

**Figure 5: Performance Metrics[1,2]**

## Circuit Emulation—Delay Versus Efficiency

T1 CES provides a method for carrying T1 TDM services over an Ethernet packet network. However, T1 CES involves some performance issues and limitations, which are not acceptable to all wireless operators and have difficulty meeting the specifications shown in Figure 5.

Circuit emulation involves a classic tradeoff between latency (delay) and bandwidth efficiency. Delay through the network can be reduced, but at the cost of reduced efficiency. Likewise, efficiency can be improved, but with consequence of longer delays.

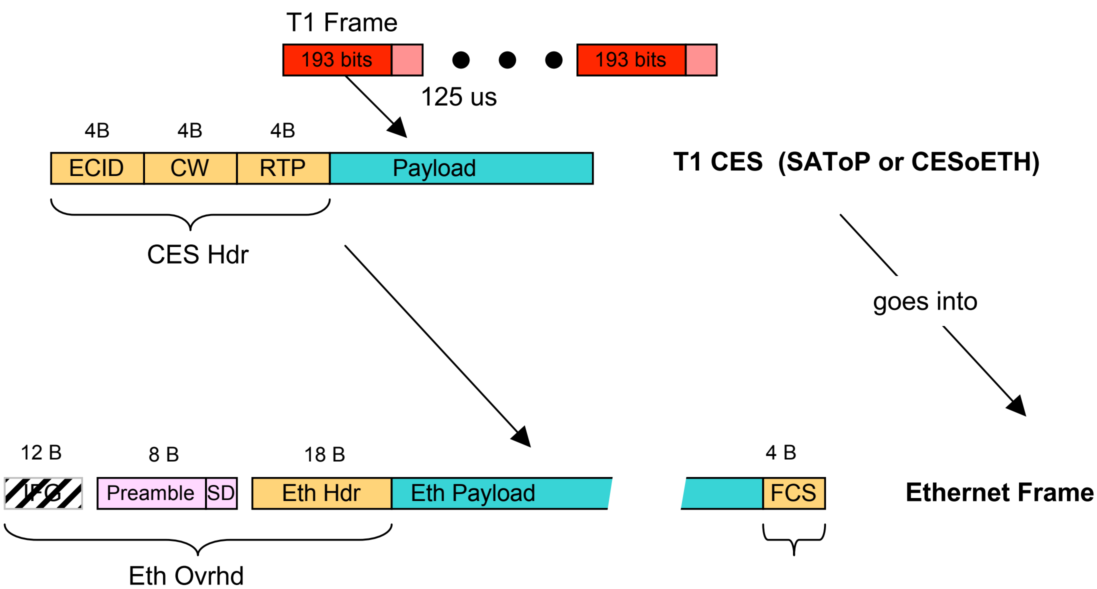



**Figure 6: CES Latency Versus Efficiency**

To form a T1 CES "packet," one or more T1 frames are inserted into a CES payload along with 12 bytes of CES header information. This entire package is inserted into an Ethernet frame, along with the Ethernet header bytes, preamble bytes, and interframe gap. If a single T1 frame is transported inside the CES payload, the latency is very low, however the efficiency of the network is not very good due to the high number of CES and Ethernet overhead bytes. The alternative is to stuff many T1 frames into the CES payload and Ethernet frame. This minimizes the impact of the overhead bytes, however the latency is much longer due to the fact that four, eight, or 16 T1 frames worth of information must be buffered prior to transmission. This is the classic tradeoff and dilemma when implementing T1 CES: it's possible to have low delay or good network efficiency but not both.

T1 circuit emulation services are typically ~60% efficient due to the amount of overhead information transmitted with each Ethernet frame (CES header, Ethernet header, preamble, interframe gap). Figure 7 shows typical T1 CES efficiency for the given number of T1 frames mapped into every packet. Using four T1 frames per Ethernet frame, approximately 2.5 Mbps is required to transport the T1 circuit (1.544 Mbps native), or 63% efficiency.

| Circuit Emulation Efficiency (typ) | | |
|---|---|---|
| **Frames** | **Efficiency** | **Bandwidth** |
| 1 | 30% | 5.1 Mbps |
| 4 | 63% | 2. 5 Mbps |
| 8 | 76% | 2.0 Mbps |

**Figure 7: Typical T1 Circuit Emulation Efficiency**

In addition to the CES packet/efficiency delay shown above, the largest source of latency is usually from the T1 CES jitter buffer. To remove unwanted jitter in packet-based architectures, jitter buffers are used to store incoming T1 CES packets, re-clocking and re-synchronizing these packets/frames prior to the output port. The size of the jitter buffer determines how much network jitter can be compensated, but it also determines the latency through the jitter buffer. Typical jitter buffer values for T1 CES applications range from 2–10 msec.

Many wireless service providers are uncomfortable with the latency, jitter and efficiency issues related to T1 CES. For these carriers, insistence on carrying TDM services in native TDM format is very understandable based on these performance metrics. It's critical for these carriers that the backhaul network and 4G LTE migration support both "native" T1 TDM services and Ethernet.

## LTE Backhaul Migration Strategies

The GSM 2G and UMTS 3G networks that are currently deployed will remain an integral part of the wireless infrastructure for the next 10–15 years. Their T1 physical interfaces and native T1 TDM transport requirements will, therefore, be present for a long time to come. At the same time, the introduction of 4G LTE systems in 2010/2011 will impose new requirements for Ethernet services and Ethernet backhaul. Successfully supporting these legacy systems, as well as the new 4G LTE Ethernet requirements, is critical to mobile backhaul business strategy.

The following sections define three mobile backhaul network migration strategies for supporting 4G LTE systems, each optimized for a particular carrier type or deployment scenario.

## TDM/Ethernet Hybrid Model

For applications with native T1 TDM requirements or that have a previously deployed MSPP at the cell site, the TDM/Ethernet model provides a very cost-efficient solution for mobile backhaul.

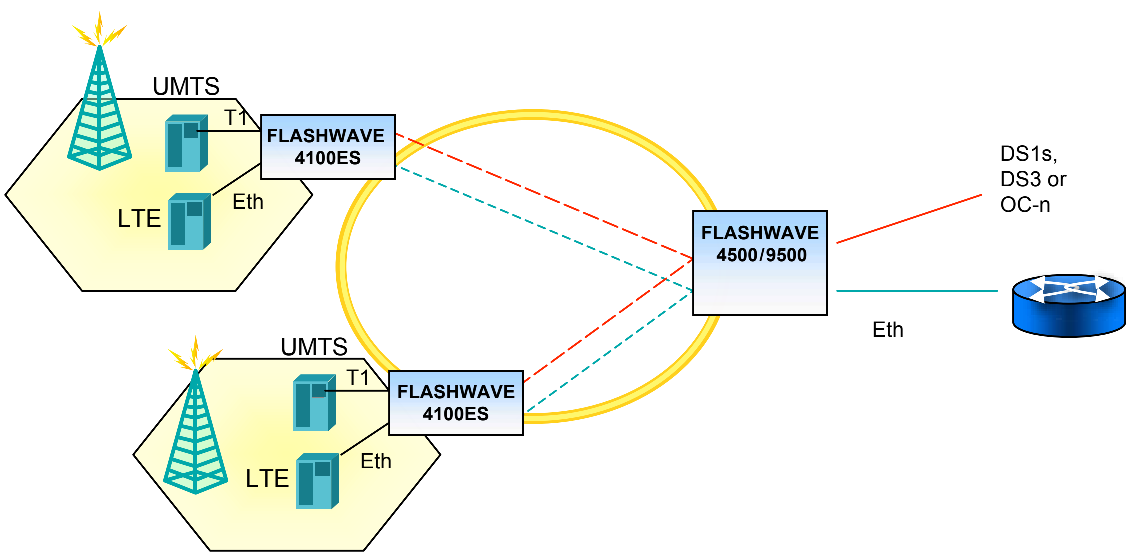



**Figure 8: TDM/Ethernet Hybrid Model**

In this scenario, MSPPs are deployed at cell sites to support native T1 TDM as well as Ethernet (EoS) services. For sites with a pre-existing FLASHWAVE® 4100 system deployed to support T1 TDM services, only a single Ethernet card needs to be added for the migration to 4G LTE Ethernet services. The FLASHWAVE 4100 Ethernet interface provides up to (8) 10/100Base-T and (2) 100FX/GigE ports to support connections to multiple carriers and radios at a cell site. This single platform provides true carrier-grade quality, performance and protection for both T1 and Ethernet services. At the MSC, an aggregation node can combine traffic from hundreds of cell sites, handing off an aggregated TDM port and an aggregated Ethernet port.

**Figure 9: FLASHWAVE 4100 Extension Shelf Rack-Mountable Unit and Outside-Plant Cabinet Solution**

As in the previous model, an aggregation node at the MSC combines the TDM and Ethernet traffic from hundreds of cell locations, providing separate handoffs to the respective TDM and packet equipment at the MSC.

The Fujitsu FLASHWAVE 4100 platform (Figure 9) is widely deployed in over 5,000 mobile backhaul applications. This temperature-hardened system is ideally suited to transport DS1/D3, Ethernet, and SONET services. It is available in a 2U high rack-mount chassis with 12 universal interface slots, as well as a number of compact outside-plant cabinets for pad, pole, and H-frame mounting.

The FLASHWAVE 4100 system is ideally suited to 4G LTE migrations, due to its extensive Ethernet flexibility. As shown in Figure 10, the platform can be initially deployed to support traditional DS1 services. As 4G LTE systems are deployed, only a single Ethernet card needs to be added to provide Ethernet (EoS) services. Some carriers may wish to separate their TDM and Ethernet traffic, carrying each over separate fiber facilities, as shown in the third diagram. The FLASHWAVE 4100 platform provides a seamless transition from a TDM-centric network to a packet-centric network, morphing from a SONET MSPP into a native Ethernet edge platform.

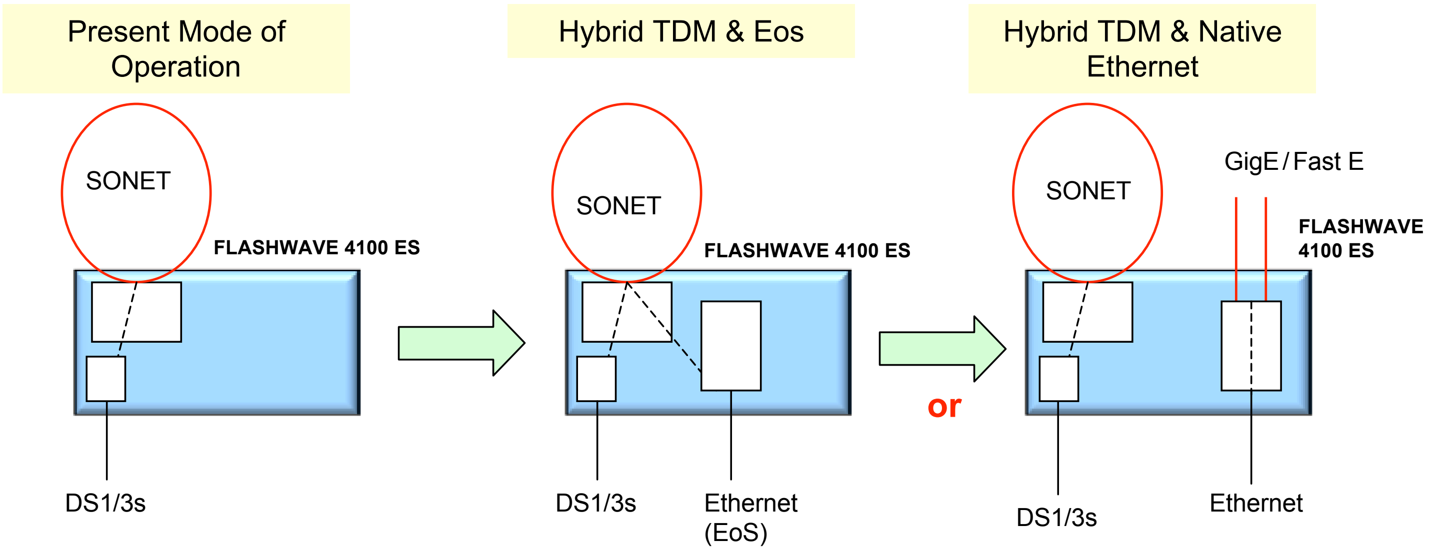



**Figure 10: FLASHWAVE 4100 Extension Shelf Ethernet Options**

## Ethernet Overlay Model

A single MSPP supporting both TDM and Ethernet services, as shown in Figure 10, is very cost-effective and efficient for mobile backhaul transport. This model also allows a seamless transition to supporting Ethernet 4G LTE services. Unfortunately, due to regulatory, administrative, or operational restrictions, not all carriers have the freedom to mix TDM and packet services on a common platform or infrastructure. For those carriers, an Ethernet overlay model, illustrated in Figure 11, is the best choice for 4G LTE mobile backhaul.

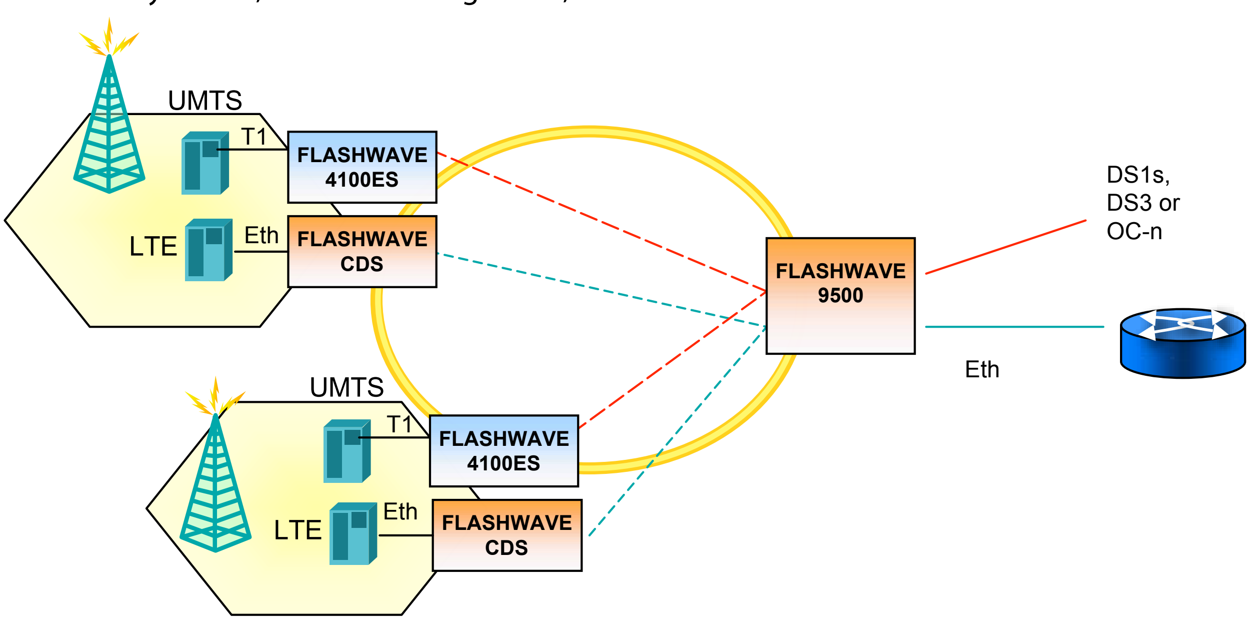



**Figure 11: Ethernet Overlay Model**

In an Ethernet overlay model, legacy T1 TDM services for 2G/3G systems are provided by existing methods; either copper-fed T1s or optically fed MSPP shown in Figure 8. As 4G LTE base stations are deployed, a separate Ethernet edge platform is deployed to provide connection-oriented, carrier-grade Ethernet services (100Base-T, 100FX, or GigE). Figure 11 shows a single fiber system for clarity, but keep in mind that each of these systems is connected by separate fiber networks—SONET for the MSPPs and GigE for the Ethernet edge platforms. The FLASHWAVE CDS Ethernet Edge platform is a compact, 2U-high platform that provides two universal interface slots. A number of different service modules are available in varying port and speed configurations, all providing carrier Ethernet and Ethernet service OAM.

**Figure 12: FLASHWAVE CDS Ethernet Edge Platform**

## Ethernet Greenfield Model

For true Ethernet greenfield models, where no TDM requirement exists, the model is the same as shown above, but without the legacy MSPP. This application might result from a new 4G LTE-only tower location, or from the fact that the legacy T1 transport requirements are already being met by existing T1 copper, microwave, or alternative carrier connections. Whatever the circumstance, the carrier requirements are for 4G LTE Ethernet-only transport and the recommended solution is a combination of an Ethernet edge platform (FLASHWAVE CDS) at the cell sites and an Ethernet aggregation node (FLASHWAVE 9500) at the MSC, as shown in Figure 13.

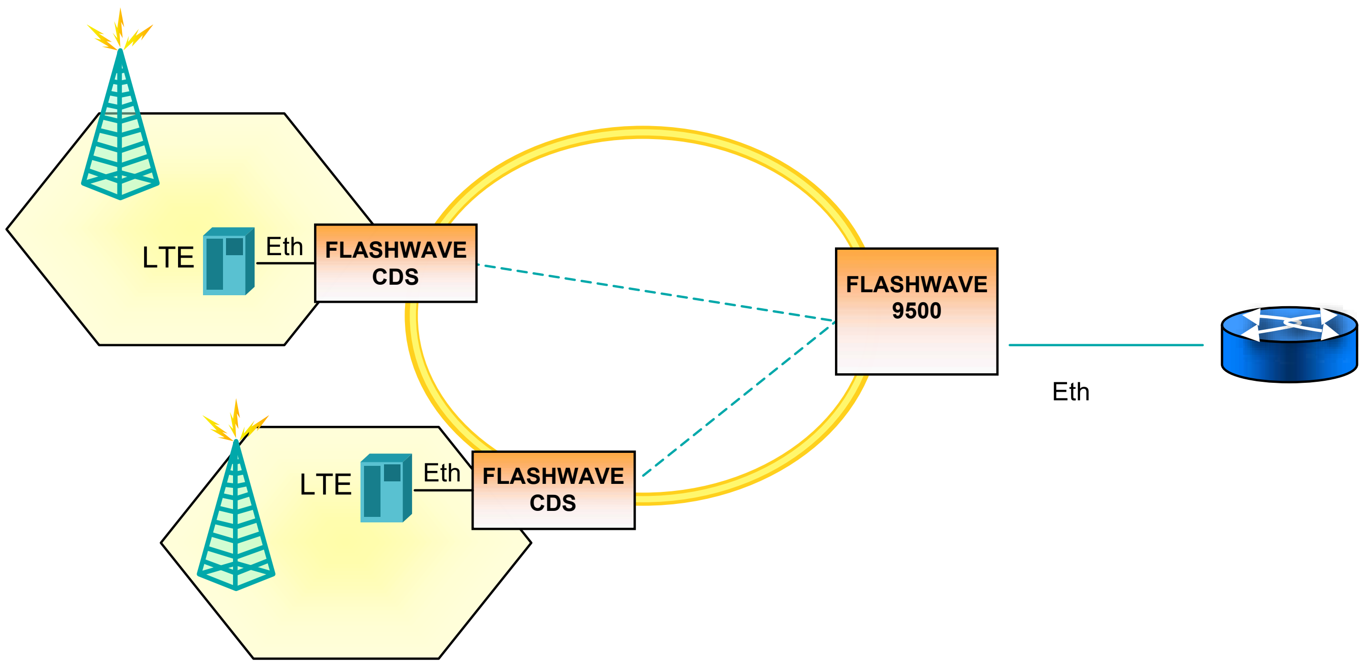



**Figure 13: Ethernet Greenfield Model**

## Conclusion

The introduction of 4G LTE wireless systems involves fundamental differences in the architecture and backhaul requirements for these networks. LTE systems are based on a flatter, all-packet (IP/Ethernet) architecture with significantly higher bandwidths than existing GSM 2G and UMTS 3G networks. Reliance on Ethernet to provide physical layer connectivity is driving the need for Ethernet services to cell sites in anticipation of LTE deployments in late 2010 or early 2011. LTE technical demonstrations have achieved remarkable data rates, but in real-world applications with more typical spectrum sizes, the bandwidth required at cell sites is projected to be 40–50 Mbps. Given the large deployments of existing GSM 2G and UMTS 3G systems, which will remain in the network for many years, there is a real need to provide backhaul transport for both T1 TDM and Ethernet services. While T1 CES offers a method of carrying TDM services over a packet-only network, many wireless carriers remain averse to allowing their TDM services to be transported over Ethernet/IP networks due to latency, jitter, and efficiency issues in T1 CES. For those cell sites with a preexisting MSPP, the addition of an Ethernet interface card provides a very simple and cost-efficient method to supporting 4G LTE networks. However, a single mobile backhaul solution will likely not fit all carriers or all deployment scenarios. Three carrier examples are provided for the TDM/Ethernet hybrid model, Ethernet overlay model, and Ethernet greenfield model.

## References

[1] MEF 3, "Circuit Emulation Service Definitions, Framework and Requirements in Metro Ethernet Networks," sections 9.1, 9.2 and 9.4, April 13, 2004

[2] GR-496-Core, "SONET ADM Generic Criteria," section 3.3.5.5, Issue 1, Dec. 1998

| Acronym | Description |
|---|---|
| 3GPP | Third Generation Partnership Project |
| 4G | Fourth Generation Wireless |
| CES | Circuit Emulation Service |
| DSL | Digital Subscriber Line |
| EDGE | Enhanced Data rate for GSM Evolution |
| EoS | Ethernet over SONET |
| FCC | Federal Communications Commission |
| GGSN | Gateway GPRS Support Node |
| GSM | Global System for Mobile Communications |
| HSPDA | High Speed Packet Downlink Access |
| LTE | Long Term Evolution |
| MEF | Metro Ethernet Forum |
| MGW | Media Gateway |
| MIMO | Multiple Input Multiple Output [antenna] |
| MSC | Mobile Switching Center |
| MSPP | Multi-Service Provisioning Platform |
| OFDM | Orthogonal Frequency Division Multiplexing |
| PDN GW | Packet Data Network Gateway |
| PSTN | Public Switched Telephone Network |
| RNC | Radio Network Controller |
| SGW | Serving Gateway |
| SONET | Synchronous Optical Network |
| TDM | Time Division Multiplex |
| TX/RX | Transmit/Receive |
| UMTS | Universal Mobile Telecommunications System |



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