APPLICATION BRIEF

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Services and Applications Perspective

Timing and Synchronization in Next-Generation Wireless Networks

Introduction

Mobile operators are racing to deploy high-speed data services in order to acquire and retain lucrative mobile professional users. Because high-speed data services require increased backhaul capacity, mobile operators are seeking alternative, lower-cost backhaul methods in order to meet increasing data demands. At the same time, cost-reduction measures must not sacrifice consistent and high-quality service. As the network shifts to an Ethernet/IP backhaul, maintaining precise frequency distribution throughout the network is essential for maintaining service level assurance. The quality of synchronization mobile operators put into their network directly impacts the quality of service (QoS) that comes out of their network.

The transmission of voice, video and data through any communication network requires a stable frequency reference, and precise frequency synchronization is especially critical in mobile networks for the successful call signal hand-off between base stations as well as for the transport of real-time services. Global System for Mobile communications (GSM) and Universal Mobile Telecommunications System (UMTS) base stations must hold a carrier frequency accuracy of ±50 parts per billion (ppb) over the 10-year service life of the equipment. If individual base stations drift outside the specified 50 ppb limit, mobile hand-off performance decays, resulting in high dropped-call rates, impaired data services, and, ultimately, lost customers. The problem is, as backhaul transmission networks transition to Ethernet/IP backhaul, base stations become isolated from their source of network synchronization. Carriers are looking to deploy stand alone clocks at the base stations, or new packet based synchronization distribution technologies.

Mobile Communication System Synchronization Today

Accepted best practice for GSM and CDMA mobile operators is to implement comprehensive synchronization plans to assure high quality of service in their competitive marketplace. Figure 1 shows a simplified view of a GSM network illustrating the synchronization requirements at each level. Common practice is to install primary reference clocks (PRC), and synchronization distribution elements in mobile switching centers (MSC), and base station controller (BSC) sites to directly synchronize all transmission equipment in the mobile network. Synchronization distribution elements take the form of synchronization supply units (SSU) in ETSI markets, and building integrated timing supplies (BITS) in ANSI markets. SSU and BITS elements lock to PRCs, and support a wide range of synchronization interfaces and protocols with full redundancy and advanced holdover capabilities to assure network uptime. The synchronization elements provide for management and distribution of all synchronization signals in the network.

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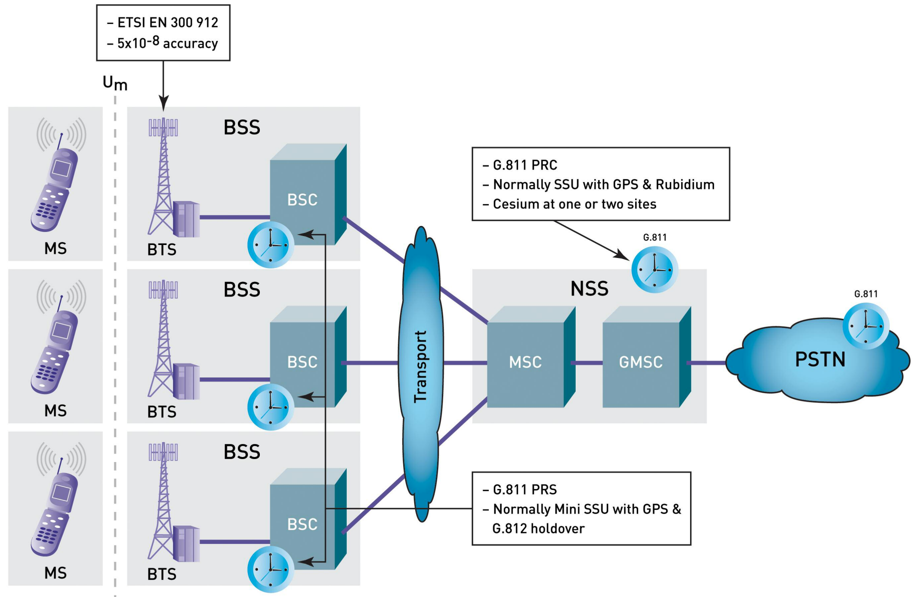

FIG. 1 Simplified view of GSM network showing placement of PRCs and SSU/BITS at MSC and BSC locations to meet synchronization requirements

Mobile networks rely on synchronization to assure high QoS.

GSM base stations have traditionally derived their long-term frequency accuracy from locking a relatively low-performance quartz oscillator embedded in the base station to a recovered clock signal from the T1/E1 leased line backhaul facility. Timing signals based on a PRC transmitted over the time-division multiplexing (TDM) backhaul keep the embedded oscillator calibrated to within sufficient accuracy. Without a well-synchronized backhaul feed to lock to, the oscillator frequency would drift out of specification in a matter of months, requiring regular and costly service calls to manually calibrate oscillators across base stations throughout the network. Thus, a reliable and accurate clock source is required for accurate synchronization.

It is important to note that even base stations that still make use of a T1/E1 backhaul are beginning to experience levels of degradation that reduce QoS to the point that customers notice. Latency, jitter and wander were fairly consistent in the past, given how well-timed T1/E1 lines were. However, as many backhaul providers increase the use of circuit emulation or IP encapsulation technologies to reduce their infrastructure costs, consistency of synchronization suffers. In addition, many providers are now transporting T1/E1s over a synchronous optical network (SONET) that introduces large phase deviations due to SONET pointer adjustments. SONET pointer adjustments can significantly degrade the stability of synchronization seen at the base station. The introduction of such errors can be large enough to isolate a base station, effectively cutting it off from its source of synchronization. As synchronization instability increases, so does the number of dropped calls contributing to user churn. Figure 2 shows results of actual field measurements taken on UMTS Node B base stations where the synchronization on the E1 backhaul was impaired. Installation of PRC quality synchronization at the base station sites immediately corrected the dropped call problem.

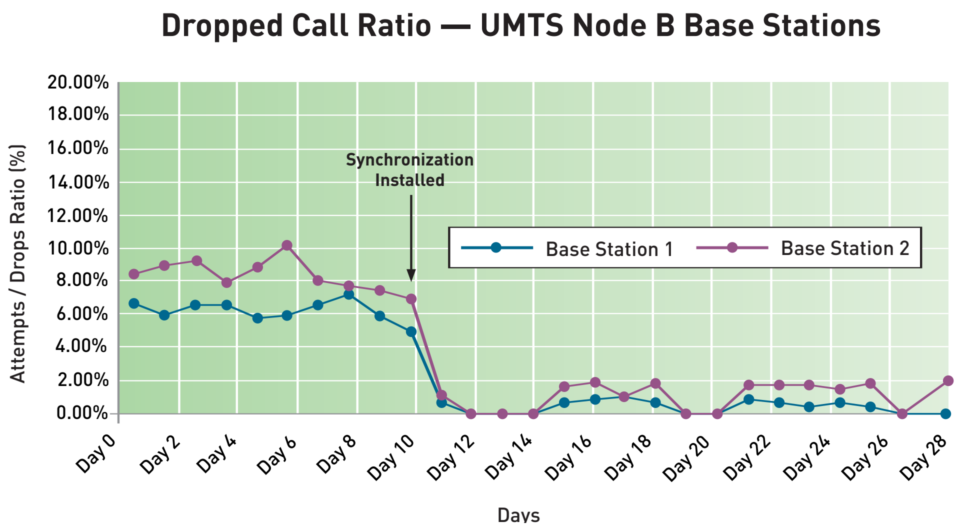

FIG. 2 Field measurements of UMTS Node B base stations show a dramatic reduction in dropped calls after correction of synchronization impairments.

Until recently, synchronization of GSM/UMTS base stations has been taken for granted. As long as the T1/E1s were well timed, the base station could hold the 50 ppb requirement indefinitely. However, as backhaul transport evolves toward IP, base stations can no longer rely on recovering synchronization from the network side. In order to maintain consistent, quality connectivity, base station equipment manufacturers and backhaul service providers must take timing into consideration. New methods of synchronization are required to meet rising expectations of next-generation mobile users (See Table 1).

Synchronization reduces dropped calls in wireless networks.

Timeframe	Base Station Backhaul Transport	BTS Sync Reliability/Availability
Yesterday	Tightly controlled transport provided by the PTT/ILECs	Reliable sync recovery
Today	Complex menu of alternate backhaul providers and transport topologies	Uncertain sync recovery
Tomorrow	High-capacity, low-cost IP/Ethernet backhaul pipes	Traditional sync recovery no longer available. New methods required.

TABLE 1 Mobile operators need to take direct control of synchronization at their base station sites to assure high QoS.

Ethernet Backhaul Creates Synchronization Islands

When base stations carried just voice traffic, a single T1/E1 connection typically provided enough bandwidth for the backhaul connection. The rollout of third-generation (3G) data services, however, has increased the bandwidth needs for the backhaul connection significantly, and moving to T3/E3 connections is simply too expensive.

Transport networks are rapidly evolving to IP-rich topologies. This offers mobile operators the increased backhaul capacity they require for deployment of high-bandwidth data services and the cost advantage of IP transport. However, the move to Ethernet backhaul will eliminate the option for base station clock recovery from the backhaul facility. Operators will need to move to an independent source of synchronization at the base station to meet the UMTS 50 ppb requirement (Figure 3).

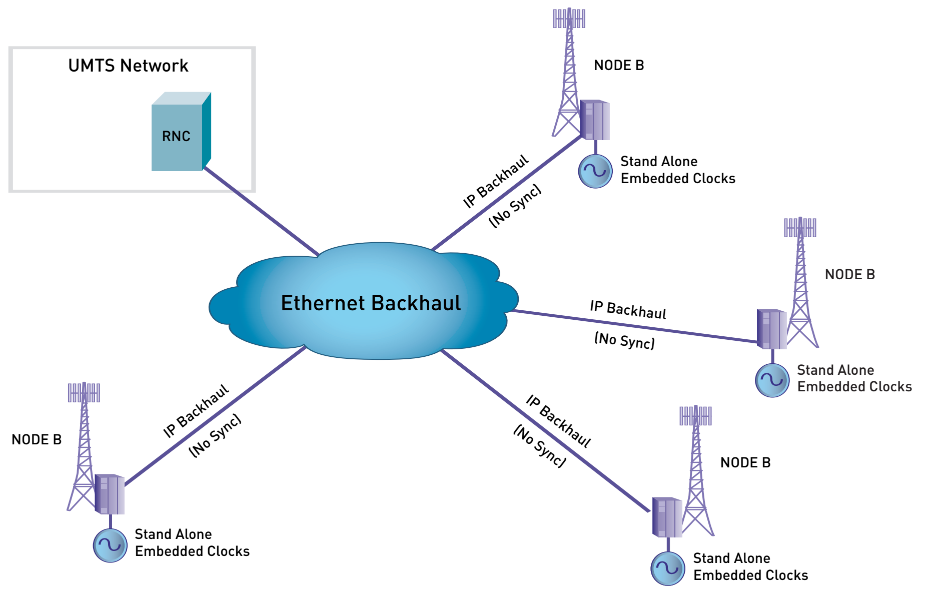

FIG. 3 The transition to high capacity Ethernet backhaul drives the need for stand-alone embedded clocks in UMTS Node B base stations.

Backhaul changes isolate base stations from their traditional source of synchronization.

Synchronization Options

There are three main options to restore synchronization to base stations that have been isolated from traditional PRC traceable TDM synchronization feeds:

- GPS-based Retimers
- Embedded stand alone clocks
- Packet based synchronization protocols

GPS-based retimers

Changing the backhaul to circuit emulation services (CES), such as the satellite transport solution shown in Figure 4, requires that a local source of synchronization be placed at the base station to deliver an accurate clock reference since the satellite network cannot support the 50 ppb requirement on its own. There are two ways to achieve this: 1) install an external GPS clock to externally time the base station equipment, or 2) use a GPS-based retimer.

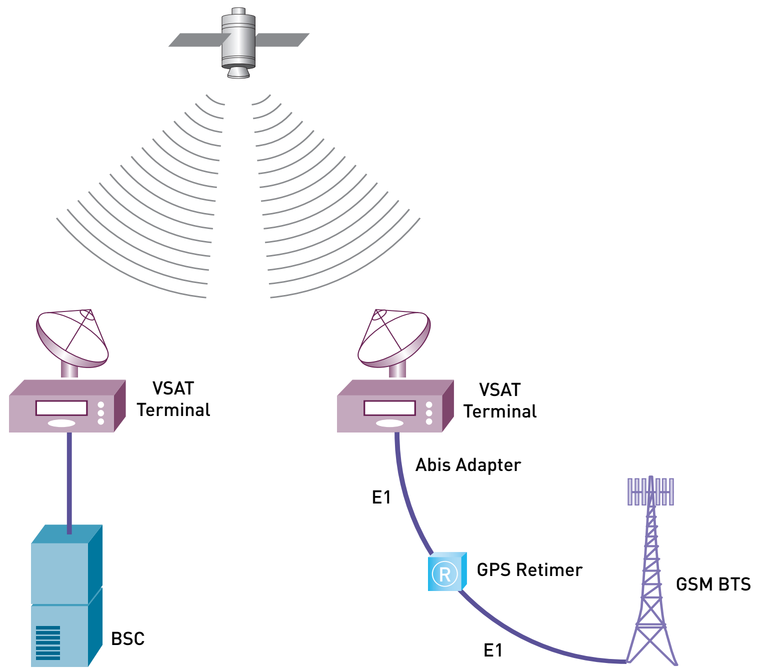

FIG. 4 Satellite backhaul providers rely on GPS based retimers to insert quality synchronization onto the T1/E1 feed to the base station.

A GPS-based retimer buffers incoming traffic and clocks it back out with PRC level stability (See Figure 5). A retimer can be transparently introduced to an existing base station as the retimer is placed on the back-haul feed directly before the base station. The timing signal the base station receives is reclocked to be precise and stable, enabling accurate synchronization between base stations. GPS based retimers are a common tool to address trouble sites where high dropped call rates are due to degraded synchronization on the T1/E1 backhaul feeds resulting from issues such as SONET pointer adjustments, or CES encapsulation.

GPS based retimers can be used to restore synchronization at remote base station sites.

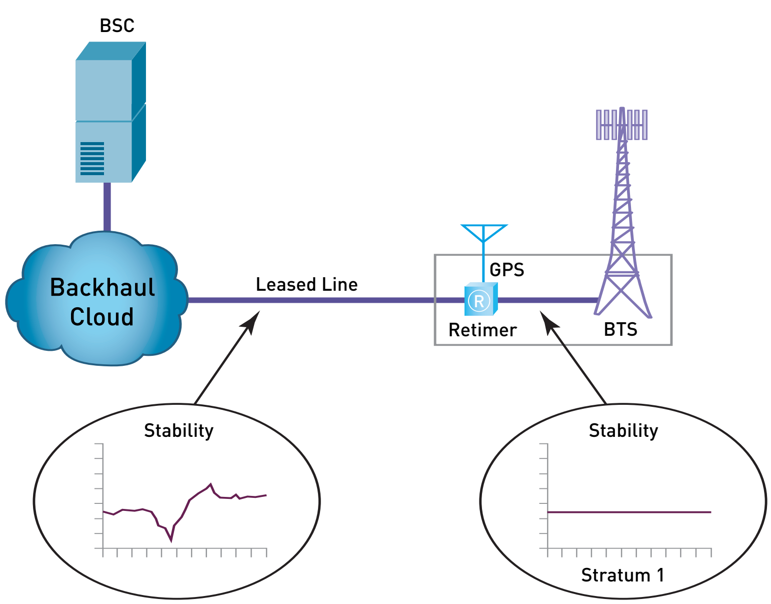

FIG. 5 Retiming at the BTS site can eliminate synchronization impairments on the backhaul connection resulting in reduced dropped calls at "trouble sites".

Embedded stand alone clocks

UMTS Node B infrastructure suppliers are introducing high-quality embedded clock options to be ready for IP/Ethernet backhaul. Many of these options mirror Code Division Multiple Access (CDMA) 2000 designs where GPS clocks are embedded into the base stations to provide a time-of-day reference needed for call hand-offs. CDMA networks have always relied on embedded GPS-based clocks with precision rubidium or quartz holdover oscillators, making them inherently prepared for the evolution to IP backhaul from a sync quality point of view.

GPS, as well as the packet base synchronization protocols discussed below, are used to drive servo control of high precision oscillators located in the base stations. There are cases where the oscillator must free run independent from the aid of any external reference. Using rubidium-based oscillators is the most robust solution for independent synchronization of UMTS base stations, as rubidium oscillators are proven to meet the 50 ppb requirement over the full service life of the equipment. Quartz oscillators, on the other hand, are subject to higher native aging rates and warm-up/restabilization characteristics that make it difficult to assure compliance to the 50 ppb requirement for more than 6-12 months. This exposes network operators to QoS degradation and potentially high maintenance costs associated with manually calibrating quartz oscillators to bring them back on frequency in the field. The danger to the operator is that this type of failure is undetectable until QoS issues reach a critical threshold.

IEEE 1588 Precision Time Protocol delivers synchronization over Ethernet.

Packet Based Synchronization Protocols

Much effort is underway to deliver a method to reliably tunnel timing signals through the IP network. One of the more promising technologies currently under study is the Institute of Electrical and Electronics Engineers (IEEE) 1588 precision time protocol (PTP). The IEEE 1588 PTP standard was developed to support Ethernet local area network (LAN) environments for applications such as factory automation where distributed motors and servos need to be accurately time synchronized. Working groups in the IEEE are currently enhancing the IEEE 1588 PTP protocol for use in telecom wide area network (WAN) applications. IEEE 1588 PTP is based on a master clock exchanging two-way timing packets over Ethernet with slave clocks embedded in the equipment requiring synchronization. For example, carriers will place master clocks in their network, which will serve multiple local base stations, typically within a few hops from the master clock (Figure 6).

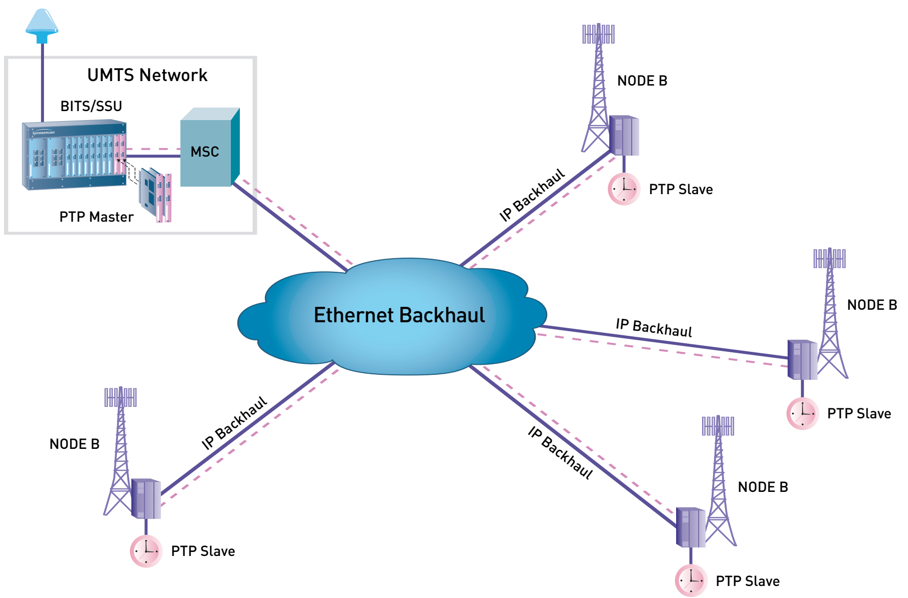

FIG. 6 Delivery of synchronization to next generation UMTS base stations will rely on PTP grandmaster clocks deployed in the MSCs. Sync packets flow from the grandmaster clock to slave clocks in the base stations.

IEEE 1588 PTP is similar in concept to NTP. Both protocols distribute time packets inband with the payload traffic. NTP is ubiquitous and operates at the upper layers. PTP is a specialized layer two protocol with hardware timestamping to provide sub-microsecond accuracy. Performance over a telecom WAN is determined by three main factors:

- The resolution and accuracy of the NTP or PTP timestamping engines in the server and client (the accuracy you begin with).
- Packet Delay Variation (PDV) through the WAN (hop count, loading, and switch/router configuration)
- Servo processing gain and oscillator selection at the client side (how effectively PDV uncertainty can be filtered out)

Carrier class NTP timestamping engines can be made to approach the accuracy of PTP engines, but they must be paired with equally precise NTP clients with hardware timestamping to realize the performance gain. Given a high degree of starting precision, Packet Delay Variation (PDV) over telecom networks rapidly becomes the dominant source of error for packet based timing solutions. Layer two switched networks with attention to QoS provisioning and loading variations will provide the best PDV performance. This aligns well with IEEE 1588 PTP as it is optimized for layer two switching environments. Performance over layer three routed networks will show little time-stamping stability difference between NTP and PTP due to the high PDV uncertainty through layer three software based routers. PDV will dominate for layer three software routed networks. Choice of oscillator stability, and servo design at the client side will be a key performance factor to assure base station compliance to the 50 ppb requirement.

NGN SSU/BITS platforms add support for NTP and PTP protocols to deliver timing over packet networks.

To support IEEE 1588 PTP, all base stations will include a PTP slave clock that will calibrate itself to the master clock using a two-way protocol. The master clock function will be implemented as new circuit cards to be installed in the existing SSU or BITS synchronization elements located in the wireless networks as detailed earlier in figure 6. Table 2 provides a summary of synchronization solutions utilized in traditional circuit switched wireless networks, as well as next generation packet switched networks. SSU/BITS synchronization platforms take on the added role of providing carrier grade NTP and PTP functionality to provide synchronization over Ethernet backhaul feeds to remote base stations.

Circuit versus Packet Transport	PRC	SSU/BITS	TDM Line Timing	T1/E1 Retimer	GPS	NTP	PTP
Circuit Switched TDM							
MSC & BSC/RNC	✓	✓					
GSM/UMTS Base Stations			✓	Optional			
CDMA Base Stations					✓		
Packet Switched IP/Ethernet							
MSC & BSC/RNC	✓	✓				Server	Master
GSM/UMTS Base Stations			N/A	N/A	Optional	Client	Slave
CDMA Base Stations					✓		

TABLE 2 NGN SSU/BITS platforms add support for NTP and PTP protocols to deliver timing over packet networks to remote base stations. Synchronization options for "All-IP" UMTS base stations include PTP, NTP, and GPS. Free running rubidium atomic oscillators are recommended in cases where PTP, NTP, or GPS are not available.

Conclusion

The future of the telecom industry is IP. However, in order to keep customers long enough to enjoy infrastructure savings, carriers must implement mechanisms for maintaining quality connectivity through synchronization accuracy. Accurate synchronization is the Achilles' heel of today's mobile cellular networks. The cost of customer churn as a result of poor QoS from dropped calls and other sources can dwarf the savings achieved by moving to IP. Efforts are in motion to increase the reliability of clock signals transported over IP. Carrier grade NTP and IEEE 1588 PTP implementations will be fully integrated into existing SSU and BITS synchronization infrastructure offering wireless carriers a robust and efficient way to support timing over IP applications.

Symmetricom

SYMMETRICOM, INC.
2300 Orchard Parkway
San Jose, California
95131-1017
tel: 408.433.0910
fax: 408.428.7896
info@symmetricom.com
www.symmetricom.com