HEAVY READING

White Paper

New Synchronization Requirements for 4G Backhaul & Fronthaul

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Introduction

With industry leaders such as Ericsson claiming that "spectrum is the new oil" driving the emerging digital economy, there can be no doubt as to the weight of expectation on mobile operators where network capacity is concerned.

Year after year, customers expect mobile operators to somehow keep at least one step ahead of the acceleration in mobile data consumption. Operators must somehow deliver on a long-term capacity roadmap that will allow customers to consume whatever high-bandwidth services they want, wherever and whenever they want them. And investors expect them to do all this without increasing the total cost of ownership of the network, taking account of both capex and opex.

This white paper examines the available options for operators with Long Term Evolution (LTE), LTE-Advanced (LTE-A) and the various small cell and centralized radio access network (C-RAN) architecture options for implementing them. The paper provides examples of early deployments of these techniques and architectures and discusses the associated requirements for network synchronization and synchronization testing as these capacity enhancements are rolled out.

Efficient Use of Spectrum & Network Assets

Consistent with a "spectrum is the new oil" perspective, mobile operators continue to value radio spectrum above any other asset. The mobile communications industry is already gearing up for upcoming World Radiocommunications Conferences (WRC) to see what spectrum can be secured for 5G below 5 GHz at WRC 2015 and above 10 GHz at the next WRC in 2018 or 2019.

Obtaining absolute quantities of spectrum represents just one part of an operator's agenda for driving network capacity. At least from a network engineering or network operations perspective, that's also by far the easiest part. The far more challenging aspect of an operator's strategy for driving its capacity roadmap is taking the spectrum resources that are available and using them with maximum efficiency.

From a very high-level perspective, this means driving the maximum possible number of bits per second through a given hertz of spectrum (bit/s/Hz). From the more granular perspective of a cellular network planner, that core objective co-exists with the key context of having to also make provision for a variety of differing end-user requirements and behaviors, such as bursts of very high speeds, good performance at the cell edge and variability in the amount of traffic hitting a given cell in the network. And the objective must be pursued in the context of daily challenges, such as interference between neighboring cells using the same frequencies.

Cell Site Densification & De-Coupling of Baseband & Radio Elements

Operators continue to drive greater efficiency out of their existing macro sites, for example by adding carriers. In addition, consistent with the primary goal of driving the greatest possible spectral efficiency, cell site densification features are at the heart of any mobile operator's strategy for growing network capacity.

With the sufficiently large sites for hosting macro cells increasingly hard to find in many urban areas, operators are increasingly looking toward small cells for increasing capacity, as well as for coverage fill-in. Small cells form a critical part of an operator's strategy because of the contribution they can make to spectral efficiency: Since they can reuse the same spectrum as the macro layers, small cells drive up the bit/s/Hz in that given spectrum.

While densifying the distribution of cell sites using smaller cells is one key objective, there is also a parallel development in cellular network architectures underway that promises further, substantial, costs savings in the RAN – the so-called C-RAN. The value proposition here is in separating out the baseband and radio frequency (RF) components of the base station. This enables capex and opex savings by using a centralized pool of baseband processing or baseband units (BBUs) to support multiple standalone remote radio units (RRUs). The primary opex savings are on real estate and power, while the primary capex savings tend to be on RAN and backhaul equipment costs.

This contrasts with deploying integrated baseband and RF elements per cell with conventional macro stations, as well as the small cell model in which integrated mini base stations are deployed. The separated RRU and BBU elements in the C-RAN model then communicate via an open interface such as Common Public Radio Interface (CPRI) or Open Base Station Architecture Initiative (OBSAI), comprising digitized RF. Because the transport from the base station back to the network is referred to as the backhaul in a conventional integrated base station architecture, the open interface between the RF head and the baseband is called the "fronthaul" in a split C-RAN architecture.

While traditional RAN architectures, supported by traditional backhaul, will remain the predominant model for many suburban and most rural cites in the coming years, C-RAN architectures, which add a CPRI-based fronthaul component to the architecture, are becoming an important option in dense urban environments.

A Menu of Options for LTE Advanced & C-RAN

The introduction above explores the mobile operators' objectives where capacity is concerned and offers a high-level view of some of the tools at their disposal. This section provides more detail with respect to some of the specific options that operators around the world are investing in. It also provides some examples of specific operators and what they are doing.

With LTE-A from 3GPP Release 10, which is now being widely rolled out, several new capacity-enhancing features are available. Few mobile operators are likely to implement every single one of them; most will implement a number from the available menu, consistent with their unique market and technology environment and business objectives. The options available to operators from R10 LTE-A features include:

- **Carrier Aggregation** provides for a phased introduction of the ability to aggregate up to five 20MHz carriers from a variety of different spectrum bands, as well as a combination of frequency-division duplex (FDD) and time-division duplex (TDD) modes. This enables very high throughput bursts without requiring contiguous frequency bands.
- **High-Order MIMO** provides up to 8x8 downlink multiple input/output (MIMO) and 4x4 uplink MIMO for higher peak data rates.
- **Enhanced Inter-Cell Interference Coordination (eICIC)** is designed to enable better management of interference between layers in heterogeneous

networks (HetNets) that feature macro, micro and small cell layers, using and reusing some of the same frequencies.

- **Coordinated Multi-Point (CoMP)** transmission/scheduling. Used on the uplink, CoMP selects and combines signals from as many as eight eNodeBs to improve cell edge throughput and performance, typically in a HetNet environment including small cells.

Figure 1: Operators Deploying LTE-A Features 2013-2015

COUNTRY	OPERATOR	TRADITIONAL OR C-RAN?	LTE/LTE-A FEATURES
U.K.	EE	Traditional RAN	Carrier Aggregation
U.S.	AT&T	Traditional RAN	Carrier Aggregation
Australia	Telstra	Traditional RAN	Carrier Aggregation
South Korea	LG uPlus	C-RAN	Carrier Aggregation, UpLink CoMP
South Korea	SKT	C-RAN	Carrier Aggregation, Uplink Comp, eICIC
China	China Mobile	C-RAN	TD-LTE
Japan	Softbank	C-RAN	4X4 Uplink MIMO, eICIC, Uplink CoMP
Japan	NTT Docomo	C-RAN	Carrier Aggregation & eICIC

Source: Heavy Reading

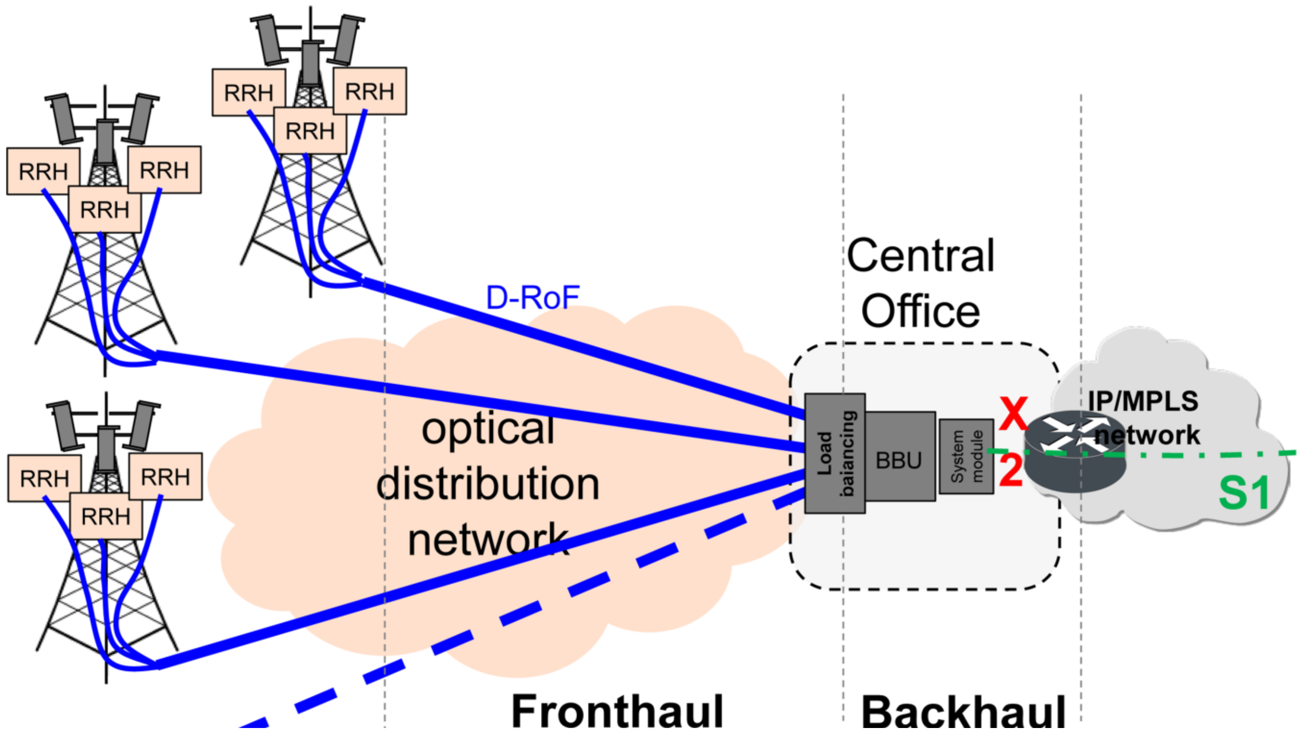
The Opportunity for C-RAN Architectures

As operators contemplate using C-RAN – either in conjunction with LTE-A features at launch, or with a view to layering in such features over time – they also face a menu of options with respect to different types of C-RAN or fronthaul architecture. These include:

- **Centralized RAN (C-RAN),** in which BBU resources serve RRUs deployed for macro or micro cell coverage and capacity.
- **Distributed RAN (D-RAN),** in which BBU resources serve RRUs deployed for small cell coverage or capacity. This will typically be in addition to that same BBU pool serving RRUs deployed for macro or micro, rather than separate from that.
- **Cloud RAN,** in which potentially hundreds of RRUs share the same pool of BBU resources, as compared with a handful of RRUs sharing the same BBU according to many of today's C-RAN models.
- **Virtualized RAN,** in which the BBU is built on commercial-off-the-shelf (COTS) hardware, rather than on a RAN vendor's proprietary hardware.

Regardless of their differences, these architectures all share the same split baseband and RF characteristic. For that reason they all support a CPRI or OBSAI interface between those two elements that the operator must take account of in its network planning. And for that reason too they can all be considered as being "fronthaul" architectures.

Figure 2: A C-RAN Architecture Using Backhaul & Fronthaul



Source: Orange

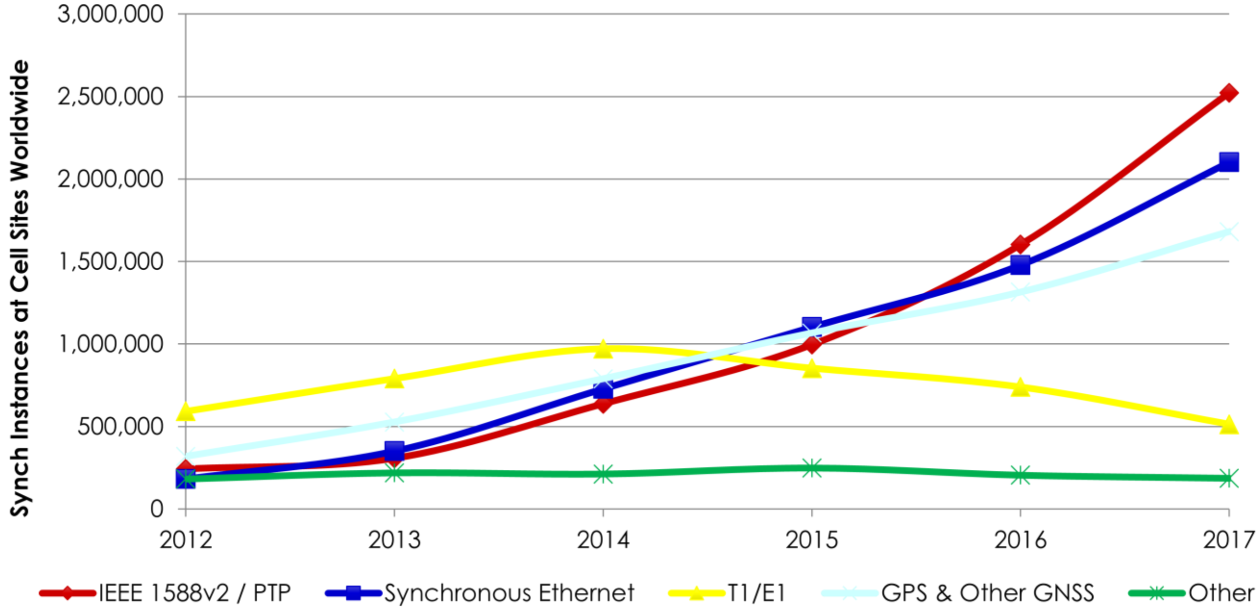
New Backhaul Synchronization Requirements

Until quite recently, most mobile backhaul networks have only needed to support frequency synchronization. 3G Wideband CDMA, for example, requires frequency synchronization accuracy as low as 50 parts per billion. When 3G W-CDMA was first rolled out, conformance to this frequency synchronization requirement was assured by the use of time-division multiplexing (TDM) backhaul, which has frequency timing baked into the standard.

Recent years have seen operators change the way that they implement frequency synchronization in the backhaul. There are still some operators using TDM for frequency synchronization of 2G and 3G networks, even when they have packet backhaul in place. But as shown in **Figure 3**, leading mobile operators throughout the world are increasingly turning to new packet-based standards, such as Synchronous Ethernet and IEEE 1588v2 PTP, as well as Global Navigation Satellite Systems (GNSS), such as GPS, to meet synchronization requirements.

Figure 3 shows that adoption of the new standards for synchronization over packet backhaul is increasing, while dependence on TDM in declining. Initially the main driver for investing in new synchronization standards was to use one of the new standards to deliver frequency synchronization while achieving overall cost savings by retiring the legacy TDM network altogether. And many operators have already done this, solely for 3G.

Figure 3: Adoption of Synchronization Standards for IP Backhaul



Source: Heavy Reading's Ethernet Backhaul Tracker, November 2014

The adoption of these synchronization standards is being given substantial impetus by the evolution to 4G. First, because LTE is an all-IP network, TDM backhaul is no longer an option for 4G. And second, the LTE roadmap increasingly requires not just frequency synchronization, but also time and phase synchronization.

New Phase Synchronization Requirements

In the LTE roadmap, the need for time and phase synchronization begins with TD-LTE. Besides requiring frequency synchronization, TD-LTE also requires phase synchronization to plus or minus 1.5 microseconds (µs) for cells with a radius lower than 3 km. This represents a fundamental change for the operator, for the following reasons:

- The only mobile operators with experience implementing phase synchronization prior to TD-LTE are the small minority that have deployed CDMA2000.
- Even those CDMA2000 operators typically required phase synchronization of 5 µs, not the more stringent 1.5 µs demanded by TD-LTE.
- Most CDMA2000 operators have delivered 5 µs phase synchronization using GPS, which is suitable for many macro cell deployments but faces significant cost and line-of-sight challenges in small cell deployments at street level. It also has some significant security vulnerabilities.
- Since TD-LTE's phase synchronization requirements are so stringent, most operators worldwide recognize the need for more than one of the three major synchronization standards to be deployed. And since Synchronous Ethernet can only support frequency and not phase synchronization, IEEE 1588 PTP will inevitably be adopted as one of the standards when 4G operators increasingly come to require phase synchronization.

According to the GSM Supplier Association there were 40 commercial TD-LTE networks in service as of October 2014. In addition to TD-LTE pioneers in India and China, those already offering commercial TD-LTE networks with phase synchronization include Sprint (U.S.), Optus (Australia), Megafon (Russia) and STC and Mobily (Saudi Arabia). Many other mobile operators will inevitably roll out TD-LTE with phase synchronization over the next couple of years.

Synchronization With LTE-A & C-RAN Architectures

And TD-LTE is only the first step on the roadmap of the LTE roadmap that requires phase synchronization. As LTE-A features and C-RAN architectures are rolled out, additional requirements are added from a synchronization perspective, and these will impact operators providing TD-LTE, as well as LTE FDD:

- Both eICIC and CoMP require phase synchronization, potentially as low as 1 µs – lower than any commercial mobile network has ever achieved.
- Once the operator has opted to roll out either TD-LTE or some LTE-A features requiring phase synchronization over any of the four fronthaul architectures listed, then full account must be taken of the very specific implications of the C-RAN architecture for the operator's synchronization targets.
- LTE Broadcast, which allows multi-casting of popular content for greater spectrum efficiency, also requires phase synchronization. This has already been launched by KT (South Korea) and many other operators, such as Everything Everywhere (U.K.), Verizon (U.S), AT&T (U.S), China Mobile (China) and Telstra (Australia), are also engaged in significant trials with a view to commercial deployment.

The rollout of new LTE releases, and the adoption of new standards to support the new synchronization requirements associated with them, is requiring the adoption of new testing solutions to ensure that these protocols are delivering synchronization to the more stringent standards mandated by 3GPP in LTE and LTE-A.

Performance Requirements for the Fronthaul

As has been described, C-RAN architectures featuring a fronthaul component are a valuable tool in the mobile operator's efforts to grow capacity in urban areas in line with user requirements, as well as high spectral efficiency targets.

When first envisaged, the CPRI interface was designed to enable open interoperability between different BBU and RRU elements over relatively short distances and assumed dark fiber. Since then, however, it has been deployed over tens of kilometers. The delay allowed between them is on the order of a few hundred µs, of which the CPRI standard allows a maximum of 5 µs for CPRI processing. The potential of that architecture has nevertheless since been extended, so operators now want to be able to pair potentially hundreds of RRUs to a baseband unit over CPRI, and to pair some of them over distances of tens of kilometers.

When developing their C-RAN architectures for commercial deployment, operators must carefully limit the amount of delay introduced to the fronthaul when the baseband and the RRU are separated by long distances. They also need to accurately measure the actual performance. The addition of some delay is inevitable, since the speed of light is finite, covering around 1 km in 5 µs. Hence a distance of 10 km inevitably adds around 50 µs of latency to the fronthaul interface.

Lit Fiber Options Create Additional Challenges

This in itself must be factored in relative to the operator's ability to achieve its end-to-end synchronization requirements for eICIC and CoMP. However, the challenge is further complicated by the fact that, in light of the number of RRUs that operators are looking to aggregate onto a single fiber, many operators intend to use shared lit fiber solutions as well as dark fiber in the fronthaul.

These operators are looking at a variety of different options for more efficient fiber utilization, including:

- Point-to-point fiber
- Coarse wavelength-division multiplexing (CWDM)
- Dense wavelength-division multiplexing (DWDM)
- Optical transport network (OTN)
- Passive optical networks (PON)
- Carrier Ethernet

Microwave solutions for fronthaul have even been evaluated. The issue with introducing any active network elements on the fronthaul is that they risk introducing additional latency and jitter. Additional delay arises in the form of latency caused by additional processing contributed by other active network elements. Similarly, some types of processing can also generate jitter, which can cause errors in clock recovery at the remote radio head.

Jitter Performance Requirements

The CPRI standard itself only allows a maximum of two parts per billion jitter contribution on the fronthaul link. Failing to achieve that can not only impact the frequency accuracy at the RRU RF output, but can also impact the performance of other elements that use that clock subsequently. This all requires careful trade-offs in the C-RAN architecture to ensure that it remains aligned with the new synchronization requirements.

Each of the candidate technologies listed above has a unique profile in terms of the additional delay and jitter it adds when used on the fronthaul interface. It is low enough to be manageable in the case of most of the above options, but it may be too much to bear in the case of some switched services like OTN and carrier Ethernet, especially if they are not sufficiently well designed.

A wholly different C-RAN architecture that integrates the lower-layer baseband processing with the RRU, leaving just the higher-layer baseband to be centralized, is currently under consideration. This doesn't require a digitized RF interface like CPRI at all and instead uses regular IP backhaul. While this may join the ranks of other potential fronthaul architecture and technology candidates over time, it is commercially a lot less well developed at this time.

Moreover, other than in very small networks, operational circumstances make it unlikely that many operators will be able to standardize on just one of these approaches if they ever want to scale their use of C-RAN architectures beyond a few islands of deployment. Consider also the variation that may exist in the service characteristics that are available from different leased backhaul services.

Summary

Mobile operators need to leverage key LTE releases such as TD-LTE, CoMP and eICIC, as well as new architectures such as C-RAN, to grow capacity and keep ahead of insatiable user demand. As they do so, performance requirements with respect to synchronization and delay become increasingly stringent.

Meeting these new requirements in the RAN – whether they be in the backhaul network or on the CPRI fronthaul interface – presents critical new challenges for operators. And these requirements aren't optional – failing to meet them will result in a degradation of the user experience, an inefficient use of critical spectrum resources or indeed both.

The introduction of standards such as IEEE 1588v2 for frequency and phase synchronization and CPRI in the fronthaul are challenging for operators, because the standards are new and they impose very tight performance requirements on the way the network is architected and dimensioned. They, therefore, require a sophisticated capability to test the performance of the network and the performance of the protocols running over it as these new standards and architectures are deployed.

About VeEX

VeEX develops innovative test and measurement solutions for next-generation communication equipment and networks. Founded in April 2006 by test and measurement industry veterans, VeEX products blend advanced technology and vast technical expertise with the discerning measurement needs of customers. For more information about VeEX, please visit www.veexinc.com.