Synchronization Aspects in LTE Small Cells

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ABSTRACT

This article addresses the synchronization needs for mobile backhaul networks when deploying LTE small cells. Existing synchronization solutions for both FDD and TDD macro networks are discussed as well as the applicability of those solutions to small cells deployed in LTE TDD and LTE FDD networks. The benefits of using radio coordination features in a small cell environment and the corresponding demands placed on synchronization solutions are highlighted. Potential issues relating to synchronization of small cells are also discussed, and some additional synchronization solutions are proposed to address those issues.

INTRODUCTION

Mobile systems are among the main drivers in the recent evolution of synchronization technologies. In particular, the recent migration of telecom networks from time-division multiplexing (TDM) to packet-based technologies has required the industry to define new methodologies for distributing accurate timing reference across the network toward the radio base stations. At the same time, the benefits of using radio coordination features in a small cell environment is now increasing the demands on synchronization solutions with the need to extend current synchronization solutions to additionally address small cell deployments.

Depending on the Third Generation Partnership Project (3GPP) radio access technology used and/or the type of radio feature(s) being deployed in a mobile network, there are different requirements at the radio base stations relating to synchronization accuracy.

The various synchronization needs, the available synchronization solutions, and their applicability to small cells deployed in Long Term Evolution (LTE) time-division duplex (TDD) and LTE frequency-division duplex (FDD) networks are discussed in this article.

SYNCHRONIZATION NEEDS IN MOBILE BACKHAUL

Different types of synchronization exist — frequency synchronization, phase synchronization, and time synchronization — each leading to different synchronization solutions (Box and Fig. 1).

Frequency synchronization is required by all mobile systems. In fact, in order to minimize disturbance, facilitate handover between base stations, and fulfill regulatory requirements, the radio signal must be generated in strict compliance with frequency accuracy requirements.

The frequency synchronization (radio interface) requirements for LTE are defined in [5]. According to this 3GPP technical specification, the same source shall be used for radio frequency and data clock generation. The modulated carrier frequency of the base station observed over a period of one subframe (i.e., 1 ms) shall be accurate to within ±50 ppb for wide area base stations. The requirement in case of pico base stations can be relaxed to 100 ppb.

Similar frequency synchronization requirements are applicable to the other 3GPP radio access technologies, including Global System for Mobile Communications (GSM) and wideband code-division multiple access (WCDMA).

Phase synchronization is required in the case of TDD systems because uplink and downlink transmission use the same frequency bands but different time slots. In order to avoid interference between adjacent cells, the base stations need to be phase aligned. In particular, when LTE is based on TDD, according to [6], the timing between base stations must be accurate to within 3 μs (for cells of equal or less than 3 km radius) and 10 μs (for cells of more than 3 km radius).

As discussed later in this article, the introduction of new LTE features, often related to small cell deployments, may now introduce new requirements for distributing both time and phase synchronization to the base stations. These features, together with the increased use of TDD technologies, are generating a global need to deliver accurate time and phase synchronization signals over the network, and this leads to new challenges in mobile backhaul networks, particularly in small cell deployments.

Table 1 provides a summary of some of the most relevant synchronization requirements for supporting some of the most popular mobile technologies and some of the potential features that could be implemented in a small cell deployment (see the next sections for further details).

Impacts from the Addition of Small Cells

With the introduction of smartphones and the rapid take-up of mobile broadband services, LTE mobile networks are facing continuously increasing demands on capacity. To meet this upsurge in the demand for capacity in mobile networks, small cells may be used as an important complement to traditional macro network deployments.

Small cells should be deployed close to known traffic hot spots in order to provide good data rates and offload the macro networks. Indoor small cells can be installed in large numbers thanks to their small size and flexible backhaul solutions, providing good indoor data rates and coverage. Outdoor small cells are particularly effective in offloading both indoor and outdoor users in dense urban environments (Fig. 2).

In order to maximize utilization of the operators' key asset, radio spectrum, small cells should be deployed on the same carrier frequency as the macro layer. This will ensure that all cells have access to the full spectrum, thereby minimizing trunking loss. However, deploying small cells on the same frequency as the macro will cause intercell interference. LTE is fundamentally a technology built for operating in interference limited environments with full reuse of frequency in all cells, but there are techniques to improve system performance by coordinating this interference.

Example of such interference coordinating mechanisms are coordinated multipoint (CoMP) and intercell interference coordination (ICIC). These mechanisms are further discussed later.

Small Cell Architectures

From a small cell deployment viewpoint, there are two distinct architectures: the distributed baseband and common baseband architectures (Fig. 3). The common baseband architecture is also referred to as distributed radio access network (D-RAN).

The common baseband architecture includes a baseband unit connected to one or more radio units. These may be macro or low-power radio units and are connected to the baseband unit via the Common Public Radio Interface (CPRI) [11]. The small cell scenario implies the use of low-power radio units. The radio units may be physically located at the same site as the baseband unit or geographically separated from the baseband unit.

CPRI is an antenna-associated interface that connects a radio unit (RU) or remote radio unit (RRU) to the baseband unit. Therefore, it is an internal base station interface, and shall not be considered as part of the mobile backhaul. This applies even when the RRUs are located at some physical distance from the baseband. In addition, the requirements on jitter, delay, and bandwidth between the baseband and the RU/RRUs are so stringent[1] that they would be extremely difficult to comply with over a typical mobile backhaul for which the expected delay would be on the order of milliseconds, not microseconds. CPRI inherently delivers synchronization to the RUs, so no additional synchronization solution is required for the RU or RRUs, and the CPRI synchronization is inde-

ITU-T has defined the following main types of synchronization (see G.810 [10] and G.8260 [4]):

- Frequency synchronization
- Phase synchronization
- Time synchronization

Two systems are *frequency synchronized* when their operations are controlled by reference timing signals with their corresponding significant instants occurring at nominally the same rate, any variation in rate being constrained within specified limits ($f_A \oplus f_B$).

The term *phase synchronization* implies that all associated nodes have access to a reference timing signal whose rising edges occur at the same instant. This term might also include the notion of frame timing (i.e., the point in time when the time slot of an outgoing frame is to be generated).

Finally, *time synchronization* is the distribution of an absolute time reference to the real-time clocks of a telecommunications network. All the associated nodes have access to information about absolute time (in other words, each period of the reference timing signal is marked and dated) and share a common timescale.

Note that distributing time synchronization is one way of achieving phase synchronization.
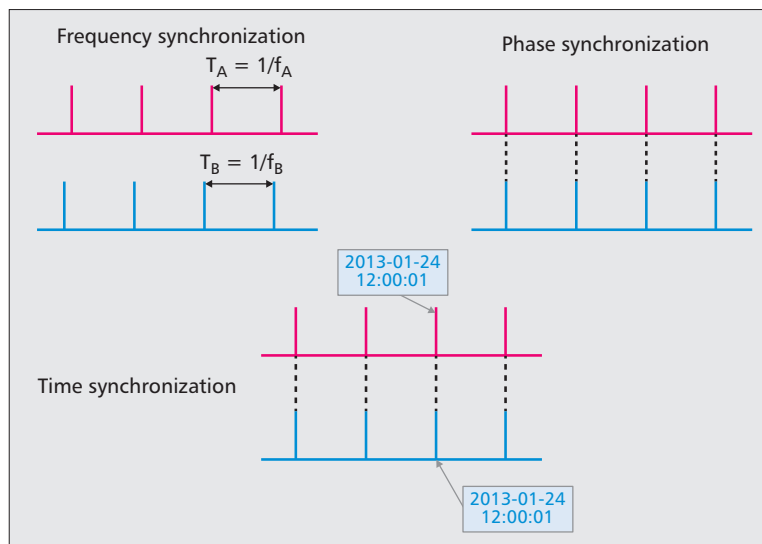

Figure 1. *Different types of synchronization.*

pendent of the synchronization solution delivered to the base station via the backhaul or Global Navigation Satellite System (GNSS).

The distributed baseband architecture includes a macro base station within whose geographical cell range(s) a number of low-power base stations are deployed. All base stations have their own baseband and radio(s), and dedicated S1 (i.e., between the eNodeB and the packet core) and X2 (i.e., between eNodeBs) interfaces [1]. The S1 and X2 interfaces are considered to be part of the mobile backhaul, and both are external eNodeB interfaces. Although it is possible that an X2 would connect two eNodeBs via a direct fiber connection to ensure an extremely low delay, in practice this is extremely unlikely to be the deployment scenario due to the cost involved.

[1] Maximum allowed jitter contribution to the frequency offset (root mean square, rms): 2 ppb; error rate: < 10^{-12}; one-way delay: typically up to 75 μs for a maximum CPRI length of 15 km; tight requirements in symmetrical channel on the order of a few tens of nanoseconds in order to allow for link delay calibration.

Technology/ application feature	Frequency accuracy	Time/phase accuracy	Notes
WCDMA (note 1)	±50 ppb (wide area) ±100 ppb (local area) ±250 ppb (home)	—	
TD-SCDMA (note 1)	±50 ppb (wide area) ±100 ppb (local area) ±250 ppb (home)	±1.5 µs	
LTE-FDD (note 1)	±50 ppb (wide area) ±100 ppb (local area) ±250 ppb (home)	—	
LTE-TDD (note 1)	±50 ppb (wide area) ±100 ppb (local area) ±250 ppb (home)	±1.5 µs (cell with radius ≤ 3 km) ±5 µs (cell with radius > 3 km)	
eICIC (enhanced intercell interference coordination)		±1 µs (note 2)	Specific for small cell No special latency demands (note 3)
Dynamic point blanking (or coordinated scheduling)		±1.5 µs (note 2)	Latency requirement 1–10 ms (note 3)
Downlink joint transmission		±1.5 µs (note 2)	Latency requirement < 0.5 ms. Targeting common baseband architecture. No mobile backhaul impact.

Note 1: The requirement is expressed in terms of deviation from an ideal reference (e.g., based on GPS, Global Positioning System).
Note 2: The requirement is expressed with respect to a common reference synchronizing the small and macro cell. Relative phase accuracy between macro and small cell is sufficient.
Note 3: Latency is measured between macro and small cell. Where a range of values is indicated, it is expected that the lower the latency, the better the gain.

Table 1. *Synchronization requirements summary.*

For small cell deployments, the requirements on synchronization accuracy will depend on the type of radio features that are planned to be used to manage intercell interference.

Low-power base stations such as pico base stations or micro base stations may be deployed with radio features that have no additional synchronization demands on the backhaul beyond the already existing macro base station demands. Features such as range extension, which is used to improve uplink coverage, and load-based handover, which is used to offload the macro network, place no new demands on synchronization accuracy compared to the already existing demands from the LTE technology (Table 1).

If it is decided to deploy small cell base stations with radio features that require tight coordination between macro and small cells, time alignment is needed between those base stations. Features such as enhanced ICIC (eICIC) and dynamic point blanking are expected to require synchronization accuracy of ~±1 µs to ±1.5 µs in terms of absolute time accuracy, applicable at the antenna reference point.

There are a number of issues that need to be considered when planning a synchronization solution for small cell deployments:
1 Indoor vs. outdoor deployment: GNSS may not work well or at all in some indoor environments when the small cell is located away from a window with limited or no view of the sky and/or located inside a building, which has high penetration loss for a weak GNSS signal.
2 Outdoors in dense urban environments with high rise buildings: Introduces the "canyon effect" whereby small cells located below rooftops in many cases have limited or no view of the sky, preventing or restricting GNSS usage.
3 Available backhaul: It is likely that in many cases operators will have to use backhaul that is not part of their own macro network backhaul. The quality of such backhaul can be quite different from that of the backhaul used for the macro network with high packet delay variation (PDV) and no or unreliable class of service support. A low-quality backhaul will make it difficult or even impossible to deliver a packet-based synchronization solution.
4 Cost considerations: Deployment of low-cost low-power base stations as a strategy generally implies a corresponding strategy of deploying a comparably low-cost synchronization solution. This means that higher-cost solu-
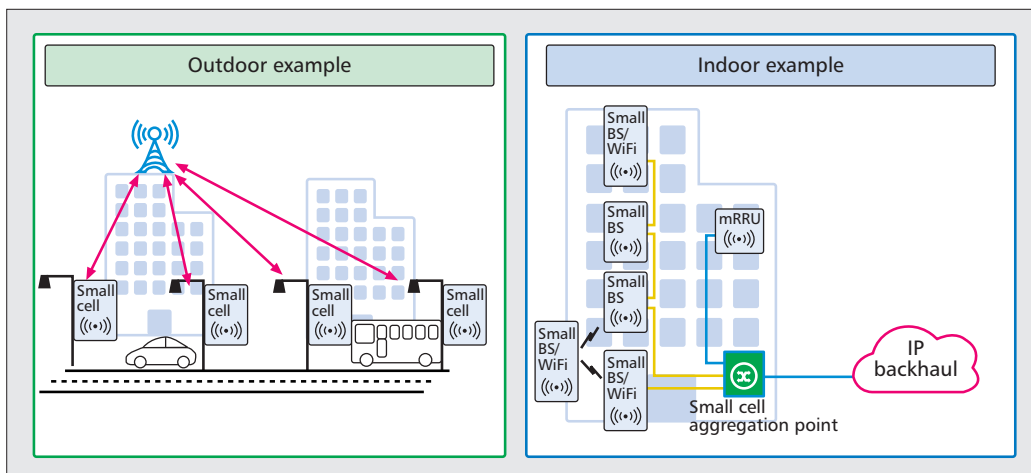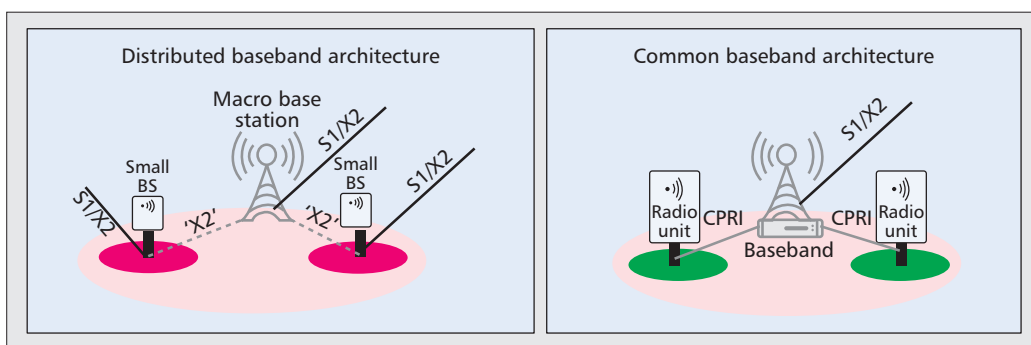
Figure 2. *Examples of small cell deployments.*

Figure 3. *Small cell architectures.*

tions involving, for example, locally placed time servers may not always be an option.

5 Security of the small base stations: Small cell nodes are, in general, more exposed physically, thus allowing more opportunities for attackers to disrupt the synchronization of the network. Although IPsec is generally expected to be used from the small base stations, this may not be possible for packet-based synchronization solutions due to the additional delays and potential related impairments.

See a later section for a detailed discussion on synchronization solutions for small cells.

LTE INTERFERENCE COORDINATION FEATURES AND TIMING-RELATED CONSIDERATIONS

When discussing synchronization requirements for interference coordination features, it is important to consider the radio propagation scenario. Taking one such example in Fig. 4, two cells are transmitting a signal to user equipment 1 (UE1), and due to radio propagation, it is natural that the UE1 is in between cells 1 and 2. UE2, which is not located between cells 1 and 2, will not be coordinated by cells 1 and 2. Therefore, the path propagation delay difference between the two coordinated cells can be assumed to be limited.

In addition, small cell deployments are driven by the need to improve capacity, meaning that small cell deployments primarily target dense urban areas. In such environments the macro-to-macro inter-site distance (ISD) is assumed to be below 1000 m, and in most cases it is much lower. Typical European cities have a macro-to-macro ISD of 400 m today, and in many large Asian cities the macro to macro ISD is below 300 m. Given that small cells are deployed within the dense urban macro grid, ISD between macro and small cell is typically 200 m or less. Given the low ISD and the expectation that the coordination need is for UE devices between the transmitting points, a maximum allowed propagation time difference of 1 μs between the two cells and the UE (UE1, Fig. 4) is assumed to be sufficient.

Furthermore, given a budget for multipath delay in the dense urban environment of 0.7 s, the resulting absolute time accuracy at the transmitting points is ±1.5 μs in order to keep the two signals within the cyclic prefix of 4.7 s (see [2]).

Following are some examples of radio coordination features that may be used in a small cell environment.

Downlink joint transmission sends data to the user from more than one transmission point simultaneously, thereby improving the probability that the data is received correctly. Since the signal is transmitted from several geographically separated points, effects of shadow fading are also reduced. The data to be transmitted needs
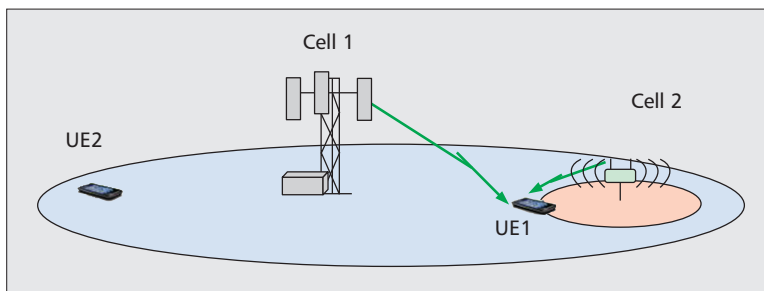
Figure 4. *Intercell coordinated multipoint scenario.*

to be available at all coordinated points simultaneously, implying the use of a common data buffer and scheduler. For most practical realizations this will limit the use of this feature to the common baseband architecture. In this scenario the synchronization source between the transmission points is the common baseband, which means that no specific backhaul synchronization solution is needed.

Dynamic point blanking, or **coordinated scheduling**, aims at improving cell edge bit rates by coordinating when to schedule users in different cells. By dynamically blanking the main interferers to a cell edge user the signal-to-interference ratio increases, which improves the bit rate. The best possible performance gain of the feature is achieved when the dynamic blanking can be executed on a per-transmission time interval (TTI) level, that is, every millisecond. Due to the very short time available for scheduling decisions, this typically requires the feature to be implemented in the common baseband architecture. It is also possible to coordinate the scheduling on a slower timescale over the X2 interface, but gains are typically lower in these scenarios since the X2 delay would usually exceed the 1 ms timeframe of the radio interface scheduler. It is possible to implement X2-based coordination in the distributed baseband architecture, but the time delay to send the coordination information over X2 should be as low as possible in order to maximize the value of the feature. The nodes being coordinated in the distributed baseband scenario need to be time aligned, thereby creating a synchronization need.

Enhanced ICIC (eICIC) is an interference coordination feature that targets small cell deployment specifically by expanding the range of small cells. This feature works by thereby increasing the amount of users attached to the small cell layer by semi-statically blanking the macro cells. eICIC could therefore be viewed as a load sharing feature, increasing load on the small cell layer at the expense of macro capacity. eICIC is typically implemented in the distributed baseband architecture, but there are no specific requirements on the X2 delay since the macro blanking is semi-static and only adopted toward long-term traffic variations. However, in order to avoid interference overlap between macro and small cells, they have to be time aligned, thereby creating a synchronization need.

See Table 1 for a summary on related synchronization requirements.

SYNCHRONIZATION SOLUTIONS FOR SMALL CELLS

Based on the considerations mentioned earlier in this article, it can be noted that the synchronization requirements applicable to small cells are analogous to those applicable to the general mobile backhaul scenarios. This suggests that similar synchronization solutions can generally be applied. However, as also highlighted earlier, some specific consideration should be made in the case of small cells, and some special solution might need to be defined for them.

FREQUENCY SYNCHRONIZATION SOLUTIONS

In order to support frequency synchronization over packet networks, two main approaches have been defined:
- **Physical-layer-based timing** (i.e., synchronous Ethernet in the case of Ethernet-based networks, as defined in Internet Telecommunication Union Telecommunication Standards Sector [ITU-T] G.8261 G.8262 and G.8264 [4])
- **Packet-based timing** (normally using Precision Time Protocol, PTP, or Network Time Protocol, NTP [9, 12]), generally in an end-to-end architecture as defined in ITU-T G.8265 [4]

These solutions can be combined in the same network with a hybrid solution, where typically a physical-layer-based segment can provide the synchronization reference to a packet-based segment.

In some special cases, an opposite scheme is also possible. As an example, the last mile, typically based on some specific access technologies such as microwave or very high-speed digital subscriber line (VDSL), could forward the timing reference received from the timing packets using its physical layer instead. The advantage of this approach is that the higher PDV some technology may introduce is eliminated by using the physical layer instead. As an example, in case of VDSL, the network timing reference (NTR) can be used to deliver frequency synchronization [8]. This approach, although not fully standardized, may often be feasible. An overview on these possible approaches is illustrated in Fig. 5. As shown in this figure, synchronous Ethernet must be handled in every node between the master primary reference clock (PRC), typically located in the switching site, and the end user (e.g., the base station at the edge of the access areas) by means of the Ethernet equipment clock (EEC).

In the case of frequency synchronization using PTP packets, an IEEE 1588-based telecom grandmaster (T-GM) with access to an accurate master (PRC) generates timing packets that are received by the end slave only ordinary clock (SOOC). If the frequency synchronization uses NTP packets, an NTP server is used instead of a T-GM.

Hybrid solutions are also shown in this figure.

TIME/PHASE SYNCHRONIZATION SOLUTIONS

If phase synchronization is required, the typical approach is to distribute a common time synchronization reference.
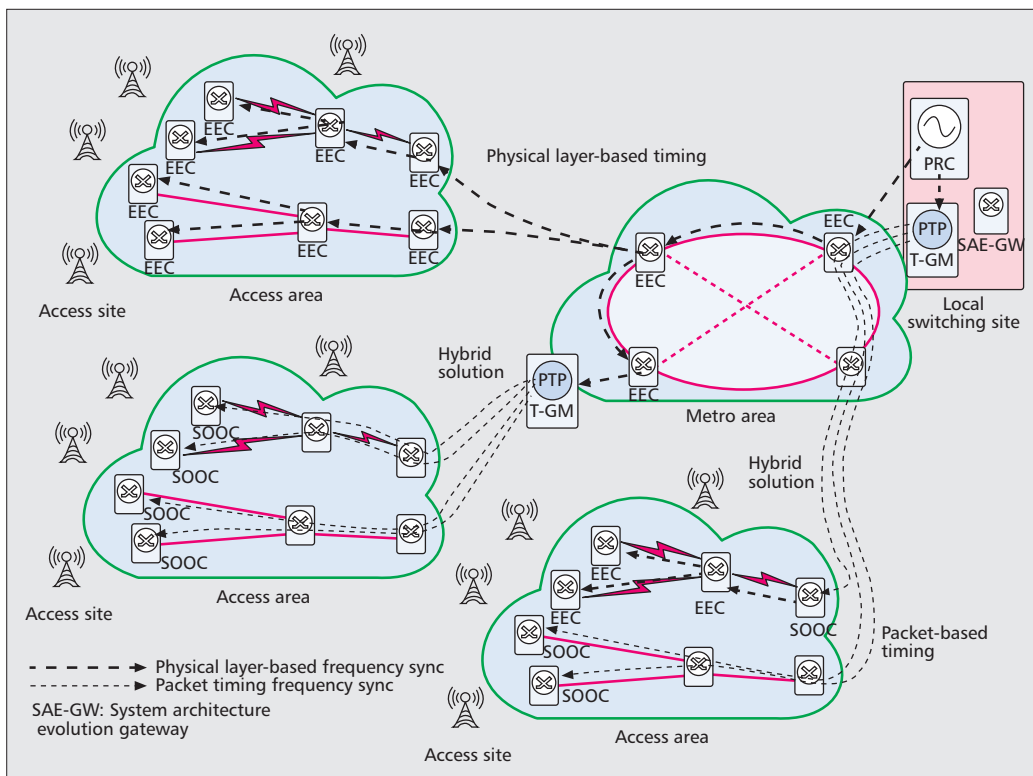
Figure 5. *Example of frequency synchronization over the physical layer and via packets in mobile backhaul scenarios.*

The requirements as listed in the previous section are in the microsecond range, which leads to sometimes difficult synchronization design. Two main general approaches are being considered in the standards [3], as depicted in Fig. 6:

• **Distributed primary reference time clock** (PRTC), typically via GNSS
• **Packet-based time synchronization**, typically using the PTP protocol [11]

A combination of the two approaches is likely to become the most common deployment choice for operators where the PRTC (typically a GPS receiver [3]) and the T-GM (i.e., the PTP master of the network [3] may also be deployed closer to the edge of the network, for example, located in a small cell cluster (local time synchronization distribution).

The definition of solutions based on packet timing is still ongoing in the standardization bodies; however, some initial considerations can already be made.

Due to the stringent requirements described in Table 1, the use of packet-based time synchronization for small cell applications in general requires that all nodes in the chain between the master (PRTC) and the base station process PTP packets either via a telecom boundary clock, T-BC, or telecom transparent clock, T-TC.

Combination with a physical layer-based frequency synchronization distribution is also often proposed as a way to enhance performance and reliability. For example, when traceability to the PRTC is lost, the stable and accurate frequency reference carried by the physical layer can be used to enhance the performance during the holdover period.

Since distributing time synchronization via packets is a method based on two-way packet exchange, and the estimation of the path delay is performed by means of round-trip delay measurements, one of the key aspects to be considered is the control of any source of asymmetry between the master and the slave. This is a major challenge when using packet-based timing as many sources of asymmetries exist in a network.

Even if every node supports PTP, thus eliminating, for instance, the impact of queueing delays, other sources of asymmetries need to be controlled such as those generated by the different cable length between the forward and reverse path. More details on these aspects are provided in G.8271 [3].

Specific solutions have been standardized to enable the transport of accurate time synchronization over the access technologies.

The solution for gigabit-capable passive optical networking (GPON) is specified in [7].

In a similar way VDSL standards have been updated to provide appropriate support [8]. One example involving the use of copper-based connections is where a fiber-based transport network is used to connect the switch site to a distribution point in a building, and copper is used internally in the building to connect the distribution point to the pico base stations. In this case, time synchronization has to be distributed over copper using VDSL2 and the time of day (ToD) distribution functionality.

Microwave solutions are also now available whereby accurate time synchronization can be carried over the radio links. These solutions have to deal with some specific issues related to
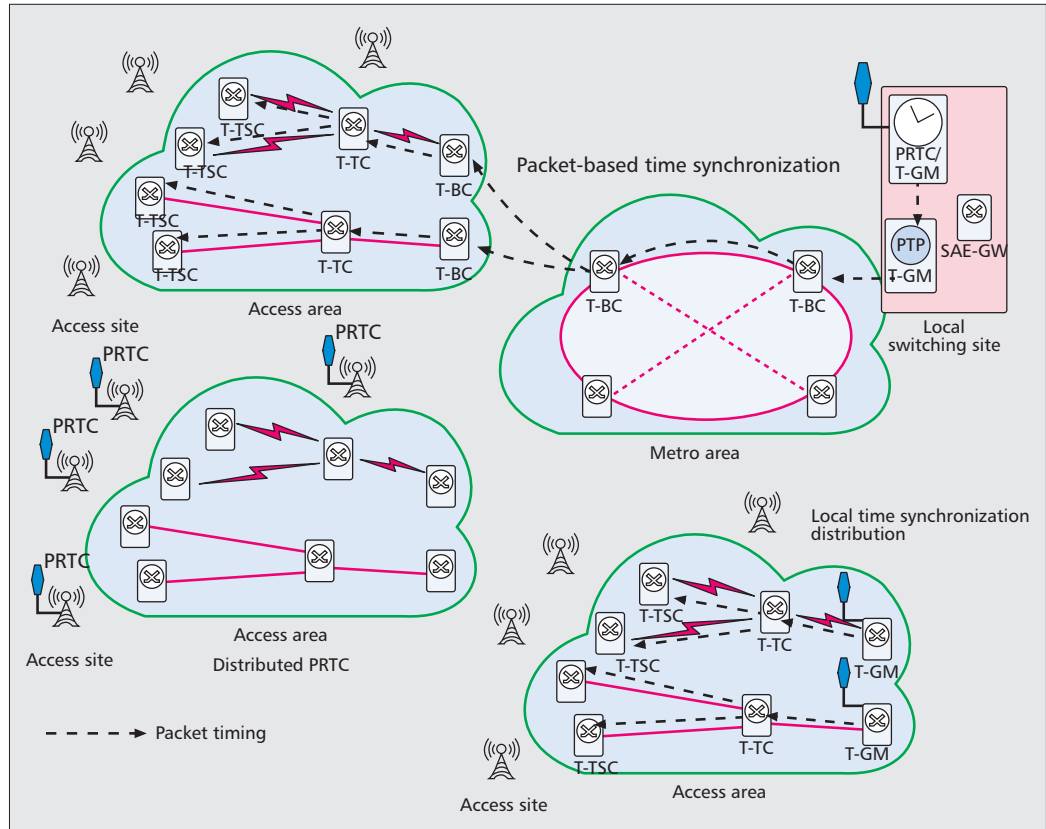
Figure 6. *Examples of PRTC distributed and packet timing solutions for distributing time synchronization.*

microwave transmission such as phase steps due to adaptive modulation schemes.

EMERGING TIME/PHASE SYNCHRONIZATION SOLUTIONS FOR SMALL CELLS

There are many and varied synchronization solutions under investigation for small cell deployment scenarios including G.fast, local time distribution, partial timing support, and over the air synchronization.

For copper-based transmission, evolution of the G.fast standard is being used as the framework for the new high-speed copper transmission being defined in ITU-T, and it includes solutions to transport frequency and time synchronization. Due to the latency requirements of certain coordination features, the work in G.fast is also being considered to optimize the latency (e.g., 250 μs to enable 1 ms round-trip delay over a small cell link). However, it should be noted that this technology might still not be suitable for CPRI due to its additional latency and capacity constraints.

The specific environments of small cell deployments in general may present some challenges in distributing the accurate time synchronization that might be required, for instance, by the pico base stations supporting eICIC (Fig. 2).

The use of PTP is heavily dependent on the control of any source of asymmetry, and IEEE 1588 support in every node is one prerequisite to make this task easier (e.g., by removing any dependence from the traffic load). However, the use of legacy infrastructure, as may often be the case for small cells, would make it impossible to have a time synchronization distribution with full support in every node as support for IEEE 1588 is a relatively new function and not yet fully standardized.

One related issue is that security will be an additional requirement for small cells, but the use of secure tunnels such as IPsec might not be compatible with a requirement to distribute accurate time synchronization. In fact, the IPsec processing itself would add unacceptable jitter and delay. More important, it could make it impossible for the intermediate nodes to process the PTP packets.

In order to address these issues, specific synchronization architectures are being considered, such as distributing the PRTC and T-GM closer to the edge to allow local time synchronization distribution. This could mean (e.g., in case of an indoor deployment) implementing a (GNSS-based) PRTC and T-GM in the small cell aggregation node and then forward timing via PTP to the connected pico base stations.

Other options under consideration are related to analyzing the conditions under which nodes may be allowed not to support IEEE 1588 so that a T-GM may be placed somewhere in the aggregation network, without requiring that support for IEEE 1588 is provided in every node. This architecture is known as partial timing support at the protocol level, and in order to complete the related study, various challenges need to be addressed (e.g., how to deal with variable asymmetry created by the queueing delays).

Concerning the use of GNSS in the cell site, as described in Fig. 6, one option could be to deploy a

GPS receiver in every base station. However, there are some well-known aspects that need to be carefully considered and that sometimes put serious constraints on the use of this technology. For instance, the GPS antenna installation and restricted view of the sky may prevent the use of this synchronization source, especially for indoor installation. An emerging issue is related to increased concerns about GPS vulnerabilities (e.g., due to potential jamming). The combination of GNSS with other solutions (e.g., IEEE 1588 itself) is often mentioned as a way to mitigate these issues.

New synchronization methodologies are being considered to address some of the previous concerns. For instance, the timing reference can be carried over the mobile radio link (over the air synchronization).

In this case, as the main task is to align the phase between the macro cell and the small cell, the pico/micro base station may listen to the macro base station radio signal and get synchronization from this signal. In other words, base station timing synchronization is derived from the transmissions of neighboring base stations. The propagation delays must also be known in order to be able to adjust the timing. As an example, 150 m distance from the macro base station to the pico base station would result in 0.5 µs phase error.

CONCLUSIONS

Depending on the 3GPP radio access technology used and/or the type of radio feature(s) being deployed in a mobile network, there are different requirements at the radio base stations related to synchronization accuracy.

Synchronization solutions already exist for frequency, time, and phase synchronization of macro base station mobile networks today. In particular, in the case of time and phase synchronization, the traditional approach of using GNSS is being complemented by means of packet-based technologies such as PTP.

With the introduction of small cells into the macro network environment, there is a need to extend current synchronization solutions to additionally address small cell deployments.

It is important to note that increased synchronization accuracy requirements are needed in a small cell environment only if certain optional radio coordination features are chosen to be used. In particular, it should be noted that for LTE FDD networks it is possible to deploy well functioning small cells without any time/phase synchronization support, and the network synchronization solutions can be addressed with the same frequency synchronization solutions used in the macro network (e.g., with synchronous Ethernet or packet-based solutions such as NTP and PTP).

For small cells deployed in an LTE TDD network, GNSS and PTP with backhaul support may be used.

In certain scenarios, for small cell deployments using low-power base stations, when higher bit rates at the cell edge and increased capacity are the main goals, more advanced features may optionally be deployed to reduce interference between the low-power base station and the macro base station (e.g., dynamic point blanking or eICIC). These features would place more stringent synchronization requirements between those base stations requiring the need for time alignment.

While existing time/phase synchronization solutions such as PTP with full backhaul support with boundary or transparent clocks in each intermediate node between the PTP client and the grandmaster, and GPS may be used to support such features, such solutions may not be as easy to deploy in a small cell environment due to various factors such as physical location of the small cell and quality and/or availability of the backhaul in the small cell location. Additional synchronization solutions such as local deployment of a synchronization server, synchronization distribution via VDSL, hybrid synchronization solutions, or over the air synchronization techniques may need to be considered in those cases. Some of the key aspects that still need to be addressed in have been described.

In summary, synchronization solutions applicable to a macrocell environment can also be used to support the deployment of small cells. Additional considerations specific to small cells may include security, availability, and quality of the backhaul, and the location of the small cell.

Synchronization solutions applicable to a macrocell environment can also be used to support the deployment of small cells. Additional considerations specific to small cells may include security, availability, and quality of the backhaul, and the location of the small cell.

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BIOGRAPHIES

DAVID BLADSJÖ (david.bladsjö@ericsson.com) holds a Master of Science degree from Luleå Technological University (Sweden). He joined Ericsson Research in 1999 within the area of radio access research, focusing on GSM/EDGE standardization in 3GPP TSG GERAN. Since 2004 he has worked as a product manager at Business Unit Networks, first with GSM RAN product responsibility and now with LTE RANs. He is responsible for small cell related functionality in LTE RANs, such as CoMP and other coordination features.

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