

A Novel SDN-Based Architecture to Provide Synchronization as a Service in 5G Scenarios

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Moving toward 5G, network synchronization is expected to play a key role in the successful deployment of the new mobile communication networks. This article presents an application of SDN (software defined networking) and NFV (network function virtualization) principles to the network synchronization area enabling to offer synchronization as a service.

Abstract

Moving toward 5G, network synchronization is expected to play a key role in the successful deployment of the new mobile communication networks. This article presents an application of SDN (software defined networking) and NFV (network function virtualization) principles to the network synchronization area, making it possible to offer synchronization as a service. The approach is based on defining a harmonization layer that orchestrates radio and heterogeneous transport domains by means of a suitable subset of abstracted information exchanged among the domains, and by making use of virtualized synchronization functions.

Introduction

5G is the next step in the evolution of mobile communication. In contrast to earlier generations, 5G wireless access should not be seen as a specific radio-access technology [1]. Rather, it is the overall wireless-access solution addressing the demands and requirements of mobile communication beyond 2020. To enable connectivity for a wide range of new applications and use cases, the capabilities of 5G wireless access must extend far beyond those of previous generations. These capabilities include the possibility to provide very high data rates everywhere, support for very low latency and ultra-high reliability, and the possibility of devices with very low cost and very low energy consumption. Furthermore, 5G wireless access needs to support a massive increase in traffic in an affordable and sustainable way, implying a need for a dramatic reduction in the cost and energy consumption per delivered bit.

Synchronization is a term used in various contexts and often with different meanings. Within the scope of this article, it relates to the “*network synchronization*” concept. This concerns the distribution of common time and/or frequency references to the nodes in a network in order to align their time and frequency scales, respectively [12]. Network synchronization is traditionally important to guarantee good performance in transport and mobile operations (e.g., user equipment handover in radio networks). Frequency synchronization is generally sufficient for these purposes. However, in recent years it has become more important to deliver accurate phase/time synchronization, for instance to enable the alignment of radio frames to better use radio resources. In time divi-

sion duplexing (TDD), for example, time division allocation of uplink and downlink allows an optimized use of radio resources. This requires radio base stations to send synchronous radio signals in order to avoid interference.

As we move toward 5G, synchronization (and time synchronization in particular) is expected to become even more critical. Following are some of the aspects that are particularly relevant:

- New radio access technologies, complementing existing technologies, for which phase/time synchronization is expected to play a key role.
- New applications, such as machine type communications (MTC) and the Internet of Things (IoT), increasing the demand for accurate and/or reliable synchronization.
- New transport solutions and technologies, especially in fronthaul, will be needed to meet the challenging transmission needs of 5G in terms of capacity, reliability, latency, and robustness.
- Application of the SDN and NFV concepts, with potential impacts on the synchronization network architecture and operations. Cloud and distributed applications are additional trends that may also become relevant from a network synchronization perspective.

The control of latency is another key aspect for a successful deployment of 5G that deserves particular attention. In fact, strict latency is one of the main targets for some of the applications that need to be supported by 5G, such as automatic traffic control, remote surgery, and tactile internet. In this respect, as reported in [2], 5G systems should provide end-to-end latency of 10 ms and, in specific use cases, end-to-end latency of 1 ms. Good synchronization may become a key enabler.

In summary, 5G will impose a number of requirements that in one way or another could require accurate and reliable network synchronization and also imply a more complex handling of network synchronization operations (e.g., due to the fact that the same infrastructure shall handle different types and levels of requirements and support multiple service providers and applications). The impact on the network architecture is also particularly relevant from a synchronization perspective due to new concepts such as NFV and SDN.

On one hand this may impact how synchronization networks will be handled, but at the same

time it could provide tools that will facilitate the support of synchronization and of the latency related requirements.

This article presents how some of the aspects listed above could benefit from applying the principles of the software defined networking (SDN) and network function virtualization (NFV). The article is structured as follows. After a brief introduction of the key technologies in network synchronization and SDN/NFV, the article discusses the main network synchronization challenges expected in a 5G environment. We describe a possible approach to apply the SDN and NFV concepts to the area of network synchronization, with examples of relevant parameters and work flow. The feasibility and relevance of the solution is then demonstrated as applied to a relevant use case.

Relevant Techniques

Distributing Synchronization in the Network

One main technology to distribute time synchronization in a network is to generate an accurate time synchronization reference at some central location, e.g., via a GNSS (Global Navigation Satellite System) receiver, and further distribute it over the network via standard timing protocols such as IEEE 1588 [11]. GNSS may also be deployed locally (e.g., directly connected to the end user).

In the case of synchronization distribution over packet networks, the highest time synchronization accuracy can be achieved when all nodes in the network support IEEE 1588 (e.g., boundary clocks or transparent clocks). Additional architectures are being defined (e.g., partial timing support ([6])). The authors in [4] derived some basic rules to meet predefined performance objectives in different parts of the network. A proper network design would make it possible to meet 1.5 us phase accuracy on the radio interface. Frequency synchronization can also be achieved by means of synchronous Ethernet ([7, 8]). An enhanced version of synchronous Ethernet (*enhanced syncE*) is currently being defined by ITU-T.

In general, a multiplicity of approaches is possible in order to meet the relevant synchronization requirements. A combination of various techniques will in general be recommended in order to improve reliability and availability (e.g., to address GNSS vulnerability due to risk from jamming).

nfV And sdn

Network functions virtualization (NFV) [10] proposes a new model based on the “as a service” concept by which the organization can be simplified and resources and services can be manipulated at different levels in order to create smart and fast services. The model enables a full decoupling of the network functions from the corresponding hardware infrastructure that can be shared, thus enabling a new business model where the end user (service providers) can be a client of an infrastructure provider with a clear demarcation of roles and responsibilities. According to the NFV, the network functions can be realized on one or more virtual machines running on different software and processes, avoiding the necessity of dedicated hardware for each service.

A key enabler of the NFV model is the software defined technology (software defined networking [9]) which, thanks to the separation

between the data-plane and the control plane, defines a clear demarcation between where the traffic is transmitted and the point where the decisions are taken. The main principle is based on providing a suitable abstraction of the hardware resources that can be considered as a commodity for any type of services. The combined use of SDN and NFV enables the defining and deploying of new services on demand, dynamically and very quickly, by software programming the resources, dramatically reducing the cost and time to market of new services.

Synchronization Challenges In 5g

Network synchronization, especially in 5G scenarios, will be relevant in several domains, with different needs and requirements. According to [2] radio and transport domains could interwork in a very tight manner, in order to provide “infrastructure as a service” (IaaS). In addition, the transport domain could evolve smoothly toward an SDN model, providing scenarios where very heterogeneous domains that differ in data-plane technology, control plane, and vendor, interwork with the radio domain to provide 5G services. In particular, some of these domains could be based on SDN, others could be based on a distributed control plane such as MPLS (Multiprotocol Label Switching)/GMPLS (Generalized Multiprotocol Label Switching), and others could be managed by a network management system. Different actors will be involved in these scenarios, both network providers and service providers.

The handling of synchronization in this framework is expected to become a challenging task, and harmonization between all involved domains will be particularly important. As an example, radio access and mobile backhaul are traditionally handled in different domains, often under different network administrators. This could make it very complex to meet some of the most stringent performance requirements, e.g., in terms of latency and network synchronization.

Network synchronization is one key example where tight cooperation between transport and radio access could provide significant benefits. Domains other than radio are also becoming of interest from a synchronization perspective. In particular, emerging synchronization needs have been reported in data centers (see as an example the “Google spanner,” where all servers must have access to a reliable and accurate time synchronization reference [14]). Other examples can be found in the financial sector, power networks, and industrial automation.

Solutions for the harmonization of different transport network domains have been proposed [13], but the case of 5G where radio and transport tightly cooperate to provide synchronization as a service is not addressed. In particular, the following synchronization related aspects still need to be fully addressed:

- Which parameters provide a suitable network model able to offer synchronization as a service?
- How to apply network virtualization principles as required by network operators?
- How to handle synchronization service level agreements (SLAs) with different levels of accuracy and with minimum operation-

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The Virtual Net Sync Harmonizer, depending on the specific requirements and applicable policies, defines a suitable synchronization solution and synchronization network architecture and via the SDN controllers sets up SW defined synchronization functions and properly provisions the network.

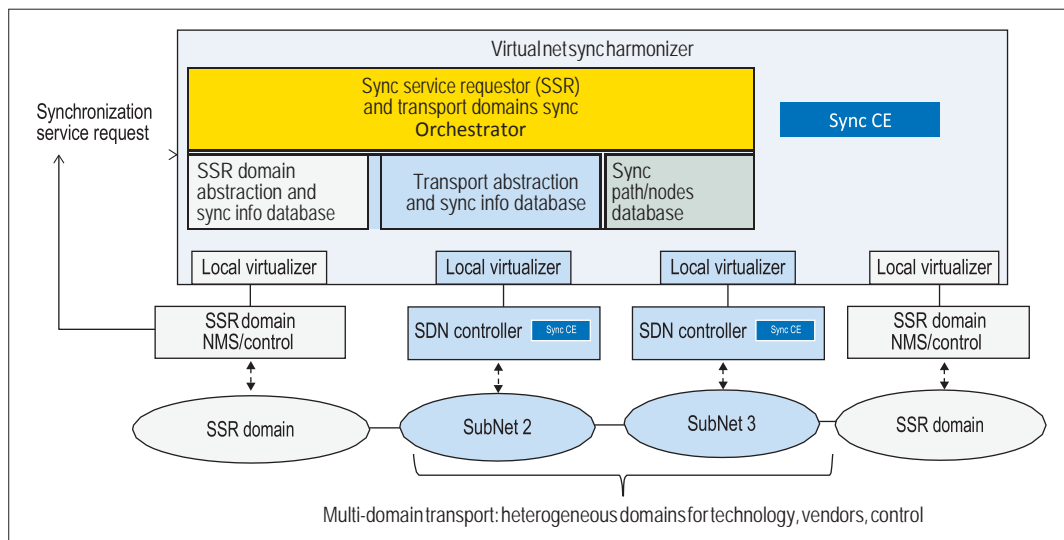


Figure 1. Virtualized Network Sync solution.

- How to differentiate the services according to the network synchronization capabilities?
- How to handle dynamic changes in synchronization capability/requirements?
- How to monitor related performance?
- How to handle contexts with multiple and heterogeneous domains?

The following sections try to answer the above questions with a potential approach based on SDN and NFV principles.

sdn-based Synchronization Service

The approach described in this article and shown in Fig. 1 is specifically related to a method to deliver synchronization services. The approach assumes an abstraction modelling of the relevant parameters for a technology-agnostic service support. In this model the client could be any type of domain with any type of synchronization needs.

According to this model, in order to set up the desired end-to-end synchronization solution, the involved domains are configured by means of virtualized synchronization functions as a result of a specific synchronization service request. The concept is based on a harmonization layer on top of each domain that allows harmonizing such domains by means of processing only a subset of the information, so that the impact on each domain is minimized.

The overall architecture is based on the following key components:

- The *virtual net sync harmonizer*, which receives relevant information from each domain through standard interfaces (e.g., the Path Computation Element Protocol (PCE-P), Netconf, etc.).
- The *SDN controller/local virtualizer* pair, which collects information on a specific domain at a suitable abstraction level, and that properly sets up/configures the domain.

In order to properly support the synchronization service requirements, the virtual net sync harmonizer receives the key parameters from multiple and heterogeneous domains: information on the related IEEE 1588 support (and which profile is supported, e.g., ITU-T G.8275.1 [5] vs. ITU-T

G.8275.2 [6]); information on synchronous Ethernet support; information on the link characteristic (e.g., link length, physical layer type, whether asymmetry compensation has been applied, etc.); and information on support for multi-clock domains (e.g., in the case of IEEE 1588, whether or not multiple boundary clock instances are implemented), clock-oscillator characteristics, etc.

The virtual net sync harmonizer receives the request for the synchronization service to support, that is, the “sync service requestor” (SSR) domain needs in terms of requirements and policy (e.g., absolute time accuracy vs. relative phase difference requirements; synchronization to be distributed only in isolated cluster of nodes; time synchronization vs. frequency synchronization, etc.). The relevant details of the SSR domains (e.g., topology, synchronization characteristics, etc.) are also exposed via the SSR domain NMS (network management system)/control block.

The *sync service requestor* domain could typically be a radio domain, but as mentioned earlier, other examples exist such as a network of servers implementing financial applications, power networks, industrial automation networks, etc.

The virtual net sync harmonizer, depending on the specific requirements and applicable policies, defines a suitable synchronization solution and synchronization network architecture, and via the SDN controllers, sets up SW defined synchronization functions and properly provisions the network. A specific synchronization algorithm could be involved in order to select among a set of multiple synchronization alternatives.

Looking further into the details, the virtual sync network harmonizer may be structured into the following logical functions:

- Sync service requestor (SSR) and *transport domains sync orchestrator*, which combines the relevant information.
- *Sync CE* (synchronization computation element), which selects a specific algorithm and identifies a suitable solution and synchronization network architecture.
- Relevant databases where the result of the sync CE calculation are stored, including the *SSR domain abstraction* and *sync info* data-

base, the *transport abstraction and sync info* database, and the *sync path nodes* database.

As an example, the nodes in the various domains could implement and support the following fundamental synchronization functions ([7, 3, 11]): oscillator of a certain quality, holdover of certain characteristics, support for synchronous Ethernet or enhanced synchronous Ethernet, and IEEE 1588 “on-path” support (e.g., boundary clock or transparent clock).

The following are software-defined functions that could be provisioned: transparent clock vs. boundary clock (e.g., in case a service requires multiple synchronization paths, a transparent clock may be more convenient); PTP (Precision Time Protocol) profile; BMCA (Best Master Clock Algorithm); PTP domains, etc.; and PTP reference priorities, synchronous Ethernet priorities, etc. This is shown with an example in Fig. 2, where the node, in addition to providing specific port capabilities, includes the concept of programmability of synchronization support (e.g., transparent clock vs. boundary clock).

Example of Synchronization Network Operation

The operation of a synchronization network based on the architecture described in this article is presented by means of an example. The following is the sequence of the steps that could be considered in the implementation of the solution.

1. The *SDN controllers/local virtualizers* collect information on the network topology and the parameters per each node/link from all involved domains (distance in Km, characteristics of the link, such as asymmetry compensated/not compensated, type of the physical layer, e.g., microwave/fiber; node synchronization function support and clock characteristics). This information provides an abstraction of the domains.

In the case of already established synchronization flows, the related information is also collected (e.g., details of the synchronization chain from the PTP grandmaster to the border nodes per each connected node, e.g., the base station). Similar information is also collected from the SSR domain (topology, supported synchronization functions, etc.).

2. The virtual net sync-harmonizer receives the request on the specific synchronization service to offer to a specific domain (the sync service requestor-SSR domain, e.g., the radio domain), with information on the type of synchronization required, (e.g., the required accuracy, etc.) and, based on the characteristics of the network, it can decide the most appropriate solution and policy to apply.

3. The virtual net sync-harmonizer asks the *local virtualizers* (if it includes sync CE functions) to properly define the virtual synchronization functions of the nodes and sets up the synchronization flow(s) according to a specific policy and service requirements. The local virtualizer, based on the relevant parameters and the related policy, calculates the best synchronization reference and provides this information to the virtual net sync-harmonizer for proper harmonization with the other domains.

4. The virtual net sync-harmonizer sends commands to the SSR domain NMS for the proper synchronization function configuration (e.g., syn-

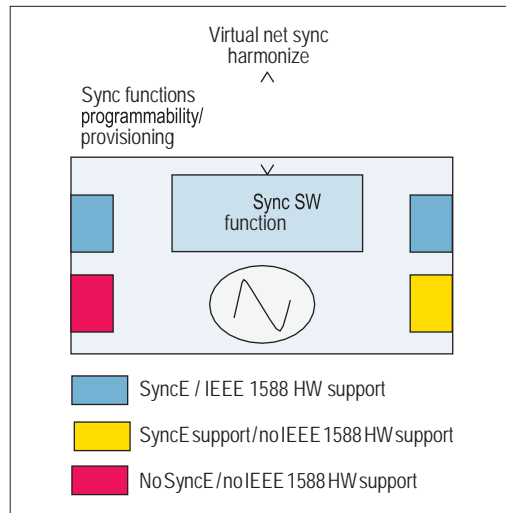


Figure 2. Sync programmability.

chronization method and reference selection) in the SSR domain. The result is to provide an end-to-end synchronization solution with certain characteristics.

5. The network is continuously monitored. Any change in the network and/or result from the performance monitoring functions, triggers a restart from step #1.

Further details on potential use cases and relevant parameters are provided later.

Relevant Parameters for Abstraction and Use Cases

Examples of parameters that can be exchanged between the net sync virtual harmonizer and the sync local virtualizer are presented below. Note that for better scalability, such information could be provided per aggregated links.

Link parameters could be: the length in Km of the link, information on IEEE 1588 support (e.g., whether or not the outgoing links from the node are with IEEE 1588 support), the physical link characteristics (e.g., fiber, microwave, xDSL), and information on asymmetry compensation (e.g., indicating whether or not the asymmetry has been compensated on that link).

Node parameters could be related to information on IEEE1588 support, synchronous Ethernet support, oscillator characteristics (e.g., clock type/stratum clock hosted by the node), type of PTP clock (e.g., max constant time error the PTP clock is expected to contribute with). Additional relevant parameters can be added in a programmable approach according to the SDN principles.

Several policies can be configured, including the following as examples:

- *Frequency/time/phase*, i.e., indicating whether only frequency synchronization or both frequency and phase synchronization are required.
- *Transparent sync*, i.e., indicating whether or not the timing shall be carried transparently across the domains.
- *Physical layer-based* frequency synchronization, i.e., indicating whether frequency synchronization shall be carried via the physical layer or via timing packets;
- *Link length-based*, i.e., in a weighted-based algorithm to evaluate the best synchroniza-

The local virtualizer based on the relevant parameters and the related policy, calculates the best synchronization reference and provides this information to the Virtual Net Sync-Harmonizer for proper harmonization with the other domains.

The specific requirement from the SSR would indicate that multiple synchronization flows should be preferably available at the radio domains, so that a dynamic selection is possible depending on variable cluster combination. Moreover, it could be assumed that there can be various degrees of phase synchronization accuracy that are acceptable.

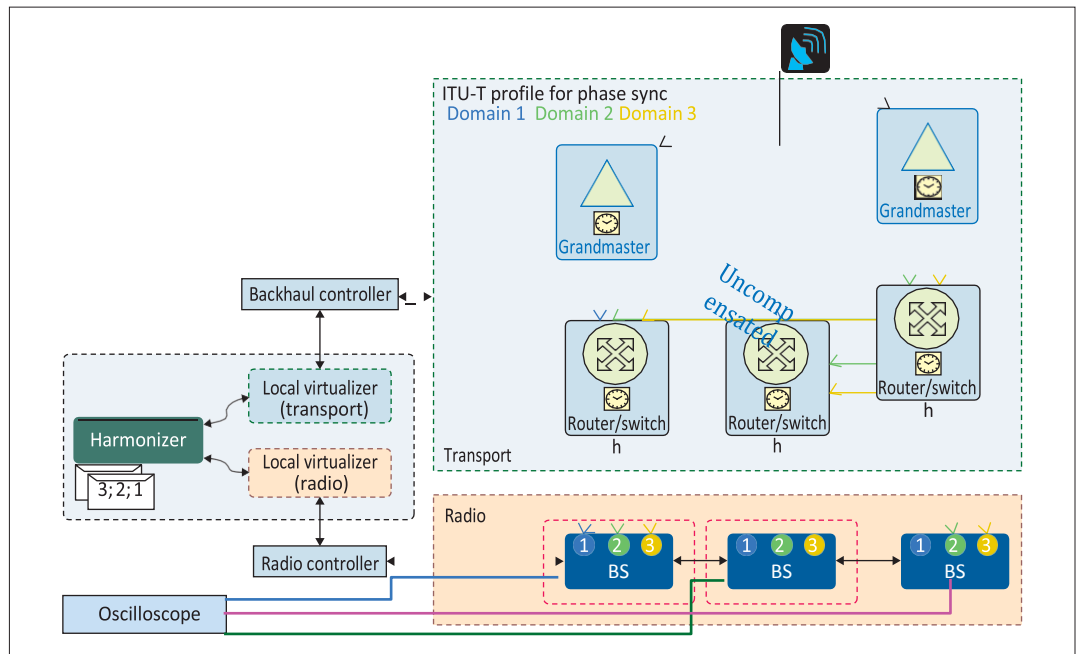


Figure 3. Synchronization for base station cluster-demo set up.

tion reference, using a multiplication factor indicating the length of the link (e.g., a multiplication factor of 2 for every 30 Km).

- *Physical layer-based*, i.e. in a weighted-based algorithm to evaluate the best synchronization reference, using a multiplication factor indicating the type of link (e.g., a multiplication factor of 1 for fibre, 2 for microwave).
- *1588 support-based*, i.e., in a weighted based algorithm to evaluate the best synchronization reference using a multiplication factor indicating whether IEEE 1588 hardware on-path support is provided (e.g. 1 if all nodes support IEEE1588; 3 if the links outgoing from a node have no IEEE1588 support).
- *Asymmetry compensated-based*, i.e., in a weighted-based algorithm to evaluate the best reference, using a multiplication factor indicating whether asymmetry has been compensated in the link (e.g., a multiplication factor of 1 if compensated; 3 if not compensated).

The solution can be applied to various use cases. A few potential examples are described below.

Use Case 1-Synchronization for a Cluster of Base Stations: In this example the SSR domain is a radio domain that needs to handle various and variable clusters of base stations that require local phase synchronization (e.g., to implement coordinated multipoint (CoMP), or enhanced inter-cell interference coordination (eICIC), with different levels of phase synchronization accuracies.

The specific requirement from the SSR would indicate that multiple synchronization flows should preferably be available at the radio domains, so that a dynamic selection is possible depending on variable cluster combination. Moreover, it could be assumed that there can be various degrees of phase synchronization accuracy that are acceptable. Based on this request, the policy selected by the virtual net sync-harmonizer (by the sync CE function) is the “transparent sync” transport so

that synchronization masters owned by the SSR operator can be used and the synchronization references can be carried transparently across the domains.

The local virtualizer identifies an MPLS based network, and in order to allow for transparent transport with the highest accuracy, makes sure that the synchronization path from the master to the base stations traverses nodes with “on-path-support” (e.g., PTP transparent clocks and residence time measurement (RTM) support (see [15]). An algorithm minimizing the phase difference per each cluster of the base stations is implemented by the sync CE, selecting the best reference per base station.

Use Case 2-Request for Network Characteristics: In this example, the synchronization request concerns the performance monitoring of the packet network as a way to understand the capabilities in distributing synchronization over a partial timing support network [6]. The IEEE1588 performance monitoring tools are configured in the network nodes and the related data is collected. Moreover, asymmetry of the links is calculated by means of automatic methodologies [3].

Use Case 3-Set-up of G.8275.2 (Partial Timing Support) Network: This example can be considered as an extension of the previous example. The SSR domain requests the set-up of PTP flows (also for local GNSS assisted partial timing support), with certain characteristics (e.g., 1 us packet delay variation measured by means of an appropriate metric and 500 ns worst case asymmetry). The SSR domain also requires G.8275.2 PTP performance monitoring across the domains.

The virtual net sync-harmonizer asks the local virtualizer to set up specific performance monitoring (PM) tools and collects and assembles the performance monitoring information. Based on this information, the sync CE evaluates the suitable synchronization paths. These are defined by means of proper MPLS paths involving as much as possible RTM-enabled label switching routers (LSRs). Per-

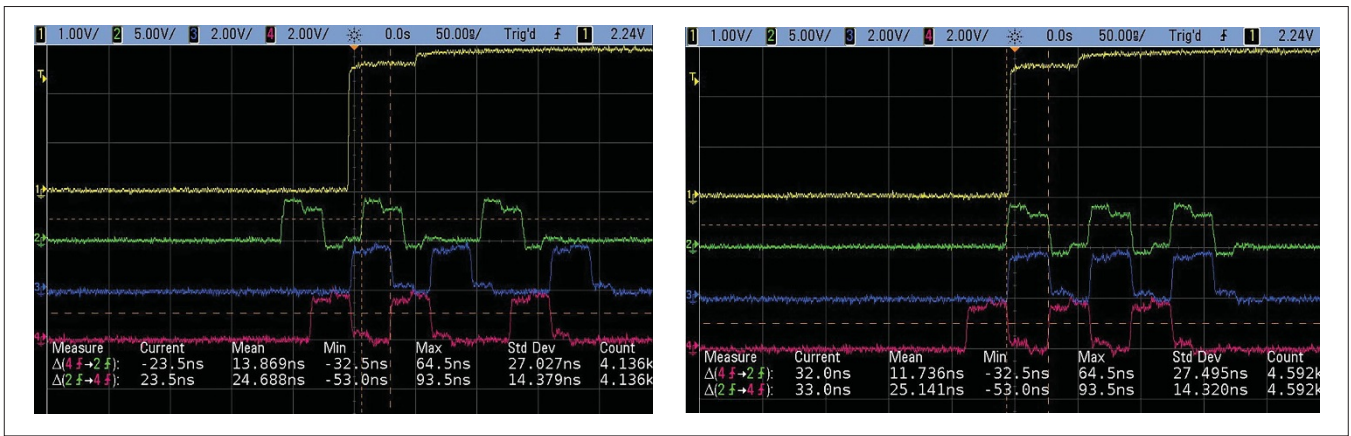


Figure 4. Phase deviation between base stations: initial status (left) and after network rearrangement (right)

formance monitoring results are continuously provided to the sync service requestor (SSR) domain.

demonstrator

The feasibility of the solution as applicable to use case #1 described above, has been assessed via a demonstrator implemented in “opendaylight” (open source project, see <https://www.opendaylight.org/>) as shown in Fig. 3.

Two synchronization masters (PTP grandmasters), connected to a GNSS source, distribute the synchronization references (PTP flows, each of them identified by means of the PTP domain number attribute) over a packet network. The PTP flows reach the end user (base station) via different paths with different characteristics (e.g., some of the links may have been compensated for asymmetry, other have not been compensated). The characteristics of the network and of the PTP flows are made available to the (virtual net sync) harmonizer.

The radio domain sends a request to optimize the synchronization between two specific base stations (BS), highlighted with dotted red lines in the figure. Various tests have been performed. In the example shown here the relative phase deviation resulting from the initial network synchronizations setup as shown by the graph on the left in Fig. 4 (green and blue lines), in the order of 50 ns.

After the rearrangement of the synchronization network, based on the information retrieved from the transport domain (in particular by avoiding the selection of PTP references that have traversed links where the asymmetry was not compensated), it was possible to improve the phase synchronization accuracy down to a few ns, thus enabling the activation of very demanding services (e.g. multiple input multiple output (MIMO)) as shown by the right graph in Fig. 4.

Future studies are being considered to address additional use cases and to refine the network abstraction models that can be used to model the network characteristics. An optimization of the algorithms used to support the various policies could also be considered.

Conclusions

Moving toward 5G, network synchronization is expected to play a key role in the successful deployment of the new mobile communication networks. 5G will impose a number of requirements that in one way or another could require

an accurate and reliable network synchronization and also imply a more complex handling of network synchronization operations.

This article has shown how the SDN and NFV concepts could be advantageously applied in this area. The architecture that has been presented is based on a client-server model. This system works on top of the existing networks and application domains (with a hierarchical architecture) in order to limit the impact on the procedures of each domain. The hierarchical architecture and independence of the domains allow for an end-to-end interworking among domains with heterogeneous synchronization capability, and makes it possible to automatically plug-and-play network domains and nodes.

The minimum set of information relevant to set up the synchronization network is collected from each domain. This information is used to harmonize and configure each domain (both radio and transport). Examples of parameters and functions that could allow tight and efficient interworking between the various domains have been presented. The nodes in the domains support some basic hardware synchronization functions with the capability to set up specific software-based functions, which makes it possible to optimize the support for a specific request. The centralized virtual net sync harmonizer properly instructs which functions need to be implemented.

The feasibility of the solution has been assessed via a demonstrator implemented in “opendaylight” and has been applied to an important radio network use case. Future studies could include the analysis of additional use cases as well as a refinement of the network abstraction models and algorithms that can be used to model the network characteristics.

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