5G for Industry 4.0

Peyman Talebi Fard

Ofinno • ofinno.com • December 2020

5G for Industry 4.0

Abstract

As Industrial Internet of Things (IIoT) emerges, reduction of human intervention becomes inevitable. To facilitate realization of promising features of future factory automation, 3GPP has launched various initiatives to study potential integration of 3GPP communication systems to support industry. Time sensitive communication offers deterministic network behavior to support real-time applications while non-public networks enable deployment of a 3GPP network for private enterprise. In this article, aspects pertaining to time sensitive communications and non-public networks as enablers of IIoT are discussed.

I. Introduction

The Fourth Industrial Revolution (or Industry 4.0) refers to evolving automation of traditional manufacturing and industrial practices using emerging technologies to minimize the need for human intervention.

Advanced features of 3rd Generation Partnership Project (3GPP) and fifth generation (5G) communication systems may facilitate enabling enhanced features of Industry 4.0. Therefore, the 5G system must interwork with the communications technologies used in relevant industries in order to deploy 5G for new and diverse use cases pertinent to Industry 4.0, such as real-time and deterministic systems, and factory automation.

In this article, two examples of 3GPP activities 1) Time Sensitive Communication (TSC), 2) Non-Public Network (NPN), pertaining to the Fourth Industrial Revolution also known as Industrial IoT (IIoT) are discussed.

II. 3GPP support for Industrial IoT

5G services of Release 16 addresses some verticals such as real-time factory and industrial automation, and extend business models to support enhanced slicing and NPNs. Non-public networks may serve as dedicated private networks that may be employed by factories and enterprise campuses.

In transitioning to release 17, additional verticals are considered such as audio-visual professional production, asset tracking, and critical medical applications that may in part be enabled with service capabilities such as network controlled interactive service (NCIS).

III. Enablers of Industrial IoT

3GPP identified three distinct areas of study that serve as the main enablers of IIoT: TSC, NPN, and support of Local Area Networks (LANs). In this section, three example enablers for IIoT are introduced.

a. Time Sensitive Communications

TSC work is based on the works of Time-Sensitive Networking (TSN) Task Group (TG), which is a part of the IEEE 802.1 Working Group (WG). TSN is intended to provide deterministic delivery of messages on standard Ethernet. TSN aims to deliver guarantees of delay bound and minimized jitter using time scheduling and synchronization for real-time applications that require deterministic network behavior. The IEEE TSN provides a set of specifications for technologies that enable deterministic, real-time and low-latency communication for industrial applications in the factories of the future, cyber physical systems, and smart systems.

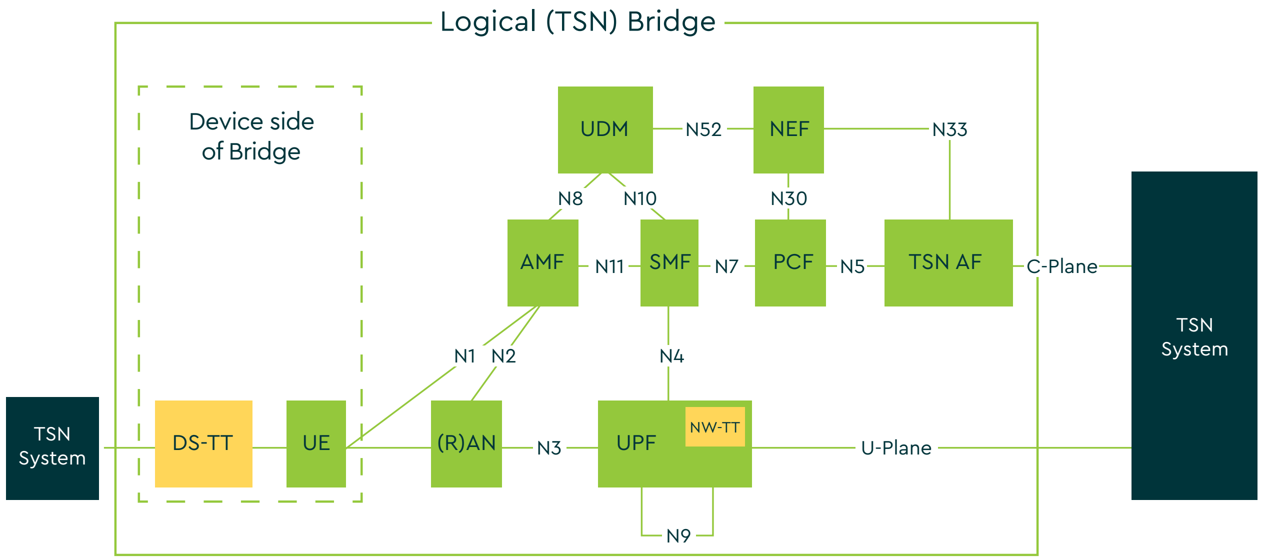

FIG. 1 System architecture view with 5GS appearing as a Time-Sensitive Networking bridge

TSC can be realized based on a 3GPP system as shown in Figure 1.

In general, a 3GPP system can act as a TSN bridge. A 3GPP system is expected to provide packet transport with bounded latency and delay requirements. Furthermore, strict time synchronization is required to meet the aforementioned.

TSN Translators (TTs) are deployed at the edge of the 3GPP system, e.g., the device side and the network side. The purpose of TTs is to support the IEEE 802.1AS operations. While only the TTs support IEEE 802.1AS, wireless devices, radio-access network (RAN) nodes, user plane and control plane functions, network side TT (NW-TT), and device-side TTs (DS-TTs) are synchronized with the 5G internal system clock. The internal system clock keeps relevant network function instances synchronized.

One of the key issues is to support uplink time synchronization and therefore to introduce support

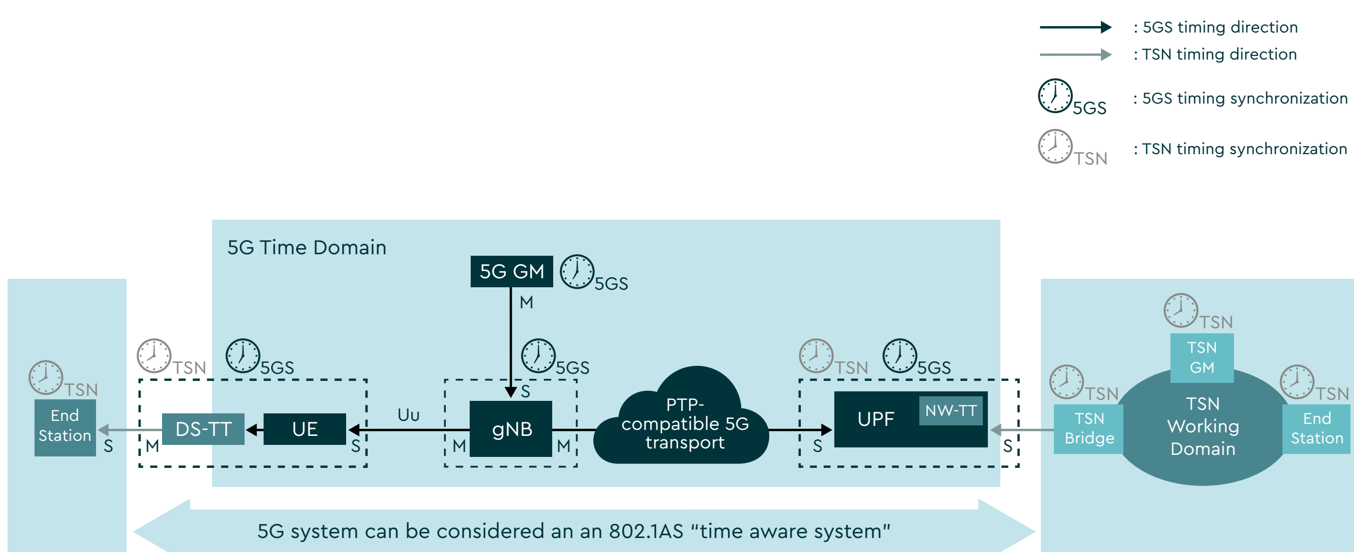

FIG. 2 5G system is modelled as IEEE 802.1AS compliant time aware system for supporting TSN time synchronization

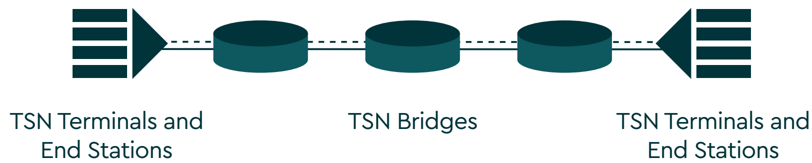

FIG. 3 Fully distributed model

for Time Synchronization with the TSN grandmaster (GM) clock. 3GPP efforts are targeted to support Time Synchronization with multiple TSN GM(s) in the TSN network attached to the device. In other words, 1) TSN end stations behind a 5G System (NW-TT) should be synchronized with the TSN GM in the network attached to the device, and 2) TSN end stations behind other user equipment(s) (UE(s)) should be synchronized with the TSN GM in the network attached to the device side via the 5G System.

Figure 2 depicts the two synchronization systems, e.g., the 5G system (5GS) synchronization and the TSN domain synchronization. Each synchronization system comprises Master (M) ports and Slave (S) ports when the TSN GM is co-located within the TSN system domain.

In order to support broader and more flexible use of 5GS TSC and Ultra Reliable Low Latency Communication (URLLC) through the 5GS, exposure of TSC service in the network may be important. A Network Exposure Function framework can serve to expose network capabilities and to enable a service operator to offer certain capabilities as services. In addition, existing features of the 5G System that allow applications to influence services may be reused. In this issue, Network Exposure Function (NEF) features are further enhanced to enable exposure of network capabilities to support TSC. For example, exposure of deterministic Quality of Service (QoS), and exposure of time synchronization can be provided by NEF.

Another issue is to support a fully distributed TSN model as shown in Figure 3. A fully distributed TSN model is defined in IEEE 802.1Qcc. Release 16 provides support for a fully centralized model as shown in Figure 4 and requires a centralized network configuration (CNC) node. Unlike the fully centralized model, in a fully distributed model, there is no centralized node like CNC that can monitor and configure the entire TSN network.

In order to configure the TSN system, configuration

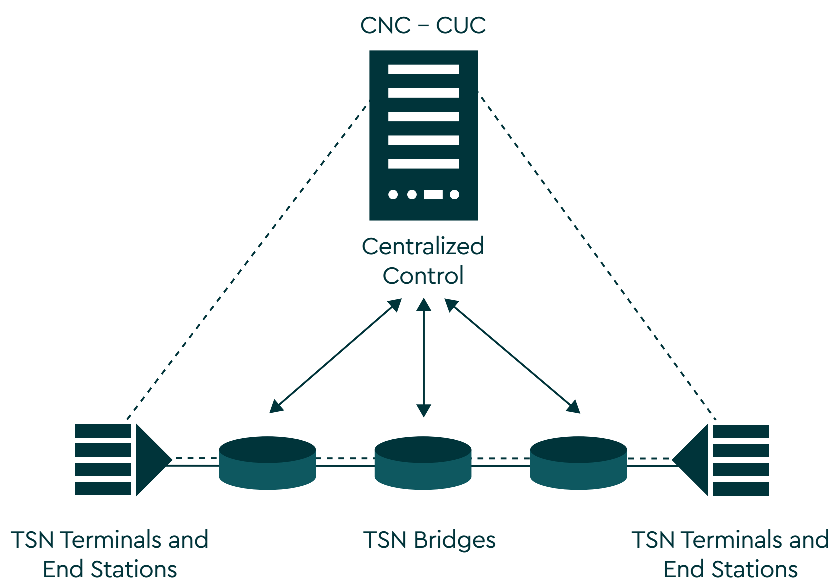

FIG. 4 Fully centralized model

information for stream resources should be propagated along the paths from the Talker to Listeners. Therefore, the 5GS should be able to read the configuration information carried in the TSN stream resource reservation messages (e.g., Stream Reservation Protocol (SRP) messages) and to modify the messages as a TSN bridge based on the 5GS capability.

b. Non-Public Networks (NPN)
Non-Public Networks may enable deployment of a 3GPP network for private use, for example, in an enterprise campus and a factory. Possible deployment options are:

1) Standalone Non-public Network (SNPN).
2) Public network integrated NPN (PNI-NPN).

Based on 3GPP stage 1 service requirements, support for Non-Public Networks is added to the Release 16 of 5GS. The scope of this study includes further enhancements to the 5GS to fulfill the not yet supported stage 1 service requirements for Non-Public Networks. In summary, the scope of this study as indicated in 3GPP documents is pertinent to the following:

- support for SNPN along with subscription/ credentials owned by an entity separate from the SNPN,
- support of UE onboarding and provisioning for non-public networks,
- support of service requirements for the production of audio-visual content and services,
- network optimizations to consider different deployment scenarios, e.g., when the NPN is deployed and managed with the support of Public Land Mobile Network (PLMN), or when the NPN is deployed for different coverage and device density,
- support for SNPN and PLMN sharing the same RAN node.

i. Problems pertinent to NPN
There are various areas that require further study as identified by 3GPP. One of the areas that 3GPP is working on is related to NPN support for Video, Imaging, and Audio for Professional Applications (VIAPA).

The VIAPA related use case requires allowing a wireless device to receive services via different networks simultaneously (e.g., SNPN and PLMN). An example scenario may allow the wireless device to receive paging from a PLMN (e.g., for voice calls) while receiving VIAPA or streaming services via an SNPN.

In the above-mentioned scenario, the assumption is that the wireless device is connected to an SNPN for SNPN services and the SNPN provides IP Security (IPSec) or other connectivity to an interworking node (e.g., non-3GPP Interworking Function, N3IWF) of the PLMN.

An important aspect of deployment of 3GPP based systems for Non-Public Networks is service continuity for VIAPA related use cases. Based on the 3GPP SA1 requirements for VIAPA services:

"The 5G system shall be able to securely reconnect within 20 ms from UE starting first network connection attempt after a UE network connection loss."

This means that the support of uplink and downlink service continuity for 3GPP systems is an essential feature. In addition, it is important that the 3GPP system maintain performance requirements, while the wireless device switches between co-located PLMN and NPN.

As shown in Figure 5, it is possible to support access of a wireless device to an overlay network via an underlay network. The overlay network or the underlay network may be a PLMN or an SNPN. Current proposals indicate the use of an interworking function such as N3IWF. The N3IWF as part of an overlay network may be accessed by the wireless device with an IPSec tunnel. The establishment of an IPSec tunnel requires a Packet Data Unit (PDU) session in the underlay network to provide connectivity to the

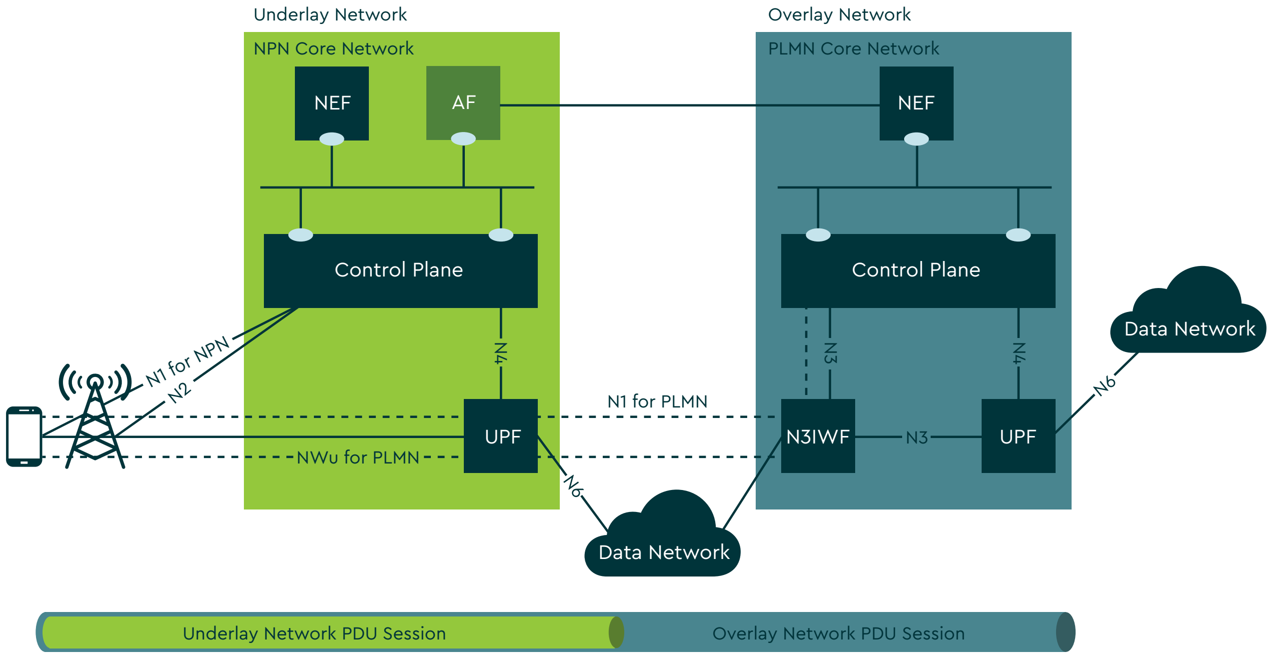

FIG. 5

N3IWF and subsequently to establish an IPSec tunnel.

In addition, it is important that for the case of accessing an overlay network (e.g., a PLMN or SNPN, NPN) via an underlay network (e.g., a PLMN or SNPN) the QoS and service level agreement (SLA) are fulfilled in order to deliver uninterrupted services to users.

IV. Summary

TSC and NPNs are two of the enablers for Industry 4.0. In this article, some selected areas of work by 3GPP are discussed.

TSC may offer deterministic network behavior to support real-time applications that require deterministic delay and latency. A TSN bridge can be realized by a 3GPP system with TSN translators at the edges of the network.

NPNs may enable deployment of a 3GPP network for private use, for example, in an enterprise campus and a factory. Possible deployment options are SNPN and PNI-NPN.

Towards stage 1 of Release 18, additional verticals and service capabilities are under consideration for prioritization by 3GPP SA1. Example verticals may include arena sport event broadcast, timing and synchronization, smart grid, and power distributions.

Acronym List

3GPP	3rd Generation Partnership Project
5GS	5G System
CNC	Centralized Network Configuration
DS-TT	Device Side TT
GM	Grand Master
IIoT	Industrial IoT
IoT	Internet of Things
IPSec	IP Security
LAN	Local Area Network
NCIS	Network Controlled Interactive Service
N3IWF	Non-3GPP Interworking Function
NEF	Network Exposure Function
NPN	Non-Public Network
NW-TT	Network Side TT
PDU	Packet Data Unit
PLMN	Public Land Mobile Network
PNI-NPN	Public network integrated NPN
TG	Task Group
QoS	Quality of Service
RAN	Radio Access Network
SA	System Architecture
SLA	Service Level Agreement

SNPN	Standalone NPN
SRP	Stream Reservation Protocol
TSC	Time Sensitive Communication
TSN	Time Sensitive Network
TT	TSN Translator
UE	User Equipment
URLLC	Ultra Reliable Low Latency Communication
VIAPA	Video, Imaging and Audio for Professional Applications
WG	Working Group

References

1. 3rd Generation Partnership Project (3GPP), Technical Specification: TS 23.501, Technical Specification Group Services and System Aspects; System architecture for the 5G System (5GS); Stage 2 (Release 16).
2. 3rd Generation Partnership Project (3GPP)TS 23.502; Technical Specification Group Services and System Aspects; Procedures for the 5G System (5GS); Stage 2 (Release 16).
3. 3rd Generation Partnership Project (3GPP)TR 23.700-07; Technical Specification Group Services and System Aspects; Study on enhanced support of non-public networks (Release 17).
4. 3rd Generation Partnership Project (3GPP)TR 23.700-20; Technical Specification Group Services and System Aspects; Study on enhanced support of Industrial Internet of Things (IIoT) in the 5G System (5GS), (Release 17).
5. 3rd Generation Partnership Project (3GPP)TR 23.734; Technical Specification Group Services and System Aspects; Study on enhancement of 5G System (5GS) for vertical and Local Area Network (LAN) services (Release 16).
6. IEEE 1588–2008: "IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems".
7. IEEE 802.1Qcc: "Stream Reservation (SRP) – Enhancements and Performance Improvements."

About the Author:

Prior to joining Ofinno, Peyman worked with Ericsson Research in Montreal, Canada and the Huawei Research and Innovation Center in Santa Clara, California.
He is an inventor of more than 200 pending or granted patent applications. Peyman has authored more than 30 papers in refereed international conferences and journals.
He has acted as a Technical Program Committee (TPC) for IEEE conferences such as IEEE Conferences on Communications (IEEE ICC), IEEE Vehicular Technology Conference (VTC), IEEE PIMRC, IEEE-CAVS, IEEE-CCNC, and as a session chair for the INFOCOM Workshops. He has reviewed for IEEE Communications Magazine, IEEE Access, IEEE wireless communications letter, as well as other journals such as ACM, Elsevier, and Springer.
Peyman has mentored and supervised students at the undergraduate, Masters and PhD levels. Peyman received his PhD and M.A.Sc in Electrical and Computer Engineering Department at the University of British Columbia (UBC), Vancouver, and his BEng from Carleton University in Ottawa, with high distinction and receiving the Senate Medal for high academic achievements.

About Ofinno:

Ofinno, LLC, is a research and development lab based in Northern Virginia, that specializes in inventing and patenting future technologies. Ofinno's researchers create technologies that address some of the most important issues faced by wireless device users and the carriers that serve them. Ofinno's inventions have an impressive utilization rate. Ofinno's research involves technologies such as 5G Radio and Core networks, IoT, V2X, and ultra-reliable low latency communications. Our innovators not only create the technologies, they oversee the entire process from the design to the time the technology is sold. For more information about Ofinno, please visit www.ofinno.com.