Comparison of Provider Backbone Bridging, TRILL, GRE and GTP-U in 5G for Time Sensitive Industrial Applications

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***Abstract*—The support of industrial communication is one of the new services targeted by 5G. This includes use cases like discrete automation, process automation and intelligent transport systems, which have strong requirements on ultra-reliability, low latency and often also on deterministic date delivery. In contrast to many other IP based services, the industrial services are typically Real-Time Ethernet based. For an efficient support of such Ethernet based services, this paper analyses alternatives to 3GPPs GTP-U/UDP/IP or GRE/IP user plane tunneling used on various interfaces inside the core, the access and between access and core. The proposal of this paper is to avoid IP-based tunneling below the Ethernet end-to-end layer and use Ethernet-over-Ethernet instead. Ethernet over Ethernet can be realized by using IEEE Provider Backbone Bridging (PBB) or the IETF TRansparent Interconnection of Lots of Links (TRILL). This paper compares the GTP-U, GRE, PBB and TRILL approach and gives a recommendation on which alternative to use in a 5G network supporting applications with deterministic traffic requirements.**

***Keywords*—5G; Protocols; Ethernet over Ethernet; Industrial Communication**

I. Introduction

Industrial automation is one of the new vertical markets addressed by 5G. With the 4th industrial revolution, also known as Industrie 4.0 [1], the industry is moving towards an intelligent and flexible production. Industrie 4.0 requires ultra reliable and low-latency wireless communication for use cases like process automation and remote process control. For certain use cases [2], an end-to-end latency of 1 ms and a communication service availability of 99,9999% within a limited service area (e.g. 100m*100m*30m) is required.

The communication inside the industrial factory, i.e. between the sensors, the actuators and the process controllers is typically based on Industrial Ethernet. In this Industrial Ethernet, protocols like PROFINET, SERCOS III or EtherCAT are running on top of this Ethernet, here also called end-to-end Ethernet. Ethernet can be enhanced with IEEE Time Sensitive Networking (TSN) [3] mechanisms to allow deterministic packet delivery across the Ethernet network. The major benefits of Ethernet based TSN are the network wide per-flow QoS mechanisms, the datagram switching allowing for low control overhead, the homogeneous topology, and the low protocol overhead. TSN promises bounded latency and low jitter with maximum flexibility using policing and filtering, queuing, gating together with the *"Time Aware Scheduler"* or the *"Cyclic Queueing and Forwarding"* scheduler.

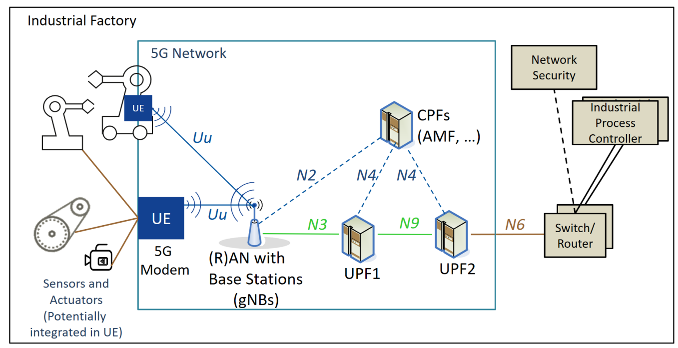

Fig. 1. Industrial network including 5G system

In order to support wireless communication in the industrial environment, a 5G network can be included in the industrial system as shown in Figure 1. The 5G network contains Control Plane Functions (CPFs) like the Access and Mobility Management Function (AMF), User Plane Functions (UPFs), the (Radio) Access Network ((R)AN) containing the Base Stations, also known in 3GPP as gNB, and the 5G modem, which hosts the 3GPP User Equipment (UE) functionality. Wireless communication takes place over the air interface called Uu-Interface.

This document focuses on alternative user plane protocols on those interfaces where today 3GPPs GPRS Tunneling Protocol User Plane (GTP-U) [4] is used on top of UDP/IP. In the 5G System (5GS) [5] and as illustrated in Figure 1, these interfaces are the N3 user plane interface located between the access and the core network and the N9 interface located between User Plane Functions (UPF) inside the core network. Furher on, GTP-U/UDP/IP is also used on the Xn-interface interconnecting different base stations [6] and the F1 interface interconnecting the Central Unit (CU) of a base station with the Distributed Unit (DU) of a base station [7].

The problem with the current 3GPP solution using an IP stack (GTP-U/UDP/IP) below the end-to-end protocol (e.g. Ethernet) is that IP is not suited for deterministic data delivery. Although there are activities on how to support deterministic data delivery on the IP layer [8], there is currently no solution.

Therefore, we propose for the 5G system - at least for *"net-*

work slices" tailored to industrial networks using deterministic networking applications - to use an Ethernet layer inside the 5G network to transport the end-to-end Ethernet data packets. Two methods for such an Ethernet-over-Ethernet transport are analysed in this document, using Provider Backbone Bridging (PBB) as standardized by IEEE or using the TRansparent Interconnection of Lots of Links (TRILL) as standardized by IETF.

This paper is organized as follows: Section II describes the concepts of Ethernet-over-Ethernet Bridging and how to apply this concept to 3GPP Nodes. Section III describes the different protocol stack options in detail. In Section IV, we compare the different alternatives and give a recommendation. Section V describes the procedures for using the recommended Ethernet-over-Ethernet option in an 3GPP system. The conclusions are given in Section VI.

II. Concept of Ethernet-over-Ethernet Bridging in 3GPP Nodes

A. Customer Ethernet over Backbone Ethernet

In this paper, we propose that the 5G system shall support Ethernet as an alternative to GTP-U on the network internal user plane interfaces (excluding the air interface). This Ethernet layer inside the mobile network is in the following called *"Backbone Ethernet"*. The end-to-end Ethernet, also known as *"Customer Ethernet"*, can then be transported over the Backbone Ethernet. The reason for having the two Ethernet layers separated is to have a complete separation of the industrial domain with the 5G domain.

The proposed modifications can be seen when comparing Figure 2 with Figure 3: Figure 2 shows the current 3GPP protocol stack using GTP-U/UDP/IP while Figure 3 showns the new concept of transporting Customer Ethernet data over the Backbone Ethernet in a mobile network.

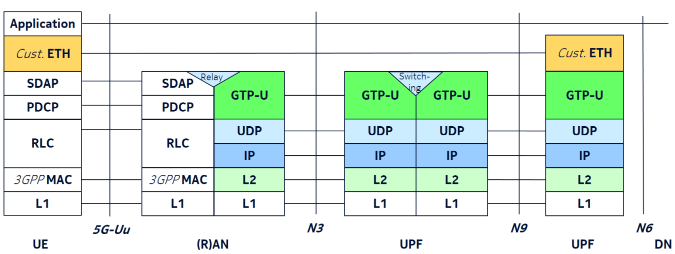

Fig. 2. Standardized 5G user plane protocol stack with GTP-U/UDP/IP on the N3 and N9 interface [5], here shown with Ethernet as end-to-end service

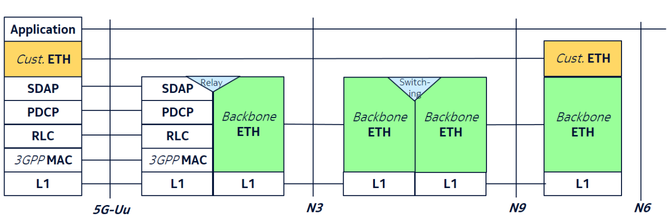

Fig. 3. Proposed 5G user plane protocol stack using Ethernet over Ethernet on the N3 and N9 interface

Such an *"Ethernet-over-Ethernet"* can be realized with two different methods, using either *"Provider Backbone Bridging"* or the *"TRansparent Interconnection of Lots of Links"*.

Provider Backbone Bridging (PBB), also known as *"mac-in-mac"* is a technology originally standardized in IEEE 802.1ah-2008 [9] and now included in IEEE 802.1Q [10] for transporting data belonging to a customer network over a provider network, also called backbone. In our case, the industrial network is the customer network and the mobile network is the providers backbone network.

TRansparent Interconnection of Lots of Links (TRILL) is an IETF Standard [11][12] for transparent unicast shortest-path and multi-destination frame routing in multi-hop networks. Similarly to 802.1aq, TRILL solves some issues of the IEEE 802.1D Spanning Tree Protocol like the detection of loops. Devices implementing TRILL are called *"Routing Bridges"* or *"RBridges"* or very short *"RBs"*. RBs run a link state routing protocol like Intermediate System-to-Intermediate System (IS-IS) [13] and Open Shortest Path First (OSPF) [14] in order to get knowledge about the topology consisting of all the RBridges and all the links between RBridges.

B. Bridging Functionality in 3GPP Nodes

The functionality of putting the Customer Ethernet Frames on top of the Backbone Ethernet is implemented in special bridges. In the case of PBB, this bridge is called Backbone Edge Bridge (BEB). In the case that TRILL is used, this bridge is called Routing Bridge (RB). The principle of having BEB/RB functionality in the 3GPP network is shown in Figure 4.

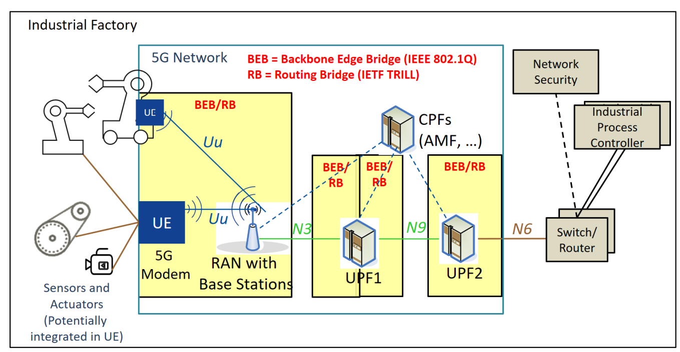

Fig. 4. Concept of introducing bridging functionality in 3GPP Nodes

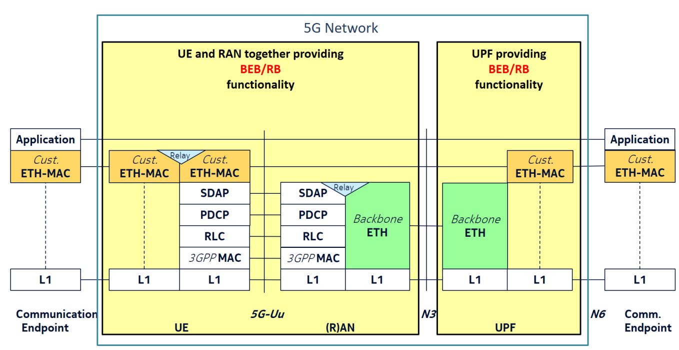

Fig. 5. Bridges in 3GPP Nodes shown with the protocol stacks (only one UPF shown)

The UE together with the Radio Access Network (RAN) can be seen in a logical view as one combined BEB/RB. This means the Customer Ethernet from the Sensors and Actors connected to the User Equipment (UE) will be put on top of the Backbone Ethernet towards the User Plane Function (UPF). The UPF at the Edge towards the Public Data Network or Industrial Network will also act as BEB/RB, e.g. the UPF2 in Figure 4.

Any intermediate UPF like the UPF1 will act as double BEB/RBridge, providing BEB/RBridge functionality on each interface. Such optional intermediate UPFs may not be needed in industrial networks but are used in 3GPP e.g. in case of roaming where UPF1 is in the visited network while UPF2 is in the home network.

Figure 5 shows the basic protocol stack inside a UE/RAN and UPF hosting BEB/RB functionality.

III. Detailed Description of Protocol Stacks

This section presents four alternative protocol options on how to transport the Customers Ethernet over the 5G system, namely the GTP-U-, GRE-, PBB- and the TRILL-based solution.

A. 3GPP solution using GTP-U over UDP/IP

The 3GPP user plane protocol stack on the N3 and N9 interface is based on the GPRS Tunneling Protocol User Plane (GTP-U) [4] which is transported over UDP/IP. The detailed header fields of the GTP-U/UDP/IP protocol stack presented before in Fig. 2 are shown in Fig. 6.

An important field is the GTP Tunnel-Endpoint Identifier (TEID). A TEID unambiguously identifies a tunnel endpoint in the receiving GTP-U protocol entity for a given UDP/IP endpoint. The receiving end side of a GTP tunnel locally assigns the TEID value the transmitting side has to use. The TEID values are exchanged between tunnel endpoints using the appropriate control plane protocol (NGAP [15] for the N2 interface, GTP-C [16] for the N4 interface). The GTP-header does not contain a protocol type field because this information is exchanged via a control plane protocol during the setup of the tunnel.

The detailled protocol header for this Ethernet/GTP-U/UDP/IPv6 protocol stack is shown in Fig. 7. The GTP-U header has a minimum size of 8 bytes (excluding the optional Sequence Number or any Extension Headers). The UDP header has also 8 bytes while the IPv6 header has at least 40 byte. Together, GTP-U/UDP/IPv6 has at least 56 bytes or, including 18 bytes for the Customers Ethernet header, 74 byte.

B. 3GPP solution using GRE over IP

On certain interfaces, 3GPP allows the IETF Generic Encapsulation Protocol (GRE) [17] on top of IP (GRE/IP) as an alternative to GTP-U (GTP-U/UDP/IP), e.g. in a 4G network on the interface between a PDN Gateway (PGW) and a Trusted Wireless Access Gateway (TWAG) and typically in combination with a mobility management based on Proxy-Mobile IP (PMIP) while GTP-C is allowed as an alternative control plane protocol. GRE uses a 32 bit Key-field [18] in a similar way as GTP uses the TEID. Both GRE and GTP-U use an underlying IP layer. The GRE header including the Key-field but without Sequence-Number has a size of 12 byte. GRE and IPv6 together thus have 52 byte.

High level view of Protocol Stack	View of Protocol Stacks Fields/TAGs	Field Length (Byte)	Content
Payload	Payload	..	Payload
Customer ETH	Ethertype	2	Ethertype
	C-TAG	4	Customer VLAN ID (Eth.Type 0x8100)
	S-TAG (opt.)	*(4)*	*Service VLAN ID (Eth. Type 0x88A8)*
	C-SA	6	(Customer) Source MAC Address
	C-DA	6	(Customer) Destination MAC Address
GTP-U	*Ext Header (Opt)*	*(0..x)*	*Extension headers (Optional)*
	N-PDU Nbr (Opt).	*(1)*	*N-PDU Nbr. e.g. for HO (Optional)*
	Sequence Nbr (Opt)	*(2)*	*Sequence Number (Optional)*
	TEID	4	**Tunnel Endpoint Identifier**
	Length	2	Length of packet
	Message Type	1	GTP-U Message Type
	Version + Flags	1	Version, PT, E, S, PN-Flags
UDP	Dest. Port Nbr.	2	Destination Port Number
	Source Port Nbr.	2	Source Port Number
	UDP Checksum	2	UDP Checksum
	UDP Length	2	UDP Length
IP (here: IPv6)	Dest. IP Addr.	16	Destination IPv6 Address
	Source IP Addr.	16	Source IPv6 Address
	Length, NH, HL	4	Payload length, next header, hop limit
	Version, TC, FL	4	Version, Traffic Class, Flow Label
L2	L2	14+..	e.g. at least 14 bytes for Ethernet
L1	L1		

Fig. 6. Protocol header fields for Ethernet over GTP-U/UDP/IP

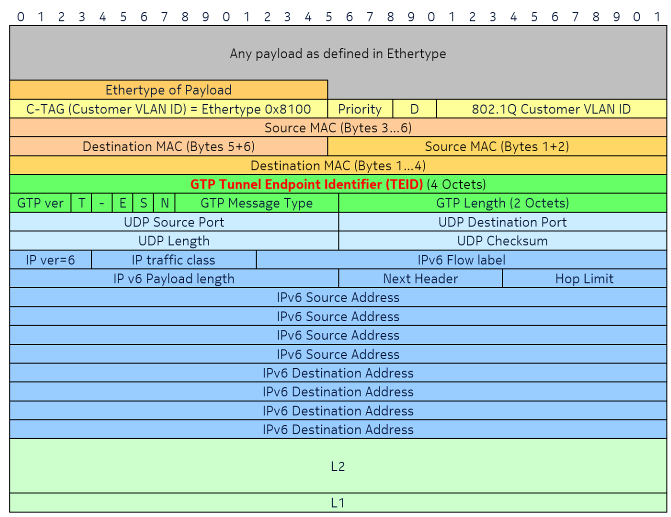

Fig. 7. Detailled protocol Header for Ethernet over GTP-U/UDP/IP

C. Ethernet over Ethernet with Provider Backbone Bridging

Figure 8 shows the protocol fields of the protocol stack using PBB according [9] [10]. Besides the Backbone Destination MAC Address (B-DA) and the Backbone Source MAC Address (B-SA), different parameters, called TAGs are used for transporting VLAN- or PBB-related information. The Customer VLAN-TAG (C-TAG) and can be used in both the Backbone Ethernet and the Customer Ethernet. An S-TAG can be used to transport a Service VLAN TAG or a Backbone VLAN TAG. The most relevant TAG for this paper is the ”Backbone Service Instance TAG” (I-TAG) which transports different flags, the Backbone Service Instance Identifier (I-

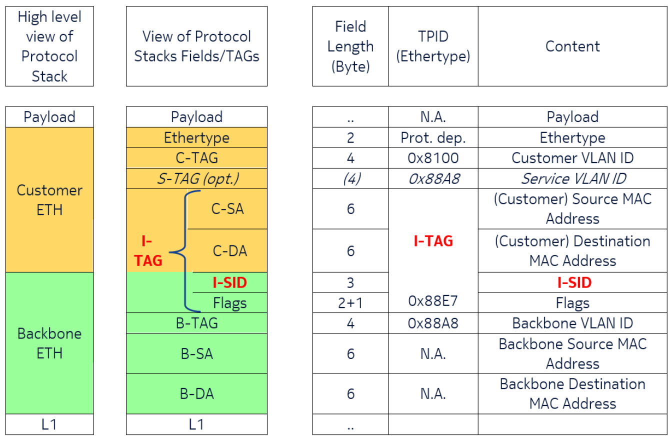

Fig. 8. Protocol header fields for Ethernet over Ethernet with PBB

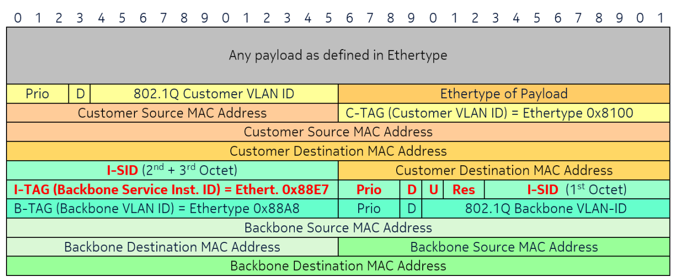

Fig. 9. Detailled protocol Header for Ethernet over Ethernet with PBB

SID) as well as the Customer Destination MAC Address (C-DA) and the Customer Source MAC Address (S-DA). The I-SID permits the identification of up to 2^{24} backbone service instances. In our case using PBB in a mobile network, the I-SID can be used to identify a user data flow or a user plane tunnel as done with the GTP TEID explained before in subsection III-A

Figure 9 shows the detailled bit-wise protocol header for using Ethernet over Ethernet with PBB according to [9] [10]. The backbone Ethernet Header including the B-DA, B-SA, B-TAG and the I-TAG including the I-SID but without Customers Ethernet C-DA and C-SA have 22 byte. The Customer Ethernet header with C-DA, C-SA, C-TAG and Ethertype have 18 byte, which makes together 40 byte.

D. Ethernet over Ethernet with TRILL

Figure 10 shows the protocol fields when using TRILL [12]. TRILL data packets have a local link header including the Outer-DA and Outer-SA and a TRILL-TAG with the Ingress RB Nickname and the Egress RB Nickname. With TRILL, the GTP tunnel endpoints would be the Ingress RB and the Egress RB while the Outer-DA and Outer-SA are used for the hop-by-hop forwarding from one intermediate switch/RB to another switch/RB. The 2-octet nicknames which are used to save space in the in the TRILL header are negotiated via a nickname acquisition protocol.

The TRILL-TAG however does not provide any field to transport some kind of tunnel or service identifier like the TEID or the I-SID. The solution is to use a further extension,

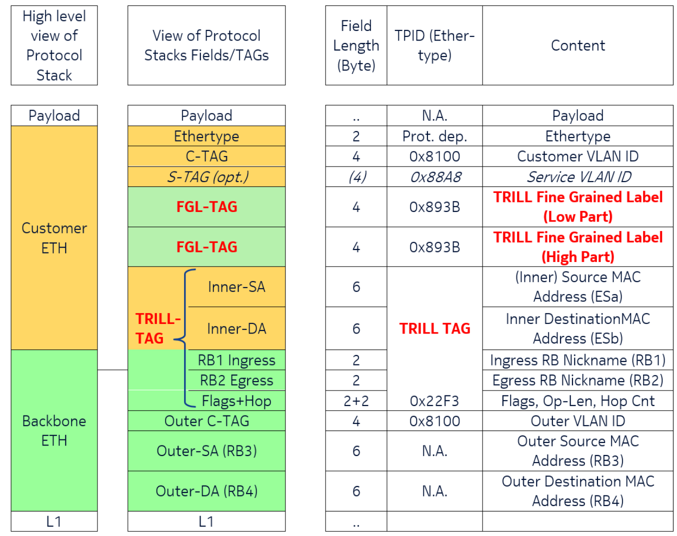

Fig. 10. Protocol header fields for Ethernet over Ethernet with TRILL

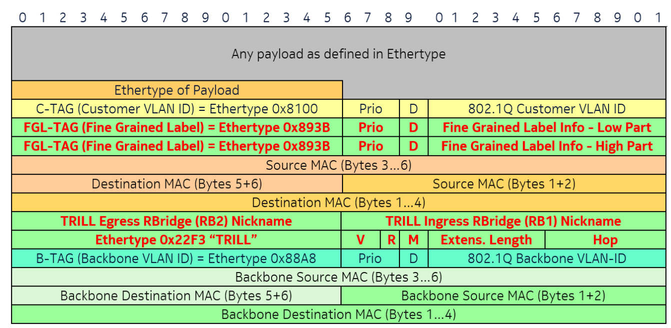

Fig. 11. Detailled protocol Header for Ethernet over Ethernet with TRILL

in this case to use a Fine Grained Label (FGL) as specified in [19]. The 24-bit FGL is transported in two FGL-TAGs as shown Figure 10, each identfied by the Ethertype 0x893B, one transporting the lower 12-bit of the FGL, the other the upper 12-bit of the FGL. A shown in the detailled protocol header in Figure 11, the FGL-TAG has a similar layout as a VLAN-TAG (C-TAG, B-TAG, S-TAG).

IV. Comparison of the Different Options

A comparison of the different protocol options is shown in Table I. GTP is the standard tunneling protocol in 3GPP and thus well suited for mobile applications. IETF GRE is also a tunneling protocol and used e.g. in 3GPP for tunneling traffic from a Gateway towards a non-3GPP access point like an WLAN Access Point. IEEE PBB targets Service Provider and Enterprise segments while the target of IETF TRILL is more on Data Center and Enterprise segments.

An estimation of the maximum delays occurring within one UPF and one corresponding cable for a high priority user plane packet with 300 bytes payload is given in Table II. The biggest difference between the options is the queuing delay. The IP-layer used with GTP-U/UDP/IP and GRE/IP has currently no mechanisms for deterministic networking as required for industrial real-time applications. For example, there is no interworking of IP with enhancements for scheduled traffic according to IEEE 802.1Qbv-2015 [20] when transporting the Ethernet packets over an IP connection. Without such a time aware scheduled traffic, the bridge/router latency in a simple example according [21] would be up to 12.336 μs. With TSN mechanisms like time aware shaping as possible in the PBB and TRILL options, there is no queuing delay for scheduled traffic.

Further on, IP adds unnecessary complexity, packets can be lost, received multiple times, IP related procedures like ICMPv6 may add further delay and due to the dynamic nature of the IP routing the routes and thus the delay may change.

TABLE I. COMPARISON OF THE DIFFERENT PROTOCOL OPTIONS

Protocol	**GTP-U**	**GRE**	**PBB**	**TRILL**
Standard	3GPP TS 29.281	IETF RFC 2784	IEEE 802.1ah/.1Q	IETF RFC 5556
Protocol Stack	GTP-U /UDP/IP	GRE /IP	Eth with PBB	Eth with TRILL
Header size Mob. Netw. part only	56 byte +L2/L1	52 byte +L2/L1	22 byte +L1	32 byte +L1
Header size incl. E2E Eth	74 byte +L2/L1	70 byte +L2/L1	40 byte +L1	50 byte +L1
Connection control protocol	NGAP or GTP-C or similar protocol in 2G/3G/4G, e.g. S1-AP	PMIP or GTP-C	Usually none but NGAP /GTP-C in mobile networks	Usually none but NGAP /GTP-C in mobile networks
Tunnel /Service identification	TEID (+ UDP Port + IP Addr)	Key (+ IP Addr)	I-SID (+ B-SA + B-DA)	2*FGL (+ RB1 + RB2)
Routing protocol	IP	IP	IEEE 802.1aq Short. Path Bridging	included in TRILL
Service instance scalability	4294967296 (32 bit TEID)	4294967296 (32 bit KEY)	16777216 (24 bit ISID)	16777216 (24 bit FGL)
Suited for deterministic traffic	No inherent determinism	No inherent determinism	Yes, with TSN	Yes, with TSN

TABLE II. MAXIMUM DELAY FOR A SCHEDULED DATA PACKET WITH 300 BYTE PAYLOAD FOR 1 HOP WITH 100 METER GIGABIT ETH. CABLE

Protocol	**GTP-U**	**GRE**	**PBB**	**TRILL**
Example packet size	300+56+42 = 398 byte	300+52+42 = 394 byte	300+40+24 = 364 byte	300+50+24 374 byte
Est. processing delay	1.0 μs	1.0 μs	1.0 μs	1.0 μs
Max. queuing delay	12.336 μs	12.336 μs	0.0 μs	0.0 μs
Transmission delay (8ns/byte)	3.184 μs	3.152 μs	2.912 μs	2.992 μs
Propagation delay/100m (Cat5e)	0.005 μs	0.005 μs	0.005 μs	0.005 μs
Max. total delay for scheduled traffic	**16.525** μs	**16.493** μs	**3.917** μs	**3.997** μs

Therefore, we recommend to use an Ethernet-over-Ethernet approach using either PBB or TRILL. PBB has the smallest header size and the I-SID is intrinsically included in the I-TAG. TRILL has more overhead as it uses a local header with the outer DA and SA as well as further adress information (Ingress RB, Egress RB) in the TRILL TAG. For transporting the Fine Grained Label, even two additional TAGs are needed. TRILL is designed for arbitrary networks while a mobile network is a well-structured hierarchical network. Therfore, certain TRILL features like loop prevention or multi-destination frame routing are not needed. Due to this overhead in TRILL in the header size as well as in the TRILL procedures, we see Provider Backbone Bridging as the recommended solution for transporting Ethernet based end-to-end traffic in a mobile network.

V. PROCEDURES

The use of a different protocol stack on the user plane has impact on the control plane procedures and parameters. In the current 3GPP solution, the most relevant parameter for managing the GTP-tunnels of a user is the TEID. The TEID is exchanged via the control plane protocols (NGAP, GTP-C) and then used in each user plane data packet. Besides the normal TEID (32 bit), 3GPP has also specified a *Fully Qualified Tunnel Endpoint Identifer (F-TEID)* [16] which includes besides the TEID value also the IPv4 and/or IPv6 address of the receiving endpoint. In case a GRE/PMIPv6 based interface is used (e.g. in 4G on the S5/S8 interface for connecting non-3GPP accesses like WLAN), the 32 bit GRE key field is encoded in the 32 bit TEID field.
In a similar way, the I-SID or the FGL can be coded into the TEID field of the control plane protocol in case PBB or TRILL is used on the user plane. This mapping of the TEID, KEY, I-SID or FGL value into the identifier used on the control plane protocol is shown in 12.

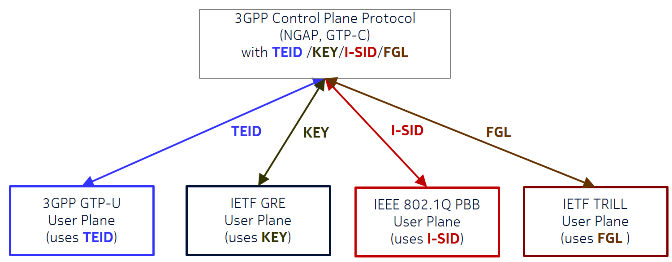

Fig. 12. Mapping of control plane identifier to user plane identifier

The required modifications to a 5G PDU Session Establishment procedure [22] are shown in 13. For the industrial use cases as described in this paper, the *Session Establishment Request* transported in the messages 1 and 2 will use a PDU Session Type set to *Ethernet* as already supported in 5G. The messages and procedures 3 to 9 also do not require a modification. Upon the reception of message 9 *Create Session Request* from the Session Management Function (SMF), the UPF assigns an I-SID value used for the uplink traffic on the N3 interface for this session. In message 10 *Create Session Response*, the I-SID value is transported towards the SMF in a new I-SID parameter or inside the existing TEID parameter. In message 12, the I-SID value is transported to the (R)AN. Thus the base station knows now which I-SID to use when sending uplink traffic and thus traffic can be sent now in uplink direction.

The base station now assigns an I-SID value for receiving downlink and sends this value in the messages 14, 15 and 16 via AMF and SMF towards the UPF1. The UPF1 knows now which I-SID to use for sending downlink traffic and can thus send the downlink traffic.

This message sequence chart shows that only minor modifications of parameters must be made in the control plane procedure for using a PBB-based user plane while the sequence of messages is unchanged.

VI. CONCLUSIONS

For supporting industrial applications with real time needs in 5G, the user plane protocol stack used inside and between

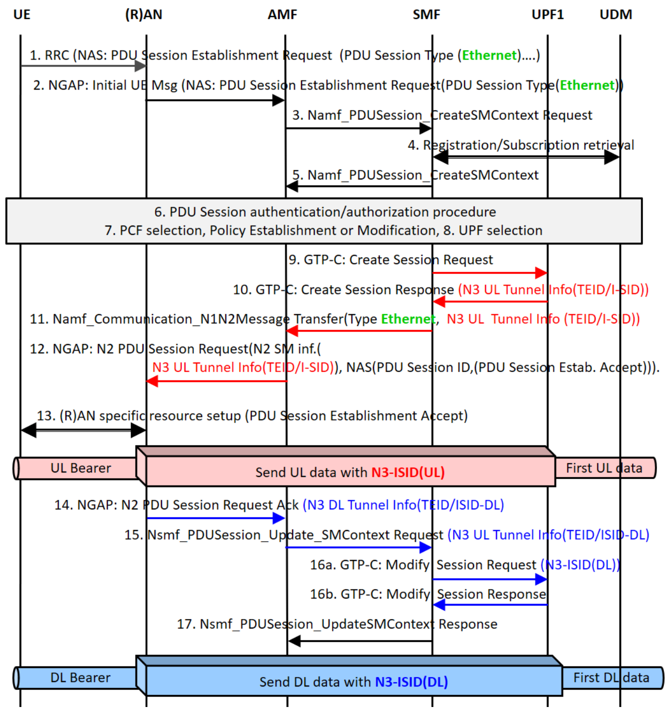

Fig. 13. 5G UE-requested Ethernet-PDU Session Establishment using Provider Backbone Briding on the N3 interface

the core- and the radio access-network required for mobility features like handover and multi-connectivity should be changed. Therefore, we analyzed four different user plane protocol stacks in this paper, namely the GTP-U/UDP/IP stack as current 3GPP state-of-the-art solution, GRE/IP as an alternative typically used for connecting non-3GPP access systems to a 3GPP core network, Ethernet based PBB as a solution from IEEE and Ethernet based TRILL as a solution from IETF.

The IP-layer used with GTP-U/UDP/IP and GRE/IP adds unnecessary complexity and does not support deterministic networking as required from the industrial real-time applications. Therefore, we propose an *"IP-less"* Ethernet over Ethernet user plane to enable such time sensitive low latency communication. From the two Ethernet over Ethernet solutions, PBB and TRILL, PBB has a more compact protocol header and avoids several routing related procedures associated with TRILL which are not required in networks with a well-structured topology like 3GPP networks. Therefore, we recommend to use Ethernet based Provider Backbone Bridging instead of GTP-Tunnelling in a 5G system supporting applications with deterministic traffic requirements.

The findings from this paper shall help interested groups like 3GPP in their work, e.g. on the enhancement of the 5G system for the support of Vertical and LAN Services [23].

VII. Acknowledgement

This work has been partially funded by the German ministry of education and research (BMBF) under grant 16KIS0720 (TACNET 4.0). The views expressed are those of the authors and do not necessarily represent the project. The consortium is not liable for any use that may be made of any of the information contained therein.

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