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TRILL-Based Mobile Packet Core Network for 5G Mobile Communication Systems

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Abstract In the Evolved Packet Core (EPC) network architecture for 4G mobile communication systems, the data delivery is performed based on the GPRS tunneling protocol (GTP) between eNodeB and the gateways. However, the use of GTP tunnels may give some drawbacks, which include large tunneling overhead for packet, non-optimal data paths between Mobile hosts within the same network, and frequent tunnel updates for every handover. In this paper, we propose a new architecture for mobile core network in the emerging 5G mobile systems. The proposed mobile core network architecture is based on the Transparent Interconnection of Lots of Links (TRILL) protocol for data delivery and mobility management, named TRILL-based Packet Core (TPC). In the proposed architecture, each eNodeB will function as a Routing Bridge (RB) of TRILL. The data delivery operations are performed between RBs by using TRILL switching mechanisms, rather than using GTP tunnels. The proposed architecture uses Mobility Management Entity (MME) to manage the mapping information between identifier (IP address of user equipment) and locator (MAC address of RB). For handover of user equipment, the location of users will be updated with MME. By numerical analysis, it is shown that the proposed 5G-TPC architecture can give more performance benefits than the 4G-EPC architecture in terms of data tunneling overhead, total transmission delay and route update delay after handover.

Keywords 5G · Mobile core network · Routing bridge · TRILL

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1 Introduction

In recent years, the advancement of smart phones and various wireless mobile communication technologies started an era of highly-efficient information society. In the coming years, it is expected that the penetration of wireless communication technologies will become much wider and deeper [1]. Observing the increasing demand of wireless communication systems in the future, one of the crucial challenges in mobile industry is how to design the 5th generation (5G) mobile networks more effectively. The need of a new 5G mobile system is based on a couple of remarkable changes of mobile network environments, such as avalanche of overwhelming Internet traffics, explosive growth of the number of various connected devices, and large diversity of use cases and requirements [2, 3].

The 5G mobile system shall be designed to effectively cope with such environmental changes. Among these changes, the most crucial factor to be considered is how to handle the explosive growth of mobile data (Internet) traffic. A report says that overall mobile data traffic is expected to grow up to 15.9 exabytes per month by 2018 [4].

To address the mobile data traffic explosion issue, a lot of ideas are being proposed, which include small cell approach, device-to-device communication, and so on. However, we note that such efforts are mainly focusing on how to increase the capacity of wireless radio links. The 5G system consists of radio link part and mobile core network part. It is believed that an effective design of mobile core network, as well as the radio link part, is also very crucial to achieve the goals of 5G system.

The 4G mobile core network, called the Evolved Packet Core (EPC), is based on the GPRS tunneling protocol (GTP) for data delivery [5]. In EPC, each eNodeB (eNB) establishes the GTP tunnels with a centralized anchor, such as Serving gateway (S-GW) or PDN gateway (P-GW), for data packet delivery. However, in the 4G-EPC architecture, the use of GTP tunnels may give some drawbacks. First, a large tunnel overhead is required for data packets, since a packet shall include the GTP/UDP/IP header. Secondly, the data path between two Mobile hosts in the same network may be not optimal, since the data packets will be delivered over the GTP tunnels with S-GW or P-GW. In addition, the GTP tunnel shall be re-established each time a mobile user moves into a new eNB region, which gives a big burden to S-GW/P-GW. These problems will become more severe, as a cell size gets smaller and the mobile Internet traffic increases in the future.

To enhance the GTP-based 4G-EPC architecture, in this paper, we propose a new architecture for 5G mobile core network, named *TRILL-based Packet Core* (*TPC*). The TPC network is based on the Transparent Interconnection of Lots of Links (TRILL) [6, 7] for data delivery, rather than the GTP tunnel. In the TPC network, each eNB will provide the TRILL Routing Bridge (RB) functionality. The Mobility Management Entity (MME) of 4G-EPC is used to manage the mapping information between identifier (IP address of user equipment) and locator (MAC address or TRILL nickname of RB). For each movement of user equipment, the location of users is updated to MME. For data delivery, the current location of mobile users will also be identified and managed by MME.

The rest of this paper is organized as follows. In Sect. 2, we briefly review the relate works. Section 3 describes the proposed 5G-TPC architecture and procedures. Section 4 compares the existing 4G-EPC and proposed 5G-TPC schemes in terms of data tunneling overhead, total transmission delay and route update delay by numerical analysis. Section 5 concludes this paper.

2 Mobility Management in 4G Architecture

The System Architecture Evaluation (SAE) [5] is the core network architecture of 3GPP which supports high throughput, low latency, and mobility between multiple heterogeneous systems. The main components of the SAE architecture are the Evolved Packet Core (EPC) and Evolved UMTS Terrestrial Radio Access Network (E-UTRAN). EPC networks are composed of different entities such as Serving Gateways (S-GW), Mobility Management Entity (MME), Packet Data Network Gateway (P-GW), Home Subscriber Server (HSS) and Policy and Charging Rules Function (PCRF). The S-GW works as a local mobility anchor for intra-3GPP handover. MME handles mobility management, authentication and bearer management. P-GW provides the IP multimedia services and allocating IP addresses. HSS is a central database which contains the user related information and the mobility management functionality, user authentication and authorization. PCRF determines the policies, such as quality of services and charging rules. The evolved Node B (eNB) constitutes the E-UTRAN network.

In the EPC architecture, a data path is established between eNB and S-GW/P-GW by a signaling protocol (e.g. GTP-C) by using the GTP tunneling. One endpoint of the tunnel is S-GW/P-GW that will play a role as a centralized anchor. Accordingly, all data packets in 4G-EPC will be delivered through the centralized anchors (S-GW/P-GW), as shown in Fig. 1.

Figure 1 shows the network model for the current Evolved Packet Core (EPC) architecture in 4G mobile networks, in which UE is classified into Internet host and Mobile host. In the figure, PDN-GW gives an access to user equipment (UE). In the figure, we consider the two communication scenarios: (1) both UE is a Mobile host that is subscribed to the same mobile domain; (2) one UE is an Internet host that is located outside the mobile network. In the figure, UE moves to another domain by handover.

Figure 2 describes the initial procedures in 4G-EPC: network attachment and binding update by UE, and the data delivery from one UE to another UE. When UE establishes a radio link with eNB, it sends an *Attach Request* to Mobility Management Entity (MME).

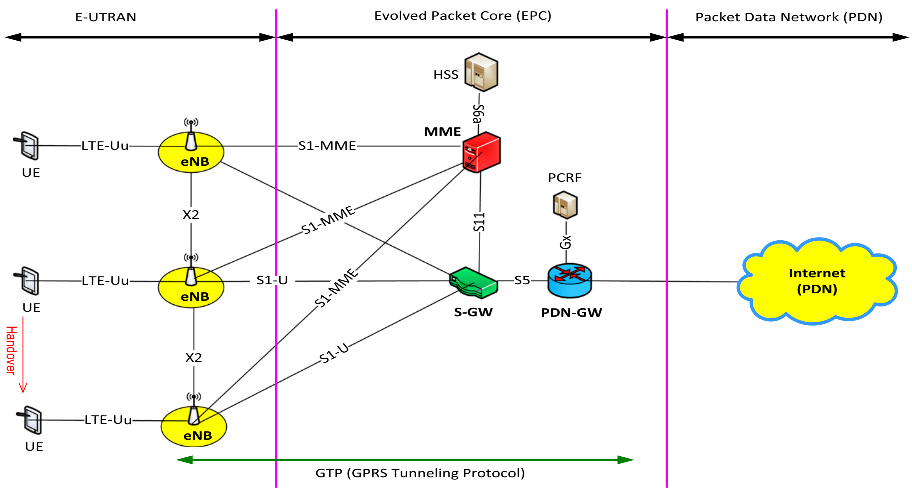


Fig. 1 Network model for 4G Evolved Packet Core

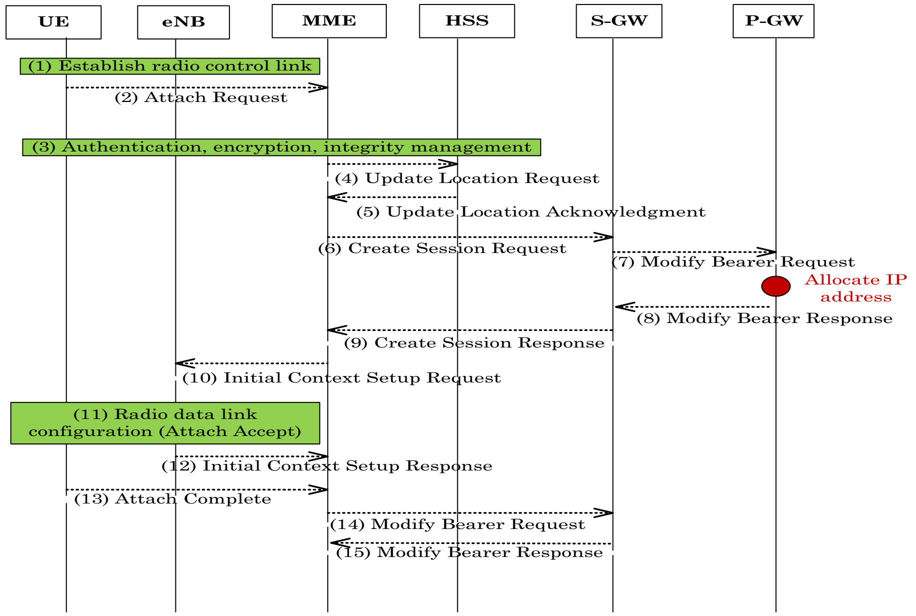


Fig. 2 Initial registration in 4G-EPC

Then, the security-related procedures are performed between UE and MME. MME will update the associated Home Subscriber Server (HSS). To establish a transmission path, MME sends a *Create Session Request* to S-GW. When S-GW receives the request from MME, it will send a *Modify Bearer Request* message to P-GW. The P-GW responds with a *Modify Bearer Response* message to S-GW. Then, S-GW will respond with a *Create Session Response* to MME. Now, MME sends the information received from S-GW to eNB within the *Initial Context Setup Request* message. This signaling message also contains the *Attach Accept* notification, which is the response of *Attach Request*. Then, eNB responds with an *Initial Context Setup Response* to MME. Then, UE sends an *Attach Complete* message to MME. Then, MME sends a *Modify Bearer Request* message to S-GW, and S-GW will respond with a *Modify Bearer Response* to MME.

For data delivery, UE sends a data packet to P-GW. Then, P-GW finds the location of corresponding UE (either Mobile host or Internet host) from its database, and it will forward the data packet to the corresponding UE, as shown in Figs. 3 and 4.

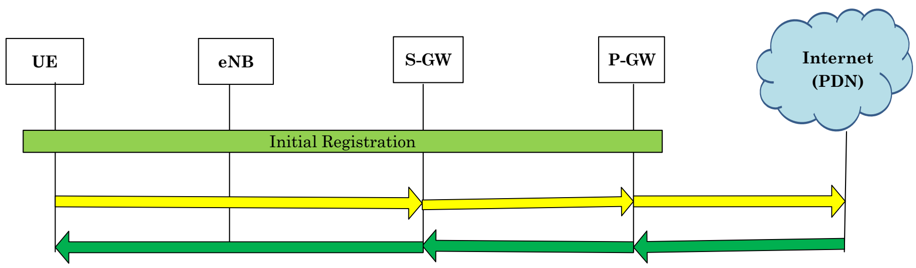


Fig. 3 Data delivery operation from Mobile host to Internet host

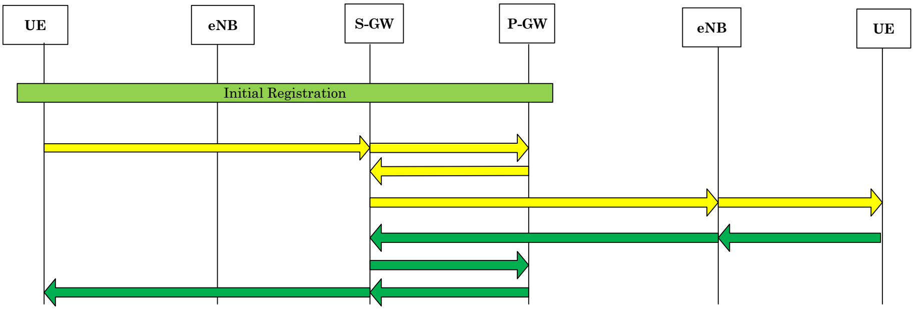


Fig. 4 Data delivery operation from Mobile host to Mobile host

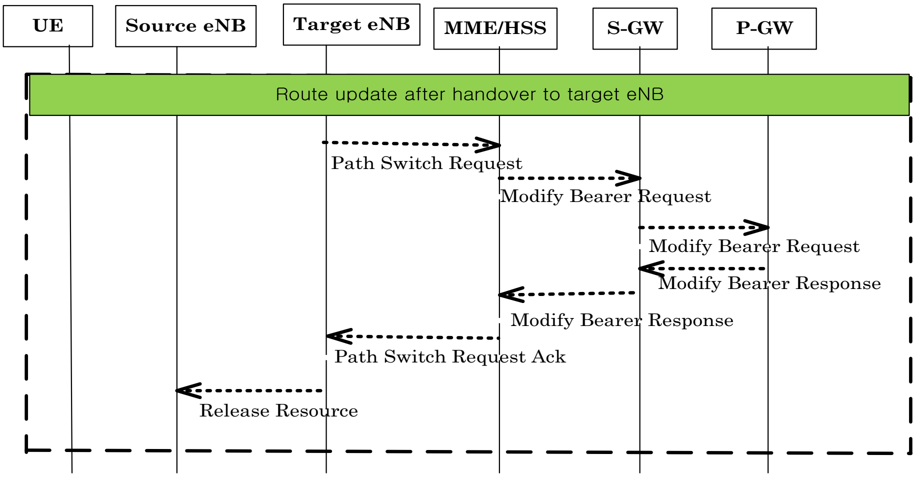


Fig. 5 Route update after handover to target eNB

Figure 5 shows the route update operation after handover of 4G-EPC [5]. By handover, UE moves from Source eNB to Target eNB. The Target eNB will send a *Path Switch Request* message to MME. Then, MME sends a *Modify Bearer Request* to S-GW. On reception of *Modify Bearer Request*, S-GW sends *Modify Bearer Request* to P-GW. Then, P-GW will respond with *Modify Bearer Response* to S-GW. S-GW will also respond with *Modify Bearer Response* to MME. Then, MME sends *Path Switch Request Ack* to Target eNB. Then, Target eNB sends *Release Resource* to Source eNB.

Figure 6 shows the protocol stack for the GTP-based data delivery in 4G-EPC. The radio access uses the protocols MAC, RLC, and PDCP. The GPRS Tunneling Protocol (GTP) is used between eNB and S-GW/P-GW. GTP encapsulates the original IP packet into an outer IP packet.

However, the 4G-EPC architecture gives some drawbacks. First of all, a large tunneling overhead is required for GTP tunneling, in which 36 bytes (in IPv4) or 56 bytes (in IPv6) will be additionally used for GTP/UDP/IP headers per data packet [8]. Secondly, non-optimal data path may be used when the two communicating Mobile hosts are within the same network, since all data packets shall be routed via the centralized anchor, such as

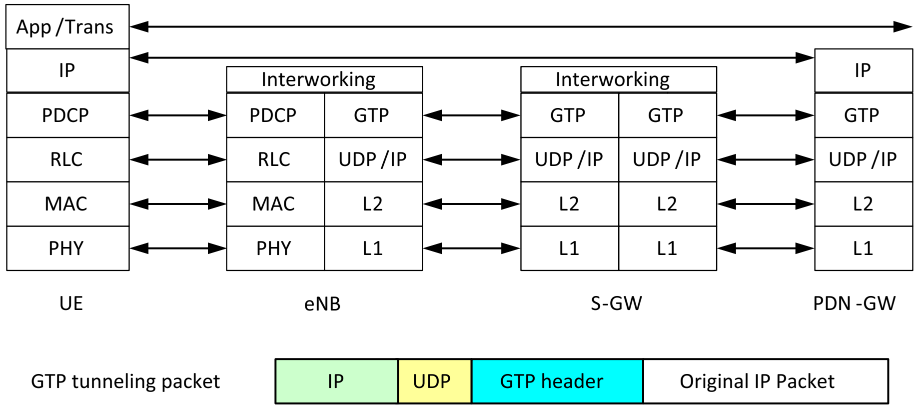


Fig. 6 Protocol stack for data delivery

S-GW and P-GW. In addition, the 4G-EPC architecture suffers from inefficient mobility management for the GTP tunnel update operations. That is, the GTP tunnel of a Mobile host must be newly established whenever it moves into a new region. This may result in the scalability problem, as the number of Mobile hosts increases significantly in the network.

To address the inefficiency problem of data delivery in 4G-EPC, a lot of schemes have so far been proposed. The data off-loading mechanism using WLAN or femto-cell [8] is a typical instance. This was proposed to reduce Internet traffics flowing into the mobile core network, in which a part of mobile data traffics will be detoured to or from the Internet without using the core network. This approach is helpful to alleviate the concentration of data traffics onto a centralized anchor.

Another representative approach to enhance the 4G system is to adopt a distributed architecture instead of a centralized one, as shown in the distributed mobility management (DMM) [9, 10]. In DMM, the route optimization will be intrinsically supported. Basically, DMM tries to change the centralized architecture of 4G-EPC into the distributed one, so as to avoid the traffic concentration on a specific central node. Ultra Flat Architecture (UFA) [10] was proposed in the similar context as DMM. The key idea of UFA is to impose non-hierarchical or flat structure on mobile networks so as to provide better performance on data services.

However, we note that most of these distributed architectures are based on the layer 3 technology, i.e. Internet Protocol (IP). From the perspectives of performance and CAPEX/OPEX, a layer 2 (link layer or MAC layer) approach is preferred to the layer 3 one. Recently, the Routing Bridge (RB) technology was proposed [6]. Use of RBs can provide the advantages of layer 2 for data packet delivery (e.g. switching rather than routing).

Due to such advantages, RB has already been considered as a promising technology for data centers and campus networks, as shown in the IETF TRILL Working Group [7, 11]. In TRILL, an Ingress Routing Bridge (IRB) prepends a TRILL header to the data packet of a source host, and then an Egress Routing Bridge (ERB) strips the TRILL header prior to final delivery to the destination host. TRILL can be used as a key technology for mobile networks.

A study on the use of RBs into mobile networks was also made in [12], which was done in the Celtic MEVICO project. In the study, the use of RBs in mobile backhaul network is proposed and discussed in terms of CAPEX/OPEX.

In this paper, we argue that TRILL can be used in mobile core network. Thus, we propose a new architecture for mobile core network of 5G system, TRILL-based Packet Core (TPC).

3 Proposed 5G-TPC Architecture

3.1 Network Model

Figure 7 shows an overview of the proposed 5G-TPC architecture. The 5G-TPC network is based on the layer 2 Routing Bridges (RBs) of TRILL. In the figure, each eNB functions as Ingress RB (IRB) or Egress RB (ERB). S-GW/P-GW will also function as IRB or ERB for Internet hosts. Transit RBs (TRBs) are used for packet delivery in the mobile core network. In the figure, UE moves to another domain by handover.

For an identifier of user equipment (UE), an IP address will be allocated to the UE by the Mobility Management Entity (MME). The MAC address (or TRILL nickname) of eNB is used as the locator of UE. The MME with the home subscriber server (HSS) is also used to manage the mapping information between identifiers and locators of UEs. For this purpose, MME maintains its ID-LOC Register (ILR) that keeps the list of identifiers and locators of UEs in the mobile network.

For routing protocol, a link state protocol is used, such as IS–IS and OSPF, as specified in the IETF TRILL Working Group. With the help of the link state protocol, each RB can obtain the routing information on the entire network topology.

3.2 Comparison of 4G-EPC and 5G-TPC

Based on the discussion so far, we compare the distinctive features of the existing 4G-EPC and proposed 5G-TPC architectures, as described in Table 1. For data delivery, 4G-EPC is

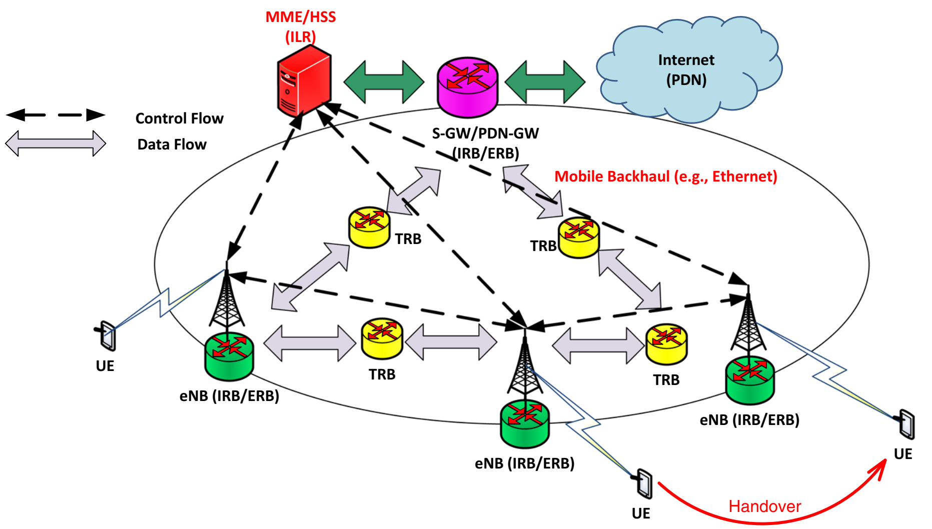


Fig. 7 Proposed TRILL-based Packet Core (TPC) for 5G network

Table 1 Comparison of 4G-EPC and 5G-TPC

Item	4G-EPC	5G-TPC
Data delivery protocol	GTP	TRILL based on RB
Locator	TEID (GTP)	MAC address of eNB (RB)
Encapsulation	GTP/UDP/IP	MAC-in-MAC
IP address allocation	Allocated by PDN-GW	Allocated by MME
Handover update	GTP tunnel re-established	Locator updated to MME
Optimal route	Non-optimal (via S-GW/P-GW)	Optimal (IRB ⇔ ERB)

based on the GTP tunneling protocol, whereas 5G-TPC uses the TRILL protocol based on Routing Bridges. In 4G-EPC, TEID of GTP is used as a locator, whereas the MAC address (or TRILL nickname) of eNB is used as a locator in 5G-TPC. In the data packet encapsulation, 4G-EPC needs the GTP/UDP/IP headers for GTP tunneling, whereas 5G-TPC uses the MAC-in-MAC encapsulation for data delivery, based on the TRILL.

For handover of UE, the GTP tunnel shall be re-established between eNB and P-GW in 4G-EPC. In 5G-TPC, only the new location information of UE (that is, MAC address of eNB/RB) will be updated with the MME. In 4G-EPC, the data path depends on the GTP tunnel with S-GW/P-GW, and thus it may induce a non-optimal path if the two communication UEs are in the same mobile network. In the meantime, the data path in 5G-TPC will be optimal, since the data packet is delivered directly between Ingress RB and Egress RB in the network.

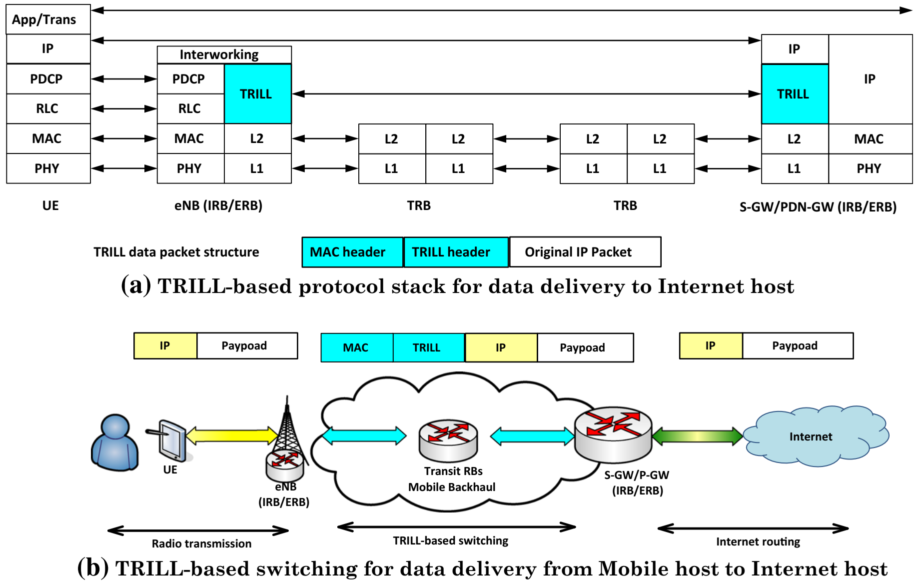
3.3 Protocol Stack and TRILL-Based Switching for Data Delivery

Figure 8 illustrates the protocol stacks and TRILL-based switching for data delivery for communication between a mobile UE and an external Internet host. In the figure, the TRILL-based data switching will be performed between eNB and S-GW/P-GW. The radio access part between UE and eNB will use the RLC and PDCP protocols. eNB (with ingress RB) encapsulates the original IP packet by using the MAC-in-MAC encapsulation. The transit RBs (TRBs) will forward the data packets from ingress RB to egress RB in mobile core network. In the figure, TRILL and MAC header are used for packet delivery in mobile network.

Figure 9 shows the protocol stack and TRILL-based switching for communications between two UEs within the mobile network. Both of the two UEs are located in the mobile network, and each UE is connected to an eNB. The data delivery over the radio link will follow the existing RLC and PDCP protocols. The data delivery between RBs over mobile core network is based on the TRILL-based switching mechanism. It is noted that eNB will function as an Ingress or Egress RB for TRILL switching. Some Transit RBs (TRBs) can be used to deliver the data packets between IRB and ERB.

3.4 Registration Procedures

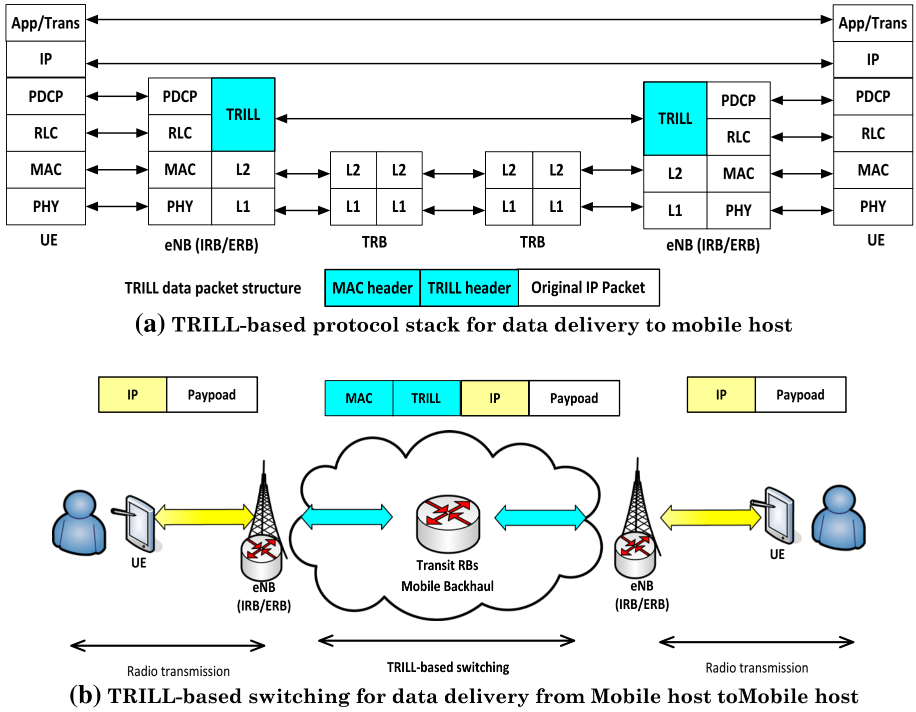
The initial registration operations of 5G-TPC are shown in Fig. 10. When UE establishes a radio link with eNB (RB), it sends an *Attach Request* message to eNB. Now, eNB sends the *Attach Request* with *Map Binding Request* to MME/HSS. On reception of this message,



(a) TRILL-based protocol stack for data delivery to Internet host

(b) TRILL-based switching for data delivery from Mobile host to Internet host

Fig. 8 Protocol stack and TRILL-based switching from Mobile host to Internet host for data delivery



(a) TRILL-based protocol stack for data delivery to mobile host

(b) TRILL-based switching for data delivery from Mobile host toMobile host

Fig. 9 Protocol stack and TRILL-based switching from Mobile host to Mobile host for data delivery

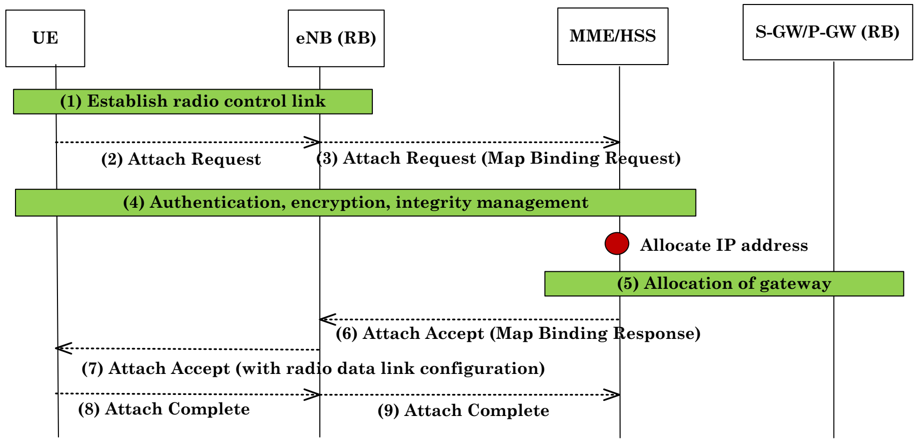


Fig. 10 Initial registration

MME/HSS will update its ID-LOC Register (ILR). ILR keeps track of the ID-LOC mappings for UEs in the mobile network. Then, the security procedures are performed between UE and MME/HSS in Step 4. MME/HSS will allocate an IP address to UE.

Then, MME/HSS will allocate a gateway for UE (Step 5). Then, the allocated S-GW/P-GW prepares a radio access bearer to eNB. Then, MME/HSS responds with an *Attach Accept* message containing *Map Binding Response* to eNB (Step 6). Then, eNB sends *Attach Accept* with radio data link configuration to UE (Step 7). After that, UE sends an *Attach Complete* message to eNB and further to MME/HSS (Steps 8, 9).

3.5 Data Delivery Procedures

After initial registration, UE can send or receive data packets. The data delivery scenarios are classified into (1) Mobile host to Internet host, and (2) Mobile host to Mobile host.

3.5.1 Mobile Host to Internet Host

Figure 11 shows the data delivery operations for Mobile host to Internet host. First, UE sends a data packet to eNB (RB). eNB will check whether the destination IP address of the data packet is in the same mobile domain or not. Note that eNB can determine this, based on the IP addresses. Then, eNB (RB) will forward the data packet to the S-GW/PDN-GW. Then, the data packet is forwarded by S-GW/PDN-GW toward the destination Internet host.

3.5.2 Mobile Host to Mobile Host

In case of the communication between the two Mobile hosts within a network, the data delivery procedure is illustrated in Fig. 12. In this figure, it is assumed that UE1 tries to communicate to UE2. UE1 first sends a data packet to eNB (RB) which is serving the UE1. Then, eNB sends *Map Query Request* to MME/HSS to find the location of UE2 (Step 1). The *Map Query Request* message contains the destination IP address to be queried. Then, MME/HSS responds with *Map Query Response* message that contains the destination eNB

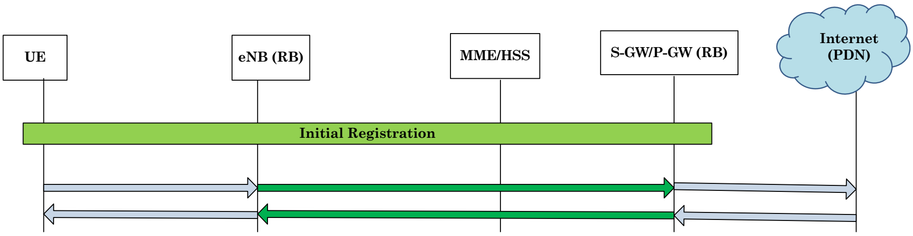


Fig. 11 Data delivery operation from Mobile host to Internet host

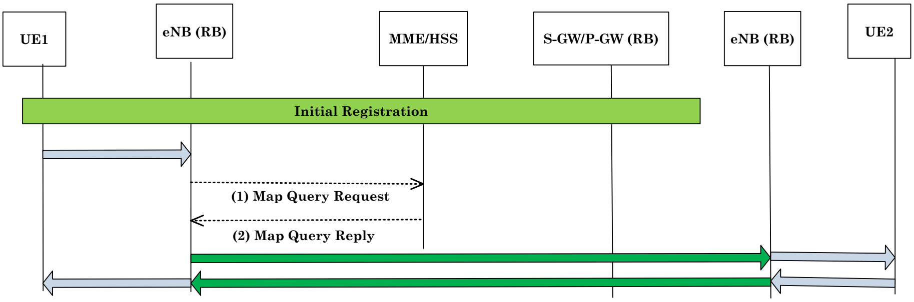


Fig. 12 Data delivery operation from Mobile host to Mobile host

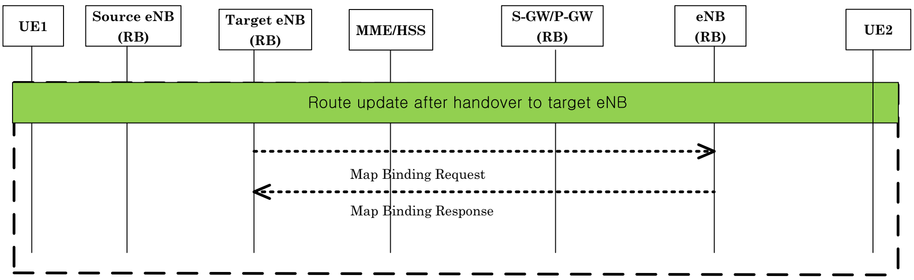


Fig. 13 Route update operation after handover: both UEs are in same domain

(RB) address of UE2, as shown in Step 2 of Fig. 6. Now, the packet is delivered to the destination eNB, and finally to the destination UE2.

3.6 Route Update After Handover

3.6.1 Both UEs are in Same Domain

Figure 13 shows the route update operations after handover in 5G-TPC, when both UEs are subscribed to same domain. By handover, UE1 moves from Source eNB to Target eNB. Then, Target eNB performs Map Binding Request operation with eNB of UE2 by exchanging *Map Binding Request* and *Map Binding Response* messages.

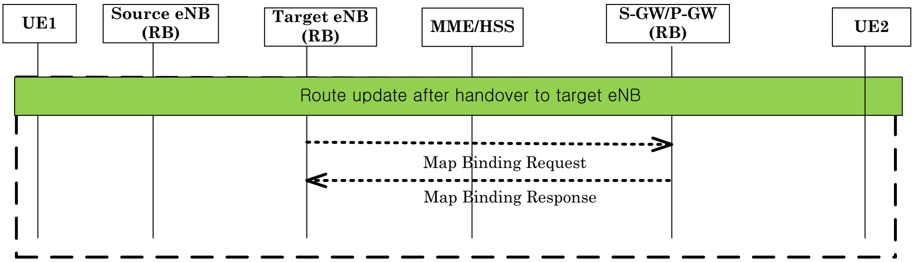


Fig. 14 Route update operation after handover: both UEs are in different domain

3.6.2 Both UEs are in Different Domain

Figure 14 shows the route update operations after handover in 5G-TPC, when both UEs are subscribed to different domain. By handover, UE1 moves from Source eNB to Target eNB. Then, Target eNB performs Map Binding Request operation with S-GW/P-GW of UE2 by exchanging *Map Binding Request* and *Map Binding Response* messages.

4 Numerical Analysis

4.1 Total Transmission Delay

For performance analysis, we compare the total transmission delay of the candidate schemes: 4G-EPC and the 5G-TPC. The total transmission delay (TTD) consists of the binding query delay and the data delivery delay.

We denote $T_{x-y}(S)$ by the transmission delay of a message with size *S* sent from *x* to *y* via the '*wireless*' link. Then, $T_{x-y}(S)$ can be expressed as $T_{x-y}(S) = [(1 - q)/(1 + q)] \times [(S/B_{wl}) + L_{wl}]$ [13]. In the meantime, we denote $T_{x-y}(S, H_{x-y})$ by the transmission delay of a message with size *S* sent from *x* to *y* via '*wired*' link, where H_{x-y} represents the number of wired hops between node *x* and node *y*. Then, $T_{x-y}(S, H_{x-y})$ is expressed as $T_{x-y}(S, H_{x-y}) = H_{x-y} \times [(S/B_w) + L_w + T_q]$.

For performance analysis, we use the notations, as defined in Table 2.

Table 2 Parameter used for analysis

Parameters	Description
S_c	Size of control packets (bytes)
S_d	Size of data packets (bytes)
B_w	Wired link bandwidth (Mbps)
B_{wl}	Wireless bandwidth(Mbps)
L_w	Wired link delay (ms)
L_{wl}	Wireless link delay (ms)
H_{a-b}	Hop count between node *a* and *b* in the network
q	Wireless link failure probability
T_q	Average queuing delay at each node

4.1.1 4G-EPC

In 4G-EPC, the binding update operations are performed as follows. When MN enters an eNB region, it establishes a radio link and sends *Attach Request* message to MME. This operation takes $T_{UE–MME}(S_c) = T_{UE–eNB}(S_c) + T_{eNB–MME}(S_c)$. Then, MME performs the update location operation with HSS by exchanging the *Update Location Request* and *Response* messages. This operation takes $2 \times T_{MME–HSS}(S_c)$. MME also sends a *Create Session Request* message to S-GW. This operation takes $T_{MME–SGW}(S_c)$.

S-GW performs the *Modify Bearer Request* and *Response* operations with P-GW. This operation takes $2 \times T_{SGW–PGW}(S_c)$. S-GW responds with a *Create Session Response* message to MME, after the *Modify Bearer Request* and *Response* operations. This operation takes $T_{MME–SGW}(S_c)$.

MME will perform the initial context setup operation with eNB by exchanging the Initial Context Setup Request and Response messages. This operation takes $2 \times T_{eNB–MME}(S_c)$.

Then, UE will send the *Attach Complete* message to MME, which takes $T_{UE–MME}(S_c)$, where $T_{UE–MME}(S_c) = T_{UE–eNB}(S_c) + T_{eNB-MME}(S_c)$. MME will perform the modify bearer operation with S-GW by exchanging the *Modify Bearer Request* and *Response* messages. This operation takes $2 \times T_{MME–SGW}(S_c)$. In 4G-EPC, UE1 sends the data packet to P-GW, and P-GW will forward the data packet to UE2. There is no binding query operation in 4G-EPC. Thus, we obtain the total transmission delay (TTD) of 4G-EPC as follows:

$$\begin{aligned} \mathrm{TTD}_{4G-EPC} = {} & 2T_{UE-eNB}(S_c) + 4T_{eNB-MME}(S_c) + 2T_{MME-HSS}(S_c) + 4T_{MME-SGW}(S_c) \\ & + 2T_{SGW-PGW}(S_c) + 2T_{UE-eNB}(S_d) + 2T_{eNB-SGW}(S_d) + 2T_{SGW-PGW}(S_d) \end{aligned} \quad (1)$$

4.1.2 5G-TPC

In 5G-TPC, the binding update operations are performed as follows. When MN enters an eNB (RB) region, it establishes a radio link and sends *Attach Request* message to eNB. This operation takes $T_{UE–eNB}(S_c)$. Then, eNB sends *Attach Request* to MME/HSS with *Map Binding Request*. This operation takes $2 \times T_{eNB–MME}(S_c)$. Then, MME/HSS will respond with *Attach Accept* message to eNB containing *Map Binding Response*. This operation takes $T_{eNB–MME}(S_c)$. Then, eNB will send the *Attach Accept* message to UE. This operation takes $T_{UE–eNB}(S_c)$. UE will send *Attach Complete* message to eNB and further to MME, which takes $T_{UE–eNB}(S_c) + T_{eNB–MME}(S_c)$.

In 5G-TPC, the binding query delay from UE1 to UE2 can be calculated as follows. First, UE1 sends data packets to eNB. Then, eNB will perform query operation with MME/HSS by exchanging *Map Query Request* and *Map Query Response* messages with MME. This operation takes $2 \times T_{eNB-MME}(S_c)$.

In data delivery, the data packets are directly sent to eNB. Then, eNB will perform the query operation. After query operation, data packets will be delivered to UE over an optimal route. Accordingly, we obtain the total transmission delay (TTD) of 5G-TPC as follows:

$$\mathrm{TTD}_{5G-TPC} = 3T_{UE-eNB}(S_c) + 5T_{eNB-MME}(S_c) + 2T_{UE-eNB}(S_d) + T_{eNB-eNB}(S_d) \quad (2)$$

4.2 Route Update Delay After Handover

4.2.1 4G-EPC

In 4G-EPC, when UE1 moves to another eNB region, the Target eNB will send *Path Switch Request* to MME. Then, MME will send *Modify Bearer Request* to S-GW. The S-GW will perform *Modify Bearer Request* and *Modify Bearer Response* operation with P-GW. Then, S-GW will respond with *Modify Bearer Response* to MME. MME will also respond with *Path Switch Request Ack* to Target eNB. Then, Target eNB send Release Recourse message to Source eNB. So, we obtain the route update delay after handover (RUD) of the 4G-EPC as follows.

$$\mathrm{RUD}_{\mathrm{4G-EPC}} = 2T_{eNB-MME}(S_{\mathrm{c}}) + 2T_{MME-SGW}(S_{\mathrm{c}}) + 2T_{SGW-PGW}(S_{\mathrm{c}}) + T_{eNB-eNB}(S_{\mathrm{c}}) \quad (3)$$

4.2.2 5G-TPC

In 5G-TPC, when UE1 moves to another eNB region, Target eNB will send *Map Binding Request* message to eNB of UE2 or S-GW/P-GW (for Internet host). Then, eNB of UE2 will respond directly with *Map Binding Response* to Target eNB. So, we obtain the route update delay after handover (RUD) of the 5G-TPC as follows.

$$\mathrm{RUD}_{\mathrm{5G-TPC}} = 2T_{eNB-eNB}(S_{\mathrm{c}}) \quad (4)$$

4.3 Data Tunneling Overhead

In the 4G-EPC architecture using a GTP tunneling, the data packet is encapsulated with the 20-byte IP header, 8-byte UDP header, and 8-byte GTP header, which is total 36 bytes. In the 5G-TPC architecture using the RB scheme, the data packet is encapsulated with 12-byte RB protocol header and 14-byte MAC header [6], which is total 26 bytes. We get the data tunneling overhead of 4G-EPC and 5G-TPC are as follows.

$$DTO_{4G-EPC} = \frac{GTP/UDP/IPHeader}{DataPacket(S_{\mathrm{d}}) + GTP/UDP/IPHeader} \times 100$$

$$DTO_{5G-TPC} = \frac{RBProtocolHeader + MACHeader}{Data\,Packet(S_{\mathrm{d}}) + RBHeader + MAC\,Header} \times 100$$

4.4 Numerical Results and Discussion

Based on the analytical equations given so far, we now compare the performance of the candidate schemes. For numerical analysis, the default values of delay parameter are configured as $\mathrm{H}_{\mathrm{eNB-SGW}} = 2$, $\mathrm{H}_{\mathrm{SGW-PGW}} = 3$, $\mathrm{H}_{\mathrm{eNB-MME}} = 2$, $\mathrm{H}_{\mathrm{MME-HSS}} = 3$, $\mathrm{H}_{\mathrm{MME-SGW}} = 2$ and $\mathrm{H}_{\mathrm{eNB-eNB}} = 2$. The other default parameter values are configured as $\mathrm{L}_{\mathrm{wl}} = 10$ ms, $\mathrm{L}_{\mathrm{w}} = 2$ ms, q = 0.2, $\mathrm{T}_{\mathrm{q}} = 5$ ms, $\mathrm{S}_{\mathrm{c}} = 50$ bytes, $\mathrm{S}_{\mathrm{d}} = 200$ bytes, $\mathrm{B}_{\mathrm{wl}} = 11$ Mbps and $\mathrm{B}_{\mathrm{w}} = 100$ Mbps which are similar to the values given in [13]. Among these parameters, we note that L_{wl}, T_{q}, $\mathrm{H}_{\mathrm{eNB-MME}}$, $\mathrm{H}_{\mathrm{eNB-eNB}}$ and S_{d} may depend on the network conditions of mobile networks. Thus, we will compare the performance of candidate schemes by varying those parameter values.

4.4.1 Total Transmission Delay

Figure 15 through Fig. 18 shows the comparisons of 4G-EPC and 5G-TPC in terms of total transmission delay. Figure 15 shows the impact of wireless link delay (L_{wl}) on total transmission delay. From the figure, we can see that the total transmission delay linearly increases, as L_{wl} gets larger, for both the candidate schemes. It is shown that the proposed scheme gives better performance than the existing centralized schemes.

Figure 16 illustrates the impact of average queuing delay (T_q) on total transmission delay. We can see that the total transmission delay linearly increases, as T_q gets larger, for the two candidate schemes. We can see that 4G-EPC gives worse performance than 5G-

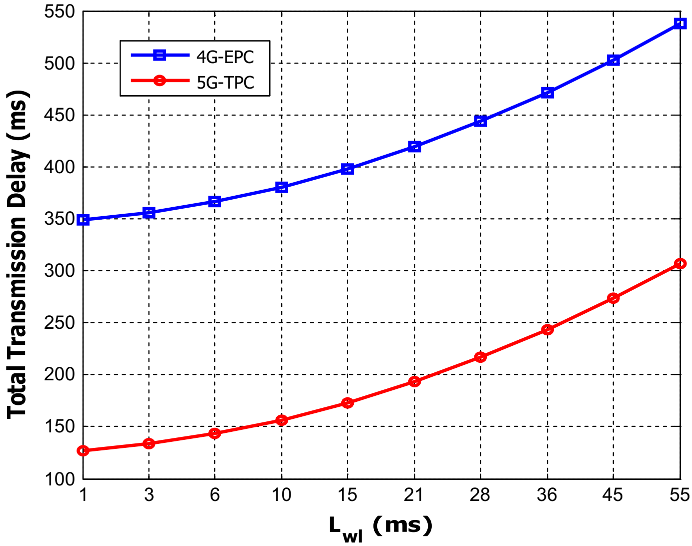


Fig. 15 Impact of L_{wl} on total transmission delay

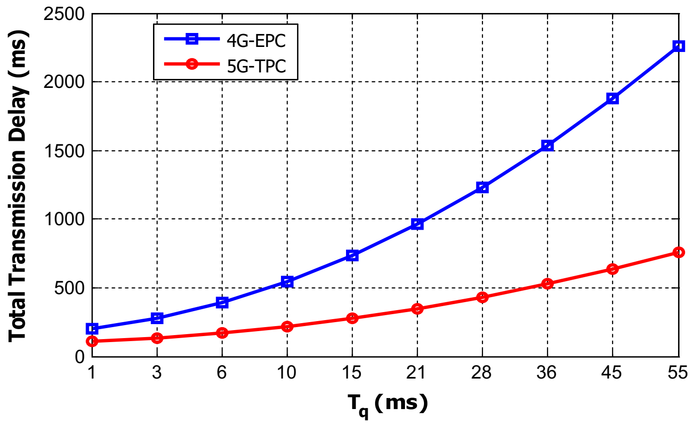


Fig. 16 Impact of average queuing delay at each node

TPC. This is because 4G-EPC relies on P-GW without the binding query operation, and the data packets are directly delivered to the centralized P-GW. It is shown in the figure that 5G-TPC gives better performance than 4G-EPC. This is because 5G-TPC does not use the centralized P-GW for data delivery, since the binding query and update operations are performed with MME/HSS and the data delivery is performed through an optimized route.

Figure 17 compares the total transmission delay for different hop counts between eNB and MME ($H_{eNB–MME}$). In the figure, we can see that $H_{eNB–MME}$ gives significant impacts on total transmission delay of 4G-EPC. This is because 4G-EPC relies on P-GW for binding update and data delivery. 5G-TPC is slightly affected by $H_{eNB–MME}$, since they uses MME/HSS only for the binding update and query operations.

Figure 18 compares the total transmission delay of the candidate schemes for different hop counts between eNB and eNB ($H_{eNB–eNB}$). In the figure, we can see that $H_{eNB–eNB}$

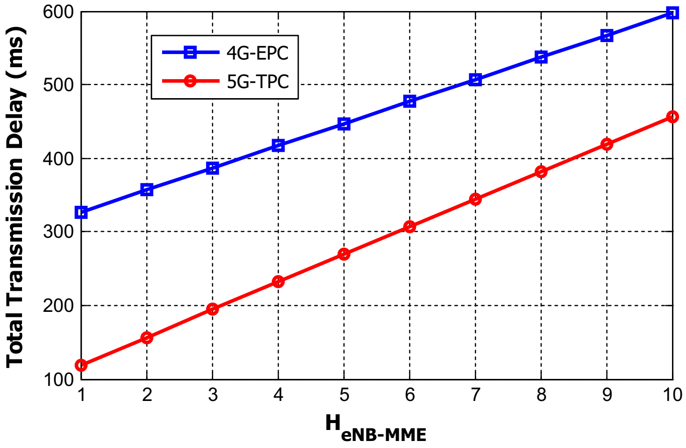


Fig. 17 Impact of hop count between eNB and MME

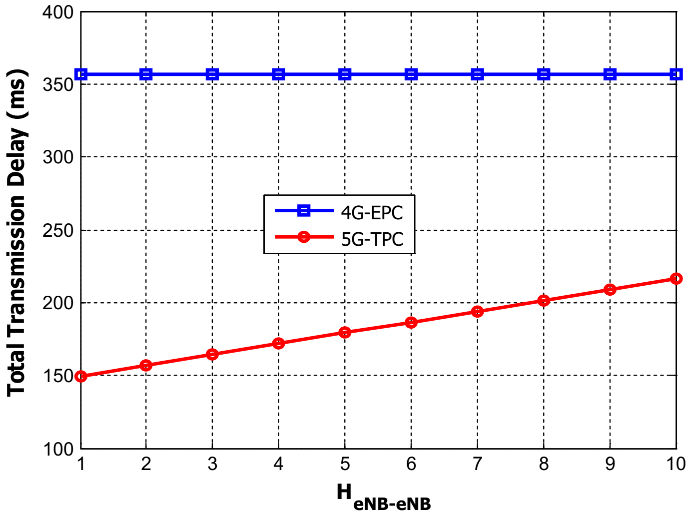


Fig. 18 Impact of hop count between eNB and eNB

gives significant impacts on total transmission delay for the proposed 5G-TPC scheme. This is because it depends on an eNB–eNB link in the data operations, when both mobile nodes are subscribed in the same domain.

4.4.2 Route Update Delay After Handover

Figures 19 and 20 show the comparisons of 4G-EPC and 5G-TPC in terms of route update delay. Figure 19 compares the route update delay of the candidate schemes for different

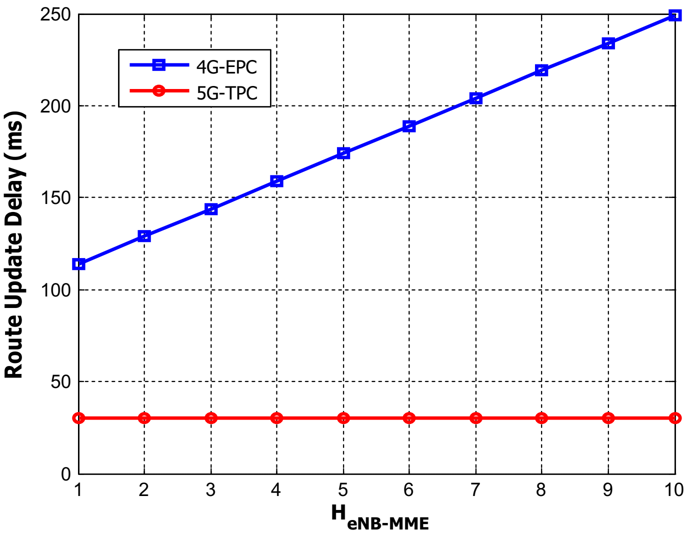


Fig. 19 Impact of hop count between eNB and MME

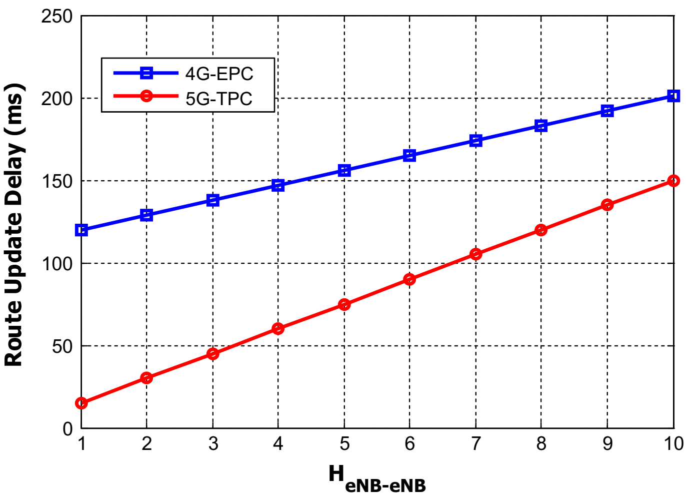


Fig. 20 Impact of hop count between eNB and eNB

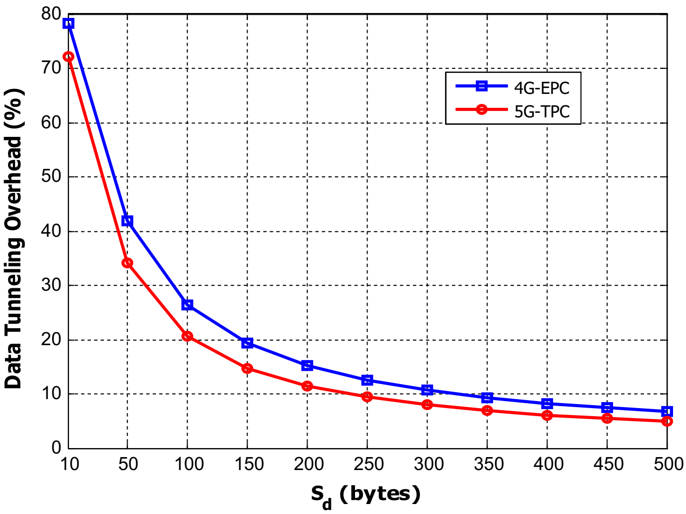


Fig. 21 Impact of S_d on data tunneling overhead

hop counts between eNB and MME ($H_{eNB–MME}$). In the figure, we can see that $H_{eNB–MME}$ gives significant impacts on route update delay for the existing scheme. This is because the target eNB performs the path switch operation with MME for route optimization.

Figure 20 compares the route update delay for different hop counts between eNB and eNB ($H_{eNB–eNB}$). In the figure, we can see that $H_{eNB–eNB}$ gives significant impacts on route update delay of 5G-TPC. This is because 5G-TPC relies on eNB and eNB link for data delivery. While 4G-EPC is slightly affected by $H_{eNB-eNB}$, since they uses eNB–eNB link for release resource signaling operations.

4.4.3 Data Tunneling Overhead

Figure 21 shows the data tunneling overhead for different payload size. In the figure, we can see that the payload size gives significant impacts on data tunneling overhead for both the existing and proposed schemes. This is because the GTP/IP/UDP headers are added with the payload size of the existing schemes and the TRILL/MAC header is added with the payload size in the proposed scheme. In the figure we can see that the proposed scheme provides better performance than the existing scheme. This is because the 36 bytes GTP/IP/UDP header is added with the payload size in the existing scheme, while the 26 bytes of TRILL/MAC header is added with the payload size in the proposed scheme.

5 Conclusions

In this paper we have proposed a new 5G core network architecture, named 5G-TPC, which is based on the TRILL protocol for data delivery and mobility control. In the proposed 5G-TPC architecture, each evolved Node B (eNB) will function as an ingress/egress Routing Bridge (RB) for TRILL-based data delivery. The Mobility Management Entity (MME) and Home Subscriber Server (HSS) of 4G-EPC are used for location binding update and binding query operations in the mobility control. For this purpose, MME/HSS will maintain the list of ID-LOC mapping for the UEs in the mobile network. Moreover, the proposed 5G-TPC is designed to eliminate the GPRS Tunneling Protocol (GTP) overhead by using link layer RBs.

For numerical analysis, we compared the proposed 5G-TPC with the existing 4G-EPC architecture. From the results, we see that the proposed 5G-TPC architecturecan give better performance than the 4G-EPC architecture in terms of data tunneling overhead, total transmission delay and route update delay after handover.

References

1. Oo, M. Z., et al. (2011). Proxy-assisted routing for efficient data transmission in mobile ad hoc networks. *Wireless Network, 17*(8), 1821.
2. FP7 METIS project. (2013). Mobile and wireless communications enablers for the 2020 Information Society. http://www.metis2020.com
3. Benn, H. (2014). Vision and Key Features for 5th Generation (5G) Cellular—Samsung, Technical Report.
4. Cisco. (2014). Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013–2018, Technical Report.
5. 3GPP TS 23.401. (2014). General Packet Radio Service (GPRS) enhancements for evolved universal terrestrial radio access network (E-UTRAN) Access, Rel-12 Ver. 12.4.0.
6. Perlman, R., et al. (2011). Routing Bridges (RBridges): Base Protocol Specification. IETF RFC 6325.
7. IETF Transparent Interconnection of Lots of Links (TRILL). http://datatracker.ietf.org/wg/trill/
8. Sankaran, C. B. (2012). Data offloading techniques in 3GPP Rel-10 networks: A tutorial. *IEEE Communications Magazine, 50*(6), 46–53.
9. IETF Distributed Mobility Management (DMM). http://datatracker.ietf.org/wg/dmm/
10. Daoud, K., et al. (2008). UFA: Ultra Flat Architecture for high bitrate services in mobile networks. In *Conference of PIMRC 2008*.
11. IEEE 802.1aq. (2012). Shortest Path Bridging, Draft 4.6.
12. Varis, N., et al. (2011). A layer-2 approach for mobility and transport in the mobile backhaul. In *Conference of ITST*.
13. Gohar, M., et al. (2014). A distributed mobility control scheme in LISP networks. *Wireless Networks, 20*(2), 245–259.

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