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## ABSTRACT

Within a 3rd Generation Partnership Project (3GPP) fifth generation (5G) environment, a number of user plane challenges may arise. For example, in order to achieve minimum latency in a 5G environment, it is critical to have the same User Plane Function (UPF) for both a Serving Gateway (SGW) control plane (SGW-C) function and a packet data network (PDN) Gateway (PGW) control plane (PGW-C) function call leg. Additionally, in order to handle the scale of user plane traffic in a 5G environment, the user planes must be as efficient and as optimized as possible regarding data packet processing while at the same time the control plane also needs to establish a mobile session as quickly as possible with minimum latency. To address the type of challenges that were described above, various solutions are provided herein through several techniques. A first technique, among other things, ensures a configuration-agnostic UPF selection (which does not depend upon static configuration in multiple places) which may be performed dynamically based on UPF profiles. A second technique, among other things, not only improves upon control path session setup time by removing unwanted delays every time a handover is processed, but also uplifts the UPF processing capacity by converging different legs of the same call at the same node. Features such as these are critically important to make the 5G story a success.

## DETAILED DESCRIPTION

In a traditional 3rd Generation Partnership Project (3GPP) deployment, the role of a Serving Gateway (SGW) is to aggregate the packet data networks (PDNs) of a User

Equipment (UE) while a PDN Gateway (PGW) performs the session management and Internet Protocol (IP) address management.

In a Control and User Plane Separation (CUPS) -based environment, and further in a 3GPP fifth generation (5G) non-standalone (NSA) solution, there exists a one-to-many relationship between a control plane and a user plane. It is essential that the user plane function nodes of a PGW control plane (PGW-C) function and an SGW control plane (SGW-C) function be collocated to achieve low latency. However, the specifications do not clearly define the methods and the procedures for selecting a collocated user plane function (e.g., a collocated user plane SGW (SGW-U) and user plane PGW (PGW-U)) for a number of use cases.

Various of the considerations at an SGW-C for user plane function (UPF) selection may include the ability to connect to multiple SGW-Us (or user plane functions (UPFs), in 3GPP 5G solutions); in order to achieve less than five milliseconds (ms) of latency, NSA deployments strive to use the same user to act as a SGW-U and a PGW-U while a SGW-C and a PGW-C are different physical nodes; not being instructed to use parameters like IP pool, PDN type, data network name (DNN), etc. for SGW-U selection; not having a defined interface with a Network Repository Function (NRF) for SGW-U selection; and the general guidelines that are described in annexes B2.2 and B2.4 of the 3GPP Technical Specification (TS) 29.244.

Additionally, various of the considerations at a PGW-C for UPF selection may include the ability to connect to multiple PGW UPF (PGW-U); subscriber IP pool management is performed between a PGW-C and a UPF; depending upon the DNN and PDN types (e.g., IP version 4 (IPv4), IP version 6 (IPv6), or IPv4v6) which are defined in a PGW-C, it may be possible that not all of the DNNs are served by all of the UPFs (e.g., voice calls may be aggregated to just a few UPFs); and the general guidelines that are described in annexes B2.3 and B2.4 of the 3GPP TS 29.244.

Neither of these control plane functions have a common parameter that may be set to support the selection of a collocated user plane function (i.e., an SGW-U and a PGW-U). For example, in the above-mentioned case, the current specifications are not able to guarantee a collocated node selection thus leading to a suboptimal, high-latency data path.

Figure 1a, below, depicts elements of the sequential selection of a UPF in an exemplary call progression.

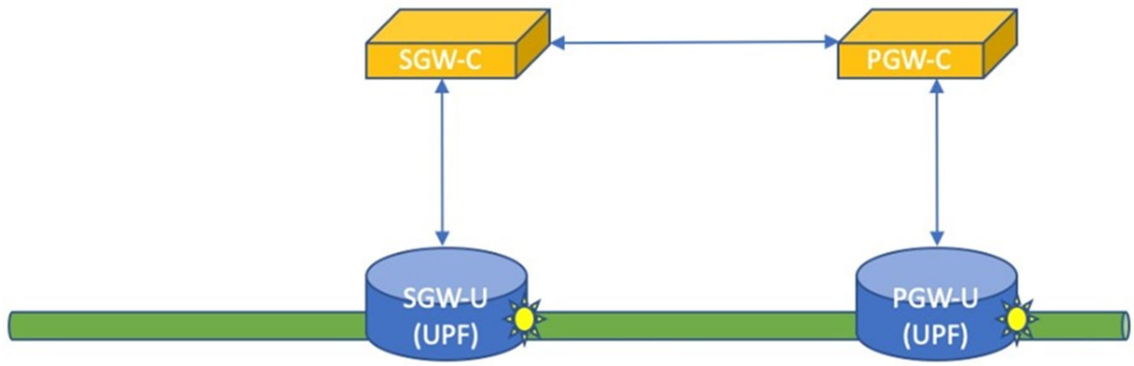


*Figure 1a: Separate SGW-U and PGW-U: Two Hops in a Data Path*

As shown in Figure 1a, above, during an initial attach operation a call arrives at an SGW-C first, hence an SGW-U selection is completed first. Subsequently, when the call reaches a PGW-C it selects the corresponding UPF for a PGW-U.

However, there could be a problem with relatively higher latency if the PGW-C is unable to select the same UPF as the PGW-U which is earlier selected by the SGW-C. For example, the desired DNN or PDN types may not be supported at a particular UPF. This can result in a non-collocated UPF selection by an SGW-C and a PGW-C. An optimized path would comprise a collocated user plane, as shown in Figure 1b, below.

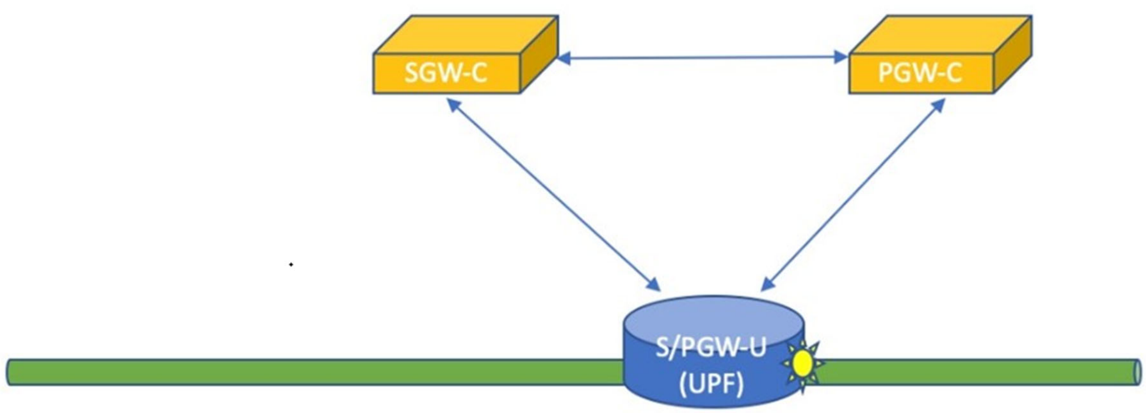


*Figure 1b: Converged SGW-U and PGW-U: Single Hop in a Data Path*

Beyond the above-described UPF selection issue, another type of user plane challenge may arise within a 3GPP 5G environment.

While 5G standalone (SA) solutions are being rolled out in many parts of the worlds, there is a long way to go to reach that finish line. Until all of the networks are completely 5G (and even after that, to provide backward compatibility) there will be a need for 5G environments to coexist with 3GPP fourth generation (4G) environments. Additionally, there will also be an increased number of handovers between 5G and 4G environments. 5G-NSA is an intermediate transition from 4G to 5G and is supposed to seamlessly provide the existing mobility services while preparing the network for 5G SA. In all of the deployments, the intent of the service is to provide subscribers with seamless IP continuity while they move around through different access types.

Figure 2, below, presents elements of several exemplary network arrangements.

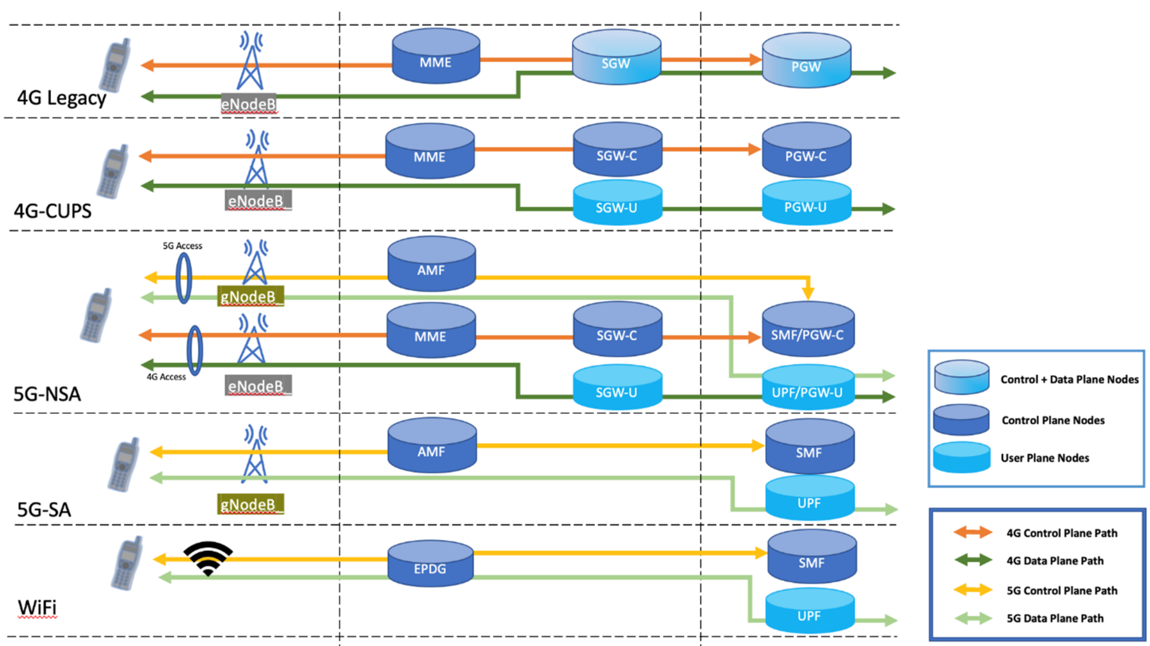


*Figure 2: Exemplary Network Arrangements*

As seen in Figure 2, above, the data path is largely simplified in both 5G SA and 5G NSA (with 5G access) environments with a direct N3-U tunnel between a Next Generation Node B (gNodeB) and a UPF.

However, in each of the predecessor generations the data path is always broken into two tunnels – one from an Evolved NodeB (eNB) to an SGW-U and then another from an SGW-U to a PGW-U (or, in the case of WiFi, from a WiFi access point (AP) to an Evolved Packet Data Gateway (ePDG) and an ePDG to a UPF).

The specifications do provide general guidance regarding attempting to select the same user plane node as an SGW-U and a PGW-U for the same call wherever possible to reduce split tunnels across two different hops. Figure 3, below, presents elements of such an ideal (i.e., most desirable) network.

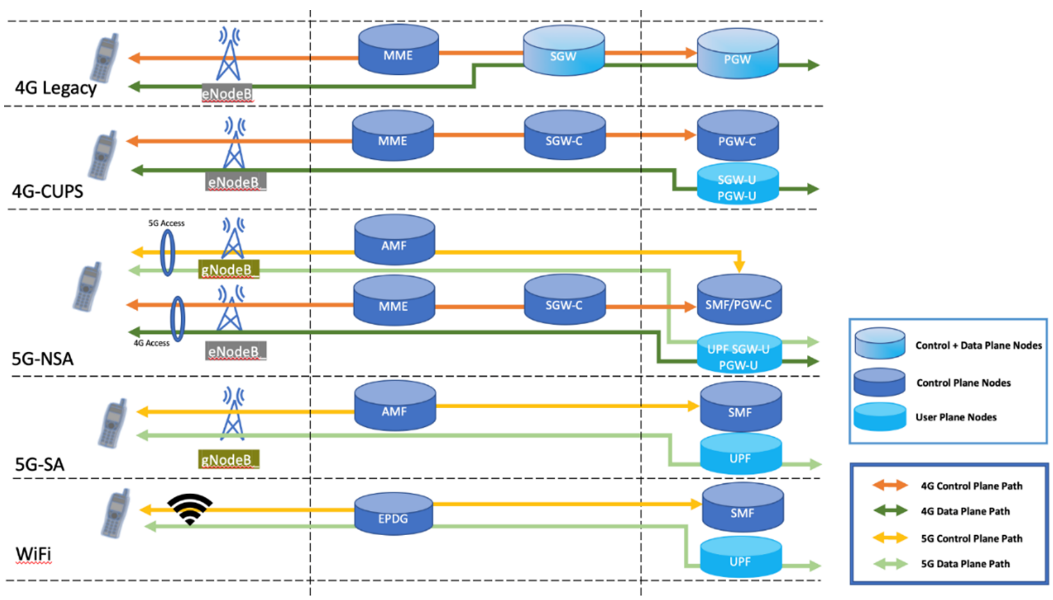


*Figure 3: Ideal Network Arrangements*

As depicted in Figure 3, above, all of the calls, be they in a 4G CUPS environment or a 5G NSA environment or a 5G SA environment, use only a single UPF as the data plane node. Note that it is not possible to optimize WiFi because of IP Security (IPsec) encryption.

It is relatively straightforward to arrive at the convergence that was depicted above in a fresh attach scenario, when a subscriber call arrives at an SGW-C first, where an SGW-U is selected for the call, and subsequently call processing is forwarded to a PGW-C whereby it can select the same user plane node as the PGW-U.

Most of the challenges arise when the subscriber is already connected to either a PGW-C or a Session Management Function (SMF) and already has a PGW-U associated to the call, through WiFi (via an ePDG) or through 5G SA, and already has a UPF associated to it. When such a call moves to a 4G radio (either in a 4G CUPS environment or a 5G NSA environment), the handover is processed at the SGW-C first. However, that element does not have direct information regarding which UPF is already selected, yet it is somehow supposed to find and select the same node as the SGW-U. Figure 4, below, illustrates elements of such a handover process.

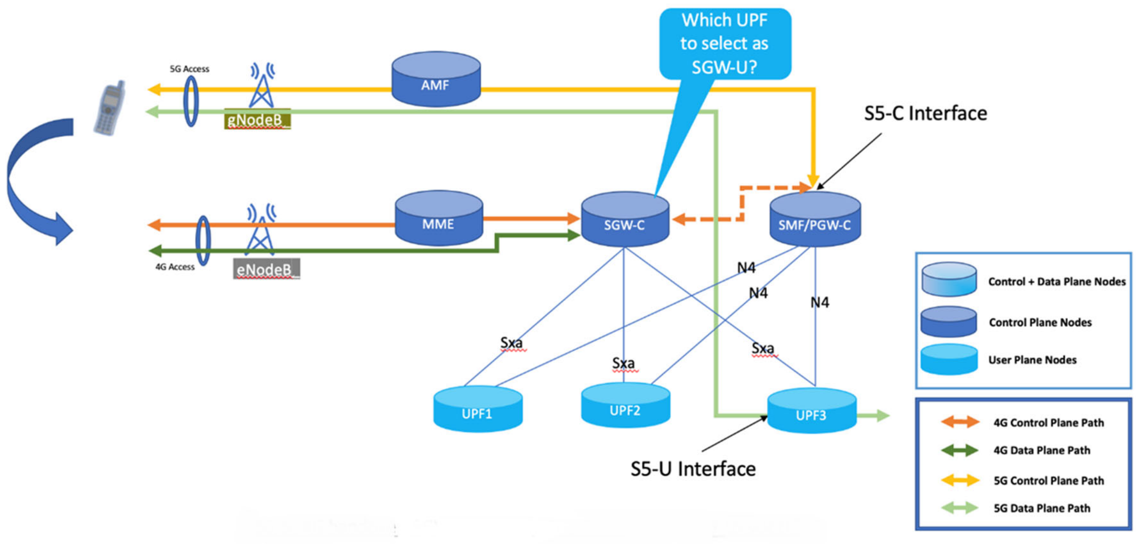


*Figure 4: 5G to 4G Handover – Which UPF Will SGW-C Select?*

The exact same scenario will also occur if a subscriber is moving to 4G access from WiFi access or 4G access (i.e., SGW relocation).

To address the types of challenges that were described above, various solutions are provided herein through several techniques. Each of the techniques will be briefly introduced below and then described in detail later in the instant narrative.

A first technique supports, among other things, a method for ensuring that the same UPF is selected by an SGW-C and a PGW-C during an initial attach operation.

A second technique supports, among other things, a method for suggesting an alternate path which achieves the same desired results while at the same time further reducing the utilization of resources. Moreover, the second technique solves this problem for all wireless access technologies with a single common approach, while other attempted solutions specifically try to solve the problem in one particular access technology.

Turning to the first technique, as referenced above, aspects of this technique support, among other things, a method for ensuring that the same UPF is selected by an SGW-C and a PGW-C during an initial attach operation.

Existing attempts at addressing the challenge that is met by the first technique have various limitations.

A first attempt encompasses Section 2.2 of Annex B of the 3GPP TS 29.244 (which endeavors to select an SGW-U first) and Section 7.2.1 of the 3GPP TS 29.274 (which allows the "SGW-U node name" of the selected SGW-U to be passed to a PGW-C over an S5-Create-Session-Request to assist with collocation). This is more of an informative approach, and it only ensures that a PGW-C is "aware" of which UPF node is selected as an SGW-U. However, it does not create a binding of the same UPF to be selected as a PGW-U because the PGW-C would have to apply its own criteria (e.g., Section 2.4 of Annex B of the 3GPP TS 29.244) for UPF selection based on the features that are requested by this particular PDN (e.g., PDN type, DNN, etc.) which might not be considered by an SGW-C for its own UPF selection criteria.

Therefore, while a PGW-C is aware of a UPF as an SGW-C, it might not choose the same node thus losing collocation.

A second attempt encompasses aspects of a cloud-based SGW control function. Such an entity has limited functionality which allows a UPF selection based on static configurations. There are two potential problems with such an approach.

First, the solution asks that the DNNs be statically mapped to a UPF group in an SGW-C configuration, wherein manual configurations are prone to errors and operations and maintenance (O&M) intervention, including a configuration management lifecycle, is complex.

Second, within the same DNN the approach does not probe further for the PDN type of the requested PDN, which can be a differentiating factor amongst UPF configuration.

As described above, neither of the two attempts include a PDN type, which is really a make-or-break factor for a call's success. For instance, if a certain DNN is IPv4v6 capable, whenever a UE connects to that DNN it would ask for both IPv4 and IPv6 addresses. It may so happen that while a UPF is configured with that DNN it could be missing either an



 

IPv4 pool or an IPv6 pool. A missing IP pool does not prevent an SGW-C from selecting the UPF because an SGW-C call leg is not concerned with the PDN IP address, but the UPF cannot be selected by an SMF as the SMF cannot assign a desired IP address as the UPF is missing a corresponding pool type.

The above-describe scenario is just one example use case based on PDN type that can break the SGW-U plus PGW-U collocation.

Aspects of the first technique provide an SGW-C with a similar set of parameters as a PGW-C "would-be" using in order to select a PGW-U for a particular PDN. Understanding that a few of those parameters would not be known to a PGW-C statically and would only come from a Policy Control Function (PCF) or a Policy and Charging Rules Function (PCRF) when the PDN would be processed at the PGW-C, the intent is to make an SGW-C aware of static parameters to a greater extent so as to increase the probability of collocation.

It is important to note that while the instant narrative uses PDN type as an example parameter, the first technique may be extended to any other parameter(s) which decisively allow or prohibit a certain UPF to be selected by a PGW for a certain call type and propagate such parameter(s) back to an SGW-C through the same path as described herein. Such an approach can help an SGW-C preemptively select UPFs which are highly likely to be selected as well by a PGW-C.

Aspects of the first technique, as described above, may be explicated with reference to the illustrative arrangement that is depicted in Figure 5, below.

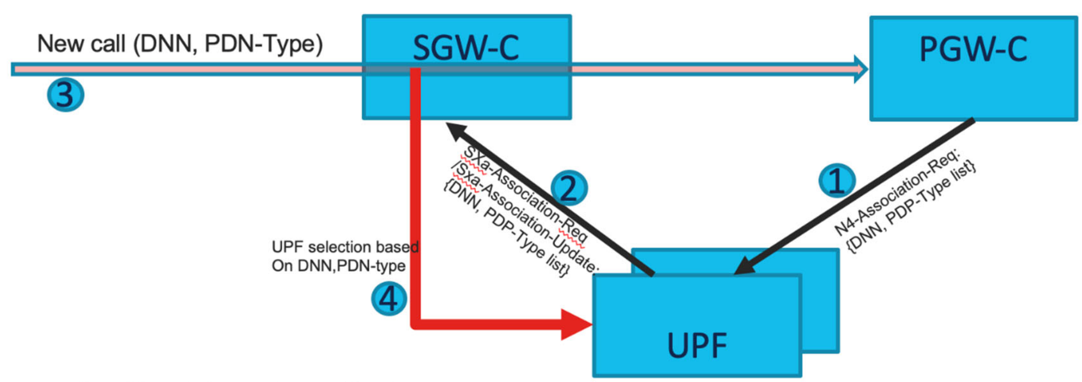


*Figure 5: Illustrative Arrangement*

Figure 5, above, identifies a series of steps, which are labeled 1 through 4 in the figure, each of which will be described below.

During Step 1, upon an initial N4 association between a PGW-C and a PGW-U (UPF) the PGW may advertise towards the UPF about the DNNs and the respective PDN types in a Packet Forwarding Control Protocol (PFCP) private extension.

At Step 2, if the UPF has not yet established Sxa (i.e., SGW-C ←→ SGW-U) then during an Sxa association request the UPF may provide these capabilities to an SGW-C. However, if the UPF has already established Sxa (i.e., SGW-C ←→ SGW-U) then in an Sxa association update message the UPF may provide these capabilities to the SGW-C.

During Step 3, the SGW-C can now take into account the DNN and PDN type while making a UPF selection for an incoming call.

Finally, at Step 4 a UPF may be selected from the group of UPFs which have advertised the same DNN and PDN type support.

Aspects of the first technique, as described and illustrated above, may be further explicated with reference to an illustrative example. Assume in a given deployment that there are 10 UPFs, six of which have an IPv6 pool and four of which have both IPv4 and IPv6 pools. If a UPF can feed this information back to an SGW-C, then for any call which asks for an IPv4 address the SGW-C can preempt the six UPFs (which do not have IPv4 addresses). The SGW-C can shrink the sample space of the UPFs that are participating in UPF selection to just the set of UPFs which are more likely to be selected by the PGW-C for the same call.

Figure 6, below, visually illustrates the above-described process.

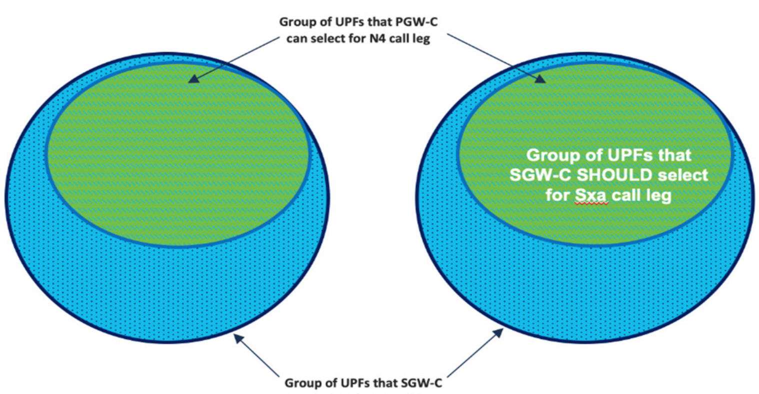


*Figure 6: Illustrative Visual Depiction*

In Figure 6, above, the large blue circle is the sample space of UPFs that an SGW-C may select from and the smaller green circle within it is a subset of the same UPFs that a PGW-C may select from.

As described and illustrated above, the intent of the first technique is to shrink as much as possible the sample space of UPFs for SGW-C selection to match the sample space of UPFs for PGW-C selection.

Turning to the second technique, as referenced above, aspects of this technique support, among other things, a method for suggesting an alternate path which achieves the same desired results while at the same time further reducing the utilization of resources.

The basic problem that the second technique concerns itself with is once a subscriber PDN already has IP connectivity by virtue of one UPF selected as a data plane node in any Radio Access Technology (RAT), if and when that subscriber moves to 4G RAT it will establish a new connection with a mobility management entity (MME) and send a Create Session Request (CSR) to a local SGW-C. In that CSR message, the subscriber also indicates that it does have an active session (PDN) with a certain PGW-C/SMF and PGWU/UPF and has an IP address that is associated with the PDN (using an interface type as S5 or S8 inside a Fully Qualified Tunnel End Point Identifier (F-TEID) information element (IE) within a Bearer Context IE, as well as a PDN Address Allocation (PAA) IE of the General Packet Radio Service (GPRS) Tunneling Protocol (GTP)-C version 2 message).

The control plane endpoint information includes the S5-C-FTEID, which can uniquely identify the PGW-C/SMF's S5-C IP address and the unique Tunnel End Point Identifier (TEID) that is associated with the session.

The user plane endpoint information may be presented in the form of a U-FTEID, consisting of either a UPF's N3-U-Interface address (if the previous session was in 5G RAT) or an S5-U-Interface address (if the previous session was in 4G RAT) or an S2B-U-Interface address (if the previous session was in WiFi) and the unique TEID within the UPF.

Since the SGW now knows the S5-C IP address of a PGW-C, it can establish an S5 connection to the correct PGW-C/SMF which had the previous session of the instant call. But towards the UPF, it inherently only knows the Sxa interface addresses to establish an

Sxa connection and hence it has to discover the Sxa link which corresponds to the S5U interface (or the N3U interface, depending upon the previous RAT) from the incoming CSR.

Figure 7, below, depicts elements of an arrangement that illustrates aspects of the above discussion.

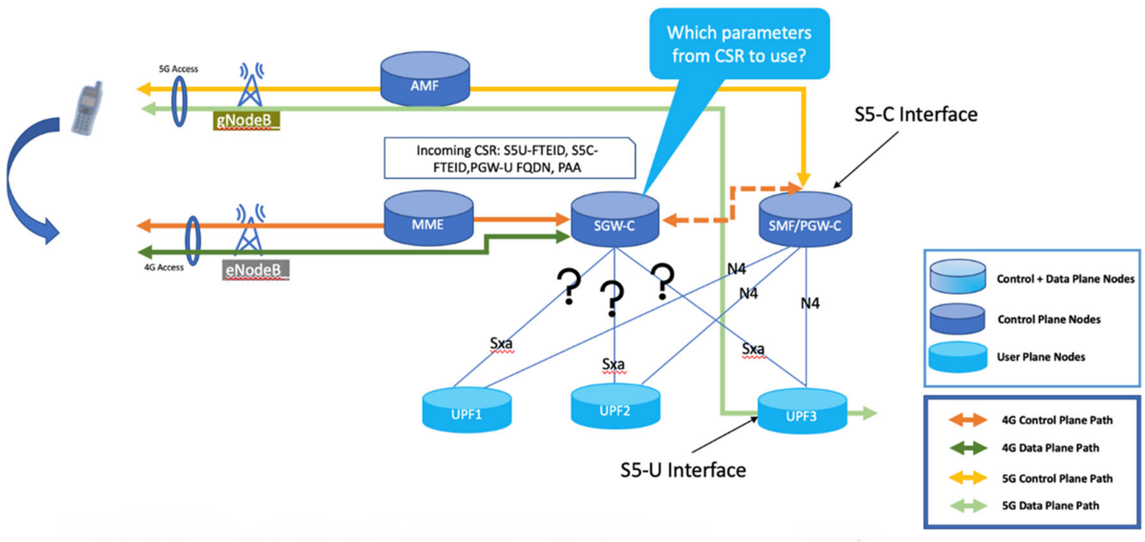


*Figure 7: 5G to 4G Handover –Which Parameter SGW-C Use to Select SGW-U*

One existing approach, which is primarily targeted to 5G to 4G Evolved Packet Core (EPC) handover, achieves the above-described information by including a custom IE comprising a UPF node's fully-qualified domain name (FQDN) in a custom JavaScript Object Notation (JSON) attribute (e.g., "UPF node name" from an SMF to an Access and Mobility Management Function (AMF) while the call is still in 5G); making that information available to an SGW-C upon handover; having the SGW-C perform a Name Authority Pointer (NAPTR) query to fetch candidate UPFs (with new query parameters added for Sxa plus N4); leveraging the fact that the Domain Name System (DNS) response contains the FQDN of all such UPFs; and picking the one UPF whose FQDN matches with one which is received upon handover and identifying the corresponding Sxa link to forward the request.

Another existing approach achieves the above-described information by using a similar mechanism (the custom IE in this case is a PGW-U node’s FQDN) but it is targeted to mobility between a 4G EPC environment and a 5G NSA environment. As part of the 4G and 5G capable UE registration procedure on a CUPS-based EPC or a 5G NSA network, the selected "PGW-U node FQDN" is passed on to an MME in a custom IE as part of the "Create Session Request" procedure. The session continues to be anchored on the PGW-U node throughout the life of the session. The MME stores the received "PGW-U node FQDN" in its session context. In the event of UE relocation requiring an SGW-C change, the MME selects a suitable SGW-C (or a System Architecture Evolution Gateway (SAEGW) control plane (SAEGW-C) combination node) that is serving the area that the UE is in and initiates a "Create Session Request" towards the new SGW-C (or SAEGW-C combination node). As part of the "Create Session Request" message, the MME includes the "PGW-U Node FQDN" that it has stored in its session context as a custom IE. The new SGW-C (or SAEGW-C combination node) queries the DNS server for user plane (UP) nodes supporting Sxa and Sxb functionality and receives a list of available UP node FQDNs. From the received list of UP FQDNs, the new SGW-C (or SAEGW-C combination node) selects the UP FQDN that matches the "PGW-U node FQDN" that it has received from the MME thus allowing both the SGW-U and PGW-U legs to be collocated on the same UP node.

In both of the above approaches, the biggest limitation is that every time an SGW-C is processing a handover it must perform a DNS query, it must wait for a DNS response and buffer the session until that time, it must match the intended parameter with the results that were received in the DNS responses, and finally it must select a UPF if a match is found.

To provide a sense of scale, one network vendor’s cloud-based SGW is capable of handling six million subscribers and is planned to move up to eight million subscribers during the next few releases. At that scale of subscribers, the rate of handovers can easily be on the order of some multiple of thousands per second. And if above-described procedure needs to be executed upon every handover request, it would have tremendous performance implications.

According to aspects of the second technique, in an Sxa association update message a UPF may provide (a) an S5U interface address and an N3U interface address as part of a new custom IE called "user plane interfaces" and (b) the IP pools that are allocated to it by an SMF or PGW in an "UP-IP-Pool" custom IE at the time of establishing an Sxa association.

An SGW-C may parse the custom IE and create an association of the interface address, as well as the IP pool information for a given UPF, in its internal database. Subsequently, whenever a handover CSR is received at an SGW-C it can simply look up the address that is provided in the S5U F-TEID, extract the S5U address, and compare it against the S5U interface information that is stored for all the UPFs its internal database to identify the one UPF which has this session already handled at a PGW side.

A secondary check may be performed by comparing the IP address from a CSR's PAA IE with that of the IP pool information in the SGW-C's internal database (especially for handovers from WiFi into 4G access, as it would not contain the S5U F-TEID) to find the PGW-U that is already in use for the instant call.

Figure 8, below, presents elements of an F-TEID IE and a PAA IE from an exemplary CSR.

```
v Fully Qualified Tunnel Endpoint Identifier (F-TEID) : S5/S8 PGW GTP-U interface, TEID/GRE Key: 0x07be2001, IPv4 10.211.153.199
    IE Type: Fully Qualified Tunnel Endpoint Identifier (F-TEID) (87)
    IE Length: 9
    0000 .... = CR flag: 0
    .... 0011 = Instance: 3
    1... .... = V4: IPv4 address present
    .0.. .... = V6: IPv6 address not present
    ..00 0101 = Interface Type: S5/S8 PGW GTP-U interface (5)
    TEID/GRE Key: 0x07be2001 (129900545)
    F-TEID IPv4: 10.211.153.199

v PDN Address Allocation (PAA) : IPv6 2607:fc20:2c69:16cd::
    IE Type: PDN Address Allocation (PAA) (79)
    IE Length: 18
    0000 .... = CR flag: 0
    .... 0000 = Instance: 0
    .... .010 = PDN Type: IPv6 (2)
    IPv6 Prefix Length: 64
    PDN Address and Prefix(IPv6): 2607:fc20:2c69:16cd::
```

*Figure 8: Illustrative IEs*

From the S5U F-TEID IP address, a match may be performed against the S5U addresses that are reported by all of the UPFs and a secondary match may be performed based on a PAA (if a PAA value is non-zero in a Create-Session-Request). Figure 9, below, depicts elements of such an approach.

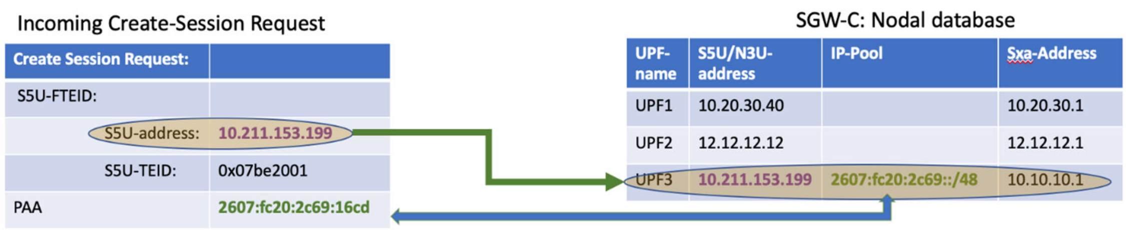


*Figure 9: Illustrative Lookup Operations*

Use of aspects of the second technique offers a number of benefits. First, the technique involves only a one-time information exchange and requires that just one custom IE be added in the existing Sxa interface. Second, the technique avoids a DNS query as part of every handover and hence improves call setup time. Third, the technique avoids any resources being used as part of DNS query creation, submission, response processing, etc. Fourth, SGW-U and PGW-U session collocation reduces one hop in a packet processing path and hence improves latency. And fifth, the same approach applies for WiFi, 5G, and 4G to 4G handover (i.e., one size fits all).

It is important to note that there is a special case regarding WiFi. All of the previous attempts at UPF collocation during inter-technology handovers have relied on information regarding a UPF and a PGW-U that was transferred through an access network interconnect (e.g., the node name of a PGW-U be propagated from an AMF to an MME or from an MME to an MME). Hence each of them failed with WiFi because there is no interface defined between WiFi access and 4G access or 5G access (i.e., between an ePDG and an MME or an AMF).

Aspects of the second technique bridge the gap using PAA, as this parameter is sent by an end user itself and does not rely on any access interconnection. If a piece of end user equipment (e.g., a mobile handset) is capable of sending the IPv6 prefix that is assigned to it during its time in WiFi access into the new Handover Service Request towards a 4G environment, then an SGW-C can make use of that information to collocate the session.

In summary, in view of different 3GPP 5G user plane challenges, various solutions have been provided herein through several techniques. A first technique, among other things, ensures a configuration-agnostic UPF selection (which does not depend upon static configuration in multiple places) which may be performed dynamically based on UPF profiles. A second technique, among other things, not only improves upon control path session setup time by removing unwanted delays every time a handover is processed, but also uplifts the UPF processing capacity by converging different legs of the same call at the same node. Features such as these are critically important to make the 5G story a success.