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SHORTEST PATH ASSISTED USER PLANE FUNCTION SELECTION ON 5G SESSION MANAGEMENT FUNCTION

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ABSTRACT

The architecture of a 3rd Generation Partnership Project (3GPP) fifth-generation (5G) network introduced, among other things, the dynamic control of user plane traffic through means of a User Plane Function (UPF). The selection of UPFs becomes an important task for the core network especially when multiple UPFs are involved. However, UPF selection is currently accomplished through the Domain Name System (DNS) and/or a static configuration, which does not provide a selection that is based on a number of hops or a delay between a gNodeB (gNB) and a UPF (or a Protocol Data Unit (PDU) session anchor (PSA)). To address the types of challenges that were described above, techniques are presented herein that support a dynamic selection of UPFs in a 5G network through the use of enhanced general packet radio service (GPRS) Tunneling Protocol (GTP) path management messages and enhanced Packet Forwarding Control Protocol (PFCP) messages. Under aspects of the presented techniques, a UPF probes the GTP-U peers (e.g., gNBs and other UPFs) to identify the distance and round-trip time to the GTP-U peers and that information is then sent to a Session Management Function (SMF) to facilitate a shortest (e.g., fewer hops) or a fastest (e.g., lowest round-trip time) UPF selection by the SMF.

DETAILED DESCRIPTION

The architecture of a 3rd Generation Partnership Project (3GPP) fifth-generation (5G) network introduced, among other things, the dynamic control of user plane traffic through means of a User Plane Function (UPF). The UPF concept in a 5G environment provides a flexible technique for dynamically distributing traffic over UPFs with, preferably, the traffic being processed closer to the user. When one UPF is not sufficient to handle a traffic scenario, a 5G environment introduces the concept of an Intermediate UPF (I-UPF) and a UPF Session Anchor (or a Protocol Data Unit (PDU) Session Anchor

(PSA)). An I-UPF supports the partial processing of traffic closer to the edge of the network and the forwarding of the balance of the traffic to a PSA.

Figure 1, below, depicts various of the network elements for a multi-UPF scenario as described above.

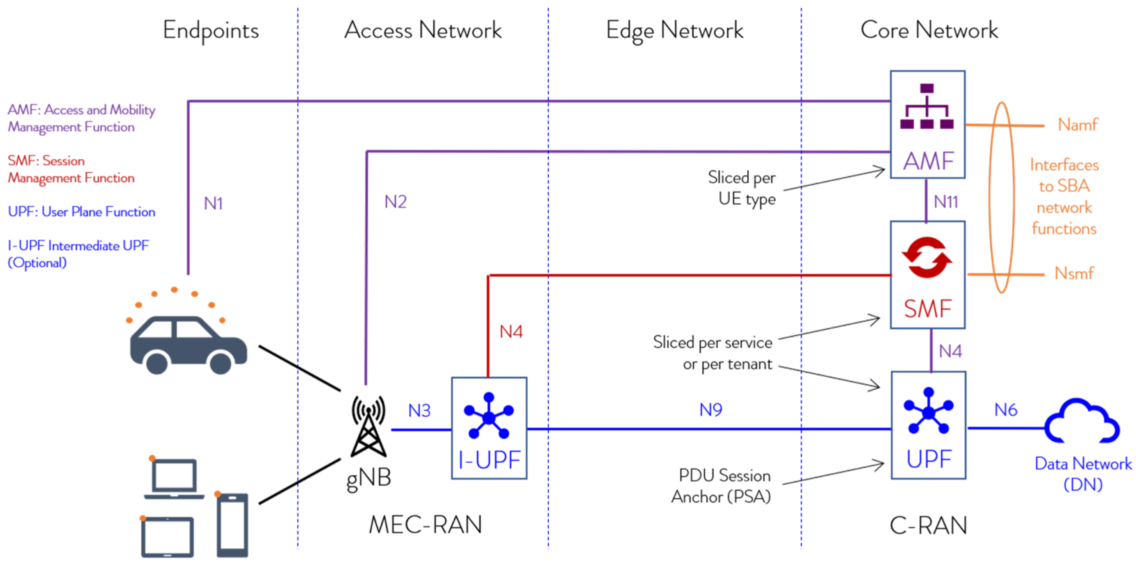

Figure 1: Exemplary Multi-UPF Architecture

The selection of the UPFs becomes an important task for the core network especially when multiple UPFs are involved. Currently, UPF selection is accomplished through the Domain Name System (DNS) and/or a static configuration. The existing UPF selection process does not yield a selection that is based on a number of hops or a delay between a gNodeB (gNB) and a UPF (or PSA).

To address the type of challenge that was described above, techniques are presented herein that facilitate the dynamic selection of UPFs in a multi-UPF scenario assuming a UPF may be instantiated in any part of a 5G network.

As will be described and illustrated in the narrative that is presented below, aspects of the presented techniques encompass a number of capabilities. For example, a UPF may share its general packet radio service (GPRS) Tunneling Protocol (GTP)-U peer Internet Protocol (IP) addresses across its UPF group inside of customized GTP path management messages.

Further, the UPF may maintain a list of internal and neighbor GTP-U peers and dispatch periodic GTP path messages (e.g., echo messages) to all of the peers in the list. For each peer, such a list may contain the peer's IP address, the GTP restart counter, the number of hops (to reach the peer), and the round-trip time (RTT) to the peer. A neighbor GTP-U peer is a GTP-U peer with which the UPF has not had traffic and the IP address of the peer was introduced by a UPF in the same group or by a control plane (e.g., a Session Management Function (SMF)). Additionally, using customized Packet Forwarding Control Protocol (PFCP) messages, the UPF may periodically send its list, with all of the parameters, to each of the SMFs with which the UPF has a PFCP association.

An SMF may periodically receive the lists from all of the controlled UPFs. The SMF may select a combination of peers that are closest to a subscriber (i.e., that have the smallest number of hops) or that are fastest to a subscriber (i.e., that have the shortest RTT). It is important to note that the gNB selection is dependent upon a subscriber's location, while the combination of an I-UPF and PSA are controlled by the SMF.

Figure 2, below, depicts elements of an exemplary list (according to aspects of the techniques presented herein and reflective of the discussion that was presented above) for the GTP-U peers from UPF 1 in UPF Group 1.

UPF 1	Number of hops	RTT	Restart Counter
Internal:			
gNB 1 IP address			
gNB 2 IP address			
UPF 2 IP address			
UPF 3 IP address			
Neighbors:			
UPF A IP address			
UPF B IP address			

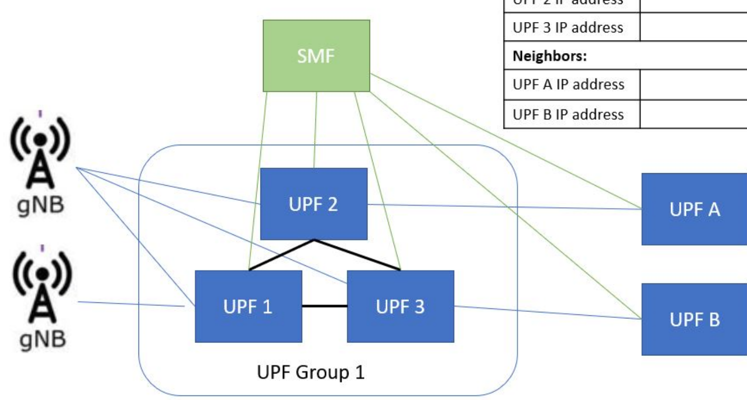

Figure 2: Exemplary UPF List

For the exemplary list that is presented in Figure 2, above, a number of hops may be calculated based on an IP header's time to live (TTL) for the GTP management messages, an RTT may be calculated based on the response for a GTP management message, and a restart counter may be the counter that is shared in a GTP path management message from the GTP-U peer. As described previously, the list of the GTP-U peers may be reported to an SMF (along with the number of hops, the RTT, and the restart counter) using PFCP messages.

Among other things, aspects of the techniques presented herein leverage enhancements to various PFCP messages.

The 3GPP technical specification (TS) 29.244 defines how a control plane (CP) and a user plane (UP) may exchange their capabilities when an association is established. New function features may be introduced in the CP and UP Function Features to report on feature availability and new information elements (IEs) may be introduced into heartbeat messages to carry GTP peer information. A CP may send GTP peer information to a UP in a heartbeat message indicating that it needs to obtain the peer information and the UP may periodically report its list to a CP. In support of such behavior, aspects of the techniques presented herein introduce new features and new information elements, each of which will be described and illustrated in the narrative that is presented below.

The CP Function Features IE indicates the features that are supported by the CP function and is defined at Chapter 8.2.58 of the 3GPP TS 29.244. Figure 3, below, illustrates the format of that IE.

	Bits							
Octets	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1 to 2	Type = 89 (decimal)							
3 to 4	Length = n							
5	Supported Features							
6 to 7	Additional Supported Features 1							
8 to (n + 4)	These octets are present only if explicitly specified							

Figure 3: CP Function Features

As noted previously, Chapter 8.2.58 of the 3GPP TS 29.244 defines the specific features that are supported by the CP function, as depicted in Table 8.2.58-1 of the TS. A portion of that TS table is reproduced, below, as Table 1.

Table 1: CP Function Features

Feature Octet/Bit	Feature	Interface	M/O	Description
5/1	LOAD	Sxa, Sxb, Sxc, N4	O	Load Control is supported by the CP function.
5/2	OVRL	Sxa, Sxb, Sxc, N4	O	Overload Control is supported by the CP function
5/3	EPFAR	Sxa, Sxb, Sxc, N4	O	The CP function supports the Enhanced PFCP Association Release feature (see clause 5.18).
.				
.				
7/8	GTPPEER	Sxa, Sxb, Sxc, N4	O	CP function supports GTP peer reporting (i.e., with UP function reporting its internal and neighbor GTP peers' information including number of hops, RTT, and restart counter).

In support of the techniques presented herein, a new feature (i.e., GTPPEER) is introduced (as depicted in the final row of Table 1, above), indicating that a CP supports the feature and is able to process a list of GTP peers from a UP.

The UP Function Features IE indicates the features that are supported by the UP function and is defined at Chapter 8.2.25 of the 3GPP TS 29.244. Figure 4, below, illustrates the format of that IE.

	Bits							
Octets	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1 to 2	Type = 43 (decimal)							
3 to 4	Length = n							
5 to 6	Supported Features							
7 to 8	Additional Supported Features 1							
9 to 10	Additional Supported Features 2							
11 to (n + 4)	These octets are present only if explicitly specified							

Figure 4: UP Function Features

As noted previously, Chapter 8.2.25 of the 3GPP TS 29.244 defines the specific features that are supported by the UP function, as depicted in Table 8.2.25-1 of the TS. A portion of that TS table is reproduced, below, as Table 2.

Table 2: UP Function Features

Feature Octet/Bit	Feature	Interface	M/O	Description
5/1	BUCP	Sxa, N4	O	Downlink Data Buffering in CP function is supported by the UP function.
5/2	DDND	Sxa, N4	O	The buffering parameter 'Downlink Data Notification Delay' is supported by the UP function.
5/3	DLBD	Sxa, N4	O	The buffering parameter 'DL Buffering Duration' is supported by the UP function.
.				
.				
10/8	GTPPEER	Sxa, Sxb, Sxc, N4	O	UP function supports GTP path reporting (i.e., with UP function reporting its internal and neighbor GTP peers' information including number of hops, RTT, and restart counter).

In support of the techniques presented herein, a new feature (i.e., GTPPEER) is introduced (as depicted in the final row of Table 2, above), indicating that a UP supports the instant feature.

Aspects of the techniques presented herein leverage various PFCP heartbeat messages. Table 3, below, indicates the IEs in a heartbeat request message.

Table 3: Heartbeat Request IE

Information Elements	P	Condition / Comment	IE Type
Recovery Time Stamp	M	This IE shall contain the time stamp when the PFCP entity was started see clause 19A of 3GPP TS 23.007.	Recovery Time Stamp
Source IP Address	O	This IE may be included when a Network Address Translation device is deployed in the network. See clause 19a in 3GPP TS 23.007.	Source IP Address
Remote GTP-U Peer	O	This IE contains the IP version 4 (IPv4) or IP version 6 (IPv6) address of the GTP peer from which a CP needs	IP Address

		to obtain data. The IE is defined as type 103 (decimal) in chapter 8.2.70 of the 3GPP TS 29.244.	

Table 4, below, indicates the IEs in a heartbeat response message.

Table 4: Heartbeat Response IE

Information Elements	P	Condition / Comment	IE Type
Recovery Time Stamp	M	This IE shall contain the time stamp when the PFCP entity was started see clause 19A of 3GPP TS 23.007.	Recovery Time Stamp
GTP Peer Info	O	This IE contains IPv4 or IPv6 IP address of the peer, the number of hops, the RTT, the restart counter, and a type (e.g., internal or neighbor).	

The final rows of Table 3 and Table 4 identify a new feature that is introduced in support of the techniques presented herein, which will be described and illustrated below.

Figure 5, below, depicts the format of a GTP-Peer-Info IE (having a decimal value of 293).

	Bits							
Octets	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1 to 2	Type = 293 (decimal)							
3 to 4	Length = n							
5	Spare		RC	RTT	NH	MPL	V4	V6
m to (m + 3)	IPv4 Address							
p to (p + 15)	IPv6 Address							
q	Mask/Prefix Length							
k	Number of Hops							
s to (s + 3)	RTT in milliseconds							
j	Restart Counter							

Figure 5: GTP-Peer-Info IE

As indicated in Figure 5, above, the following flags are encoded within octet 5:

Bit	Description
1	V6. If this bit is set to "1", then the IPv6 address field shall be present, otherwise the IPv6 address field shall not be present.

2	V4. If this bit is set to "1", then the IPv4 address field shall be present, otherwise the IPv4 address field shall not be present.
3	Mask/Prefix Length (MPL). If this bit is set to "1", then the mask (for IPv4) or prefix (for IPv6) length field shall be present, otherwise this field shall not be present.
4	Number of Hops (NH). If this bit is set to "1", then the number of hops shall be present, otherwise this field shall not be present.
5	RTT. If this bit is set to "1", then the round-tip time shall be present, otherwise this field shall not be present.
6	Restart Counter (RC). If this bit is set to "1", then the rest counter shall be present, otherwise this field shall not be present.
7 to 8	Spare (for future use and set to zero ("0"))

Additionally, as indicated in Figure 5, above, octets "m to (m+3)" and "p to (p+15)" will, if present, contain an IPv4 address or IPv6 address, respectively. Further, the MPL field will, if present, be encoded as an 8-bit binary integer and the RTT will be encoded as an unsigned 32-bit binary integer value (whose unit of measure is milliseconds). Importantly, a combination of an NH equal to 255, an RTT equal to zero, and an RC equal to zero indicates that the peer is not reachable through GTP path management.

Aspects of the techniques presented herein employ enhancements to various GTP-U messages. Chapters 7.2.1 and 7.2.2 of the 3GPP TS 29.281 define (respectively) the GTP Echo Request message and the GTP Echo Response message, to which aspects of the techniques presented herein introduce new IEs (which will be described and illustrated below).

A GTP-U peer may send an Echo Request message on a path to another GTP-U peer to find out if it is alive (e.g., see the clause Path Failure) and Echo Request messages may be sent for each path that is in use. Table 5, below, indicates the IEs in an Echo Request message.

Table 5: Echo Request IE

Information Element	Presence Requirement	Reference
Private Extension	Optional	8.6

Table 6, below, indicates the IEs in an Echo Response message.

Table 6: Echo Response IE

Information Element	Presence Requirement	Reference
Recovery	Mandatory	8.2
Private Extension	Optional	8.6

According to aspects of the techniques presented herein, the Restart Counter value in the Recovery IE is not be used (i.e., it will be set to zero by the sender and it will be ignored by the receiver). It is important to note that the Recovery IE is mandatory for reasons of backwards compatibility.

The Private Extension IE contains vendor-specific information. The Extension Identifier is a value that is defined in the Private Enterprise number list in the most recent "Assigned Numbers" Internet Engineering Task Force (IETF) Request for Comments (RFC) (i.e., RFC 1700 or later). This is an optional IE that may be included in any GTP signaling message and a signaling message may include more than one IE of the Private Extension type. For purposes of exposition, the balance of the instant narrative will employ an exemplary Private Enterprise number of 2345.

According to aspects of the techniques presented herein, and reflective of the discussion that was presented above, Figure 6, below, depicts the format of a Remote GTP-U Peer IE that the GTP-U protocol may employ to share information concerning GTP-U peers across UPFs.

	Bits							
Octets	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1	Type = 255 (decimal)							
2 to 3	Length = n							
4 to 5	Extension Identifier = 2345 (decimal)							
6	Spare					MPL	V4	V6
m to (m + 3)	IPv4 Address							
p to (p + 15)	IPv6 Address							
q	Mask/Prefix Length							

Figure 6: Remote GTP-U Peer IE

As indicated in Figure 6, above, the following flags are encoded within octet 6:

Bit	Description
1	V6. If this bit is set to "1", then the IPv6 address field shall be present, otherwise the IPv6 address field shall not be present.
2	V4. If this bit is set to "1", then the IPv4 address field shall be present, otherwise the IPv4 address field shall not be present.
3	MPL. If this bit is set to "1", then the mask (for IPv4) or the prefix (for IPv6) length field shall be present, otherwise this field shall not be present.
4 to 8	Spare (for future use and set to zero ("0"))

Additionally, as indicated in Figure 6, above, octets "m to (m+3)" and "p to (p+15)" will, if present, contain an IPv4 address or IPv6 address, respectively. Further, the MPL field will, if present, be encoded as an 8-bit binary integer.

Among other things, aspects of the techniques presented herein leverage various UPF algorithms. For example, the UPF can maintain a list of the internal and neighbor GTP-U peers. The path management messages that are presented in Chapter 7.2 of the 3GPP TS 29.281 describe how path management is performed for the GTP-U peers, the existing GTP-U peers (i.e., the peers that have existing subscriber sessions) and GTP-U peers from the UPF group as internal. Additionally, aspects of the techniques presented herein introduce a neighbors list that contains the GTP-U peers from other UPFs in the same group and GTP-U peers from a CP (e.g., from an SMF in a 5G world). A UPF sends the same path management messages as defined in Chapter 7.2 of the 3GPP TS 29.281 to its neighbor peers to identify their parameters.

The UPF measures a number of items for the internal and neighbor list by using GTP path management messages, including a number of hops to the GTP-U peer (based on the TTL in the IP header of a GTP message), a RTT (based on the arrival time of a GTP-U Echo Response message), and a restart counter (based on the Recovery value in a GTP Echo Response message).

The UPF may, if needed, periodically "clean up" its neighbor list. Additionally, a UPF may send its internal GTP peer list to the other UPFs in the same UPF group. Further, a UPF may periodically send its GTP peer list, along with parameters, to the CP (e.g., an SMF).

Figures 7a and 7b, below, present exemplary flowcharts that capture various of a UPF's action when it receives a PFCP heartbeat message with a Remote GTP-U peer

(Figure 7a) and when it receives a GTP Echo Request with a Remote GTP-U message (Figure 7b).

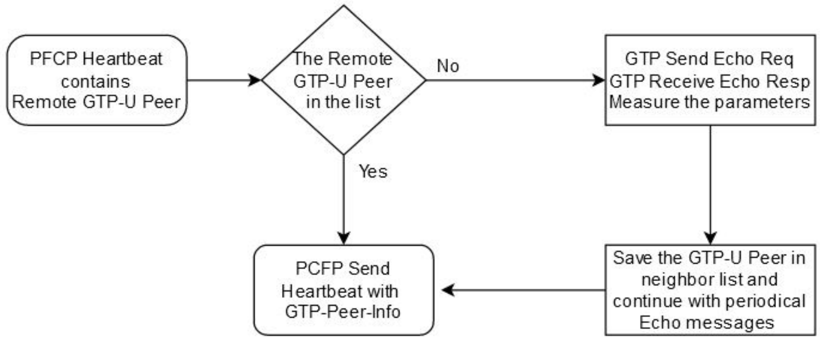

Figure 7a: Exemplary Flowchart – PFCP Heartbeat Message

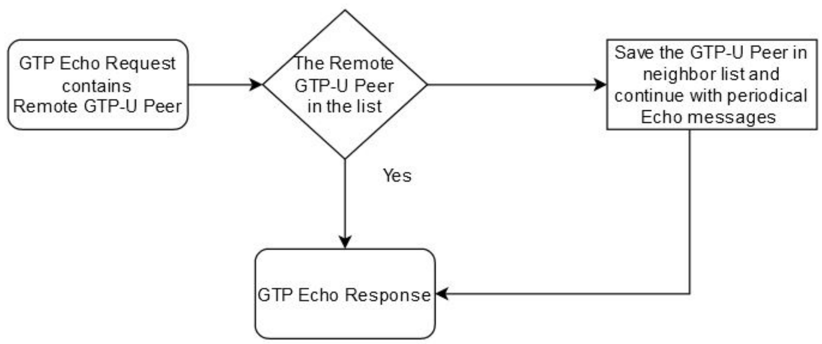

Figure 7b: Exemplary Flowchart – GTP Echo Request Message

As depicted in Figure 7a, above, when a UPF receives a PFCP heartbeat message with a Remote GTP-U peer the UPF checks if that is a known peer and if the UPF already has the data for that peer. If it is an unknown peer, then the UPF performs GTP path management and sends a report back to a CP. If it is a known peer, the UPF sends current GTP-U peer information, along with all of the parameters, to a SMF

As depicted in Figure 7b, above, when a UPF receives GTP peer(s) in a GTP echo message from the members of the same UPF group, the UPF checks if that is a known peer. If that is a new peer, the UPF adds it into its neighbor list and continues with the GTP path management to new peer. The GTP Echo Response message does not contain anything back from the UPF.

Among other things, aspects of the techniques presented herein leverage various SMF algorithms. For example, the SMF maintains a GTP-U peer list, along with all of the parameters, from each UPF. The UPFs periodically send their list, with parameters, in PFCP heartbeat messages. If the SMF detects a new GTP-U peer then the SMF updates its UPFs with the peer IP address.

The SMF follows the process that is described in the 3GPP TS 23.502 when selecting a UPF. When the SMF has multiple UPF from which to choose, the SMF calculates the shortest path (e.g., the fewest number of hops) or the smallest processing time (e.g., the smallest RTT) between the gNB and the anchor UPF. The calculation includes all of the GTP-U peers. In the case of a gNB, an I-UPF, and a PSA, it includes a calculation of the total number of hops and RTT times for all of the possible combinations of the three peers, thus ensuring that the shortest or fastest peers are selected for the traffic.

Figure 8, below, presents an exemplary flowchart that captures aspects of the SMF calculation activities according to aspects of the techniques presented herein and reflective of the discussion that was presented above.

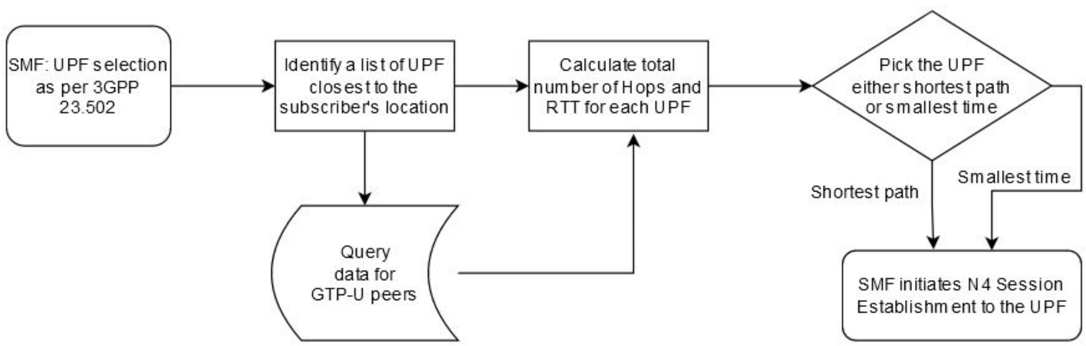

Figure 8: Exemplary SMF Calculation Activities

As described and illustrated in the narrative that was presented above, the techniques presented herein encompass a number of novel features. For example, a UPF may share its GTP-U peer information across UPFs in their group in modified GTP echo messages. Such an approach directs GTP path management towards the peer before traffic hits the UPF or the UPF is selected to handle traffic. Further, the UPF may periodically share its GTP-U peer reachability parameters (including, for example, number of hops, round trip time, and restart counter) with SMF(s) in modified PFCP heartbeat messages.

Such an approach enables an SMF to select the shortest or fastest path for a subscriber based on periodic measurements on the UPF side.

In summary, techniques have been presented herein that support a dynamic selection of UPFs in a 5G network through the use of enhanced GTP path management messages and PFCP messages. Under aspects of the presented techniques, a UPF probes the GTP-U peers (e.g., gNBs and other UPFs) to identify the distance and round-trip time to the GTP-U peers and that information is then sent to a SMF to facilitate a shortest (e.g., fewer hops) or a fastest (e.g., lowest RTT) UPF selection by the SMF.