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Multiple Access Management Services
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Abstract

In multiconnectivity scenarios the end-user devices can simultaneously connect to multiple networks based on different access technologies and network architectures like WiFi, LTE, DSL. Both the quality of experience of the users and the overall network utilization and efficiency may be improved through a smart selection and combination of access and core network paths that can dynamically adapt to changing network conditions. This document presents the problem statement and proposes solution principles. It specifies the requirements and architecture for the multi-access management services framework that can be used to 1) flexibly select the best combination of access and core network paths for uplink and downlink, as well as 2) determining the user plane treatment and traffic distribution over the selected links ensuring better network efficiency and enhanced application performance.

Status of This Memo

This Internet-Draft will expire on July 2, 2018.

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1. Introduction

Multi Access Management Services (MAMS) is a programmable framework that provides mechanisms for flexible selection of network paths in a multi-access communication environment, based on application needs. It leverages network intelligence and policies to dynamically adapt traffic distribution across selected paths and user plane treatment to changing network/link conditions. The network path selection and configuration messages are carried as user plane data between the functional elements in the network and the end-user device, and thus without any impact to the control plane signaling schemes of the individual access network. For example, in a multi-access network with LTE and WiFi technologies, existing LTE and existing WiFi signaling procedures will be used to setup the LTE and WiFi connections, respectively, and MAMS specific control plane messages are carried as LTE or WiFi user plane data. The proposed MAMS framework offers the capabilities of smart selection and flexible combination of access paths and core network paths, as well as the user plane treatment when the traffic is distributed across the selected paths. Thus, it is a broad programmable framework providing functions beyond just sharing network policies, e.g. ANDSF that provides policies/rules for assisting 3GPP devices to discover and select available access networks. Further, it allows choosing and configuring user plane treatment for the traffic over the multiple paths, depending on needs of the application.

The document presents the requirements, solution principles, functional architecture, and protocols for realizing the MAMS framework. MAMS mechanisms are not dependent on any specific access network type or user plane protocols like TCP, UDP, GRE, MPTCP etc. It co-exists and complements the existing protocols by providing a way to negotiate and configure these protocols based on client and network capabilities to match the multi-access scenario. Further it allows exchanges of network state information and leveraging network intelligence to optimize the performance of such protocols.

An important goal for MAMS is to ensure that it either requires minimum dependency or (better) no dependency on the actual access technologies of the participating links, beyond the fact that MAMS functional elements form an IP-overlay across the multiple paths. This allows the scheme to be future proof by allowing independent technology evolution of the existing access and core networks as well as, seamless integration of new access technologies.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

"Client": The end-user device supporting connections with multiple access nodes, possibly over different access technologies.

"Multiconnectivity Client": A client with multiple network connections.

"Access network": The segment in the network that delivers user data packets to the client via an access link like WiFi airlink, LTE airlink, or DSL.

"Core": The functional element that anchors the client IP address used for communication with applications via the network.

"Network Connection manager"(NCM): A functional entity in the network that handles MAMS control messages from the client and configures distribution of data packets over the multiple available access and core network paths, and user plane treatment of the traffic flows.

"Client Connection Manager" (CCM): A functional entity in the client that exchanges MAMS Signaling with the Network Connection Manager and configures the multiple network paths at the client for transport of user data.

"Network Multi Access Data Proxy" (N-MADP): This functional entity in the network handles the user data traffic forwarding across multiple network paths. N-MADP is responsible for MAMS related user-plane functionalities in the network.

"Client Multi Access Data Proxy" (C-MADP): This functional entity in the client handles the user data traffic forwarding across multiple network paths. C-MADP is responsible for MAMS related user-plane functionalities in the client.

"Anchor Connection": Refers to the network path from the N-MADP to the user plane gateway (IP anchor) that has assigned an IP address to the client.

"Delivery Connection": Refers to the network path from the N-MADP to the client.

3. Problem Statement

Typically, an end-user device has access to multiple communication networks based on different technologies, say LTE, WiFi, DSL, MuLTEfire, for accessing application services. Different technologies exhibit benefits and limitations in different scenarios. For example, WiFi provides high throughput for end users when under good coverage, but the throughput degrades significantly as the user moves closer to the edge of WiFi coverage (typically in the range of few tens of meters) or with large user population (due to contention based WiFi access scheme). In LTE networks, the capacity is often constrained by the limited availability of licensed spectrum. However, the quality of the service is predictable even in multi-user scenarios due to controlled scheduling and licensed spectrum usage.

Additionally, the use of a particular access network path is often coupled with the use of its associated core network and the services that are offered by it. For example, in an enterprise that has deployed both WiFi and LTE networks, the enterprise services, like printers, Corporate Audio and Video conferencing, are accessible only via WiFi access connected to the enterprise hosted (WiFi) core, whereas the LTE access can be used to get operator core anchored services including access to public Internet.

Thus, application performance in different scenarios becomes dependent on the choice of the access networks (e.g. WiFi, LTE, etc.) because of the coupling of the access and the core network paths. Therefore, to achieve the best possible application performance in a wide range of scenarios, a framework is needed that allows the selection and flexible combination of access and core network paths for uplink and downlink data delivery.

For example, to ensure best performance for enterprise applications at all times, in uncongested scenarios, when the user is under good WiFi coverage, it would be beneficial to use WiFi access in both uplink and downlink for connecting to enterprise applications. However in congested scenarios or when the user is getting close to the edge of its WiFi coverage, the use of WiFi in uplink by multiple users can lead to degraded capacity and increased delays due to contention. In this case, it would be beneficial to at least use the LTE access for increased uplink coverage while WiFi may still continue to be used for downlink

4. Requirements

The requirements set out in this section are for the definition of behavior of the MAMS mechanism and the related functional elements.

4.1. Access technology agnostic interworking

The access nodes may use different technology types like LTE, WiFi, etc. The framework, however, MUST agnostic to the type of underlying technology used at the access network.

4.2. Support common transport deployments

The network path selection and user data distribution MUST work transparently across various transport deployments that include e2e IPsec, VPNs, and middleboxes like NATs and proxies.

4.3. Independent Access path selection for Uplink and Downlink

Client should be able to transmit on the uplink and, receive on the downlink, using one or more accesses. The selection of the access paths for uplink and downlink SHOULD happen independent of each other.

4.4. Core selection independent of uplink and downlink access

A client SHOULD flexibly select the Core, independent of the access paths used to reach the Core, depending on the application needs, local policies and the result of MAMS control plane negotiation.

4.5. Adaptive network path selection

The framework MUST have the ability to determine the quality of each of the network paths, e.g. access link delay and capacity. The network path quality information needs to be considered in the logic for selection of the combination of network paths to be used for transporting user data. The path selection algorithm can use network path quality information, in addition to other considerations like network policies, for optimizing network usage and enhancing QoE delivered to the user.

4.6. Multipath support and Aggregation of access link capacities

The framework MUST support distribution and aggregation of user data across multiple network paths at the IP layer. The client SHOULD be able to leverage the combined capacity of the multiple network connections by enabling simultaneous transport of user data over multiple network paths. If required, packet re-ordering needs to be done at the receiver. The framework MUST allow flexibility to choose the flow steering and aggregation protocols based on capabilities supported by the client and the network data plane entities. The multi-connection aggregation solution MUST support existing transport and network layer protocols like TCP, UDP, GRE. The framework MUST allow use and configuration of existing aggregation protocols such as Multi-Path TCP(MPTCP) and SCTP.

4.7. Scalable mechanism based on user plane interworking

The framework MUST leverage commonly available routing and tunneling capabilities to provide user plane interworking functionality. The addition of functional elements in the user plane path between the client and the network MUST not impact the access technology specific procedures. This makes solution easy to deploy and scale when different networks are added and removed.

4.8. Separate Control and Data plane functions

The client MUST use the control plane protocol to negotiate with the network, the choice of access and core network paths for both uplink and downlink, as well as the user plane protocol treatment. The control plane MUST configure the actual user plane data distribution function per this negotiation. A common control protocol SHOULD allow creation of multiple user plane function instance with potentially different user plane (e.g. tunneling) protocol types. This enables maintaining a clear separation between the control and data plane functions, allowing the framework to be scalable and extensible, e.g. using SDN based architecture and implementations.

4.9. Lossless Path (Connection) Switching

When switching data traffic from one path (connection) to another, packets may be lost or delivered out-of-order, which will have negative impacts on the performance of higher layer protocols, e.g. TCP. The framework SHOULD provide necessary mechanisms to ensure in-order delivery at the receiver, e.g. during path switching. The framework MUST not cause any packet loss beyond that of access network mobility functions may cause.

4.10. Concatenation and Fragmentation to adapt to MTU differences

Different network paths may have different security and middlebox (e.g NAT) configurations, which will lead to use of different tunneling protocols for transport of data between the network user plane function and the client. As a result, different effective payload sizes (e.g. due to variable encapsulation header overheads) per network path are possible. Hence, MAMS framework SHOULD support fragmentation of a single IP packet payload across MTU sized IP packets to avoid IP fragmentation when aggregating packets from different paths. Further, concatenation of multiple IP packets into a single IP packet to improve efficiency in packing the MTU size should also be supported.

4.11. Configuring network middleboxes based on negotiated protocols

The framework SHOULD enable identification of the optimal parameters that may be used for configuring the middle-boxes, like radio link dormancy timers, binding expiry times and supported MTUs, for efficient operation of the user plane protocols, based on parameters negotiated between the client and the network, e.g. Configuring longer binding expiry time in NATs when UDP transport is used in contrast to the scenario where TCP is configured at the transport layer.

4.12. Policy based Optimal path selection

The framework MUST support consideration of policies at the client, in addition to guidance from the network, for network path selection addressing different application requirements.

4.13. Access Technology Agnostic Control signaling

The control plane signaling MUST NOT be dependent on the underlying access technology procedures, e.g. be carried transparently as user plane. It should support delivery of control plane signaling over the existing Internet protocols, e.g. TCP or UDP.

4.14. Service discovery and reachability

There can be multiple instances of the control and user plane functional elements of the framework, either collocated or hosted on separate network elements, and reachable via any of the available user plane paths. The client MUST have flexibility to choose the appropriate control plane instance in the network and use the control plane signaling to choose the desired user plane functional element instances. The choice can be based on considerations like, but not limited to, quality of link through which the network function is reachable, client preferences, pre-configuration etc.

5. Solution Principles

This document proposes the Multiple Access Management Services(MAMS) framework for dynamic selection and flexible combination of access and core network paths independently for the uplink and downlink, as well as the user plane treatment for the traffic spread across the selected links. MAMS framework consists of clearly separated control and user plane functions in the network and the client. The control plane protocol allows configuration of the user plane protocols and desired network paths for transport of application traffic. The control plane messages are carried as user plane data over any of the available network paths between the peer control plane functional elements in the client and the network . The selection of paths and user plane treatment of the traffic, is based on negotiation of capabilities (of device and network) and network link quality between the user plane functional elements at the end-user device/client and the network. The framework enables leveraging network intelligence to setup and dynamically configure the best network path combination based on device and network capabilities, application needs and knowledge of the network state.

6. MAMS Reference Architecture

```
        +--------------------------------------------------------+
        |           +---------------+       +---------------+    |
        |           !               !       !               !    |
        |           !Core(IP anchor)! +---+ !Core(IP anchor)!    |
        |           !network 1      !       !(network 'n'   !    |
        |           !               !       !               !    |
        |           +---------------+       +---------------+    |
        |                           \             /              |
        |                     Anchor \   +---+ Anchor            |
        |                     Connection 1     Connection 'n'    |
        |                              \       /                 |
        |              +---------------+\+---+/+------+          |
        |              | |-----+      +----------+    |          |
        |            +----|NCM !      |  N-MADP  |    |          |
        |            | | |-----+      +----------+    |          |
        |            | +------------------------------+          |
        |            |                /           \              |
        |    Control Plane     Delivery  +----+Delivery          |
        |    Path (over any    Connection 1    Connection 'n'    |
        |    access user plane)    /                 \           |
        |            |            /                   \          |
        |         +------------------+        +---------------+  |
        |         |  |  Access       | +---+  | Access        |  |
        |         |  |  n/w 1        |        |  n/w 'n'      |  |
        |         +------------------+        +---------/-----+  |
        +-----------------------------\----------------/---------+
                     |                 \              /
                     |           +---- -\------------/-+
                     |           | +---+ \ |------+ /  |
                     +------------+CCM |  \|C-MADP|/   |
                                 | +---+   +------+    |
                                 |        Client       |
                                 +---------------------+
```

Figure 1: MAMS Reference Architecture

Figure 1 illustrates MAMS architecture for the scenario of a client served by multiple (n) networks. It introduces the following functional elements,

o Network Connection Manager (NCM) and Client Connection Manager (CCM) in the control plane, and

o Network Multi Access Data Proxy (N-MADP) and Client Multi Access Data Proxy (C-MADP) handling the user plane.

NCM: It is the functional element in the network that handles the MAMS control plane procedures. It configures the network (N-MADP) and client (C-MADP) user plane functions like negotiating the client on the use of available access network paths, protocols and rules for processing the user plane traffic, as well as link monitoring procedures. The control plane messages between the NCM and CCM are transported as an overlay, without any impact to the underlying access networks.

CCM: It is the peer functional element in the client for handling MAMS control plane procedures. It manages multiple network connections at the client. It is responsible for exchange of MAMS signaling messages with the NCM for supporting functions like UL and DL user network path configuration for transporting user data packets, link probing and reporting to support adaptive network path selection by NCM. In the downlink, for the user data received by the client, it configures C-MADP such that application data packet received over any of the accesses to reach the appropriate application on the client. In the uplink, for the data transmitted by the client, it configures the C-MADP to determine the best access links to be used for uplink data based on a combination of local policy and network policy delivered by the NCM.

N-MADP: It is the functional element in the network that handles the user data traffic forwarding across multiple network paths, as well as other user-plane functionalities like encapsulation, fragmentation, concatenation, reordering, retransmission, etc. It is the distribution node that routes the uplink user plane traffic to the appropriate anchor connection towards the core network, and the downlink user traffic to the client over the appropriate delivery connection(s). In the downlink, the NCM configures the use of delivery connections, and user plane protocols at the N-MADP for transporting user data traffic. The N-MADP should implement ECMP support for the down link traffic. Or alternatively, it may be connected to a router with ECMP functionality. The load balancing algorithm at the N-MADP is configured by the NCM, based on static and/or dynamic network policies like assigning access and core paths for specific user data traffic type, data volume based percentage distribution, and link availability and feedback information from exchange of MAMS signaling with the CCM at the Client.. N-MADP can be configured with appropriate user plane protocols to support both per-flow and per-packet traffic distribution across the delivery connections. In the uplink, N-MADP selects the appropriate anchor connection over which to forward the user data traffic, received from the client (via the delivery connections). The forwarding rules in the uplink at the N-MADP are configured by the NCM based on application requirements, e.g. Enterprise hosted Application flows via Wi-Fi Anchor, Mobile Operator hosted applications via the Cellular Core.

C-MADP: It is the functional element in the client that handles the MAMS user plane data procedures. C-MADP is configured by CCM based on signaling exchange with NCM and local policies at the client. The CCM configures the selection of delivery connections and the user plane protocols to be used for uplink user data traffic based on the signaling exchanged with NCM. The C-MADP entity handles user plane data forwarding across multiple delivery connections and associated user-plane functions like encapsulation, fragmentation, concatenation, reordering, retransmissions, etc.

The NCM and N-MADP can be either collocated or instantiated on different network nodes. NCM can setup multiple N-MADP instances in the network. NCM controls the selection of N-MADP instance by the client and the rules for distribution of user traffic across the N-MADP instances., This is beneficial in multple deployment scenarios, like the following examples.

- Different N-MADP instances to handle different sets of clients for load balancing across clients
- Address deployment topologies e.g. N-MADP hosted at the user plane node at the access edge or in the core network, while the NCM hosted at the access edge node)
- Address access network technology architecture. For exanple, N-MADP instance at core network node to manage traffic distribution across LTE and DSL networks, and N-MADP instance at access network node to manage traffic distribution across LTE and Wi-Fi traffic.
- A single client can be configured to use multiple N-MADP instances. This is beneficial in addressing different application requirements. For example, separate N-MADP instances to handle TCP and UDP transport based traffic.

Thus, MAMS architecture flexibly addresses multiple network deployments.

7. MAMS Protocol Architecture

This section describes the protocol structure for the MAMS User and Control plane functional elements.

7.1. MAMS Control-Plane Protocol

Figure 2 shows the default MAMS control plane protocol stack. WebSocket is used for transporting management and control messages between NCM and CCM.

```
                 +-----------------------------------------+
                 |    Multi Access (MX) Control Message    |
                 |                                         |
                 +-----------------------------------------+
                 |                WebSocket                |
                 |                                         |
                 +-----------------------------------------+
                 |               TCP/TLS                   |
                 |                                         |
                 +-----------------------------------------+
```

Figure 2: TCP-based MAMS Control Plane Protocol Stack

7.2. MAMS User Plane Protocol

Figure 3 shows the MAMS user plane protocol stack.

```
          +-----------------------------------------------------+

          |      User Payload (e.g. IP PDU)                     |

          +-----------------------------------------------------+


       +-----------------------------------------------------------+

       |  +-----------------------------------------------------+  |

       |  | Multi Access (MX) Convergence Sublayer               |  |

       |  +-----------------------------------------------------+  |

       |  +-----------------------------------------------------+  |

       |  | MX Adaptation   | MX Adaptation  | MX Adaptation    |  |

       |  | Sublayer        | Sublayer       | Sublayer         |  |

       |  | (optional)      | (optional)     | (optional)       |  |

       |  +----------------++--------------+-+------------------+  |

       |  | Access #1 IP   | Access #2 IP  | Access #3 IP       |  |

       |  +-----------------------------------------------------+  |

       |                             MAMS User Plane Protocol Stack|

       +-----------------------------------------------------------+
```

Figure 3: MAMS User Plane Protocol Stack

It consists of the following two Sublayers:

o Multi-Access (MX) Convergence Sublayer: The MAMS framework configures the Convergence sublayer to perform multi-access specific tasks in the user plane. This layer performs functions like access (path) selection, multi-link (path) aggregation, splitting/reordering, lossless switching, fragmentation, concatenation, etc. MX Convergence layer can be implemented using existing user plane protocols like MPTCP or by adapting encapsulating header/trailer schemes (e.g Trailer Based MX Convergence as specified in [I-D.zhu-intarea-mams-user-protocol]).

- Multi-Access (MX) Adaptation Sublayer: The MAMS framework configures the Adaptation Sublayer to address transport network related aspects like reachability and security in the user plane. This layer performs functions to handle tunnelling, network layer security, and NAT. MX Adaptation can be implemented using IPsec, DTLS or Client NAT (Source NAT at Client with inverse mapping at N-MADP [I-D.zhu-intarea-mams-user-protocol]). The MX Adaptation Layer is optional and can be independently configured for each of the Access Links. E.g. In a deployment with LTE (assumed secure) and Wi-Fi (assumed not secure), the MX Adaptation Sublayer can be omitted for the LTE link but MX Adaptation Sublayer is configured as IPsec for securing the Wi-Fi link. Further details on the MAMS user plane are described in [I-D.zhu-intarea-mams-user-protocol].

8. MAMS Control Plane Procedures

8.1. Overview

CCM and NCM exchange signaling messages to configure the user plane functions, C-MADP and N-MADP, at the client and network respectively. The means for CCM to obtain the NCM credentials (FQDN or IP Address) for sending the initial discovery messages are out of the scope of MAMS document. As an example, the client can obtain the NCM credentials using methods like provisioning, DNS query. Once the discovery process is successful, the (initial) NCM can update and assign additional NCM addresses for sending subsequent control plane messages.

CCM discovers and exchanges capabilities with the NCM. NCM provides the credentials of the N-MADP end-point and negotiates the parameters for user plane with the CCM. CCM configures C-MADP to setup the user plane path (e.g. MPTCP/UDP Proxy Connection) with the N-MADP based on the credentials (e.g. (MPTCP/UDP) Proxy IP address and port, Associated Core Network Path), and the parameters exchanged with the NCM. Further, NCM and CCM exchange link status information to adapt traffic steering and user plane treatment with dynamic network conditions. The key procedures are described in details in the following sub-sections.

```
                      +-----+                +-----+
                      | CCM |                | NCM |
                      +--+--+                +--+--+
                         |    Discovery and     |
                         |    Capability        |
                         |    Exchange          |
                         <---------------------->
                         |                      |
                         |    User Plane        |
                         |    Protocols         |
                         |    Setup             |
                         <---------------------->
                         |    Path Quality      |
                         |    Estimation        |
                         <---------------------->
                         | Network capabilities |
                         | e.g. RNIS[ETSIRNIS]  |
                         <----------------------+
                         |                      |
                         | Network policies     |
                         <----------------------+
                         +                      +
```

Figure 4: MAMS Control Plane Procedures

8.2. Common fields in MAMS Control Messages

Each MAMS control message consists of the following common fields:

- o Version: indicates the version of MAMS control protocol.
- o Message Type: indicates the type of the message, e.g. MX Discovery, MX Capability REQ/RSP etc.
- o Sequence Number: auto-incremented integer to uniquely identify a transaction of message exchange, e.g. MX Capability REQ/RSP.

8.3. Common procedures for MAMS Control Messages

This section describes the common procedures for MAMS Control Messages.

8.3.1. Message Timeout

MAMS Control plane peer (NCM or CCM) waits for a duration of MAMS_TIMEOUT ms, after sending a MAMS control message, before timing out when expecting a response. The sender of the message will retransmit the message for MAMS_RETRY times before declaring failure. A failure implies that the MAMS peer is dead, and the sender reverts back to native non-multi access/single path mode. CCM may initiate the MAMS discovery procedure for re-establishment of the MAMS session.

8.3.2. Keep Alive Procedure

MAMS Control plane peers execute the keep alive procedures to ensure that peers are reachable and to recover from dead-peer scenarios. Each MAMS control plane end-point maintains a MAMS_KEEP_ALIVE timer that is set for duration MAMS_KEEP_ALIVE_TIMEOUT. MAMS_KEEP_ALIVE timer is reset whenever the peer receives a MAMS Control message. When MAMS_KEEP_ALIVE timer expires, MAMS KEEP ALIVE REQ message is sent. On reception of a MAMS KEEP ALIVE REQ message, the receiver responds with a MAMS KEEP ALIVE RSP message. If the sender does not receive a MAMS Control message in response to MAMS_RETRY number of retries of MAMS KEEP ALIVE REQ message, the MAMS peer declares that the peer is dead. CCM may initiate MAMS Discovery procedure for re-establishment of the MAMS session.

CCM shall additionally send MX KEEP ALIVE REQ message immediately to NCM whenever it detects a handover from one base station/access point to another. During this time the user equipment shall stop using MAMS user plane functionality in uplink direction till it receives a MX KEEP ALIVE RSP from NCM.

MX KEEP ALIVE REQ includes following information:

- Reason: Can be ’Timeout’ or ’Handover’. Reason ’Handover’ shall be used by CCM only on detection of handover.
- Unique Session Identifier: As defined in Section 8.4.
- Connection Id: This field shall be mandatorily be included if the reason is ’Handover’.
- Delivery Node Identity (ECGI in case of LTE and WiFi AP Id or MAC address in case of WiFi). This field shall be mandatorily be included if the reason is ’Handover’.

8.4. Discovery & Capability Exchange

Figure 5 shows the MAMS discovery and capability exchange procedure consisting of the following key steps:

```
         CCM                                                  NCM

          |                                                    |

          +------- MX Discovery Message ---------------------->|

          |                                         +-----------------+

          |                                         |Learn CCM        |
          |                                         | IP address      |

          |                                         |& port           |

          |                                         +-----------------+

          |                                                    |

          |<--------------------------------MX System INFO-----|

          |                                                    |

          |---------------------------------MX Capability REQ->|

          |<----- MX Capability RSP----------------------------|

          |---------------------------------MX Capability ACK->|
          |                                                    |

          +                                                    +
```

Figure 5: MAMS Control Procedure for Discovery & Capability Exchange

Step 1 (Discovery): CCM periodically sends out the MX Discovery Message to a pre-defined (NCM) IP Address/port until MX System INFO message is received in acknowledgement.

MX Discovery Message includes the following information:

- MAMS Version

MX System INFO includes the following information:

- Number of Anchor Connections

  For each Anchor Connection, it includes the following parameters:

  - Connection ID: Unique identifier for the Anchor Connection
  - Connection Type (e.g., 0: Wi-Fi; 1: 5G NR; 2: MulteFire; 3: LTE)
  - NCM Endpoint Address (For Control Plane Messages over this connection)

    - IP Address or FQDN (Fully Qualified Domain Name)
    - Port Number

Step 2 (Capability Exchange): On receiving MX System Info message CCM learns the IP Address and port to start the step 2 of the control plane connection, and sends out the MX Capability REQ message, including the following Parameters:

- MX Feature Activation List: Indicates if the corresponding feature is supported or not, e.g. lossless switching, fragmentation, concatenation, Uplink aggregation, Downlink aggregation, Measurement, probing, etc.
- Number of Anchor Connections (Core Networks)

  For each Anchor Connection, it includes the following parameters:

  - Connection ID
  - Connection Type (e.g., 0: Wi-Fi; 1: 5G NR; 2: MulteFire; 3: LTE)
- Number of Delivery Connections (Access Links)

  For each Delivery Connection, it includes the following parameters:

  - Connection ID
  - Connection Type (e.g., 0: Wi-Fi; 1: 5G NR; 2: MulteFire; 3: LTE)
- MX Convergence Method Support List

  - Trailer-based MX Convergence
  - MPTCP Proxy
  - GRE Aggregation Proxy
- MX Adaptation Method Support List

  - UDP Tunnel without DTLS
  - UDP Tunnel with DTLS
  - IPsec Tunnel [RFC3948]
  - Client NAT

In response, NCM creates a unique identity for the CCM session, and sends out the MX Capability RSP message, including the following information:

- MX Feature Activation List: Indicates if the corresponding feature is enabled or not, e.g. lossless switching, fragmentation, concatenation, Uplink aggregation, Downlink aggregation, Measurement, probing, etc.
- Number of Anchor Connections (Core Networks)

  For each Anchor Connection, it includes the following parameters:

  * Connection ID
  * Connection Type (e.g., 0: Wi-Fi; 1: 5G NR; 2: MulteFire; 3: LTE)
- Number of Delivery Connections (Access Links)

  For each Delivery Connection, it includes the following parameters:

  * Connection ID
  * Connection Type (e.g., 0: Wi-Fi; 1: 5G NR; 2: Multi-Fire; 3: LTE)
- MX Convergence Method Support List

  * Trailer-based MX Convergence
  * MPTCP Proxy
  * GRE Aggregation Proxy
- MX Adaptation Method Support List

  * UDP Tunnel without DTLS
  * UDP Tunnel with DTLS
  * IPsec Tunnel [RFC3948]
  * Client NAT

Unique Session Identifier: Unique session identifier for the CCM which has setup the connection. In case the session for the UE already exists then the existing unique session identifier is sent back.

- NCM Id: Unique Identity of the NCM in the operator network.
- Session Id: Unique identity assigned to the CCM instance by this NCM instance.

In response to MX Capability RSP message, the CCM sends confirmation (or reject) in the MX Capability ACK message. MX Capability ACK includes the following parameters

- Unique Session Identifier: Same identifier as provided in MX Capability RSP.
- Acknowledgement: An indication if the client has accepted or rejected the capability phase.

- MX ACCEPT: CCM Accepts the Capability set proposed by the NCM.
- MX REJECT: CCM Rejects the Capability set proposed by the NCM.

If MX_REJECT is received by the NCM, the current MAMS session will be terminated.

If CCM can no longer continue with the current capabilities, it should send an MX SESSION TERMINATE message to terminate the MAMS session. In response, the NCM should send a MX SESSION TERMINATE ACK to confirm the termination.

8.5. User Plane Configuration

Figure 6 shows the user plane configuration procedure consisting of the following key steps:

```
CCM                                                   NCM
 |                                                     |
 |------MX Reconfiguration REQ (setup)--------------->|
 |<------------------------+MX Reconfiguration RSP+---|
 |                                        +-----------+----------------+
 |                                        | NCM prepares N+MADP for    |
 |                                        | User Plane|Setup           |
 |                                        +----------------------------+
 |<----------------------------- MX UP Setup Config---|
 |-----| MX UP Setup CNF+---------------------------->|
+-------------------+                                  |
|Link "X" is up/down|                                  |
+-------------------+                                  |
 |-----MX Reconfiguration REQ (update/release)------->|
 |<------------------------+MX Reconfiguration RSP+---|
```

Figure 6: MAMS Control Procedure for User Plane Configuration

Reconfiguration: when the client detects that the link is up/down or the IP address changes (e.g. via APIs provided by the client OS), CCM sends out a MX Reconfiguration REQ Message to setup / release / update the connection, and the message SHOULD include the following information

o Unique Session Identifier: Identity of the CCM identity at NCM, created by NCM during the capability exchange phase.

- Reconfiguration Action: indicate the reconfiguration action (0:release; 1: setup; 2: update).
- Connection ID: identify the connection for reconfiguration

If (Reconfiguration Action is setup or update), then include the following parameters

- IP address of the connection
- SSID (if Connection Type = WiFi)
- MTU of the connection: MTU of the delivery path that is calculated at the UE for use by NCM to configure fragmentation and concatenation procedures[I-D.zhu-intarea-mams-user-protocol] at N-MADP.
- Delivery Node Identity: Identity of the node to which the client is attached. ECGI in case of LTE and WiFi AP Id or MAC address in case of WiFi.

At the beginning of a connection setup, CCM informs the NCM of the connection status using the MX Reconfiguration REQ message with Reconfiguration Action type set to "setup". NCM acknowledges the connection setup status and exchanges parameters with the CCM for user plane setup, described as follows.

User Plane Protocols Setup: Based on the negotiated capabilities, NCM sets up the user plane (Adaptation Layer and Convergence Layer) protocols at the N-MADP, and informs the CCM of the user plane protocols to setup at the client (C-MADP) and the parameters for C-MADP to connect to N-MADP.

Each MADP instance is responsible for one anchor connection. The MX UP Setup Config is used to create (multiple) MADP instance(s) and consists of the following parameters:

- Number of Anchor Connections (Core Networks)

  For Each Anchor Connection, it includes the following parameters

  - Anchor Connection ID
  - Connection Type (e.g., 0: Wi-Fi; 1: 5G NR; 2: MulteFire; 3: LTE)
  - MX Convergence Method

    - Trailer-based MX Convergence
    - MPTCP Proxy
    - GRE Aggregation Proxy
  - MX Convergence Method Parameters

    - Convergence Proxy IP Address

        + Convergence Proxy Port
    * Number of Delivery Connections

    For each Delivery Connection, include the following:

        + Delivery Connection ID
        + Connection Type (e.g., 0: Wi-Fi; 1: 5G NR; 2: MulteFire; 3: LTE)
        + MX Adaptation Method

            - UDP Tunnel without DTLS
            - UDP Tunnel with DTLS
            - IPSec Tunnel
            - Client NAT
        + MX Adaptation Method Parameters

            - Tunnel Endpoint IP Address
            - Tunnel Endpoint Port
            - Shared Secret

e.g. When LTE and Wi-Fi are the two user plane accesses, NCM conveys to CCM that IPsec needs to be setup as the MX Adaptation Layer over the Wi-Fi Access, using the following parameters - IPsec end-point IP address, Pre-Shared Key. No Adaptation Layer is needed or Client NAT may be used over the LTE Access as it is considered secure with no NAT.

Similarly, as an example of the MX Convergence Method configuration is to indicate the convergence protocol as MPTCP Proxy along with parameters for connection to the MPTCP Proxy, namely IP Address and Port of the MPTCP Proxy for TCP Applications.

Once the user plane protocols are configured, CCM informs the NCM of the status via the MX UP Setup CNF message. The MX UP Setup CNF consists of the following parameters:

o Unique Session Identifier: Session identifier provided to the client in MX Capability RSP.
o MX Probe Parameters (included if probing is supported):

    * UDP Port Number for receiving Probes
o Client Adaptation Layer Parameters:

    * Number of Delivery Connections
    * For each Delivery Connection, include the following:

        + Delivery Connection ID

  - UDP port number: If UDP based adaptation is in use, the UDP port at C-MADP side

8.6. MAMS Path Quality Estimation

Path quality estimations can be done either passively or actively. Traffic measurements in the network could be performed passively by comparing the real-time data throughput of the device with the capacity available in the network. In special deployments where the NCM has interfaces with access nodes, direct interfaces can be used to gather path quality information. For example, the utilization of a cell/eNB attached to a device could be used as an indicator for path quality estimations without creating an extra traffic overhead. Active measurements by the device are an alternative for estimating path quality.

```
        CCM                                                 NCM
        |                                                     |
        |<--------------+ MX Path Estimation Configuration+--|
        |-----+ MX Path Estimation Results+----------------->|
        |                                                     |
```

Figure 7: MAMS Control Plane Procedure for Path Quality Estimation

NCM sends following the configuration parameters in the MX Path Estimation Configuration message to the CCM

- Connection ID (of Delivery Connection whose path quality needs to be estimated)
- Init Probe Test Duration (ms)
- Init Probe Test Rate (Mbps)
- Init Probe Size (Bytes)
- Init Probe Ack Required (0 -> No/1 -> Yes)
- Active Probe Frequency (ms)
- Active Probe Size (Bytes)
- Active Probe Test Duration (ms)
- Active Probe Ack Required (0 -> No/1 -> Yes)

CCM configures the C-MADP for probe reception based on these parameters and for collection of the statistics according to the following configuration.

- Unique Session Identifier: Session identifier provided to the client in MX Capability RSP.
- Init Probe Results Configuration

  * Lost Probes (%)
  * Probe Receiving Rate (packets per second)
- Active Probe Results Configuration

  * Average Throughput in the last Probe Duration

The user plane probing is divided into two phases - Initialization phase and Active phase.

- Initialization phase: A network path that is not included by N-MADP for transmission of user data is deemed to be in the Initialization phase. The user data may be transmitted over other available network paths.
- Active phase: A network path that is included by N-MADP for transmission of user data is deemed to be in Active phase.

In Initialization phase, NCM configures N-MADP to send an MX Idle Probe REQ message. CCM collects the Idle probe statistics from C-MADP and sends the MX Path Estimation Results Message to NCM per the Initialization Probe Results configuration.

In Active phase, NCM configures N-MADP to send an MX Active Probe REQ message.. C-MADP calculates the metrics as specified by the Active Probe Results Configuration. CCM collects the Active probe statistics from C-MADP and sends the MX Path Estimation Results Message to NCM per the Active Probe Results configuration.

8.7. MAMS Traffic Steering

```
     CCM                                                 NCM
      |                                                   |
      |                                +-------------------------------+
      |                                |Steer user traffic to Path "X"|
      |                                +-------------------------------+
      |<------------------MX Traffic Steering (TS) REQ--|
      |----- MX Traffic Steering (TS) RSP ------------->|
```

Figure 8: MAMS Traffic Steering Procedure

NCM sends out a MX Traffic Steering (TS) REQ message to steer data traffic. It is also possible to send data traffic over multiple connections simultaneously, i.e. aggregation. The message includes the following information:

- Connection ID of the Anchor Connection
- Connection ID List of Delivery Connections for DL traffic
- For the number of Specific UL traffic Templates, include the following

  * Traffic Template for identifying the UL traffic
  * Connection ID List of Delivery connections for UL traffic identified by the traffic template
- MX Feature Activation List: each parameter indicates if the corresponding feature is enabled or not: lossless switching, fragmentation, concatenation, Uplink aggregation, Downlink aggregation, Measurement, probing

In response, CCM sends out a MX Traffic Steering (TS) RSP message, including the following information:

- Unique Session Identifier: Session identifier provided to the client in MX Capability RSP.
- MX Feature Activation List: each parameter indicates if the corresponding feature is enabled or not: lossless switching, fragmentation, concatenation, Uplink aggregation, Downlink aggregation, probing

8.8. MAMS Network ID Indication

```
       CCM                                               NCM
        |                                                 |
        |                            +---------------------------------+
        |                            |NCM determines preferred Networks|
        |                            +---------------------------------+
        |<------------------MX SSID Indication------------|
```

Figure 9: MAMS Network ID Indication Procedure

NCM indicates the preferred network list to the CCM to guide client on networks that it should connect to. To indicate preferred Wi-Fi Networks, the NCM sends the list of WLAN networks, represented by SSID/BSSID/HESSID, available in the MX SSID Indication.

8.9. MAMS Client Measurement Configuration and Reporting

```
             CCM                                               NCM
              |                                                 |
              |<------------------MX MEAS CONFIG----------------|
              |                                                 |
             +---------------------------------+                |
             |Client Ready to send measurements|                |
             +---------------------------------+                |
              |                                                 |
              |----- MX MEAS REPORT---------------------------->|
```

Figure 10: MAMS Client Measurement Configuration and Reporting Procedure

NCM configures the CCM with the different parameters (e.g. radio link information), with the associated thresholds to be reported by the client. The MX MEAS CONFIG message contains the following parameters. For each Delivery Connection, include the following:

- Delivery Connection ID
- Connection Type (e.g., 0: Wi-Fi; 1: 5G NR; 2: MulteFire; 3: LTE)
- If Connection Type is Wi-Fi
  - WLAN_RSSI_THRESH: High and Low Thresholds for sending Average RSSI of the Wi-Fi Link.
  - WLAN_RSSI_PERIOD: Periodicity in ms for sending Average RSSI of the Wi-Fi Link.
  - WLAN_LOAD_THRESH: High and Low Thresholds for sending Loading of the WLAN system.
  - WLAN_LOAD_PERIOD: Periodicity in ms for sending Loading of the WLAN system.
  - UL_TPUT_THRESH: High and Low Thresholds for sending Reverse Link Throughput on the Wi-Fi link.
  - UL_TPUT_PERIOD: Periodicity in ms for sending Reverse Link Throughput on the Wi-Fi link.
  - DL_TPUT_THRESH: High and Low Thresholds for sending Forward Link Throughput on the Wi-Fi link.
  - DL_TPUT_PERIOD: Periodicity in ms for sending Forward Link Throughput on the Wi-Fi link.
  - EST_UL_TPUT_THRESH: High and Low Thresholds for sending Reverse Link Throughput (EstimatedThroughputOutbound as defined in [IEEE]) on the Wi-Fi link.

  - EST_UL_TPUT_PERIOD: Periodicity in ms for sending Reverse Link Throughput (EstimatedThroughputOutbound as defined in [IEEE]) on the Wi-Fi link.
  - EST_DL_TPUT_THRESH: High and Low Thresholds for sending Forward Link Throughput (EstimatedThroughputInbound as defined in [IEEE]) on the Wi-Fi link.
  - EST_DL_TPUT_PERIOD: Periodicity in ms for sending Forward Link Throughput (EstimatedThroughputInbound as defined in [IEEE]) on the Wi-Fi link.
- If Connection Type is LTE
  - LTE_RSRP_THRESH: High and Low Thresholds for sending RSRP of Serving LTE link.
  - LTE_RSRP_PERIOD: Periodicity in ms for sending RSRP of Serving LTE link.
  - LTE_RSRQ_THRESH: High and Low Thresholds for sending RSRQ of the serving LTE link.
  - LTE_RSRQ_PERIOD: Periodicity in ms for sending RSRP of Serving LTE link.
  - UL_TPUT_THRESH: High and Low Thresholds for sending Reverse Link Throughput on the serving LTE link.
  - UL_TPUT_PERIOD: Periodicity in ms for sending Reverse Link Throughput on the serving LTE link.
  - DL_TPUT_THRESH: High and Low Thresholds for sending Forward Link Throughput on the serving LTE link.
  - DL_TPUT_PERIOD: Periodicity in ms for sending Forward Link Throughput on the serving LTE link.

The MX MEAS REPORT message contains the following parameters

- Unique Session Identifier: Session identifier provided to the client in MX Capability RSP.
- For each Delivery Connection, include the following:
  - Delivery Connection ID
  - Connection Type (e.g., 0: Wi-Fi; 1: 5G NR; 2: MulteFire; 3: LTE)
  - Delivery Node Identity (ECGI in case of LTE and WiFi AP Id or MAC address in case of WiFi)
  - If Connection Type is Wi-Fi
    - WLAN_RSSI: Average RSSI of the Wi-Fi Link.
    - WLAN_LOAD: Loading of the WLAN system.
    - UL_TPUT: Reverse Link Throughput on the Wi-Fi link.
    - DL_TPUT: Forward Link Throughput on the Wi-Fi link.
    - EST_UL_TPUT: Estimated Reverse Link Throughput on the Wi-Fi link (EstimatedThroughputOutbound as defined in [IEEE]).

- + EST_DL_TPUT: Estimated Forward Link Throughput on the Wi-Fi link (EstimatedThroughputInbound as defined in [IEEE]).
- * If Connection Type is LTE
  - + LTE_RSRP: RSRP of Serving LTE link.
  - + LTE_RSRQ: RSRQ of the serving LTE link.
  - + UL_TPUT: Reverse Link Throughput on the serving LTE link.
  - + DL_TPUT: Forward Link Throughput on the serving LTE link.

8.10. MAMS Session Termination Procedure

```
             CCM                                NCM
              |                                  |
              |+----MX Session Terminate--------->|
              |                                  |
              |                                  |
              |<---MX Session Terminate Ack-------|
              |                              +---------------+
              |                              Remove Resources
              |                              +---------------+
              |                                  |
```

Figure 11: MAMS Session Termination Procedure - Client Initiated

```
                     CCM                                     NCM
                      |                                       |
                      |<----------MX Session Terminate--------|
                      |                                       |
                      |                                       |
                      |                                       |
                      +--------MX Session Terminate Ack------->
                      |                                       |
                      |                                       |
          +-----------+-----------+                           |
          |    Remove Resources   |                           |
          +-----------+-----------+                           |
                      |                                       |
```

Figure 12: MAMS Session Termination Procedure - Network Initiated

At any point in MAMS functioning if CCM or NCM is unable to support the MAMS functions anymore, then either of them can initiate a termination procedure by sending MX Session Terminate to the peer, the peer shall acknowledge the termination by sending MX Session Terminate ACK message. After the session is disconnected the CCM shall start a new procedure with MX Discover Message. MX Session Terminate message shall contain Unique Session Identifier and reason for termination in Request. Possible reasons for termination can be:

- Normal Release
- No Response from Peer
- Internal Error

9. Generic MAMS Signaling Flow

```
                            +----------------------------------------+
                            |   MAMS enabled Network of Networks     |
                            | +-----+    +-----+   +-----+    +------+
     +-----------------+    | |     |    |     |   |     |    |     ||
     |     Client      |    | |Netwo|    |Netwo|   |     |    |     ||
     | +-----+ +-----+ |    | |rk 1 |    |rk 2 +   |NCM  |    N-MADP||
     | C-MADP  |CCM  | |    | |(LTE)|    |(WiFi)   |     |    |     ||
     | +-----+ +-----+ |    | +-----+    +-----+   +-----+    +------|
     -+----------------+    +----------------------------------------+
      |   |       |              |          |         |          |
      |   |       |              |          |         |          |
      |   |    1.SETUP CONNECTION|          |         |          |
      |<-----------+------------>|          |         |          |
      |   |       |              +          +         |          |
      |   |       |  2. MAMS Capabilities Exchange    |          |
      |   |       |<-------------+----------+-------->|          |
      |   |       |              |          |         |          |
      |   |       +              |          |         |          |
      |   |    3. SETUP CONNECTION          |         |          |
      |<--+-------------------------------->|         |          |
      | 4c. Config| 4a. NEGOTIATE NETWORK PATHS, FLOW |4b. Config|
      | C-MADP    | PROTOCOL AND PARAMETERS |         |N-MADP    |
      |   |<----->|<-------------+----------+-------->|<-------->|
      |   |       |              +          +         |          |
      |   |       |5. ESTABLISH USER PLANE PATH ACCORDING TO     |
      |   |       | SELECTED FLOW PROTOCOL  |         |          |
      |   |<-------------------+----------+------------------>|
      |   |       |              |          |         |          |
      +   +       +              +          +         +          +
```

Figure 13: MAMS call flow

Figure 13 illustrates the MAMS signaling mechanism for negotiation of network paths and flow protocols between the client and the network. In this example scenario, the client is connected to two networks (say LTE and WiFi).

1. UE connects to network 1 and gets an IP address assigned by network 1.
2. CCM communicates with NCM functional element via the network 1 connection and exchanges capabilities and parameters for MAMS operation. Note: The NCM credentials (e.g. NCM IP Address) can be made known to the UE by pre-provisioning.
3. Client sets up connection with network 2 and gets an IP address assigned by network 2.
4. CCM and NCM negotiate capabilities and parameters for establishment of network paths, which are then used to configure user plane functions N-MADP at the network and C-MADP at the client.

    4a. CCM and NCM negotiate network paths, flow routing and aggregation protocols, and related parameters.

    4b. NCM communicates with the N-MADP to exchange and configure flow aggregation protocols, policies and parameters in alignment with those negotiated with the CCM.

    4c. CCM communicates with the C-MADP to exchange and configure flow aggregation protocols, policies and parameters in alignment with those negotiated with the NCM.

5. C-MADP and N-MADP establish the user plane paths, e.g. using IKE [RFC7296] signaling, based on the negotiated flow aggregation protocols and parameters specified by NCM.

CCM and NCM can further exchange messages containing access link measurements for link maintenance by the NCM. NCM evaluates the link conditions in the UL and DL across LTE and WiFi, based on link measurements reported by CCM and/or link probing techniques and determines the UL and DL user data distribution policy. NCM and CCM also negotiate application level policies for categorizing applications, e.g. based on DSCP, Destination IP address, and determining which of the available network paths, needs to be used for transporting data of that category of applications. NCM configures N-MADP, and CCM configures C-MADP, based on the negotiated application policies. CCM may apply local application policies, in addition to the application policy conveyed by the NCM.

10. Applying MAMS Control Procedures with MPTCP Proxy as User Plane

If NCM determines that N-MADP is to be instantiated with MPTCP as the MX Convergence Protocol, it exchanges the MPTCP capability support in discovery and capability exchange procedures. NCM then exchanges the credentials of the N-MADP instance, setup as MPTCP Proxy, along with related parameters to the CCM. CCM configures C-MADP with these parameters to connect with the N-MADP, MPTCP proxy (e.g. [I-D.wei-mptcp-proxy-mechanism], [I-D.boucadair-mptcp-plain-mode]) instance, on the available network path (Access).

Figure 14 shows the call flow describing MAMS control procedures applied to configure user plane and dynamic optimal path selection in a scenario with MPTCP Proxy as the convergence protocol in the user plane.

```
+------+   +---------+   +---------+   +---------+   +---------+   +------+
|      |   |         |   |         |   |         |   |         |   |      |
|CCM   |   |  C-MADP |   |Wi-Fi N/W|   | LTE N/W |   |  NCM    |   |N-MADP|
+------+   +---------+   +---------+   +---------+   +---------+   +------+
 +------------------------------------------------------------------------+
 |                  1. LTE Session Setup and IP Add. Allocation           |
 -------------------------------------------+-------------+-------------+-+
  |2. MAMS Discovery Message (MAMS Version) |             |             |
  +-----------------------------------------+------------->             |
  | 3. MX SYSTEM INFO (Serving NCM IP/Port Address)       |             |
  <-------------+-------------+-------------+-------------+             |
  |             |             |             |             |             |
  |4. MX CAPABILITY REQ(Supported Anchor/Delivery Links ( Wi-Fi, LTE )  |
  +-----------------------------------------------------+->             |
  |5. MX CAPABILITY RSP(Convergence/Adaptation Parameters)|             |
  <-----------------------------------------+-------------+             |
  | 6. MX CAPABILITY ACK(ACCEPT)            |             |             |
  +-------------+-------------+--------------------------->             |
  |             |             |             |             |             |
  |7. MX MEAS CONFIG (WLAN/LTE Measurement Thresholds/Period)           |
  <-------------------------------------------------------+             |
  |8. MX MEAS REPORT ( LTE RSRP, UL/DL TPUT )             |             |
  +-----------------------------------------+------------->             |
  |9. MAMS SSID IND(List of SSIDs)          |             |             |
  <-------------+-------------+---------------------------+             |
  |             |             |             |             |             |
  |10. MX RECONFIGURATION REQ (LTE IP)      |             |             |
  +------------------------------------------------------->             |
  |11. MX RECONFONFIGURATION RSP            |             |             |
  <-----------------------------------------+-------------+             |
  |12. MX UP SETUP REQ (MPTCP Proxy IP/Port, Aggregation) |             |
  <---------------------------+-------------+-------------+             |
  |13. MX UP SETUP RSP        |             |             |             |
  +-------------+-------------+-------------+------------->             +
  |             | 14. MPTCP Connection with designated MPTCP Proxy over LTE
  |             +-------------+-------------+-------------+------------->
  |             |             |             |             |             |
  +             +             +             +             +             +
```

Figure 14: MAMS-assisted MPTCP Proxy as User Plane - Initial Setup with LTE leg

Following are the salient steps described in the call flow. The client connects to the LTE network and obtains an IP address (assume LTE is the first connection), and initiates the NCM discovery procedures and exchange capabilities, including the support for MPTCP as the convergence protocol at both the network and the client.

The CCM informs the LTE connection parameters to the NCM. NCM provides the parameters like MPTCP Proxy IP address/Port for configuring the convergence layer. This is useful if N-MADP is reachable via different IP address or/and port, from different access networks. The current MPTCP signaling can’t identify or differentiate the MPTCP proxy IP address and port among multiple access networks. Since LTE is the only connection, the user plane traffic flows over the single TCP subflow over the LTE connection. Optionally, NCM can provide assistance to the device on the neighboring/preferred Wi-Fi networks that it can associate with.

```
+------+   +---------+   +---------+   +---------+   +---------+   +------+
|      |   |         |   |         |   |         |   |         |   |      |
|CCM   |   |  C-MADP |   |Wi-Fi N/W|   | LTE N/W |   |  NCM    |   |N-MADP|
+------+   +---------+   +---------+   +---------+   +---------+   +------+
 +------------------------------------------------------------------------+
 |   Traffic over LTE in UL and DL over MPTCP Connection                  |
 +------------------------------------------------------------------------+
 +------------------------------------------------------------------------+
 |   Wi-Fi Connection Establishment and IP Address Allocation             |
 +---------------------------------------------------------------------+--+
 |15. MX RECONFIGURATION REQ (Wi-Fi IP)    |             |             |
 +------------------------------------------------------->             |
 |16. MX RECONFONFIGURATION RSP            |             |             |
 <-----------------------------------------+-------------+             |
 |17. MX UP SETUP REQ (MPTCP Proxy IP/Port, Aggregation) |             |
 <---------------------------+-------------+-------------+             |
 |18. MX UP SETUP RSP        |             |             |             |
 +-------------+-------------+-------------+------------->             |
 |             | 19. IPsec Tunnel Establishment over WLAN path         |
 |             <-----------------------------------------|------------->
 | 20. MX MEAS REPORT (WLAN RSSI, LTE RSRP. UL/DL TPUT)  |+-------------+
 +-------------+-------------+-------------+------------->+Wait for     |
 |             |             |             |             |+good reports |
 |             |             |             |             |+-------------+
 |   21. MX TRAFFIC STEERING REQ (UL/DL Access, TFTs)    | +------------+
 <-----------------------------------------+-------------+ |Allow Use of|
 |   22. MX TRAFFIC STEERING RSP (...)     |             | |Wi-Fi link  |
 +-------------+-------------+---------------------------> +-----------++
 |             |             |             |             |             |
 |            Add TCP subflow to the MPTCP connection over the WiFi link
 |             |<----------------------------------------------------->|
+-----------------------------------------------------------------------+
||              Aggregated Wi-Fi and LTE capacity for UL and DL        ||
+-----------------------------------------------------------------------+
 |                                                                     |
 |                                                                     |
```

Figure 15: MAMS-assisted MPTCP Proxy as User Plane - Add Wi-Fi leg

Figure 15 describes the steps, when the client establishes a Wi-Fi connection. CCM informs the NCM of the Wi-Fi connection along with parameters like the Wi-Fi IP address, SSID. NCM determines that the Wi-Fi connection needs to be secured and configures the Adaptation Layer to be IPsec and provides the required parameters to the CCM. In addition, NCM provides the information to configure the convergence layer, (e.g. MPTCP Proxy IP Address), and provides the Traffic Steering Request to indicate that client should use only the

LTE access. NCM may do this, for example, on determination from the measurements that the Wi-Fi link is not consistently good enough. As the Wi-Fi link conditions improve, NCM sends a Traffic Steering Request to use Wi-Fi access as well. This triggers the client to establish the TCP subflow over the Wi-Fi link with the MPTCP proxy

```
+------+   +---------+   +---------+   +---------+   +---------+   +------+
|      |   |         |   |         |   |         |   |         |   |      |
|CCM   |   |  C+MADP |   |Wi+Fi N/W|   | LTE N/W |   |  NCM    |   |N+MADP|
+------+   +---------+   +---------+   +---------+   +---------+   +------+
 +------------------------------------------------------------------------+
 |   Traffic over LTE and Wi Fi in UL And DL over MPTCP                   |
 +-------------+-------------+-------------+-------------+------------+---+
 |             |             |             |             |            |
 | 23. MX MEAS REPORT (WLAN RSSI, LTE RSRP ,UL/DL TPUT)  |+-----------+---+
 +-------------+-------------+-------------+------------>|| Reports of bad|
 |             |             |             |             |+ Wi-Fi UL tput|
 |             +             +             +             ++---------------+
 |   24. MX TRAFFIC STEERING REQ (UL/DL Access, TFTs)    | +-------------+
 |<-----------------------------------------+------------+ |Disallow  use|
 |   25. MX TRAFFIC STEERING RSP (...)     |             | |of Wi-Fi UL  |
 |-------------+-------------+-------------------------->| +----------+--+
 |             |             |             |             |            |
++-------------+-------------+-------------+-------------+------------+-+
|  UL data to use TCP subflow over LTE link only,                       |
|  Aggregated Wi-Fi+LTE capacity for DL                                 |
++-------------+-------------+-------------+-------------+-------------++
 |             |             |             |             |            |
 +             +             +             +             +            +
```

Figure 16: MAMS-assisted MPTCP Proxy as User Plane - Wi-Fi UL degrades

Figure 16 describes the steps, when the client reports that Wi-Fi link conditions degrade in UL. MAMS control plane is used to continuously monitor the access link conditions on Wi-Fi and LTE connections. The NCM may at some point determine increase in UL traffic on Wi-Fi, and trigger the client to only LTE in the UL via Traffic Steering Request to improve UL performance.

```
+------+   +---------+   +---------+   +---------+   +---------+   +------+
|      |   |         |   |         |   |         |   |         |   |      |
|CCM   |   |  C+MADP |   |Wi+Fi N/W|   | LTE N/W |   |  NCM    |   |N+MADP|
+------+   +---------+   +---------+   +---------+   +---------+   +------+
+-----------------------------------------------------------------------+
|  UL data to use TCP subflow over LTE link only,                       |
|  Aggregated Wi+Fi+LTE capacity for DL                                 |
++-------------+-------------+-------------+-------------+------------+-+
 |             |             |             |             |            |
 |             +             +             +             |            |
 | 23. MX MEAS REPORT (WLAN RSSI, LTE RSRP, UL/DL TPUT)  +------------+---+
 +-------------+-------------+-------------+------------>|| Reports of bad+
 |             |             |             |             || Wi+Fi UL/DL tput
 |             +             +             +             +----------------+
 |   24. MX TRAFFIC STEERING REQ (UL/DL Access, TFTs)    | +-------------+
 +<------------------------------------------+-------------+ |Disallow  use|
 |   25. MX TRAFFIC STEERING RSP (...)       |             | |of Wi+Fi     |
 +-----------------------------------------+------------->+ +-------------+
 |             |Delete TCP subflow from MPTCP conn. over Wi-Fi link   |
 |             +<------------------------------------------------------>|
+-----------------------------------------------------------------------+
|| Traffic over LTE link only for DL and UL              |            | |
|| (until Client reports better Wi-Fi link conditions)   |            | |
+-----------------------------------------------------------------------+
 |             |             |             |             |            |
 +             +             +             +             +            +
```

Figure 17: MAMS-assisted MPTCP Proxy as User Plane - Part 4

Figure 17 describes the steps, when the client reports that Wi-Fi link conditions degrade in both UL and DL. As the Wi-Fi link conditions deteriorate further, the NCM may determine to send Traffic Steering Request guiding the client to stop using Wi-Fi, and to use only LTE access in both UL and DL. This condition may be maintained until NCM determines, based on reported measurements that Wi-Fi link has become usable.

11. Applying MAMS Control Procedures for Network Assisted Traffic Steering when there is no convergence layer

Figure 18 shows the call flow describing MAMS control procedures applied for dynamic optimal path selection in a scenario convergence and Adaptation layer protocols are not omitted. This scenario indicates the applicability of a MAMS Control Plane only solution.

In the capability exchange messages, NCM and CCM negotiate that Convergence and Adaptation layer protocols are not needed (or supported). CCM informs the NCM of the availability of the LTE and Wi-Fi links. NCM determines the access links, Wi-Fi or LTE to be used dynamically based on the reported link quality measurements.

```
+------+   +---------+   +---------+   +---------+   +---------+   +------+
|      |   |         |   |         |   |         |   |         |   |      |
|CCM   |   |  C+MADP |   |Wi+Fi N/W|   | LTE N/W |   |  NCM    |   |N+MADP|
+------+   +---------+   +---------+   +---------+   +---------+   +------+
 +------------------------------------------------------------------------+
 |                1. LTE Session Setup and IP Add. Allocation             |
 +------------------------------------------+-------------+-------------+-+
  |2. MAMS Discovery Message (MAMS Version) |             |             |
  +-----------------------------------------+------------>|             |
  | 3. MX SYSTEM INFO (Serving NCM IP/Port Address)       |             |
  <-------------+-------------+-------------+-------------+             |
  |             +             +             +             +             |
  |4. MX CAPABILITY REQ(Supported Anchor/Delivery Links ( Wi-Fi, LTE )  |
  +------------------------------------------------------>|             |
  |5. MX CAPABILITY RSP(No Convergence/Adpatation parameters)           |
  |<-----------------------------------------+------------+             |
  | 6. MX CAPABILITY ACK(ACCEPT)            |             |             |
  +-------------+-------------+-------------------------->|             |
  |             +             +             +             +             |
  |7. MX MEAS CONFIG (WLAN/LTE Measurement Thresholds/Period)           |
  |<------------------------------------------------------|             |
  |8. MX MEAS REPORT ( LTE RSRP, UL/DL TPUT )             |             |
  |-----------------------------------------+------------>|             |
  |9. MAMS SSID IND(List of SSIDs)          |             |             |
  |<------------------------------------------------------|             |
+-----------------------------------------------------------------------++
|             10. Wi|Fi connection setup and IP Address allocation       |
+-+-------------+-------------+-------------+-------------+-------------++
  |             +             +             |             |             |
  |10. MX RECONFIGURATION REQ (LTE IP, Wi-Fi IP)          |             |
  +-----------------------------------------+------------>|             |
  |11. MX RECONFONFIGURATION RSP            |             |             |
  <-----------------------------------------------------+|             |
+-----------------------------------------------------------------------++
|    Initial Condition, Data over LTE link only, WLAN link is poor       |
+---------------------------------------------------------+-------------++
  |12. MX MEAS REPORT (WLAN RSSI, LTE RSRP, UL/DL TPUT)   |+-------------+
  |------------------------------------------------------>||Wi-Fi Link   |
  |             |             |             |             ||conditions   |
  |             |             |             |             ||reported good|
  |             |             |             |             |+-------------+
  |             |             |             |             |             |
  |13. MX TRAFFIC STEERING REQ (UL/DL Access, TFTs)       |+--------------+
  |<------------+-------------+-------------+-------------||Steer traffic |
  |14. MX TRAFFIC STEERING RSP (...)        |             ||to use Wi-Fi  |
  |<------------+-------------+-------------+-------------||link          |
  |             |             |             |             |+--------------+
+-----------------------------------------------------------------------++
|    Use Wi-Fi link for Data                                             |
+---------------------------------------------------------+-------------++
  |             |             |             |             |             |
  +             +             +             +             +             +
```

Figure 18: MAMS With No Convergence Layer

12. Co-existence of MX Adaptation and MX Convergence Layers

MAMS user plane supports multiple instances and combinations of protocols to be used at the MX Adaptation and the Convergence layer.

For example, one instance of the MX Convergence Layer can be MPTCP Proxy and another instance can be Trailer based. The MX Adaptation for each can be either UDP tunnel or IPsec. IPSec may be set up when network path needs to be secured, e.g. to protect the TCP subflow traversing the network path between the client and MPTCP proxy.

Each of the instances of MAMS user plane, i.e. combination of MX Convergence and MX Adaptation layer protocols, can coexist simultaneously and independently handle different traffic types.

13. Security Considerations

13.1. MAMS Control plane security

The NCM functional element is hosted on a network node which is assumed to be within a secure network, e.g. within the operator’s network, and is assumed to be protected against hijack attacks.

For deployment scenarios, where the client is configured (e.g. by the network operator) to use a specific network path for exchanging control plane messages and if the network path is assumed to be secure, MAMS control messages will rely on security provided by the underlying network.

For deployment scenarios where the security of the network path cannot be assumed, NCM and CCM implementations MUST support the "wss" URI scheme [RFC6455] and Transport Layer Security (TLS) [RFC5246] to secure control plane message exchange between the NCM and CCM.

For deployment scenarios where client authentication is desired, the WebSocket server can use any client authentication mechanisms available to a generic HTTP server, such as cookies, HTTP authentication, or TLS authentication.

13.2. MAMS User plane security

User data in MAMS framework relies on the security of the underlying network transport paths. When this cannot be assumed, NCM configures use of protocols, like IPsec [RFC4301] [RFC3948] in the MX Adaptation Layer, for security.

14. Implementation considerations

MAMS builds on commonly available functions available on terminal devices that can be delivered as a software update over the popular end-user device operating systems, enabling rapid deployment and addressing the large deployed device base.

15. Applicability to Multi Access Edge Computing

Multi Access Edge Computing (MEC), earlier known as Mobile edge computing, is an access-edge cloud platform being standardized at ETSI, whose initial focus was to improve quality of experience by leveraging intelligence at cellular (e.g. 3GPP technologies like LTE) access edge, and the scope is now being extended to support access technologies beyond 3GPP. This applicability of the framework described in this document to the MEC platform has been evaluated and tested in different network configurations.

The NCM is hosted on the MEC cloud server that is located in the user plane path at the edge of multi-technology access networks. The NCM and CCM negotiate the network path combinations based on application needs and the necessary user plane protocols to be used across the multiple paths. The network conditions reported by the CCM to the NCM is complemented by Radio Analytics application[ETSIRNIS] residing at the MEC to configure the uplink and downlink access paths according to changing radio and congestion conditions.

The user plane functional element, N-MADP, can either be collocated with the NCM at the MEC cloud server (e.g. MEC hosted applications), or placed at a separate network element like a common user plane gateway across the multiple networks.

Also, even in scenarios where N-MADP is not deployed, NCM can be used to augment the traffic steering decisions at the device.

The aim of these enhancements is to improve the end-user’s quality of experience by leveraging the best network path based on application needs and network conditions, and building on the advantages of significantly reduced latency and the dynamic and real-time exposure of radio network information available at the MEC.

16. Contributing Authors

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18. IANA Considerations

This draft makes no requests of IANA

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Appendix A. MAMS Control Plane Optimization over Secure Connections

If the connection between CCM and NCM over which the MAMS control plane messages are transported is assumed to be secure, UDP is used as the transport for management & control messages between NCM and UCM (see Figure 19).

```
+------------------------------------------------------+
|        Multi-Access (MX) Control Message             |
|------------------------------------------------------|
|                UDP                                   |
|------------------------------------------------------|
```

Figure 19: UDP-based MAMS Control plane Protocol Stack

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