      Control Plane Protocols and Procedures for Multiple Access Management
                                  Services
                  draft-zhu-intarea-mams-control-protocol-02

Abstract

   Today, a device can be simultaneously connected to multiple
   communication networks based on different technology implementations
   and network architectures like WiFi, LTE, DSL. In such multi-
   connectivity scenario, it is desirable to combine multiple access
   networks or select the best one to improve quality of experience for
   a user and improve overall network utilization and efficiency. This
   document presents the control plane protocols, as well as describes
   control plane procedures for configuring the user plane in a multi
   access management services (MAMS) framework that can be used to
   flexibly select the combination of uplink and downlink access and
   core network paths, and user plane treatment for improving network
   efficiency and enhanced application quality of experience.

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1. Conventions used in this document

   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].

2. Introduction

   Multi Access Management Service (MAMS)
   [I-D.kanugovi-intarea-mams-protocol] is a framework to select and
   configure network paths when multiple connections can serve a client
   device. It allows the path selection and configuration to adapt to
   dynamic network conditions. It is based on principles of user plane
   interworking that enables the solution to be deployed as an overlay
   without impacting the underlying networks.

   This document presents the control plane protocols for the MAMS
   framework. It co-exists and complements user plane protocols (e.g.
   MPTCP [RFC6824], MPTCP Proxy [I-D.boucadair-mptcp-plain-mode],
   [I-D.wei-mptcp-proxy-mechanism], GRE
   [I-D.zhu-intarea-mams-user-protocol]) by providing a way to negotiate
   and configure them based on client and network capabilities. It
   allows exchange of network state information and leverages network
   intelligence to optimize the performance of such protocols.

3. Terminology

   "Anchor Connection": Refers to the network path from the N-MADP to
   the Application Server that corresponds to a specific 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.

   "Network Connection Manager" (NCM), "Client Connection Manager"
   (CCM), "Network Multi Access Data Proxy" (N-MADP), and "Client Multi
   Access Data Proxy" (C-MADP) in this document are to be interpreted as
   described in [I-D.kanugovi-intarea-mams-protocol].

4. MAMS Control-Plane Protocol

The MAMS architecture [I-D.kanugovi-intarea-mams-protocol] 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.

Figure 1 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                  |
        |                                         |
        +-----------------------------------------+
```
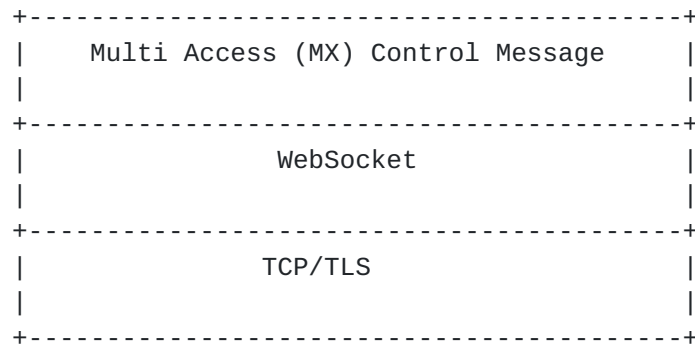
Figure 1: TCP-based MAMS Control Plane Protocol Stack

5. MAMS User Plane Protocol

Figure 2 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|
    +------------------------------------------------------------+
```
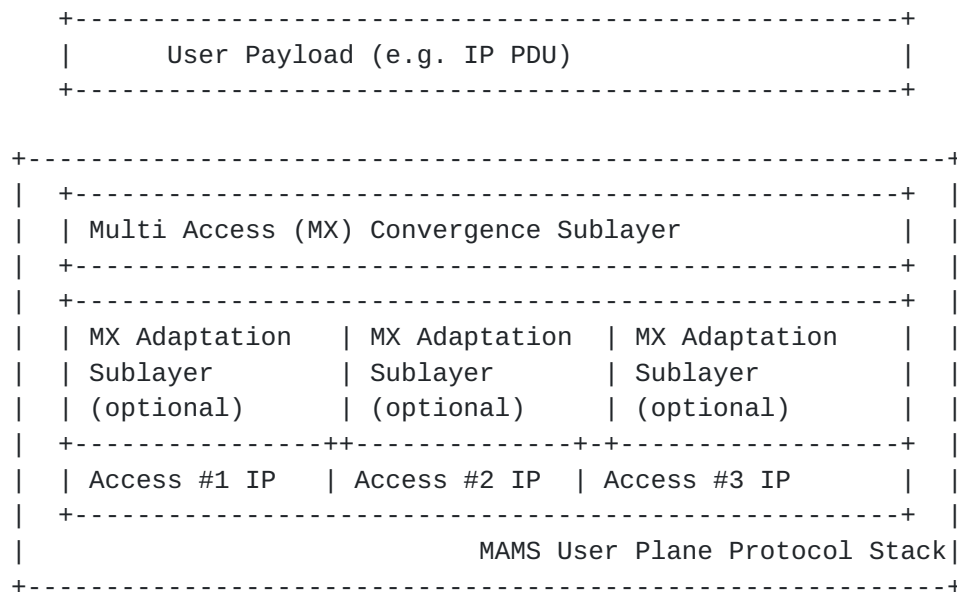

                 Figure 2: MAMS User Plane Protocol Stack

   It consists of the following two Sublayers:

   o Multi-Access (MX) Convergence Sublayer: This layer performs multi-
      access specific tasks, e.g. access (path) selection, multi-link
      (path) aggregation, splitting/reordering, lossless switching,
      fragmentation, concatenation, etc. For example, 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]).
   o Multi-Access (MX) Adaptation Sublayer: This layer performs
      functions to handle tunnelling, network layer security, and NAT.
      For example, 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 the Wi-Fi link.

6. **MAMS Control Plane Procedures**

6.1. **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, e.g. 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. 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       |
                     <----------------------+
                     +                        +
```
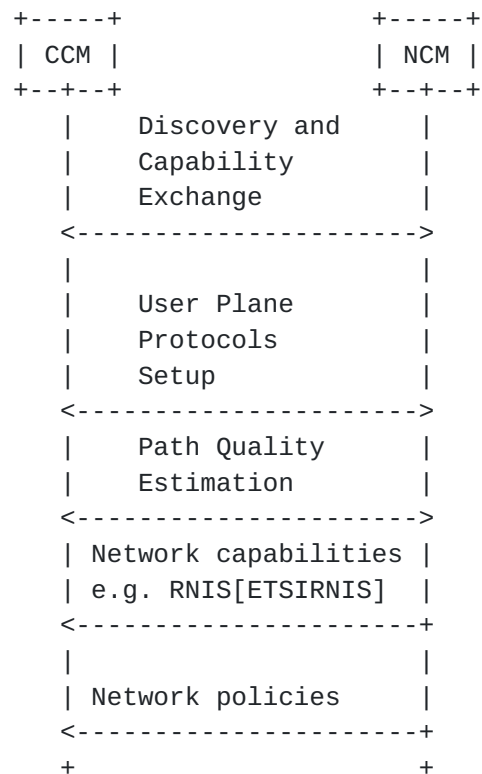

                    Figure 3: MAMS Control Plane Procedures

6.2. 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.

6.3. Common procedures for MAMS Control Messages

   This section describes the common procedures for MAMS Control
   Messages.

6.3.1. 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. CCM may initiate the
   MAMS discovery procedure for re-establishment of the MAMS session.

6.3.2. 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:

   o Reason: Can be 'Timeout' or 'Handover'. Reason 'Handover' shall
      be used by CCM only on detection of handover.
   o Unique Session Identifier: As defined in Section 6.4.
   o Connection Id: This field shall be mandatorily be included if the
      reason is 'Handover'.
   o 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'.

6.4. Discovery & Capability Exchange

   Figure 4 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->|
         |                                                |
         +                                                +
```
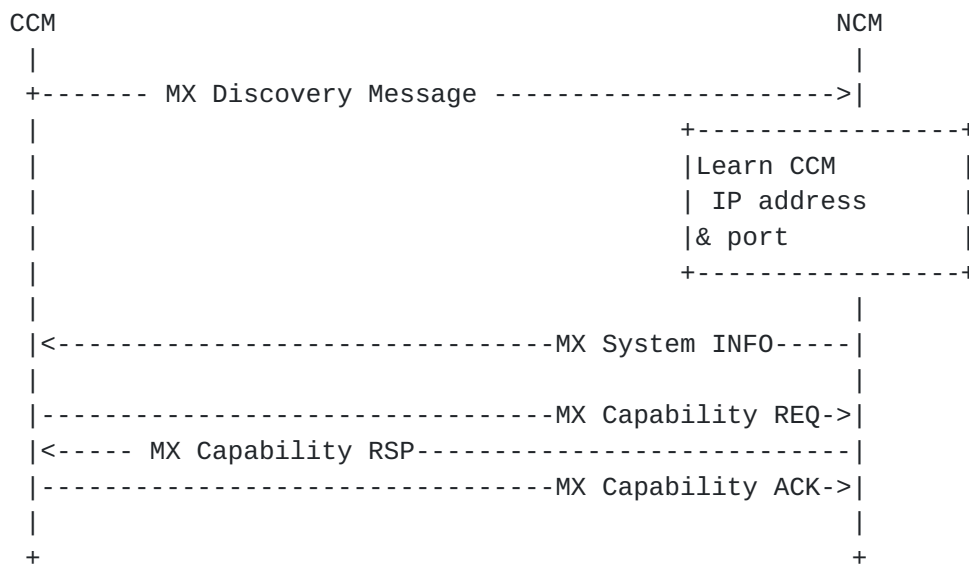
Figure 4: MAMS Control Procedure for Discovery & Capability Exchange

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:

o MAMS Version

MX System INFO includes the following information:

o 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:

o 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.
o 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)
o 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)
o MX Convergence Method Support List

   * Trailer-based MX Convergence
   * MPTCP Proxy
   * GRE Aggregation Proxy
o 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:

o 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.
o 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)
o 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)
   o MX Convergence Method Support List

     * Trailer-based MX Convergence
     * MPTCP Proxy
     * GRE Aggregation Proxy
   o 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.

   o NCM Id: Unique Identity of the NCM in the operator network.
   o 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

   o Unique Session Identifier: Same identifier as provided in MX
      Capability RSP.
   o 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.

6.5. **User Plane Configuration**

   Figure 5 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+---|
```
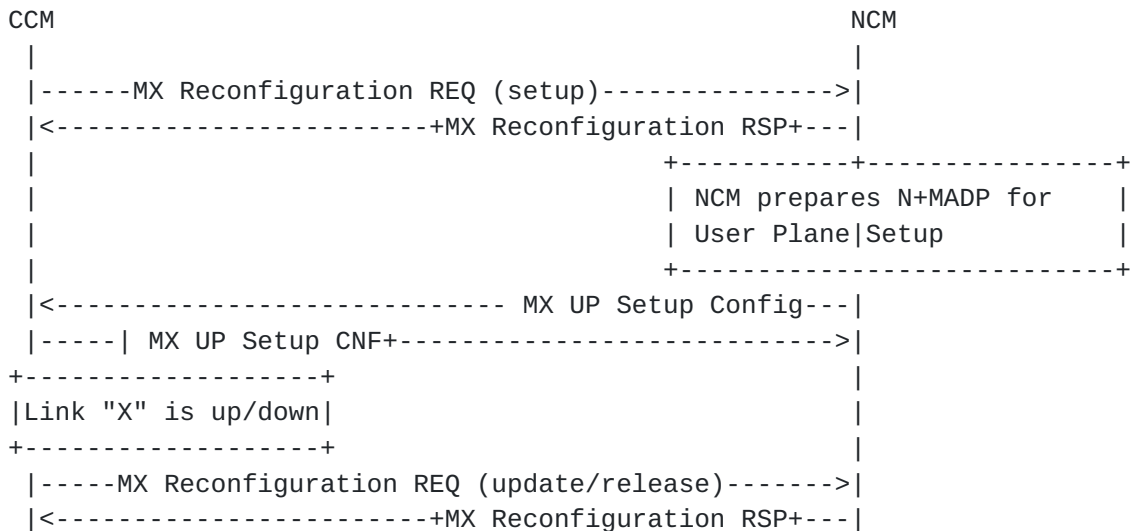

          Figure 5: MAMS Control Procedure for User Plane Configuration

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

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

   o IP address of the connection
   o SSID (if Connection Type = WiFi)
   o 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.

o 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 consists of the following parameters:

o 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. The MX Convergence Method is configured 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

6.6. 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. 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 alternatives to measure path quality
   estimations.

```
        CCM                                                      NCM
         |                                                        |
         |<-------------+ MX Path Estimation Configuration+--|
         |-----+ MX Path Estimation Results+---------------->|
         |                                                        |
```
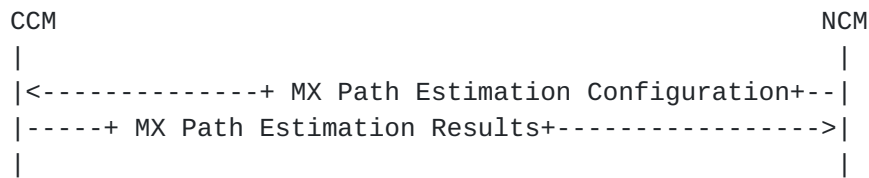
Figure 6: MAMS Control Plane Procedure for Path Quality Estimation

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

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

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

   * Lost Probes (%)
   * Probe Receiving Rate (packets per second)
o 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.

o 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.

   o 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.

6.7. MAMS Traffic Steering


```
  CCM                                                      NCM
   |                                                        |
   |                              +-----------------------------+
   |                              |Steer user traffic to Path "X"|
   |                              +-----------------------------+
   |<------------------MX Traffic Steering (TS) REQ--|
   |----- MX Traffic Steering (TS) RSP ------------->|
```
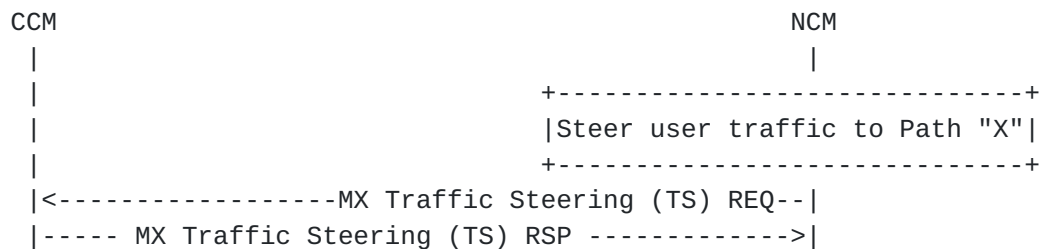
                Figure 7: MAMS Traffic Steering Procedure

   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:

   o Connection ID of the Anchor Connection
   o Connection ID List of Delivery Connections for DL traffic
   o 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
   o 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:

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

6.8. MAMS Network ID Indication

```
 CCM                                                    NCM
  |                                                      |
  |                            +--------------------------------+
  |                            |NCM determines preferred Networks|
  |                            +--------------------------------+
  |<-----------------MX SSID Indication------------|
```
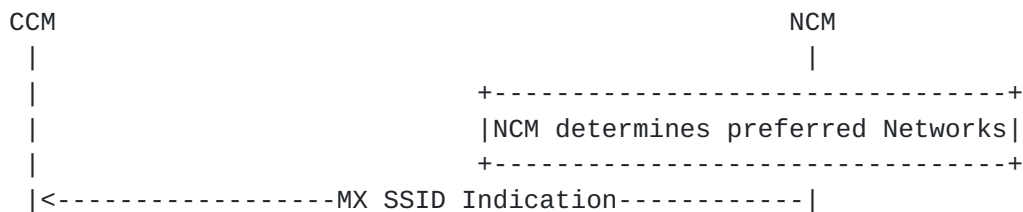
Figure 8: MAMS Network ID Indication Procedure

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.

6.9. MAMS Client Measurement Configuration and Reporting

```
     CCM                                                    NCM
      |                                                      |
      |<-----------------MX MEAS CONFIG----------------|
      |                                                      |
   +--------------------------------+                        |
   |Client Ready to send measurements|                       |
   +--------------------------------+                        |
      |                                                      |
      |----- MX MEAS REPORT---------------------------->|
```
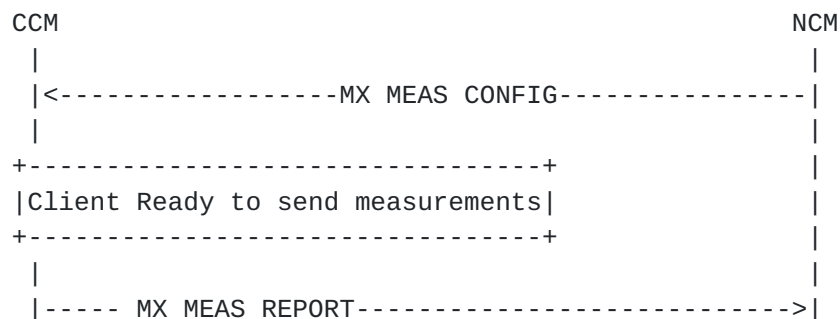
Figure 9: MAMS Client Measurement Configuration and Reporting
                          Procedure

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:

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

   o Unique Session Identifier: Session identifier provided to the
      client in MX Capability RSP.
   o 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.

6.10. MAMS Session Termination Procedure

```
          CCM                                    NCM
           |                                      |
           |+----MX Session Terminate--------->|
           |                                      |
           |                                      |
           |<---MX Session Terminate Ack-------|
           |                         +--------------+
           |                         Remove Resources
           |                         +--------------+
           |                                      |
```
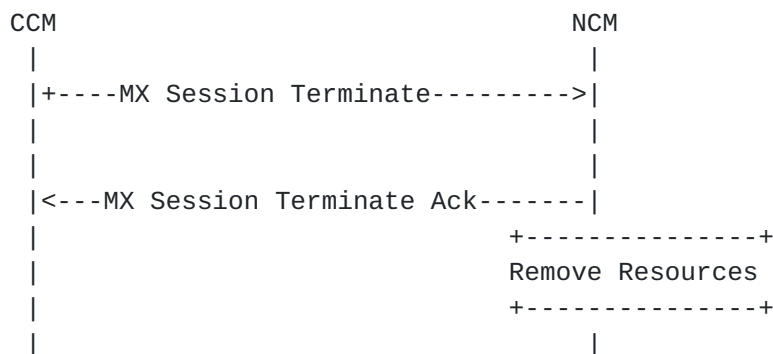
       Figure 10: MAMS Session Termination Procedure - Client Initiated

```
                    CCM                                  NCM
                     |                                    |
                     |<----------MX Session Terminate--------|
                     |                                    |
                     |                                    |
                     |                                    |
                     +--------MX Session Terminate Ack------->
                     |                                    |
                     |                                    |
           +-----------+-----------+                      |
           |    Remove Resources   |                      |
           +-----------+-----------+                      |
                     |                                    |
```
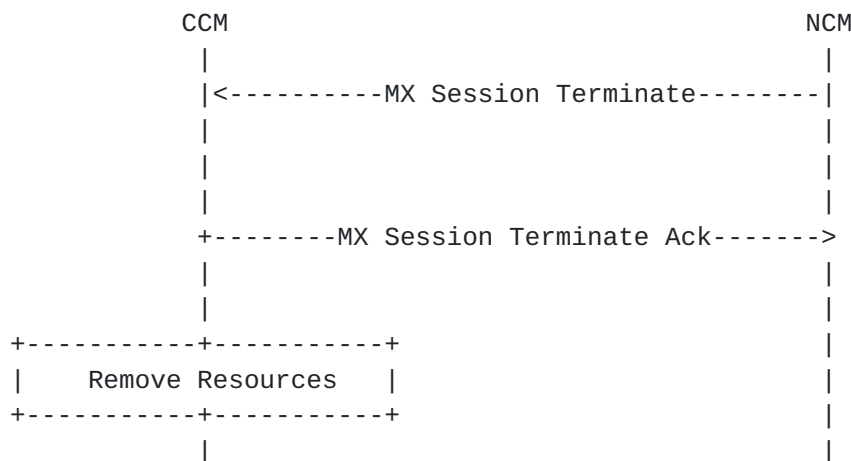
        Figure 11: MAMS Session Termination Procedure - Network Initiated

   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:

   o Normal Release
   o No Response from Peer
   o Internal Error

7. 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 8 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 12: 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       ||
 +-----------------------------------------------------------------------+
 |                                                                   |
 |                                                                   |
```
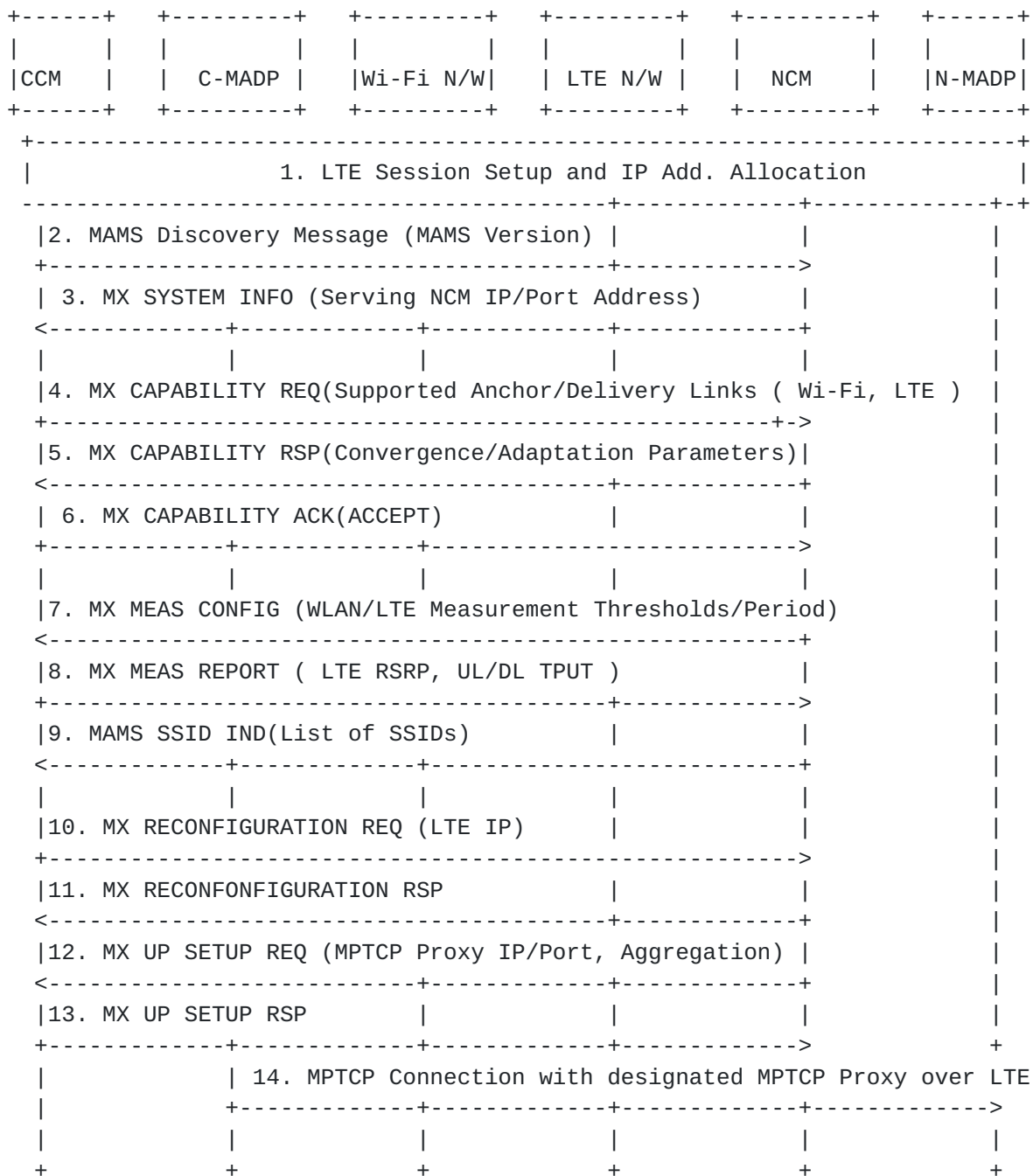
       Figure 13: MAMS-assisted MPTCP Proxy as User Plane - Add Wi-Fi leg

   Figure 9 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 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                              |
++-------------+------------+------------+------------+------------++
 |             |            |            |            |            |
 +             +            +            +            +            +
```
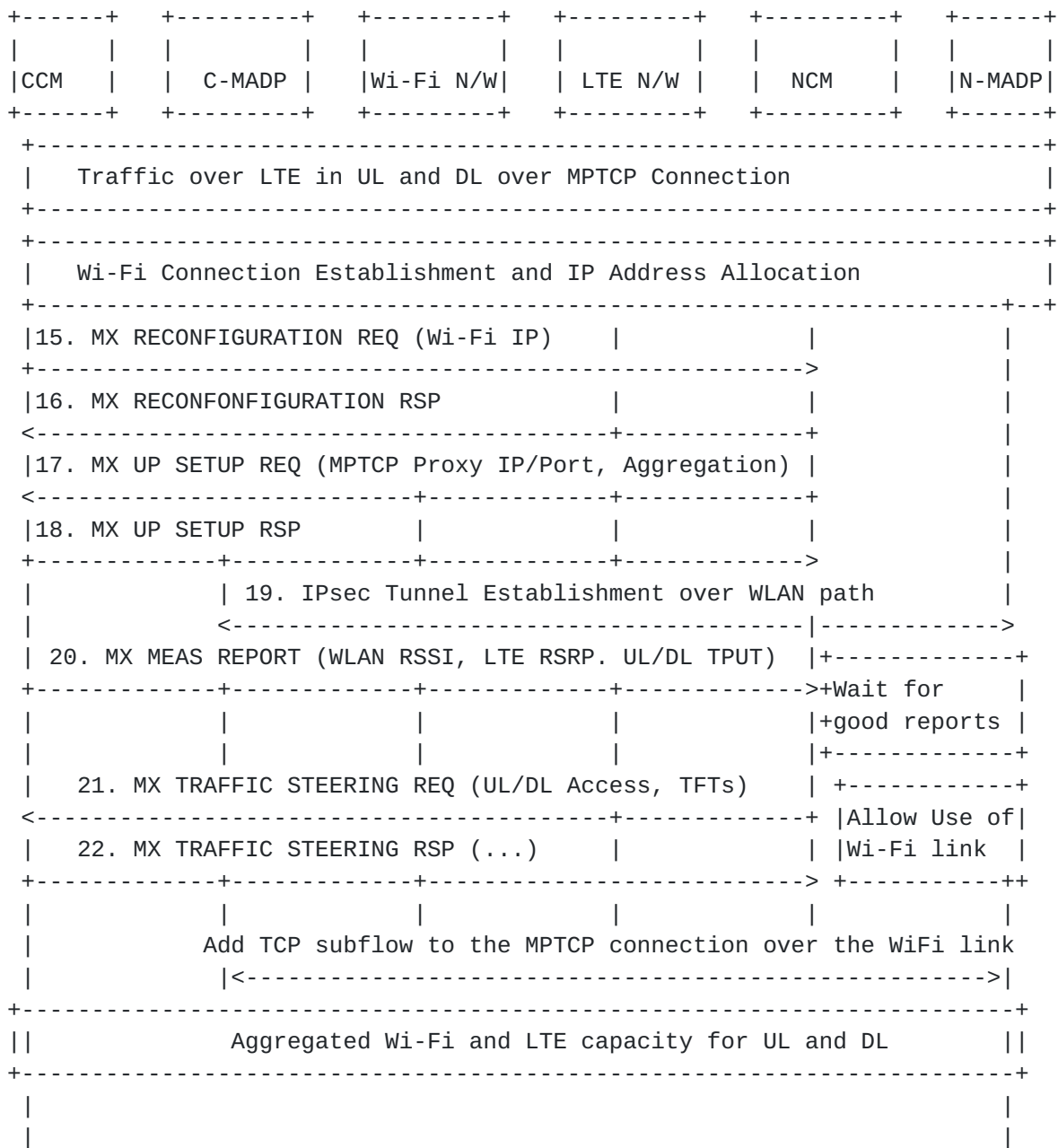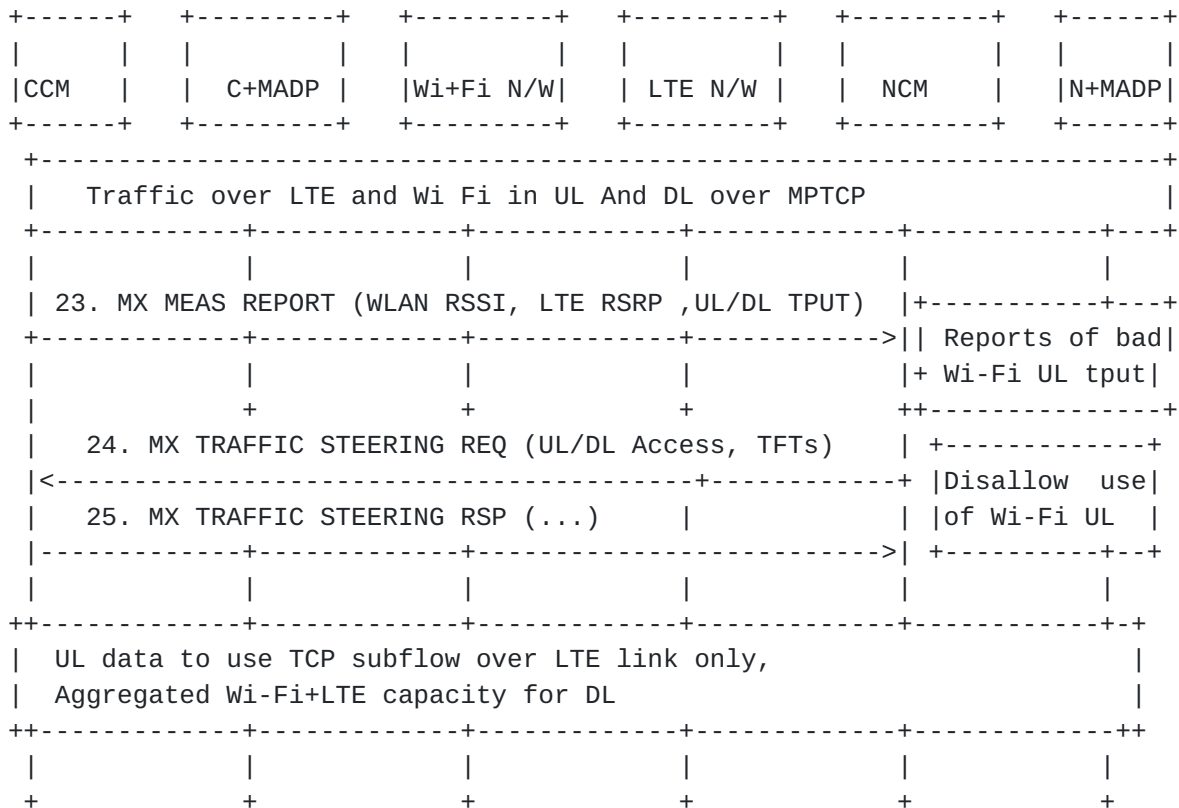
Figure 14: MAMS-assisted MPTCP Proxy as User Plane - Wi-Fi UL
degrades

Figure 10 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)|           | |
 +-------------------------------------------------------------------------+
  |            |            |            |            |            |
  +            +            +            +            +            +
```
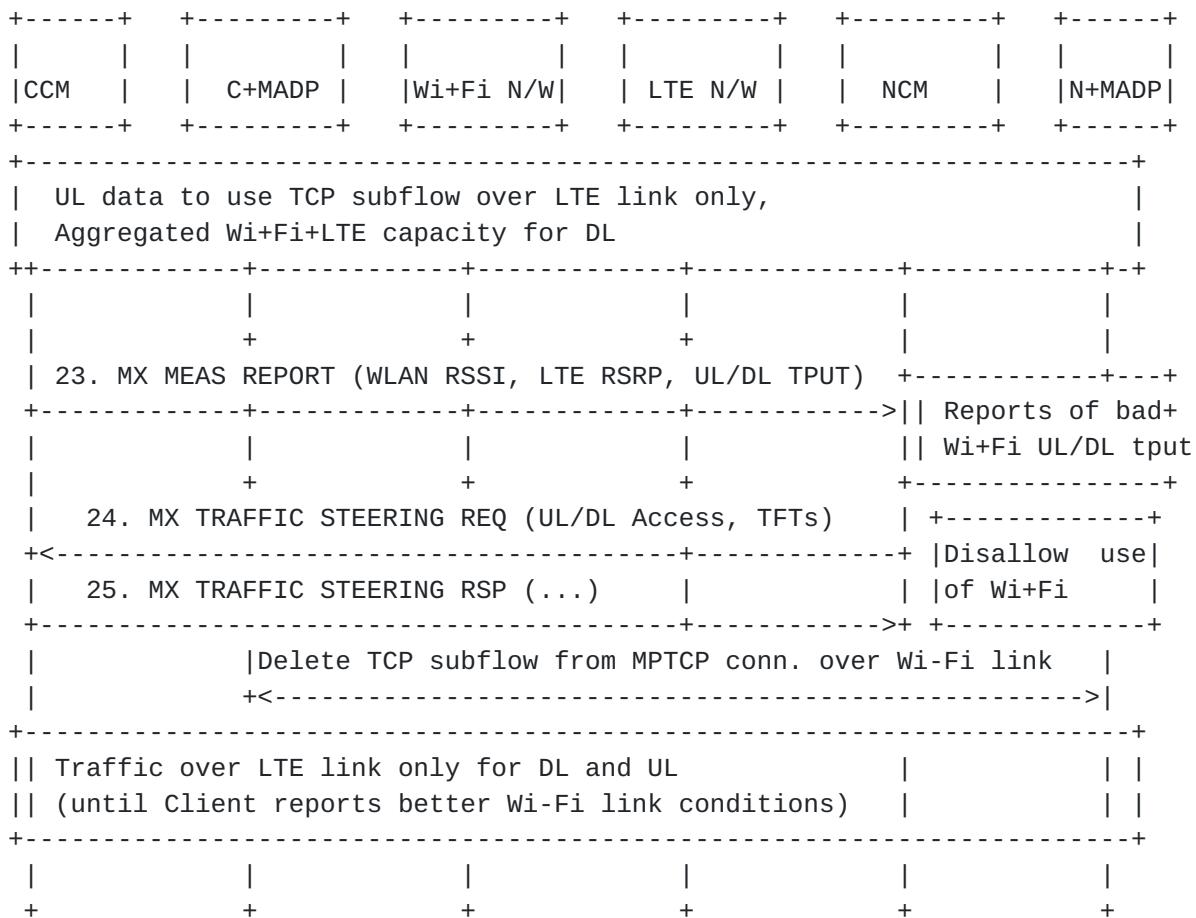
              Figure 15: MAMS-assisted MPTCP Proxy as User Plane - Part 4

   Figure 11 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.

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

   Figure Y shows the call flow describing MAMS control procedures
   applied for dynamic optimal path selection in a scenario convergence
   and Adaptation layer protocols are not ommitted. 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)     |+-------------+
```
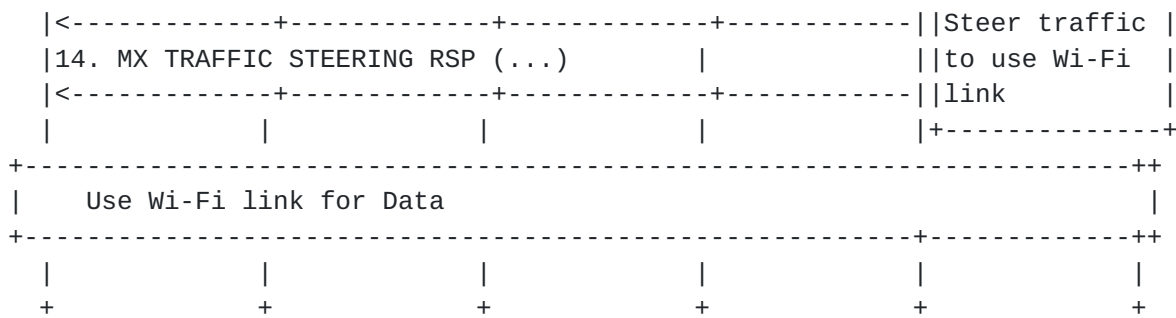
```
 |<-------------+------------+------------+-----------||Steer traffic |
 |14. MX TRAFFIC STEERING RSP (...)       |          ||to use Wi-Fi  |
 |<-------------+------------+------------+-----------||link          |
 |             |            |            |           |+--------------+
+----------------------------------------------------------------------++
|    Use Wi-Fi link for Data                                           |
+-------------------------------------------------------+------------++
 |             |            |            |           |            |
 +             +            +            +           +            +
```

Figure 16: MAMS-assisted MPTCP Proxy as User Plane - Part 3

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

MAMS u-plane protocols support multiple combinations and instances of user plane protocols to be used in 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 pathneeds 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.

10. Security Considerations

10.1. MAMS Control plane security

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

For deployment scenarios where the security of the network path cannot be assumed, NCM and CCM implementations MUST support the "https" URI scheme [RFC2818] 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, HTTP
Digest Authentication MUST be supported. TLS Client Authentication
is the preferred mechanism if it is available.

10.2. 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.

11. Contributing Authors

The editors gratefully acknowledge the following additional
contributors in alphabetical order: A Krishna Pramod/Nokia, Hannu
Flinck/Nokia, Hema Pentakota/Nokia, Nurit Sprecher/Nokia

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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 9).

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

Figure 17: UDP-based MAMS Control plane Protocol Stack

Authors' Addresses

   Satish Kanugovi
   Nokia

   Email: satish.k@nokia.com

   Subramanian Vasudevan
   Nokia

   Email: vasu.vasudevan@nokia.com

   Jing Zhu
   Intel

   Email: jing.z.zhu@intel.com

   Florin Baboescu
   Broadcom

   Email: florin.baboescu@broadcom.com

   Shuping Peng
   Huawei

   Email: pengshuping@huawei.com

    SungHoon Seo
    Korea Telecom

    Email: sh.seo@kt.com

    Julius Mueller
    AT&T

    Email: jm169k@att.com