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ACCESS FLOW BASED MULTI-RADIO ACCESS CONNECTIVITY

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ABSTRACT

This paper describes the steps and the procedures involved to establish access flows for a user data session in multi-radio access networks. The description is evolved around the overall connectivity abstraction model defined in the Ambient Networks (AN) project. This model uses access flows as its fundamental objects which are the result of two main access selection procedures: network attachment and flow setup. All access abstractions and procedures have been developed to handle the requirements of efficient multi-access resource management through all stages of access connectivity. The paper discusses some design trade-off for the establishment of access flows concerning setup delays and resource efficiency.

I. INTRODUCTION

A multi-radio access system consists of control functionality to jointly manage multiple Radio Access (RA) technologies at the level of user data sessions. The rationale for designing and building such a system is mainly two-fold: 1) there already exists a large set of different RA technologies with an enormous amount of devices in use, some of them already equipped with multiple RA interfaces; and 2) different RA technologies are typically designed for different usage scenarios (in terms of coverage, capacity, traffic types, etc) and may handle different services at varying degrees of resource-efficiency. An integrated multi-access system may lower deployment cost for operators and improve overall resource usage efficiency. Both advantages may ultimately benefit end users greatly. Multi-access control functionalities fill the gap between end users manually choosing RA technology on a per session basis, which is not really an operation of interest for them, and operators doing the same thing manually, which would be an enormously costly and unrealistic activity.

The Ambient Networks (AN) project [1] investigates and develops a unified set of networking control technologies to simplify, diversify, and improve network control and network management [3] One design principle is a view on all networking as connectivity between networks as opposed to distinguishing between nodes and networks and having separate schemes for node-to-network connectivity. The functionalities are based on a general connectivity abstraction model [3].

The AN control functionalities includes a multi-radio access component, which has features for resource management across different RA technologies. It is structured into a Multi-Radio Resource Management (MRRM) entity that is supported by a Generic Link Layer (GLL) entity. The GLL interfaces with the specific RA technology at a level such that it has access to typical (radio) resource and link layer related metrics. It abstracts resource and performance values as well as control primitives into a generic AN format [5]. It may also contain complementing functionalities such as data forwarding between GLL entities during an inter-RA handover of an ongoing user data session. MRRM is the main control logic that (momentarily) decides on which RA to use for each user data session based on abstracted information reported by GLL.

In the paper the access flow-based AN connectivity model, its network attachment and flow setup procedures as well as the MRRM data structures and functions involved are thoroughly illustrated and described along with major design tradeoffs.

II. ACCESS FLOW CONNECTIVITY: BASIC CONCEPTS

In the AN connectivity abstraction model an AN can be divided in an access consumer entity called User Ambient Network (U-AN), e.g., a single AN terminal, and an access provider referred to as Access Ambient Network (A-AN) e.g., a network provider. A-AN owns and provides access resources (ARs) to U-ANs on which access links can be established. In wireless networks an access resource corresponds to the radio resources of a radio cell. These radio resources are allocated to active access links in a TDMA, FDMA, CDMA, or SDMA fashion or combinations thereof. An access link is the connectivity provided by an access resource to an access flow (AF); the access flow as such can span further than the access link, e.g. up to an anchor node in the network. In general, a flow is the unidirectional transfer of data between two flow endpoints, a source and a destination, each having a locator that uniquely identifies it. For example, such a locator determining an access flow is the GTP Tunnel Endpoint Identifier (TEID). An AF is the connectivity that allows communication between the U-AN and the A-AN, as well as, between U-AN and other peers beyond A-AN. At least one access flow is required for a U-AN to be reachable from the outside. An Access Flow is managed by a set of cooperating MRRM entities and can be based on different communication technologies and thus be defined by different types of locators, e.g. TEIDs or Mobile IP care-of-addresses [4].

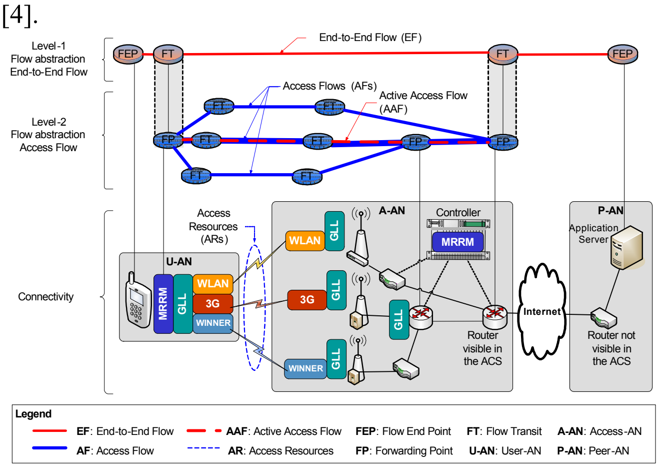

Figure 1. Generic access resource abstraction

Fig. 1 illustrates the abstractions used by MRRM. The flow abstraction as defined in the AN System Description [3] allows for hierarchical flows (level-1, level-2, …) and flows that are connected with each other via Flow Transit (FT) points. The scope of MRRM operation is clearly limited to those parts of a flow that concern access links and cannot control the parts that are outside of the access domain. Hence, MRRM will typically only monitor and control a subset of the end-to-end structure of flows used to transport bearers (which transport the information end-to-end). There may, for example, be a single level-1 flow end-to-end with MRRM controlling a subset defined by a level-2 flow, or there may be a sequence of flows end-to-end connected via a number of FTs with MRRM controlling one (or more) of them. From MRRM perspective it is only important to distinguish between the "access" parts and the "other" parts. Hence, the following two terms are used:

– Regardless of the configuration, the flow part that is controlled by MRRM is called Access Flow (AF).
– The end-to-end flow structure including the other parts beyond the access flow is called End-to-End Flow (EF).

Fig. 1 shows an example with access resources, access flows, and end-to-end flows. The End-to-End Flow (EF) is the data transfer of an active data session going through the access domain. The requirements (e.g. QoS) desired for the session are associated to it. The MRRM task is to provide the best access flows to transport the end-to-end flow. The end-to-end flow comes "from the outside" into the domain managed by MRRM and it is the one on which MRRM operates, i.e. it provides the best connectivity for it. Compared to EF, an AF does not require that data transfer is currently ongoing. It is rather the pre-requisite for data to be transmitted. An example of establishing an access flow is when a local locator (for example, address) is received and registered (bound) in a forwarding point (for example, home agent, mobility anchor point). Another example is (Hierarchical) Mobile IP registration of a care-of-address in a home agent / mobility anchor point [4]. An established access flow with data transfer ongoing is referred as an Active Access Flow (AAF).

III. MRRM FUNCTIONS AND SETS

Access resources, access links and access flows are all abstractions used for the two main access selection procedures: network attachment and flow (data transfer) setup. In order to establish an access link for an AF, it is required that the identifier for that flow is mapped on the access resource so that (parts of) the access resources can be allocated to the flow. The establishment of an access link is denoted as link attachment, it happens during network attachment, or when the U-AN wants to "speak" with the A-AN and establish a GLL signalling connection (network attachment already done). The aim of network attachment is to register to the network and ensure that the U-AN is reachable. The network attachment process comprises an AAA process which authorizes the establishment of an access link and the access to the A-AN. It further can comprise a

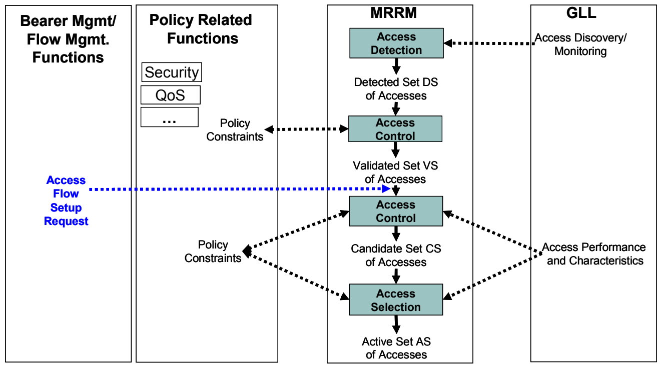

Figure 2. Managing of different sets in the MRRM

reservation of a portion of the access resources to the access link, this AR would be used for signalling and a possible user data request. An access resource belongs to the resource owner. As part of the network attachment an agreement between the A-AN and the U-AN is established, which permits the usage of access resources for the access link. Network attachment is usually preceded by the access discovery procedure, which is performed by means access scanning and advertisement functions, provided by GLL, which detects a number of AR and reports them to MRRM, which then validates and determines the best AR(s) to perform link attachment. The network attachment procedure at U-AN sets-up a default "access flow" to the A-AN (which owns the AR) with locator identifiers registered. Via this access flow signaling between U-AN and A-AN can be transmitted so that the U-AN can be reached and access flows for data transfers (specified in terms of bearers) can be initiated according to certain QoS requirements. The establishment of access flows for data transfer requires additional access control mechanisms that determine which ARs are suitable candidates to support the requested access flows. The candidates undergo admission control which may result in more than one RA being used. When multiple RAs are used in parallel, data flows can be transmitted via multiple access flows whose resources are then pooled. Typically, admission control results in one single RA.

Radio resources are allocated to active access links by means of MRRM access selection. An important part of MRRM access selection is the management of the access resources and their state. Therefore the concept of MRRM sets has been defined. The MRRM sets correspond to access resource states maintained by the MRRM functions. As shown in Fig. 2, there are four different MRRM sets:

– Detected Set (DS): The elements of this set are the access resources detected by the U-AN, e.g. detected potential access links. It can be created from the information received by GLL from scanning (information from broadcast channel/beacon) or from an advertisement. The elements are not specific to any request for a flow. There is one DS per U-AN. The DS can contain ARs from different ANs.
– Validated Set (VS): The elements of this set are a subset of the access resources in the DS that are validated by policy functions in the U-AN. There is one VS per U-AN.

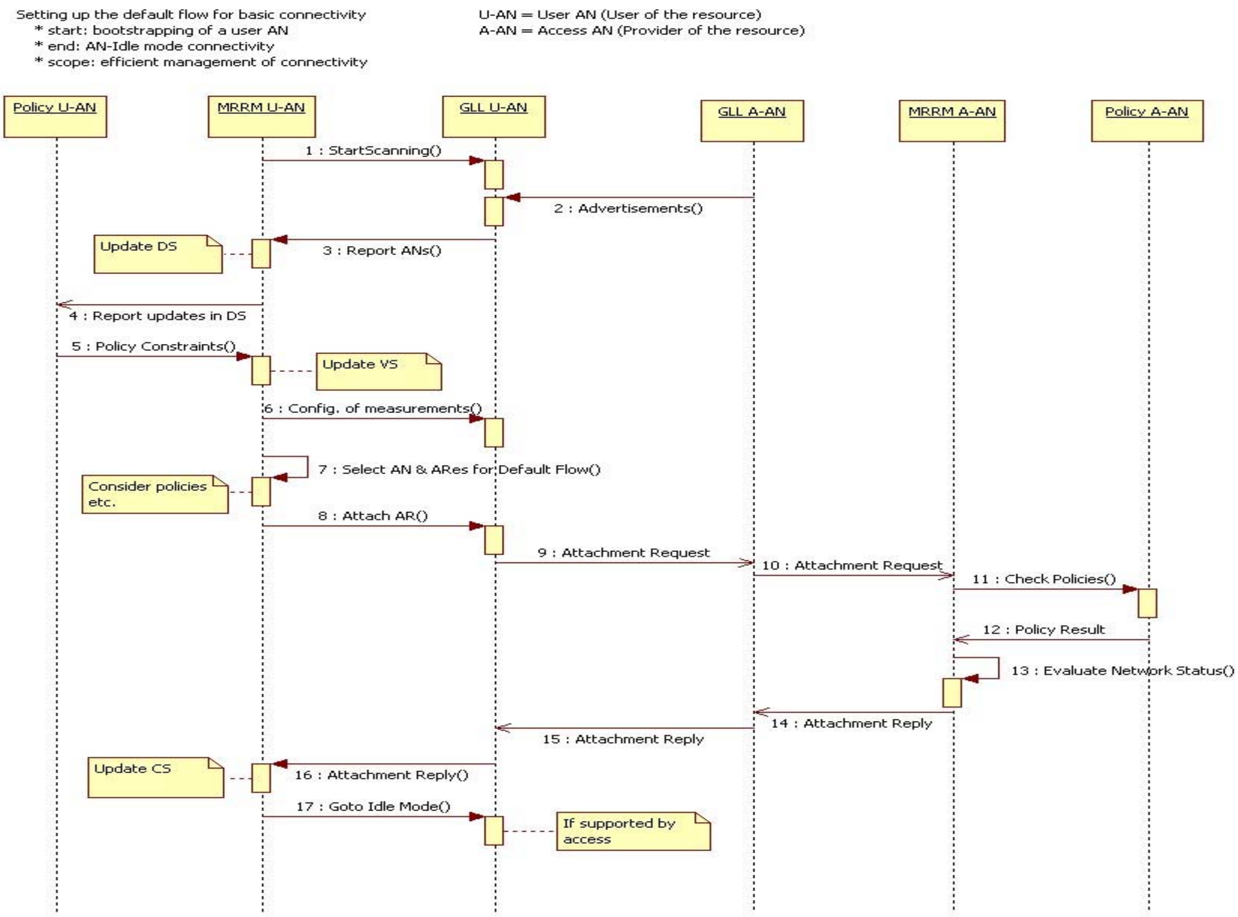

Figure 3. MRRM sets during network attachment and "make reachable" procedures

- Candidate Set (CS): The elements of this set are a subset of the access resources in the VS that are suitable to provide adequate access resources for the end-to-end flow. Suitability means that the policies for the usage of these resources are acceptable, that their capabilities can meet the requirements of the end-to-end flow, and that sufficient resources are available. There is one CS for every end-to-end flow. Obviously, the CS can only contain elements that are also part of the VS. These elements could be re-configured later as necessary.
- Active Set (AS): The elements of this set are a subset of the access resources in the CS that have been selected by the MRRM through dynamic access selection to handle the end-to-end flow. There is one AS per end-to-end flow. The access flow, which is the access part of the end-to-end flow, will be mapped on the elements of this AS.

IV. NETWORK ATTACHMENT

Among the first things a U-AN does after being powered on are access discovery and possibly network attachment (see Fig. 3). The goal of this procedure is to register the terminal to the network and make the U-AN reachable for other ANs.

During the access discovery and network attachment, the MRRM activates GLL for access scanning. GLL detects a number of Access Resources (AR), if available, and reports them to MRRM. Additional AN information may be included in broadcast advertisements.

After receiving the report, MRRM builds the Detected Set with the reported ARs and sends it (or the new elements) to policy functions for validation. Policy validation is based on locally stored policies and data received from broadcast advertisements: MRRM receives a policy list (weights) and builds the Validated Set. If ARs have been banned, MRRM signals to GLL to stop monitoring those ARs (or all ARs belonging to that AN) or otherwise tunes the measurement intervals of different ARs based on the calculated priorities.

MRRM (U-AN) determines the best suitable A-AN and the best AR(s) for the default access flow. If the VS contains more than one A-AN, the user may choose one, after which the MRRM selects the AR of the selected A-AN. This AR will then be used to perform network attachment.

MRRM then initiates the network attachment. From a connectivity perspective this is done by GLL, however, in close interaction with other functions, e.g. underlying network specific attachment procedures. The AN attachment procedure sets up an access flow to the A-AN which owns the AR. The network attachment involves MRRM, policy (e.g. security and compensation) and mobility related functions on the A-AN side.

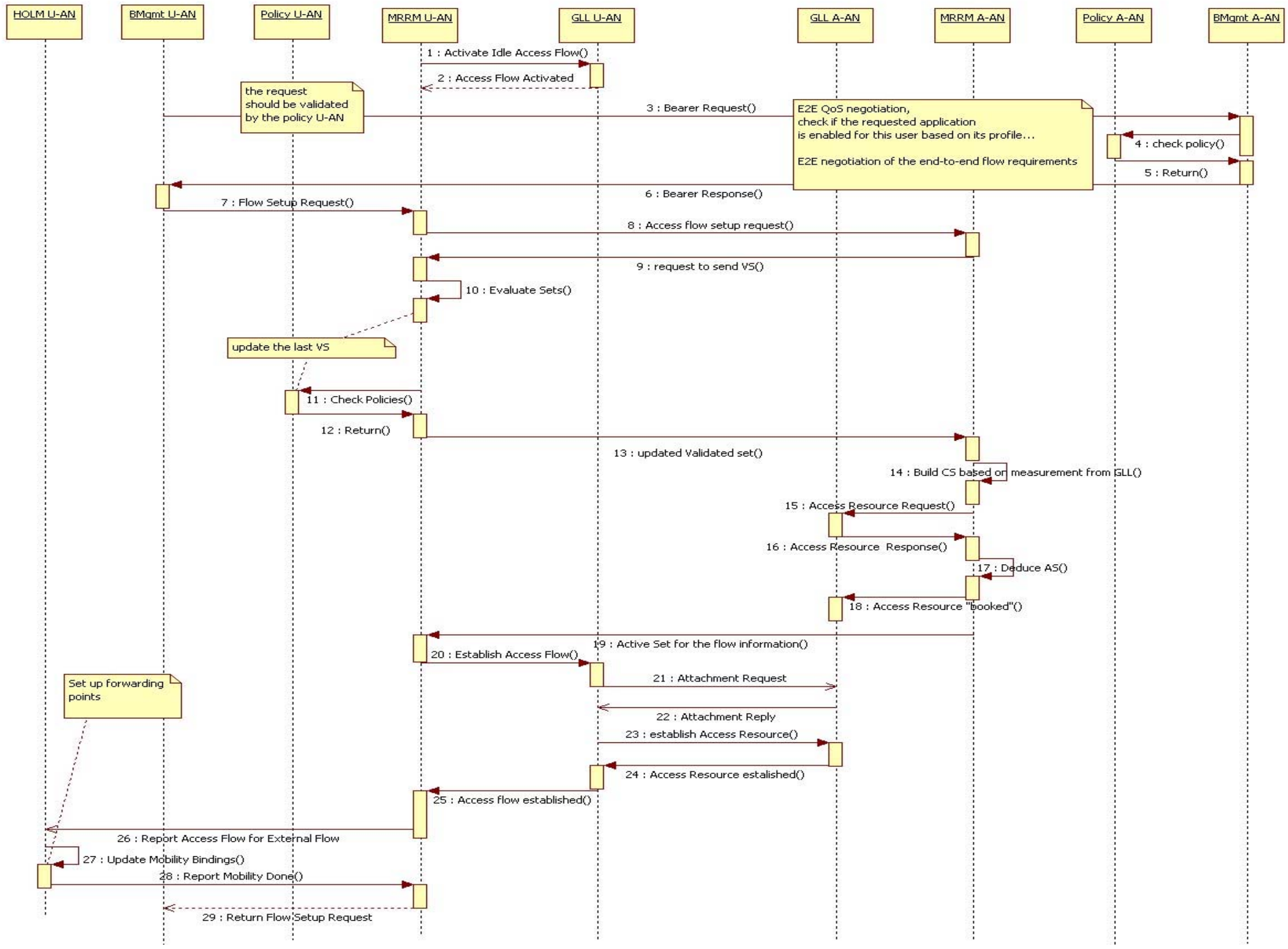

Figure 4. Sequence diagram for establishment of an access flow for a data session

As a result of AN attachment new information about the A-AN/AR may become available. This can be information on MRRM level (e.g. the AR is overloaded), but also general A-AN related information, which is checked against the policy constraints again. As a result, the A-AN/AR may be banned/downgraded in the access preference list. As a consequence, network attachment with other ARs in the VS may be initiated, possibly preceded by a new scanning phase for ARs to be added to the VS first.

After the default access flow has been established, the access technology can change to idle mode if that is supported. This default access flow enables the U-AN to be reachable for data bearers initiated externally. Access flow establishment signaling can now be transmitted between the U-AN and A-AN. MRRM typically keeps the DS/VS set size small in AN-Idle mode to reduce battery usage for access scanning. MRRM may also keep less interesting ARs in the DS/VS, but reconfigure these with longer measurement intervals.

V. Flow Setup

Fig. 4 shows the steps that need to be undertaken when an application within a U-AN needs to establish a connection towards an A-AN. This is mapped on the bearer concept; the appropriate FE (Bearer Management) uses the default access flow (the one which was established during Network Attachment) to transport the corresponding signalling to the peer FE at the A-AN, which checks whether the end-to-end characteristics can be handled by the network; after positive acknowledgment, the Flow Management FE at the user side maps the service characteristics requirements onto end-to-end flow requirements, sending the corresponding request to the MRRM. The request is transmitted to the MRRM (Access Flow Request) at the network side, which requests the VS from the user. Upon its reception, and following a stepwise approach, the MRRM in the network side builds the Candidate Set – based on the measurements provided by the GLL – and then determines the Active Set, after performing the corresponding admission control procedure.

The AS is communicated back to the MRRM at the user side, which, via GLL completes the attachment. Last, this is communicated to the Handover and Locator Management (HOLM) FE, which updates the corresponding mobility bindings and sets up the consequent forwarding points. As can be seen, in this diagram, it is assumed that the U-AN builds the DS and VS and the A-AN builds the CS and AS (network centric scenario). However, we could also imagine a user-centric scenario, where the U-AN builds all sets based on information provided by the A-AN.

VI. Design Tradeoffs

The MRRM sets generally contain ARs required for the setup and maintenance of access links. They include the signalling part of ARs that support the changes in the MRRM sets (setup and maintenance of attachment and connectivity). For example, during the link attachment process, certain signalling is required over the access link and in the backhaul link for e.g. AAA procedures. Usually, the signalling part of ARs is only a small fraction. Therefore, we may neglect the signalling part of ARs when we consider the tradeoffs. However, in the design tradeoffs, we must consider the costs incurred by the different delays, which are usually not negligible. For example, the setup/maintenance delay could have high importance for a given access. We must thus consider it as part of the design tradeoffs.

At the stage of attachment, we may have the two following cases (Case A and B). In Case A, resource reservation (for a possible future data request) is part of the link attachment. This prohibits the usage of the resources by other access links whenever the attachment exits. Also local resources are required for maintaining a link state such as security keys. When the access link is established even a passive user has to closely observe traffic on the access resource to determine if it is part of the own access link. Thus, processing and battery resources are also consumed even when the U-AN is idle. We can see these obvious drawbacks for reserving the resources at the time of attachment. However, one advantage from this case can be that there is very small delay for the setup of the access flow and the actual data communication over the access link, given that some resources are needed to be reserved for the access flow. Therefore, this case could be needed when the very small delay is the most important factor to consider, which may mean the attachment and the allocation of ARs for MRRM CS set happen sequentially at the same time. In Case B, there is no need of reserving any resources for a possible coming data access flow setup, which may mean the attachment and the allocation of ARs for MRRM CS set are not done at the same time. In this case, only little ARs are consumed for the attachment. Though, this case could usually present a bigger delay for the setup of an access flow, when comparing with Case A.

Concerning the update of the MRRM CS set, there are some interesting cases (Case C and D) again. In Case C, adding an AR into the MRRM CS may actually reserve the resources needed for the access flow to support the active user data communication at the same time, with the cost of increased signalling and higher resource consumption (e.g. in terms of terminal battery and the communication resources). This means that the CS update happens sequentially with the reservation of resources for the updated element in CS to have enough resources as if it would have been an element in the AS already. We call this AS readiness, while it may not be selected into AS at the end. The drawback of Case C is certainly that the resources for AS readiness at the stage of CS update may waste parts of the access resources. This is because some access flows in the CS may not be utilized for the actual data communication. The advantage may be the smaller delay for activating (i.e., adding an access flow into the AS set) an access flow to support an actual data communication. In Case D, adding an access flow into the MRRM CS does not reserve those resources enough for the access flow to support the active user data communication right away. As a drawback, this could usually mean a bigger delay to activate the access flow for an actual data communication. As another drawback, there is a risk that the access flow activation fails later, e.g. due to a shortage of access resources or for policy reasons. However, Case D can certainly prevent the drawback of Case C. In addition, if an access resource is unreliable or insufficient for the access selection decision, the MRRM in Case D may decide to establish an access flow (AF) before admitting AR into the MRRM CS. For example, for a small access flow setup delay, MRRM may decide to establish AFs before adding AR to the CS, if dynamic access selection algorithms are used or system parameters influencing access selection change quickly.

The described design trade-off can be adapted to the characteristics of the access technology, e.g. the connection setup delay, and the overhead associated with reserved resources.

VII. Summary

In this paper, we presented the Access flow (AF) which is the highest abstracted level of the access part of the AN. An AF is defined by two endpoints (locators) and gives the requirements on the resources that shall be provided to it to support signalling or user data. The MRRM is responsible for allocating access resources (AR) to the AF. An AF is requested during attachment and user data setup phases that we detailed. We have shown that there are many possible combinations of steps for establishing an AF, each on these combinations has its advantages and drawbacks, and can be applied depending on the characteristics of the considered access technology. For example, if the establishment delay is important, resources shall be reserved early in these steps but the drawback is a resource waste.

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