Multilink Wireless Access Network Architecture and Functions

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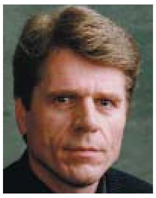

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Telecommunication network operators, service providers, and end users are all expecting higher capacities, increased reach and improved service experience, for existing and new services at an acceptable cost. Multiple links for simultaneous utilisation by a single user is an attractive way forward. It differs from other approaches in boosting capacity and coverage as it may use completely different and already existing types of networks such as mobile, broadband and broadcast networks at the same time. This paper first presents the benefits from such an approach, primarily the ability to make better use of the available networks on a dynamic basis, to increase the available aggregate capacity and improve utilization, extend the geographical coverage, or manage resources on a larger scale for higher efficiency. The goal is to translate this into better services for the customer and to lower the cost compared to the single technology approach. In order to allow for multilink operations, a new architectural framework has been considered, including splitting and merging functionalities placed in multilink gateways operating at different locations depending on service context as well as user and service provider objectives. Multilink gateways can be an add-on to existing terminals, base stations, access gateways or core networks enabling smooth transition to new capabilities and services. Initial business opportunities have been described and new actors and roles identified. This work has been done as part of the international CELTIC project MARCH.

1 Introduction

Telecommunication services have developed a lot during the last decades. The users expect all types of services at sufficient quality, irrespective of the geographical location. Amongst network operators and service providers the trend is network and service convergence, using the Internet protocol (IP) for transferring the end-to-end data packets. This trend equally applies to broadband access, mobile telecommunication, and broadcasting. These networks are per date fairly easily distinguished from each other. The broadband access network offers always-on high-speed two-way telecommunication links, the mobile telecommunication is recognized mainly by the mobility feature offering services irrespective of location, and broadcast is unidirectional mass distribution of media content. However, this former clear distinction is blurring.

In the past digital networks have mainly been characterised in terms of capacity and coverage. While these two key parameters remain important, other dynamic features will be added. For instance, the ability to offer a service according to customer preferences is of paramount importance also under highly varying network conditions (availability and capabilities of networks). The network's robustness, ie. keeping users connected for the wanted services can be very challenging if the network is overloaded, has insufficient capacity, or does not reach the location where it is needed.

An attractive way to overcome a single network's shortcomings (eg. coverage, capacity, and robustness) is to consider all available networks as a whole. Such multilink approach allows simultaneous use of more than one physical access network for providing a service to a user, as illustrated in Figure 1. One example is to use a wireless local area network (WLAN) combined with a cellular mobile network to increase the available bandwidth, thereby allowing faster Internet access or access to better quality video streaming services.

The challenge is to use and coordinate several physical links and networks simultaneously, not only to switch from one link to another. For full mobility support, intra-network handover (eg. from one cell to another in a mobile network) as well as inter-network handover (eg. from a mobile network to WLAN) must be appropriately supported; in general handover from *n* to *m* networks can occur at any time during a session. For nomadic use, the handover requirements during a session are less stringent. In any case, the simultaneous use of several networks will be transparent to the user; he will not know which networks are in use at every instant. Annoying service interrupts during handover must also be avoided.

A successful multilink network approach is a win-win situation where the users are served with a stronger, more robust and more available (heterogeneous) network, and the operators can keep the customers connected for longer periods and optimise the degree of networks utilisation. The network operators get better

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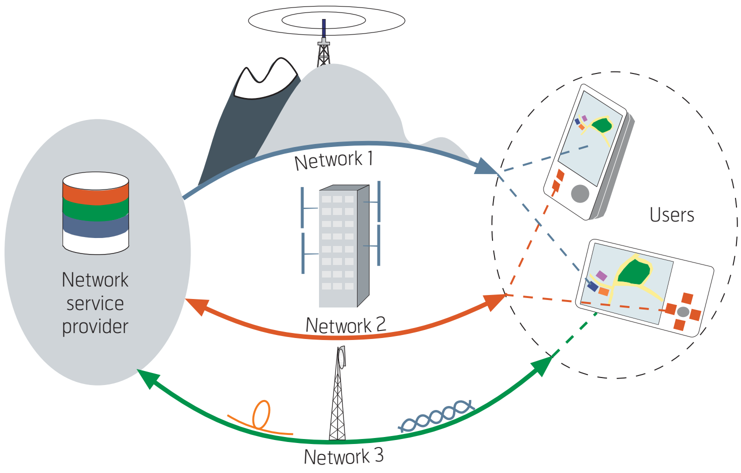

Figure 1 Multilink network technology taking advantage of several available access networks simultaneously

return from their investments. The service providers maintain connections with the users, and the cost of using the network may be reduced. Also new types of services can be offered, for example broadcast content adapted to personal interests and enhanced with interactive elements on an individual basis.

The CELTIC project Multilink architecture for multi-play service (MARCH) [1] researches the possibilities of such multilink services and network solutions. This article describes the most promising multilink technological solutions under development and how they can be deployed using existing networks. It is organised in six sections including Introduction and Conclusion. Section 2 discusses important broadband media trends. Section 3 draws attention to the main benefits of multilink technologies. Section 4 presents the multilink architectural framework under development by MARCH, while Section 5 discusses business aspects.

2 Trends Towards Broadband Media Services in All Networks

The Internet in the form of the world wide web, and the digital mobile communications since its launch in 1993, have played and continue to play a very important role in telecommunication networks. They are part of almost everyone's daily life. Also the more recently launched digital terrestrial broadcasting service adds to the picture of providing all types of telecommunication and broadcasting services, ie. the convergence of services and networks accessed by a single multi-mode terminal. For instance, the handset for mobile communications still serves for telephone calls, but more so for sending messages, connecting to the Internet, taking photos and videos, and viewing and listening to online entertainment.

The capacity in terms of bit/s is steadily increasing in the access networks, but at a very different cost depending on location and at very varying possible income. Building a high capacity broadband network everywhere represents a significant cost and the potential return on the investment has to be carefully calculated.

2.1 Mobile Networks

The fourth generation (4G) mobile networks is currently being specified and roll-out is expected to start in a couple of years. The ambition for sector capacity to the end user is very high, about 100 Mbit/s in full mobility and 1 Gbit/s access for fixed users [2].

From the service side the mobile handset is already a true multi-media terminal serving users with telecommunication and broadcasting services. The terminal can connect to several different physical networks, but currently switching between them is not automatic.

The 4G mobile networks will provide broadband mobile services, broadband fixed services, and broadcast type of services. The mobile network operator will continue to do the mobile part better, but will also wish to serve fixed and broadcast customers. But the capacity issue is challenging.

2.2 Fixed Broadband Networks

Broadband fixed access networks have steadily been offering higher and higher capacities with a doubling rate well within two years [3]. In many countries triple-play services including telephony, data, and television are provided. As the majority of these networks connect to a wireless access point at the customer's premises, the services are accessed from a nomadic user. Some will claim that the fixed technology can provide a kind of mobile access through a very fast switch time from one access point to another.

It is conceivable that the broadband fixed access network provides all other networks' services. The operator continues to offer fixed broadband including broadcast and mobile services. But the mobility issue is challenging.

2.3 Broadcast Networks

Most satellite and cable broadcast networks have been digital for many years. More recently, the digital switchover for terrestrial broadcast networks started, involving the large broadcast bandwidths in the VHF and UHF frequency bands. In Europe all countries will have switched to digital terrestrial networks within a few years [4]. The traditional television service is one-way; there is no return link. Still, the idea of a return link facilitating service types like video-

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on-demand and interactive TV has been studied for many years, and some solutions exist for both in-band and out-of-band technologies.

Broadcast operators are able to provide a large amount of channels at a very low cost for the end user. It is also possible to provide other content such as Internet and personalised services, however the cost increases and a return link is needed.

With proper two-way solutions the wireless broadcast operator will continue to offer low-cost broadcast services, but also broadband and mobile services. But the return link issue is challenging.

2.4 The Composite View

All three technologies; mobile, broadband, and broadcast can continue to improve what each technology already is doing today. In addition they can offer solutions competing with the other technologies' services.

By combining the networks into one logical multilink resource operators can benefit from each technology's strength. It is possible to provide improved broadband, mobile, and broadcast services with less investment than needed if one single network is built to do so.

However, the ecosystem with several different operators and various networks represents a more challenging environment where it might be cumbersome to identify viable business models.

2.5 International Standardisation Initiative Limitations

Two recently issued IEEE standards, 802.21 [5] and SCC41 1900.4 [6], address important interoperability and radio resource management aspects, respectively, of heterogeneous networks.

IEEE 802.21 deals with horizontal handover from one network to another and the procedures associated with it. Some of the techniques embedded in horizontal handover will be common to the management of multilink. However, the primary focus of multilink is not handover but rather the concurrent and coordinated usage of two or more links.

SCC41[1)] addresses cognitive radio techniques that make dynamic use of the radio environment to recognize the opportunities of unused spectrum. However, it is important to point out some differences between multilink and cognitive radio. In cognitive radio, a primary user (most often licensed) temporarily not using the network resources makes the frequency resource available for a secondary user (most often not a regular customer) whose terminal or related base station polls for available frequency slots in the area. The allocation is basically the frequency band while the radio access networks of the respective terminals are unchanged, except for the operating band. In contrast, multilink merely uses the available radio access networks as they are and aggregates the capacity or combine them in a more sophisticated fashion but still without modification of the radio access networks. Another important difference is that once the primary user in a cognitive radio context wishes to resume a communication, the secondary user must exit as fast as possible. In contrast, the exit strategy for multilink can be more flexible and context dependent or no exit strategy is required at all. Note also that multilink is not restricted to focus on frequency bands and radio resources. Multilink mechanisms can be deployed at several layers where the preferred option depends on the current objectives and preferences of the actors involved.

3 Multilink Technology Benefits

MARCH has identified six main areas in which users, service providers and network providers can benefit from multilink capable networks [7]. These are

- Capacity aggregation
- Load balancing with optimized network utilization
- Improved service quality
- Enhanced service functionality
- Easing the load on cellular networks
- Increased coverage.

The following sections present some examples that illustrate the categories above. In these examples, two links have been considered as a starting point but clearly more than two can be envisaged, in particular in dense environments where mobile networks (eg. third (3G) and fourth generation (4G) 3GPP networks, and mobile worldwide interoperability for microwave access (WiMAX) networks), fixed networks (eg. fixed WiMAX) and broadcast networks (eg. digital video broadcast handheld (DVB-H) and terrestrial (DVB-T), digital multimedia broadcast (DMB), and 3GPP integrated mobile broadcast (IMB)) coexist.

In Figures 2–6 illustrating the different benefit areas, there are three main columns. The middle column indicates the capacity demanded by a number of users at a given time. The left column shows how the situation will be handled in a non-multilink capable environment (legacy), while the right column illustrates

[1)] *Standard Coordination Committee*

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the same when the networks are prepared for multi-link operation. The partly filled rectangles in the left and right columns illustrate how much of the total capacity provided by a network is actually used.

3.1 Capacity Aggregation

One of the most obvious benefits of multilink is the ability to aggregate the capacity of the different links in order to have a larger total capacity and satisfy capacity-demanding services like video streaming. Instead of a single capacity, a multilink arrangement of say, two similar links will provide just about twice the capacity. This is illustrated in Figure 2.

3.2 Load Balancing with Optimized Network Utilization

Over time, applications can demand more capacity or the load of the different networks vary according to other users in the vicinity. Networks with more than say 3/4 load have instable behaviour and go fast into saturation. Having two or more links available allows the transfer of load from one link to the other while smoothing the variations of the total aggregated capacity. This is shown in Figure 3. Statistically, the more links, the more stable aggregated capacity, and the more stable service quality.

3.3 Improved Service Quality

A variation of the first example of capacity aggregation is to use the second link for a precise purpose, eg. for error correction information or media enhancement data. In the case of error correction, the net capacity delivered to/from the user will be unchanged, but the extra capacity devoted to error correction information will allow for more robust transmission. In the case of media enhancement, the extra capacity is used to transmit more media data, eg. additional video frames to increase the video frame rate or additional pixels per frame to increase the spatial resolution of each picture.

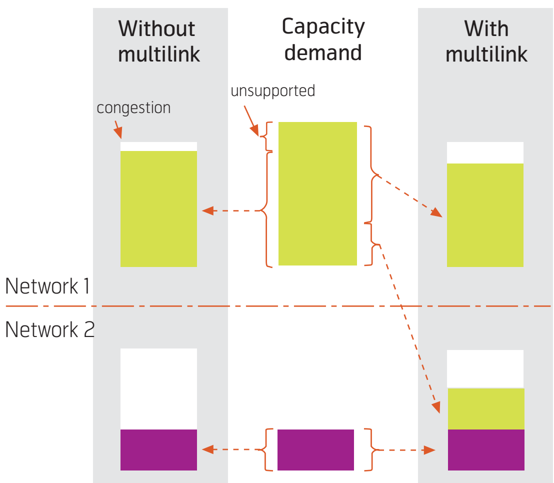

Figure 2 Illustration of multilink capacity aggregation

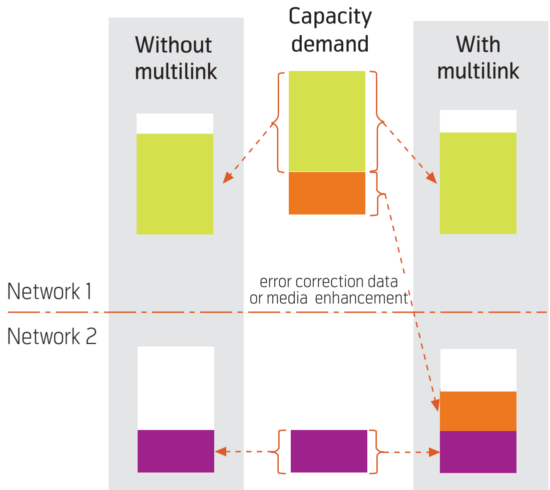

Figure 4 Illustration of multilink improved service quality

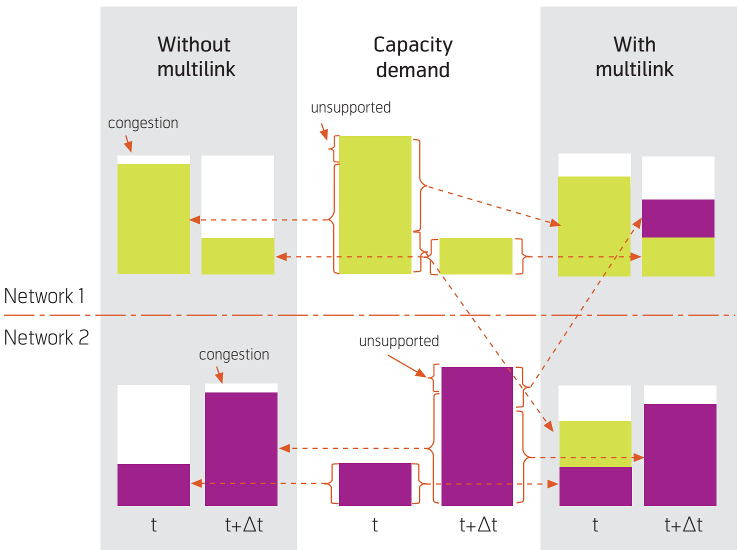

Figure 3 Illustration of multilink load balancing

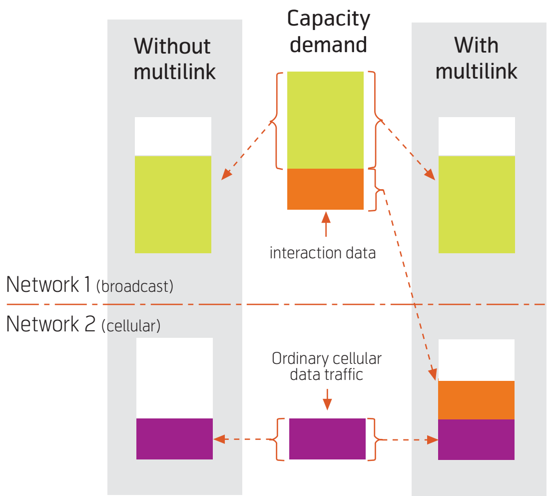

Figure 5 Illustration of multilink enhanced service functionality

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An alternative use of the two links is to send data on two different frequency bands, which allows for frequency diversity that in turn will contribute to more reliable communications.

3.4 Enhanced Service Functionality

Recognizing the different properties needed for communications services and broadcast services, one can exploit the different radio links accordingly. Video streaming and TV services will be better suited for a broadcast network while conversational and data services will be better served in a cellular network. The choice of link can therefore be application driven. Going one step further, from monolink to multilink, interactivity and personalisation can be more easily integrated with broadcast services by using a cellular return or interactivity channel. Each service component will be sent on the link most suitable for the purpose as illustrated in Figure 5. If sufficient capacity is available on the cellular link, some capacity can be dedicated to broadcast enhancements, eg. voting or the like that are linked to the broadcast video service. In this way, the links reinforce each other and allow for new services compared to monolink.

3.5 Easing the Load on Cellular Networks

The benefits from capacity aggregation and load balancing can both be used to off-load cellular networks for instance in hot-spot locations. In addition, the use of broadcast solutions may be used to off-load cellular networks. Currently most cellular networks are used in unicast mode only. If many users access the same content simultaneously, one unicast session is provided to each of them. This puts extra strain on both access and core networks. If the cellular downlink capacity is overloaded, traffic meant for many users should be transferred from the cellular to a broadcast network; thus freeing cellular capacity for other unicast services as shown in Figure 6. The capacity gain is of course more substantial the larger the proportion of the traffic represents content of interest to many users, eg. popular linear mobile TV services.

3.6 Extending Broadband Coverage

A cellular, eg. 2G network may have a wide coverage. The same is expected for a digital broadcast network such as DVB-T. For some of the sparsely populated areas at the edge of these networks, it is sometimes difficult or at least costly to provide a fixed broadband network. A multilink network composed of these two networks can offer more than just a return link for the broadcast network. The networks can be used to offer broadband-like services, thus extending the broadband coverage significantly.

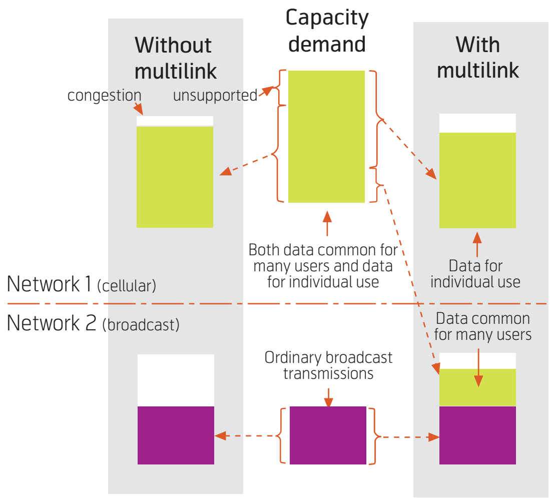
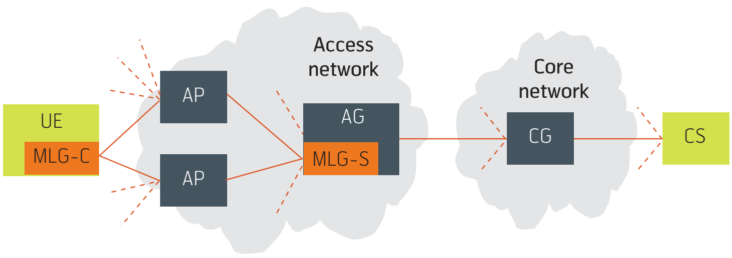


Figure 6 Illustration of multilink easing the load on cellular networks

4 Multilink Architectural Framework

This chapter presents the initial work on establishing an architectural framework for the MARCH project. The intention of the framework is to provide a consistent terminology and a common architectural structure where the main building blocks and reference points are identified. The reference architecture must cover the use of mobile, fixed and broadcast networks as part of a multilink environment. Recognising that the mobile, fixed, or fixed-mobile-convergent service providers are in the midst of transferring to next generation networks (NGN) standardized by ITU-T and ETSI (TISPAN and 3GPP), existing reference architectures and frameworks that are of relevance to multilink must be taken into account. This should ensure that the MARCH solutions are harmonized and well positioned with state-of-the-art standardization.

As the work on multilink techniques and solutions develops, more detailed architectures will be developed for specific technical scenarios and multilink cases. The initial focus of the MARCH technical architecture work has been on cases where there is a need and support for splitting and merging of a single service data flow where each of the sub-flows are delivered over multiple links. This is of great value when the delivery of a large content stream can only be accommodated if delivered over mutliple links. Another main case of interest is where the UE has one or more applications with several service data flows delivered over multiple links; that is, one flow over one link while another flow over another link, without splitting/merging of single flows. However, this case has so far not been in focus. Moreover, detailed structuring and architectural positioning of functional capabilities and further refinement of the multilink control and management functions are expected.



UE - User Equipment
MLG - Multilink Gateway
MLG-C - Client Multilink Gateway
MLG-S - Serving Multilink Gateway
AP - Access Point
AG - Access Gateway
CG - Core Gateway
CS - Content Server

Figure 7 Simple multilink example with serving multilink gateway in the access gateway

4.1 Multilink Network Topology

4.1.1 Network Element Building Blocks

Figure 7 identifies functional building blocks forming an end-to-end multilink environment focusing on the network element level. In which building block(s) the multilink splitting and merging of data flows are carried may vary. This is further addressed below; a simple example is shown in Figure 7. MARCH addresses server↔client applications as well as peer-to-peer client↔client communication. The figures used in this article illustrate the server↔client case.

The user equipment (UE) and the content server (CS) can be considered as separate physical elements. The user equipment must most often be multilink enabled, ie. it needs an interface towards each link and the necessary capabilities to split (uplink) or merge (downlink) the data flows. The content server might or might not be multilink aware, depending on the specific multilink case addressed. In most cases an off-the-shelf non-multilink-aware content server will suffice.

The access point (AP) is a radio base station, access point or broadcast transmitter station. It can support a single radio technology or be capable of supporting multiple radio technologies.

The access gateway (AG) is a mobility anchor point for transport tunnel level mobility. The mobility management and radio resource management functions can in general be distributed among the access point and the access gateway. Both these entities are considered as part of the multilink access network.

The core gateway (CG) is the IP service node of the end user, providing the user equipment with the service level IP address and ensuring the main end-to-end IP service. It is a gateway to the IP core network and interacts with any session control entity of the core network such as an IMS entity (IP multimedia subsystem). In case the IP core network and/or the core gateway are multilink capable it is a multilink core network.

The access point, access gateway and core gateway are logical entities that can either be standalone physical elements or combined into more complex physical elements. Which of these building blocks are multilink aware and capable of supporting multilink functionality will depend on the specific multilink case. Note that a non-multilink-aware building block in the chain does not jeopardize the multilink end-to-end operation; it simply means that the data flow splitting and merging operations are performed in other building blocks. Still, without a splitting and/or merging (gateway) operation a network element building block may need to support multilink related functionality, such as multilink specific link or RAN status reporting.

The important functions of splitting and merging data flows in a multilink enabled network are performed by multilink gateways (MLG). There are two main types of multilink gateways: the client multilink gateway sitting in the user equipment (MLG-C) and the serving multilink gateway sitting in the access or core networks (MLG-S). In Figure 7 the serving multilink gateway is located in or by the access gateway. However, several options exist as elaborated below. Depending on the location a multilink gateway must handle packets or flows at different layers. A serving multilink gateway can relate to several entities (user equipment, access points, access or core gateways) at a time, while a client multilink gateway relates to typically only one serving multilink gateway.

To save computational efforts and power (particularly important for battery powered handheld equipment) MARCH aims at keeping the gateway functionality simple while this is not so important in servers or network elements.

4.1.2 Example Multilink Configurations

In general the access point serves multiple user terminals, the access gateway serves multiple access points, and the core gateway serves multiple access gateways. The user equipment can be served by one or more access points. However, in the case the user equipment is served by only one access point it may still be a multilink case since many links belonging to the same network can be used. One access point is typically served by only one access gateway, and one access gateway is typically served by only one core gateway. However, due to resilience requirements the access point may be served by for instance two access gateways, and one access gateway may be served by for instance two core gateways.

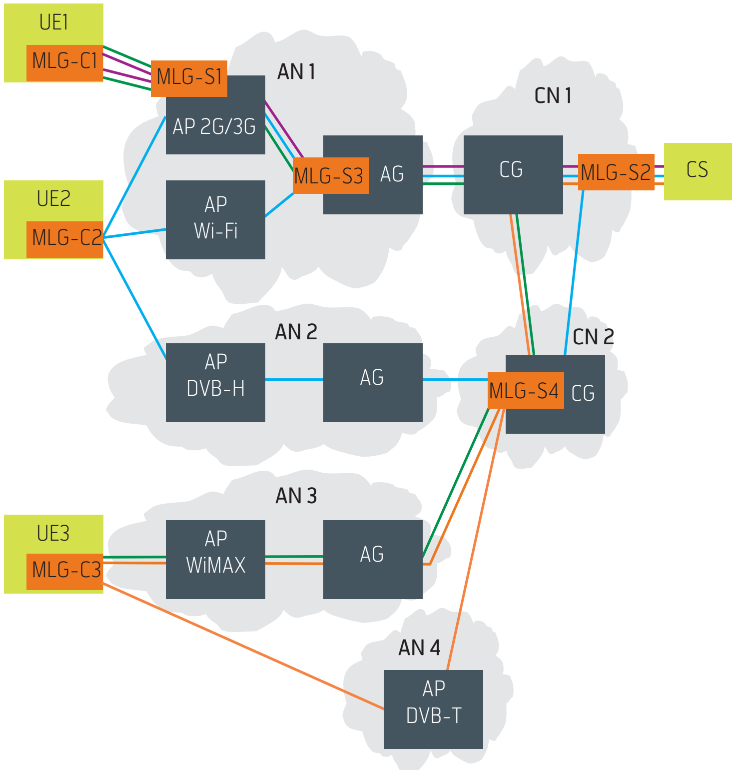
As the multilink gateway, representing the flow splitting and merging points, can be placed at different locations, multiple optional multilink configurations will exist. In Figure 8 several options are captured in one illustration. In general any access network can be used, but to easier explain the different configurations, specific access networks are used as examples (2G, 3G, Wi-Fi, DVB-H, WiMAX and DVB-T).

Figure 8 shows network element building blocks located in different network domains possibly operated by different operators. There are four access networks (AN1 – AN4) and two core networks (CN1 and CN2) in the figure. The three user terminals (UE1, UE2, and UE3), hereafter referred to as terminal 1, 2 and 3, are all multilink-capable and have an embedded client multilink gateway (MLG-C).

The main difference between the examples explained below is the location of serving multilink gateways, ie. where the split-and-merge functionality is placed. The four examples are illustrated in Figure 8 using the red, blue, yellow and green lines, respectively. In examples 1, 2 and 3 the terminals receive streaming flows from the content server, while example 4 addresses client-to-client communications between terminals 1 and 3.

Example 1 (red): Terminal 1 receives content from the content server via two links. The content flows through core network CN1 and access network AN1 and is not split before reaching the 2G/3G access point (in MLG-S1). The streams are merged again in the terminal (in MLG-C1). That is, terminal 1 receives content from two links set up by the same access point (either two 2G links, two 3G links, or one 2G and one 3G link). The set of links to use may change during a session if conditions change, dependent on the dynamics of the resource allocation implementation. No changes are required in the core network and content server compared to traditional monolink operation.

Example 2 (blue): Terminal 2 receives content from the content server via three links. Next to the server (in MLG-S2) the content flow is split between core networks CN1 and CN2. The flow through CN1 is split again in the access gateway of access networks AN1 (in MLG-S3), thus one sub-flow is forwarded to the 2G/3G access point, and the other to the Wi-Fi access point. Hence, this case involves a hierarchy of serving multilink gateways for one given service. The flow through CN2 is not split any further and is received by the terminal via the DVB-H access point. All the three sub-flows received via 2G/3G, Wi-Fi and DVB-H are merged again in the terminal (in MLG-C2). From a data transport point of view, the



UEn - User Equipment number *n*
MLG - Multilink Gateway
MLG-Cn - Client Multilink Gateway number *n*
MLG-Sn - Serving Multilink Gateway number *n*
ANn - Access network number *n*
CNn - Core Network number *n*
AP - Access Point
AG - Access Gateway
CG - Core Gateway
CS - Content Server

Figure 8 Network topology showing several multilink configurations

elements of access network AN2 may behave as in traditional monolink operation, namely transporting data to the terminal without caring whether the data is related to data in other networks. It is important to note that cell size and resource allocation dynamics can differ a lot from one network (type) to another. This is likely to be the case in this example, where fairly different networks are combined: a DVB-H broadcast network (downlink only), a 2G/3G mobile network, and a fixed/nomadic Wi-Fi network.

Example 3 (yellow): Terminal 3 receives content from the content server via two links. The flow is split between access networks AN3 and AN4 in core network CN2 (in MLG-S4) and received via the WiMAX and DVB-T access points. The two flows received via the WiMAX network and the DVB-T broadcast network (downlink only), respectively, are merged again in the terminal (in MLG-C3). From a data transport point of view, both the WiMAX and DVB-T networks can behave as in traditional monolink operation in this case.

Example 4 (green): Terminal 1 communicates with terminal 3, for instance a real-time video conversation,

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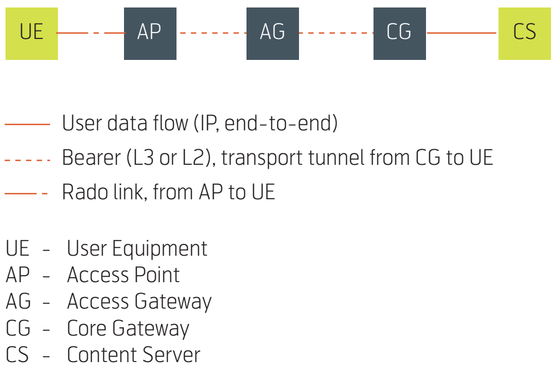

Figure 9 Network element building block reference model

using two links. In the direction from terminal 1 to terminal 3, the stream is split into two flows in terminal 1 (in MLG-C1). These flows are merged again already by the 2G/3G access point (MLG-S1). Then the combined flow may go without further splitting all the way to terminal 3, which then receives it as a traditional monolink stream. In the direction from terminal 3 to terminal 1, the operation will be similar (the splitting and merging operations will change places).

4.2 Reference Architecture

Given the intention of the MARCH architectural framework and the discussion above, this section presents the (preliminary) MARCH reference architecture focusing on multilink gateways. As MARCH also needs a more detailed view on the capabilities of the network elements, a network element building block reference model is proposed. The terms and building blocks can be mapped to any specific access network technology in the scope of MARCH.

The role and the need of a user or session level bearer between the core network gateway and the user equipment will depend on the specific case. The network element building blocks may be combined in various ways or they may constitute separate self-contained network elements. Considering the concept of bearer in the latter case, which is illustrated in Figure 9, it may pass more or less complex networks segments. Typically, these bearers are used to support and control QoS across an aggregation network segment.

The bearer (or tunnel[2)]) from the core gateway to the user equipment is fundamental to both mobility handling and QoS in mobile networks. The bearer uniquely identifies packet flows that receive a specific QoS treatment between the user equipment and the core gateway. All packet flows mapped to the same bearer receive the same packet-forwarding treatment (eg. scheduling policy, queue management policy, rate-shaping policy, link-layer configuration, etc.) [8]. It is assumed that the bearer will play the same important role in multilink solutions. Hence, providing different QoS and packet-forwarding treatment requires separate bearers. Several QoS strategies exist ranging from allocating individual user application streams into a specific bearer to the allocation of traffic of several users into one bearer.

As seen from the discussion in Section 4.1 the serving multilink gateway can be placed in several locations, each of which will require specific capabilities of the multilink gateway. The aim of the multilink gateway reference architecture presented in Figure 10 is to provide a generalized perspective allowing for further development of efficient and reusable solutions.

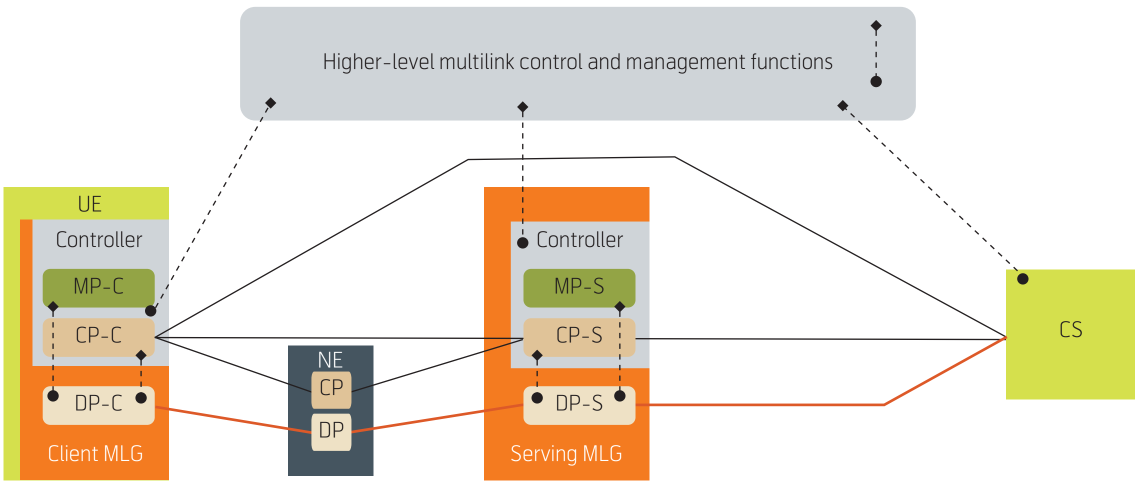

Figure 10 Multilink gateway reference architecture

2) *Example bearer technologies are GPRS tunnelling protocol (GTP), Mobile IP, IPsec.*

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The main elements of the architecture are the client and the serving multilink gateways respectively. The data plane elements perform splitting and merging of flows. This split and merge is not illustrated as the architecture only captures each type of element and does not intend to show potential topologies of these elements.

The basic functions of the multilink gateway data plane element are as follows:

- Packet flow splitting / multilink packet scheduling
  - Time slot mapping
- Packet flow merging
- Packet flow adaptation
  - Packet deletion
  - Packet transcoding

The expected control plane relationships are shown in Figure 10. Direct coordination is needed between the controller of the client multilink gateway and the controller of the serving multilink gateway. These gateway control plane elements are assumed to be confined with its multilink gateway; that is, with the data plane of the multilink gateway. These control elements may also need to interact with the control elements of existing network element building blocks. In the case of a multilink capable content server interaction between this element and the serving multilink gateway is needed in order to adapt the flow in the most appropriate way. Interaction between the client multilink gateway and the content server may be needed in order to provide feedback directly from the client to the content server.

The control and management of the multilink gateways must be supported by higher-level multilink control and management functions. These functions are further elaborated in Section 4.3. For instance functions of NGN and IMS related to this context have to be considered. The notion of *higher-level* is used relative to the associated functions in the multilink gateways. These functions can be put into two broad categories; i) functions related to service usage and session control, and ii) functions related to operating the multilink gateway, either according to operator or user preferences taking into consideration various service and network conditions.

The QoS handling of the packet flows and the related policy and charging control are fundamental in mobile systems and defined by the 3GPP Policy and Charging Control Architecture [9], [10]. A key challenge in the development of successful multilink solutions is to integrate the control and management features of the multilink gateway with the elements defined in the 3GPP policy and charging control architecture. The above reference architecture does not explicitly address policy and charging functional elements, but such functions will be addressed as more detailed and case specific architectures are developed.

The multilink access network is responsible for selecting the proper access point per end user equipment, available resources of access points are dynamically changing with required demand of services which varies in time, mobility of devices in the cell area or between cells. The access network therefore must implement a centralised or distributed approach for radio resource management (RRM) of the access network. Related functions are:

- Context management handling
- Network Initiated handover based on radio resource management decisions
- Admission control
- Quality of service

The MARCH project has taken into account, and will further assess existing reference architectures of international standards bodies as a guide in making viable architectural choices. MARCH recognises the NGN and IMS reference architectures of ITU-T [11], ETSI TISPAN and 3GPP [12] and depending on the specific multilink case in focus these reference architectures may be of relevance in different ways.

4.3 Multilink Control and Management Functional Areas

A variety of control and management functions are applicable to multilink operations. These functions can be allocated in a distributed or centralized fashion, either allocated in or collocated with the network element building blocks or allocated in separate control and/or management elements. Which of the (core) multilink control and management functions should reside in the network building blocks, in the multilink gateway, or in higher-level elements can be case dependent and is not decided as of this reference model. Note also that the configuration actions or control signalling may be initiated in other building blocks at other locations than at the multilink gateway split and merge points. This is illustrated in Figure 11.

Associated functional areas have been identified. These may be involved in multilink solutions but their main purpose is not solely multilink oriented. The core control and management functions required for multilink operations interact with and rely on input data from the user equipment, content provisioning systems, the network and network elements, and other control or support systems. Associated

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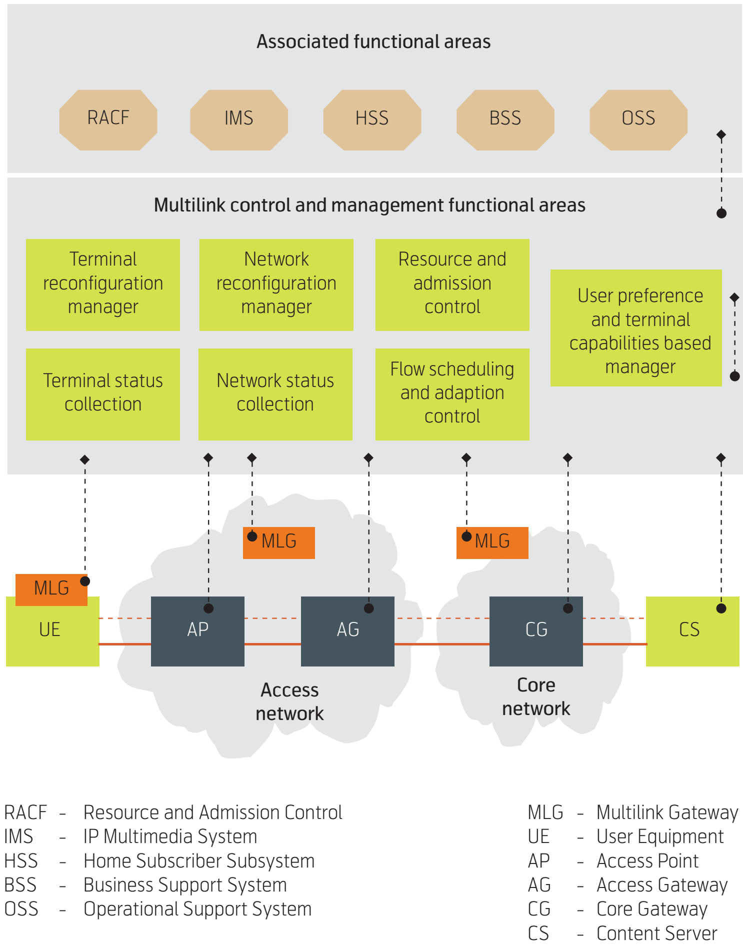

Figure 11 Control and management functional areas

functions or functional areas are the resource and admission control function (RACF), IP multimedia subsystem (IMS), home subscriber subsystem (HSS), business support systems (BSS) and operational support systems (OSS).

In the case of network operator driven multilink decisions sufficient information to make the best link decisions will be obtained by monitoring user, application, equipment, service, and network status; respecting user preferences and equipment capabilities; and obeying operational policies.

Initially, the main control and management functions are arranged in seven groups:

Terminal status collection collects context information from the terminal. It will include many sorts of information, eg. available terminal resources, link measurements, geographical location, battery status, and user preferences.

Terminal reconfiguration management interacts with the network reconfiguration management function and reconfigures the user equipment when demanded by new link decisions. Cases can be foreseen allowing terminal reconfiguration only at session initiation, as well as during a session.

Network status collection collects context information from the access and core networks. It will include many types of information, eg. access network capabilities, radio measurements and other context information from all connected terminals, radio resource optimisation objectives, and available core capacity status.

Network reconfiguration management reasons why and when reconfiguration is desired for optimisation. The complete access and aggregation network is managed, and requested reconfigurations performed in all affected parts of the network.

Resource and admission control supports dynamic verification of resource availability, and performs QoS related resource control within the access and core networks. The decisions made are based on subscription information, service level agreements, operational policy rules, service priority and network status and utilization information.

Flow scheduling and adaptation control controls when, where and how content flow and adaptation should be performed in relation to multilink in order to make the best of the available resources at any time. It also controls the scheduling of flows on different links, and the allocation of resources to each user.

User preference and terminal capability management collects information about a user and his preferences concerning services, terminals and networks. This includes subscription information and related guarantees, preferences, possibilities and restrictions.

The time base for all input parameters required to make well founded link decisions varies a lot; thereby where and how often they should be checked or updated also varies. The network load changes from one second to the next; the service requirements may stay stable during a complete session; the user equipment capabilities are fairly stable over days, weeks and maybe months, while spectrum assignment policies and service level agreements between operators are based on long term relationships. This advocates the multilink control and management functions being distributed according to the level of dynamics. Some decisions should preferably be based on frequently updated information, eg. radio resource measurements, possibly leading to intra-session access point and terminal reconfigurations. Such decisions could probably be made close to the access point or access gateway. Other decisions will primarily be

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based on information gathered and checked at the time of session set-up, possibly affecting all parts of the network as well as the terminal. A centralised decision based on information about all users and networks in the multilink environment may then make sense.

The MARCH architectural framework does not mandate a specific location of any multilink control or management function. This can be up to each of the specific multilink cases and their assumptions.

5 Business and Operational Perspectives

A multilink network providing broadband access over fixed, broadcast and mobile networks reveals many changes; like changes in user pattern, new and more advanced services and new actors and roles. This will lead to new business opportunities and also new cost structures.

The MARCH ecosystem describes roles, actors, relations between the actors, revenues, money flows between the actors, and cost structures [7].

5.1 Business Roles

A multilink network can potentially open market opportunities for new and existing actors. The actors can in some cases represent several roles, while in others there is a one-to-one mapping. The most relevant roles for enabling multilink services as business are:

- Users
- Network owner
- Service provider
- Content provider
- Multilink service enabler/mediator
- Multilink network enabler/mediator
- Multilink broker
- Terminal provider
- Multilink terminal enabler

In Figure 12 the relationship between some of the roles in a multilink system is shown in an end-to-end service delivery chain.

5.1.1 End User

The user might have the most important role in a MARCH ecosystem; most of the money generated to the other actors in the system comes from end users. Multilink support is not yet available as a complete well-functioning service, thus some prediction about how users will adopt and use such services has to be made. There will be a bidirectional dependency between business models and user behaviour. From a business perspective, the users will be divided into professional and private users. The former can be content producers like camera teams with professional terminals, while the latter will typically be a single user with a personal terminal.

In cases where the users subscribe to a multilink service, a user can either subscribe to multiple network owners / service providers, or subscribe to a single broker or mediator.

5.1.2 Network Owner

A network owner owns one or more of the networks that the multilink service is utilizing. A network operator can be involved in multilink business serving several roles. The owner can offer network access and capacity to other actors; it can be a service provider or a mediator.

5.1.3 Service Provider

A service provider is in this case defined to be the provider of a service, such as network access, mobile phone subscription or content distribution that has a business relationship to a user or customer. A service provider can control content and network, or rely on a business relationship to a network owner or content provider. A service provider as an actor can provide multilink support, or rely on multilink support from a network owner or other actors that offer multilink support.

5.1.4 Content Provider

A content provider owns and/or distributes content to users. Multilink support will give content providers an opportunity to distribute more and other types of content; in particular content that requires higher capacity, higher quality and reliability. It is not very likely that a content provider himself will provide technical multilink support for the content. It is more likely that a content provider collaborates with other actors filling the roles of a multilink enabler.

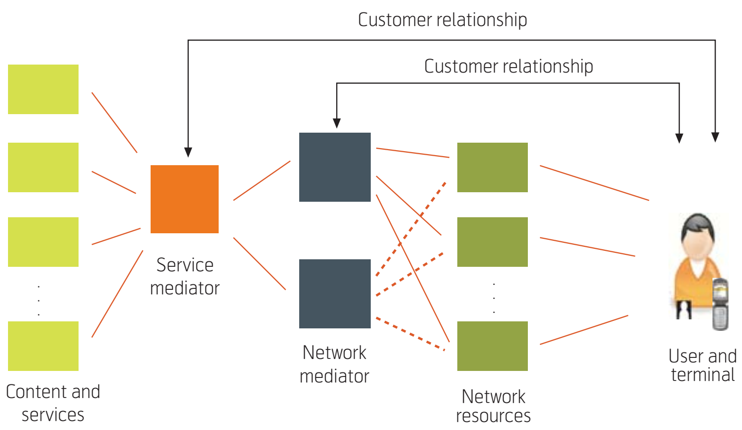

Figure 12 Roles in a multilink system

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5.1.5 Multilink Service Enabler/Mediator

The MARCH multilink ecosystem will include new roles, like an enabler or mediator. This role has been nonexistent or insignificant in the traditional telecommunication business. A multilink service enabler or mediator provides the hardware and software platforms that are necessary to distribute particular content in a best possible manner over multiple heterogeneous and dynamic links. A multilink service mediator can himself offer this service to users as shown in Figure 12. Alternatively, a service mediator can deliver this system to other actors.

5.1.6 Multilink Network Enabler/Mediator

A multilink network enabler or mediator provides hardware and software that is necessary for enabling a network connection to multiple links. Compared to a multilink service enabler that operates on the service and content level, a network enabler operates on the network level and does not consider particular content types. A multilink network mediator can himself offer this service to users as shown in Figure 12. Alternatively, a network mediator can deliver this system to other actors.

5.1.7 Multilink Broker

A multilink broker provides users with a single multilink service subscription enabling services over multiple links owned or provided by different actors. The multilink broker role does only include business relationships with customers and other actors.

5.1.8 Terminal Provider

A terminal provider provides terminals like cell phones and laptops to users. Multilink services will affect a terminal provider by higher demand for terminals with multiple network interfaces and required software.

5.1.9 Multilink Terminal Enabler

A multilink terminal enabler provides software or other equipment to enable multilink services on a terminal. In most cases, the role of a terminal enabler will be combined with the role as service enabler and/or network enabler.

5.2 Inter-Operator Collaboration

The above discussion shows that new inter-operator or inter-provider collaboration capabilities will be needed to realize a successful multilink solution. The multilink gateway reference architecture shown in Figure 10 indicates potential interfaces or reference points between functions in separate building blocks that potentially may reside in different administrative domains. Hence, inter-operator interaction at the network element building block is needed, and standardization of interfaces is needed in order to enable multi-vendor interoperability.

Considering network and service operations the management interfaces – whether at the network element, the network, or the service level – are typically intra-operator interfaces. In multilink ecosystems however, we expect that increased needs for inter-domain interworking supporting automation of business, service and operations related tasks are needed, both at the wholesale level and at the individual user level. Increased automation of otherwise costly human intensive operational tasks is required to keep the costs down to get a positive business case.

Topics that require support of such inter-domain collaboration are for instance:

- Roaming support. Supporting dynamic aspects of business and service level agreements at the wholesale level, including fulfilment, assurance and billing. Dynamic exchange of user preferences and policies is needed to enable the flexibility and service experience expected by the users.

- Service quality and customer experience management. Service quality is dependent on several parameters at different levels. Appropriate reporting and auditing is needed if service guarantees (soft or hard) are offered. At the end, the quality and usability as experienced over time by the end user is of paramount importance. Inter-domain alarm management and trouble ticketing are essential underlying capabilities.

- Wholesale leasing and management of multilink related resources. It is anticipated that these business relationships must be supported by dynamic resource handling in order to lower the overall capacities needed and the associated costs.

The following main inter-domain collaboration categories must be supported:

- Interworking between the multilink broker or network mediator and the network operator (access and/or core network operators);

- Interworking between the multilink service provider and the multilink broker or network mediator;

- Interworking between the multilink service provider and the network operator (access and/or core network operators).

The TM Forum[3)] offer relevant technical, information, process and architectural frameworks, models, guidelines and interface specifications addressing network and service operations at different levels. These provide a good starting point for the further analysis and design work by the MARCH project. The TM Forum IPsphere program specifically addresses SOA[4] and Web-services based inter-domain interfaces. Models and specification for a generic inter-domain interaction framework is under development by TM Forum. The MARCH program will address specific multilink related extensions based on the TM Forum work.

5.3 Business Opportunities

The business potentials differ for the different actors, and the requirement for a successful multilink ecosystem is that the most important actors have sufficient incentives for participating. Typically, the most important incentive is money. The key question is often: in what way can the revenue be increased while keeping the costs at an acceptable level? The benefits by multilink solutions (see Section 3) will be a starting-point and must be translated into the new business models showing how value can be created for the key roles and actors.

Multilink scenarios can potentially open business opportunities for new and existing actors. In addition, actors that are not taking an active role in this market can potentially experience increased revenues due to for instance increased demand for content and increased traffic volume in existing networks. In the MARCH project, the focus will be on business models for new actors and for existing actors respectively. The business models for individual actors such as service mediators, network mediators and brokers will be studied; these are all considered as new roles in a multilink ecosystem. In addition, actors that fill a combination of these roles will be defined and studied. Some of the actors in a multilink system will alone fill many of the roles. This could for instance be large operators, which could serve the network owner role, the service provider, the mediator role etc. Business models and opportunities for these more 'complete' actors will also be studied.

5.4 Operational Efficiency and Modularity

Network operations, whether they are mobile, broadband, or broadcast, cost significantly in investments as well as operational costs. The challenge is to build, manage and maintain the network to meet the user's requirements to services and quality. There is not a lot of space for mistakes if an operator wishes to stay in business.

The MARCH project will in particular focus on improving modularity. The topic of modularity can be addressed from different angles at different levels. Hardware and embedded software modularity is of primary importance in the design and development of network elements by the vendors. An interesting industry trend is to open up the network element platforms by standardizing network element modules and interfaces. An interesting initiative here is the Advanced Telecommunications Computing Architecture (ATCA). ATCA is a large specification effort by the PCI[5] Industrial Computer Manufacturers Group. Furthermore, the Service Availability Forum[6] develops and publishes high availability and management software interface specifications that promote openness for carrier-grade and mission-critical network platforms.

In addition, the network and service providers must also address modularity at the service control level, the application level as well as the level of service delivery, operations support, and business support systems.

On the other hand, increased modularity can also be an operational challenge. The cost-benefit analysis is non-trivial. Auto-configuration, self-organizing networks and policy-based management are concepts and solutions that can enable better modularity while achieving the needed operational efficiency.

With a modular network the operators can keep the network evolving and updated according to business strategy by replacing modules, or parts of the network. With well defined functions and interfaces such internationally standardised modules can be acquired from several vendors without the risk of not fitting in or performing as expected.

One example is the new operator entering into the market place with its own network. In the beginning the number of customers will be limited, but the investments might be high. It depends very much on how much traffic the network needs to carry. With a modular approach the network modules are replaced and perhaps reused other places, and the business grows with a much better control of costs.

From the operational side well-defined modules can be replaced without running into error situations that are costly to find and repair.

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3) *http://www.tmforum.org/*

4) *Service-oriented architecture, http://www.oasis-open.org/*

5) *Peripheral Component Interconnect*

6) *http://www.saforum.org/*

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6 Conclusion

This paper has presented an innovative approach enabling broadband delivery by simultaneously using two or more links. This solution can give improved services, a more efficient and dynamic utilisation of already existing network resources, and increased broadband access coverage. If cost efficient multilink control and management solutions can be developed, services may be offered at a lower cost than a single technology approach can do. Several scenarios have been identified showing the benefits of multilink technology, such as increasing aggregate capacity, extending the range, and managing resources on a larger scale for higher efficiency.

In order to allow for multilink operations, a new architectural framework has been considered, including splitting and merging functionalities placed in gateways at different locations between a client and a server. Multilink gateways can be an add-on to existing terminals, base stations, access gateways or core networks enabling smooth transition to new capabilities and services. Initial business opportunities have also been described and new actors and roles identified.

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