

# Service Differentiation in Residential Broadband Networks

Halldór Matthías Sigurðsson<sup>1</sup>

*Center for Information and Communication Technologies,  
Danish Technical University, 2800 Lyngby, Denmark*

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## **Abstract**

While residential broadband adoption is on the rise, revenue generating voice- and video-services have not yet taken off. This slow uptake is often attributed to a lack of Quality of Service management in residential access networks. To resolve this and facilitate service variety, network access providers are considering service differentiation in their networks where voice and video is prioritised before data.

This paper discusses the role of network access providers in multipurpose packet based access networks and the available migration strategies for supporting multimedia services in digital subscriber line (DSL) based residential broadband networks. Four possible implementation scenarios and their technical characteristics and implications are described. To conclude, the paper discusses implications of alternative strategies on two currently experienced trends of i) vertically integrated business models and ii) open access, and discusses their implications.

*Keywords:* Broadband, Access Networks, Service Differentiation

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## **1. Introduction**

A recognized goal in networking is to realise the convergence of all communications services, voice, video, and data, onto a common IP platform. (Roberts, 2004; ITU, 2003; Analysys, 2004). However, most current residential broadband networks were designed to offer limited capacity “best effort” data transmission and with the foreseen

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<sup>1</sup> Tel.: +45 24 84 86 42  
E-mail address: halldor@cict.dtu.dk

addition of voice and video services in the broadband service portfolio, operators have to redefine their role and redesign their networks<sup>2</sup>. The migration strategy chosen not only affects the technical performance of the network, but can also have profound effects on the development and competition in service provisioning.

While a broad body of literature discusses and proposes quality of service mechanisms that can facilitate multimedia services in residential broadband networks (Courcoubetis, 2003; Ram, 2004; Mandjes 2003) there are practical concerns about realising these proposals, as well as criticism that many of the proposed schemes are 'overly concerned with congestion control to the detriment of the primary pricing function of return on investment' (Roberts, 2004, p.1389). In line with this, equipment vendors have proposed more simple and inexpensive ways using a combination of bandwidth over provisioning and service differentiation (Alcatel, 2004c).

The chosen service delivery model is also affected by the role that network access providers assume in the broadband value chain. An ideal position for customers is to have open access to different service providers for different types of content. In theory, this should increase service selection, innovation, and competition (Bourreau, and Dogan, 2003). In a commercial networking context, this is likely to happen when the viability of the network access provider is assured by the sale of transport services. However, in the case of dominant Incumbent Local Exchange Carriers (ILECs), they also act as competing service providers. Because they are guarding their own interest at the service level and also determining the future structure of residential broadband networks can cause conflicts of interest and affect the path of network and service evolution.

In this paper, we assume that the choice of migration strategy of residential broadband networks is intertwined with the role that network access providers assume in the broadband value chain. By analysing the technical requirements of multimedia services and putting them into context with possible implementation scenarios, this paper tries to describe the likely deployment path of multimedia services in residential broadband networks. To conclude, the paper discusses the implications of different strategies, focusing on the difference between vertically integrated business models and emerging access networks based on open access at the service level.

The paper starts with a description of potential roles of network access providers in Section 2. Section 3 presents the nature and requirements of multimedia services. Section 4 provides an introduction to packet based networks. In section 5, the current

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<sup>2</sup> As an example of this transformation is reported in TVinternational (2006) which reports that Danish incumbent TDC 'is embarking on a major network upgrade to enable most of its system to support a triple play of video, broadband and telephony'.

structure of DSL networks is described, along with how scarce resources can be managed. In section 6, the available technical migration strategies are described. Section 7 summarises the analysis by discussing the strategic selection criteria and how it can be influenced. Section 8 states some conclusions.

## 2. The Role of Network Access Providers

Central to an efficient deployment of multimedia services is the role that network access providers assume in the broadband value chain. Alcatel identifies three basic service models for telecommunications operators (Alcatel, 2004a). The current Internet is an example of the so called “public garden” model, where the application layer is independent of an open access transportation layer and users can freely choose service providers.

The second model is called the “walled garden” model, where the operator locks the customers solely to his platform. Throughout the history of telecommunication, this model has been the goal of operators. Examples are the early telephony and the current satellite broadcasting industry.

The third model, called the “gated garden” model, is becoming the preferred model of many modern telecommunication operators where they can control the supply of services by specifically granting access to third-party service providers. Being service gatekeepers rather than sole service providers increases innovation and service diversity. Networks access providers can then focus on their core business while reaping profits from service provision through fixed fees or profit-sharing. An example of successful implementation of this model is NTT DoCoMo’s i-mode in Japan.

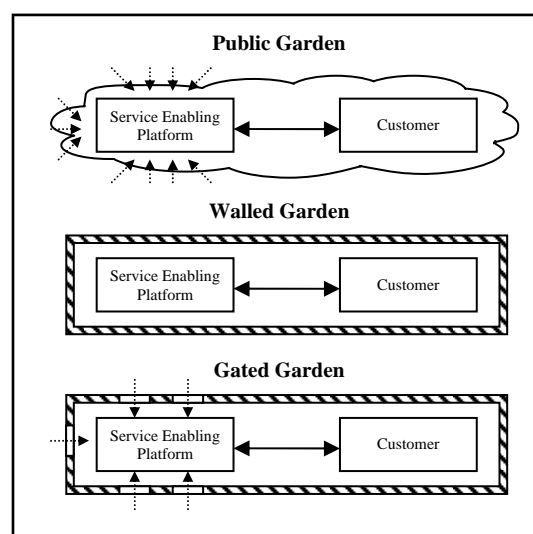


Figure 1, Service Models for Broadband Services

In today's competitive environment the path taken in the development of residential broadband networks is driven by short term profit-maximization aims. In many cases this does not fully coincide with public interest and therefore regulatory interventions are necessary. These later measures have mainly been focused on granting access to the last mile, i.e. local loop unbundling. (Gabelmann, 2001)

### **3. Packet Based Networks**

From the introduction of telephony in the late 19th century the basic concept of setting up a dedicated tunnel capable of transmitting information in a more or less recognisable form between two end points has not changed. However, with the advent of digital electronics and computers a new phase in communication began, the era of packet based transmission.

In packet based networks information is split up into packets. Each packet contains a part of the transmitted information in addition to a header with support information such as where the packet comes from and where it is going. The packet based network then forwards each packet from node to node through the network until it reaches the destination. Packet based networks use different methods for transmitting packets, but in general they are either connection oriented, such as Asynchronous Transfer Mode (ATM), or connectionless datagram oriented, such as the Internet Protocol (IP).

In connection oriented networks a channel is set-up between the originating and destination nodes before the transmission starts. Many channels can exist on the same path and each can have different Quality of Service (QoS) parameters. This differs from the method used in pure IP networks where each packet is sent from the originating node without checking if or how the network can get it to the destination node. Each IP packet can have QoS parameters specified but by treating all packages in the same way and removing the need for any mechanism of recovering lost or corrupted data, the network operates more efficiently and has lower delay.

### **4. Multimedia Services**

The formal definition of multimedia is 'a service in which the interchanged information consists of more than one type, such as text, graphics, sound, image and video (ITU, 1997). In this paper the term is used to indicate services that rely on different media types (not necessarily a combination). Multimedia services can be classified based on how tolerant they are in regards to error and delay. In this classification, interactive voice and video pose real-time requirements on error tolerance and delay.

When real-time information is transmitted over a packet based network, information is sent in flows of packets between senders and receivers. As the transmission delay (known as latency), the transmission delay variance (known as jitter), and the loss of packets, increases the perceived quality of the communication deteriorates. Quantitative measurements of these values are called Quality of Service (QoS) parameters. While advanced coding schemes can reduce perceived quality decay, successful real-time multimedia systems are always contingent upon loss and timing constraints with respect to end-to-end QoS requirements.

Internet applications that require transport functions suitable for real-time data use the Real-time Transport Protocol (RTP). RTP was developed to support real-time transmission of audio and video over User Datagram Protocol (UDP) and IP multicast (Schulzrinne, 1996). Due to the lack of end-to-end guaranties of UDP and inherent problems on the Internet such as Network Address Translation (NAT) and firewalls, much of today's real-time traffic in residential broadband networks is transported using the Transmission Control Protocol (TCP) instead of UDP. TCP flow control mechanisms assure the correctness of TCP streams, but the delay introduced by the retransmission of lost packets creates a bigger problem than the loss itself, if the rate of loss is reasonably small (i.e. below 10%) (Su, 1999).

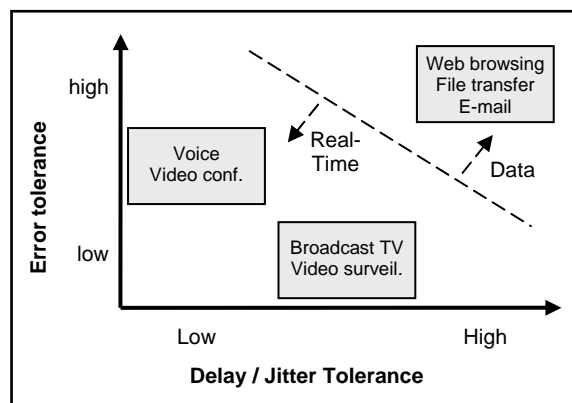


Figure 2, Classification of multimedia services

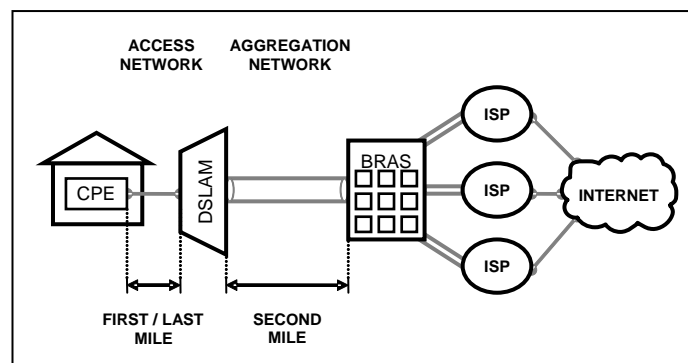
## 5. Residential Broadband Networks

The most widely deployed access technology in residential broadband networks today is digital subscriber line (DSL) (OECD, 2005; ITU, 2003). DSL allows operators to build upon their existing infrastructure by reusing the existing copper lines. This was initially done by splitting up the available frequency band of the copper wire and using the lower frequencies for the public switched telephone network (PSTN) and higher frequencies for packet based data transmission. Today, the tendency is to discard the

separate low frequency transmission of PSTN traffic and use the high frequency band for packet based transmission of all types of traffic, including packetized voice.

There are several different flavours of DSL, each with different characteristics in speed and range. What they all have in common, is that they use advanced digital signal processing to transmit data packets over twisted copper lines. Each customer has a dedicated connection, called the first mile (sometimes also called the last mile), from his/her customer premises equipment (CPE) to a terminating equipment in the nearest aggregation point, called a DSL Access Multiplexer (DSLAM). From the DSLAM, traffic from all customers is aggregated on a common connection, connecting in various ways to one of possibly several competing Internet service providers (ISPs), either directly attached to the aggregation network or through a Broadband Remote Access Server (BRAS).

There are two technical variants of aggregation networks, based on either Ethernet or ATM technology. The ATM solution is a legacy from first generation ADSL and still the currently most widespread. The Ethernet solution is still evolving, but will most likely prevail for reasons of cost and simplicity (Alcatel, 2004b). As both variants will ultimately offer similar possibilities of establishing virtual channels through the aggregation network, the analysis in this paper should be applicable in both cases.



**Figure 3,** Typical DSL deployment scenario

### 5.1. Current DSL networks

The most widely deployed type of DSL to residential customers is Asymmetrical DSL (ADSL). As the name implies, the downstream transmission rate is higher than upstream reflecting an expectation of higher consumption of content than generation. The most common delivery model is based on offering internet access, by setting up one Permanent Virtual Channel (PVC) for each user. This channel then functions as a “best-effort” transport medium for all devices and services in the home. The underlying

technical architecture is rather similar around the world, at the DSLAM traffic is aggregated over an ATM link to a BRAS.

This delivery model is data centric and was designed for web services that can tolerate high levels of delay and packet-loss from network congestion. It offers no prioritisation of content and utilises the statistical nature of traffic to multiplex and aggregate traffic from many users onto a common second mile link that generally has much lower capacity than the sum of dedicated first-mile capacity. The multiplexing practice stems from statistical calculations of blocking probability in the Public Switched Telecommunications Network (PSTN) and is acceptable for Web based data services, but can severely affect real-time voice and video services that do not know the network load prior to service setup.

## 5.2. Resource Provisioning Strategies

In recognition of the fact that current DSL network architectures provide insufficient capacity and support for robust multi-service offering, evolution toward some sort of resource provisioning is inevitable. There have been several proposals for solutions to this problem where most fall into one of three main provisioning strategies: over provisioning, loose control, and strict admission. Each has its strengths and weaknesses, but none has yet reached widespread acceptance. Below is a short summary of the available solutions.

### **Over provisioning**

Over provisioning is based on circumventing the lack of resources by providing capacity that is far in excess of the total required load. While this does not guarantee available resources, it provides a viable solution when providing bandwidth is cheaper than controlling it. Over provisioning can be combined with measurements and monitoring that indicate when upgrades or decreasing capacity is advisable. The strength of over provisioning is cost effectiveness while the weakness is lack of explicit QoS management.

### **Loose Control**

Loose control is based on prioritising portions of the traffic, such that no admission control is required per flow. Then the rest of the traffic competes in a best effort fashion for the remaining resources. In Differentiated Services (DS) (Blake, 1998) and service differentiation in general, intelligence is distributed to the edge of the network, where traffic is aggregated into different classes and packet forwarding is scheduled for each class. The strength of service

differentiation is scalability, because traffic aggregates correspond to connection types rather than individual connections. The weaknesses of service differentiation, is its loose quality guarantees, and lack of admission control and resource assurance.

### **Strict Admission**

Strict admission is based on strict resource provisioning and admission control per flow. This solution is needed in scenarios where resources are scarce and portions of the traffic require QoS guarantees. The Resource ReSerVation Protocol (RSVP) (Braden, 1997) and Integrated Services (IS) (Braden, 1994) architecture are based on resource reservation and conceptually similar to the end-to-end service architecture of ATM. Both can provide a controlled level of service to individual network connections. The strength of IS is its ability to provide strict quality guarantees. The weakness is scalability, setup delays, and additional per packet processing. Additionally, strict admission can not be implemented in current IP based network infrastructures and therefore requires wide scale infrastructure upgrades.

Implementing resource reservation is thus expensive and additionally suffers from technical challenges and therefore many believe that alternative delivery models are needed (Goderis, 2001). Among the proposed solution is admission control by implicit signalling (Ram, 2004). This proposal supports premium and regular service categories for voice traffic and best effort service category for data traffic. More generally, this proposal is among those requiring elements of resource reservation in the access network and service differentiation in the aggregation network. These proposals have in common that voice and video traffic demand is limited by the application session control and/or using provisioning rules to ensure that services never oversubscribe to the available bandwidth. Queuing mechanisms can then give priority to voice and video applications with secondary priority to less delay sensitive applications.

However, Roberts (2004) uses analysis of the statistical nature of IP traffic and the way this impacts the performance of voice, video, and data services to question the appropriateness of commonly proposed quality-of-service mechanisms. He argues that many proposed schemes are overly concerned with congestion control. One of his observations is that despite disadvantages of simple over provisioning 'an over provisioned best effort network can meet most requirements and has the advantage of relatively low capital and operational cost' (Roberts, 2004, p. 1389). In line with his reasoning, Alcatel a major DSL equipment vendor proposes and has started offering

equipment based on a combination of over provisioning and service differentiation, using Ethernet VLANs to differentiate between media flows (Alcatel, 2004c). However, this and other proposed solutions from Alcatel are usually focused on solving the downstream quality of service requirements, required by telecom operators to introduce new video services.

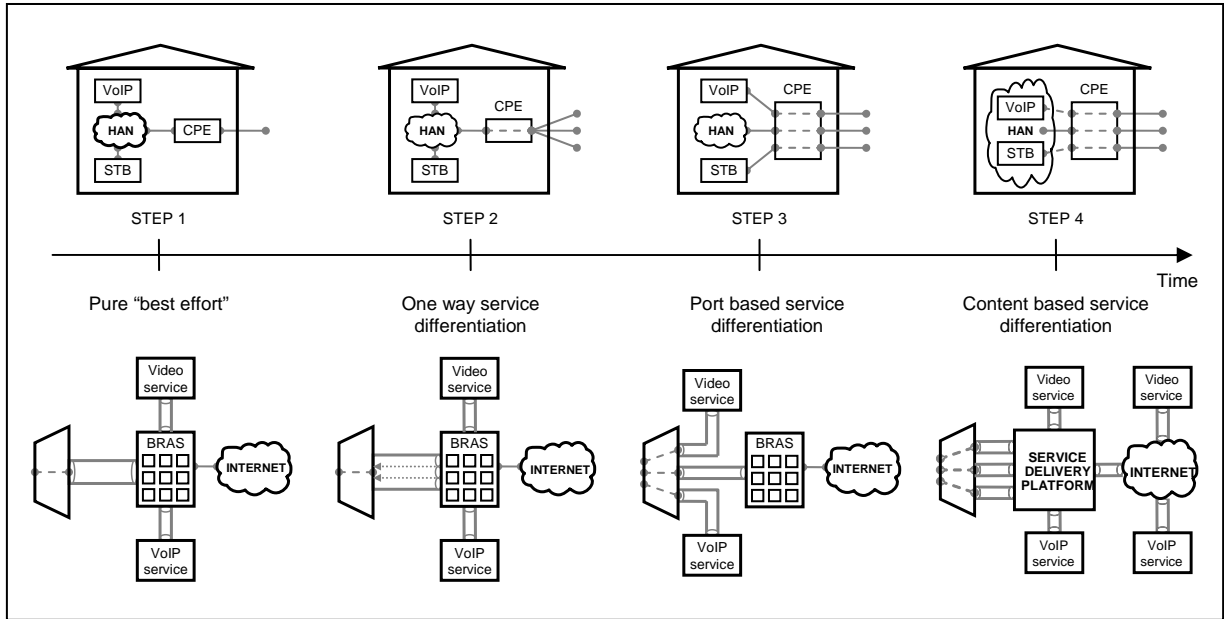
Offering two-way service differentiation in access networks is deadlocked since without service differentiation support in Customer Premises Equipment (CPE) there is no use in implementing it in the access network and vice versa. As a consequence, Network Access Providers (NAPs) can be expected to seek solutions that inexpensively result in new revenue generating services rather than making controversial infrastructure upgrades.

## **6. Service Differentiation in Residential Broadband Networks**

The migration of service differentiation in access networks from the current model towards the near future goal of content based service differentiation can be classified into four steps. They do not represent consecutive steps that operators should or will take, but rather enumerate available development alternatives that operators can choose or migrate between.

In step 1, the CPE is neither able to differentiate nor prioritise traffic and therefore voice and video services have to compete with data traffic for resources. This is the situation in most access networks today and can be called a pure “best effort” model and can only work if resources are abundant, i.e. by over provisioning.

Step 2 is characterised by advances in termination equipment at the NAP side. It is based on prioritising downstream video and voice content over data at the BRAS. Since this is based on the same CPE as before, all upstream traffic still competes equally for resources. In the case of video on demand this model works fine as downstream content is guaranteed priority and only signalling has to travel upstream. If the solution is implemented using the Point-to-Point Protocol (PPP) as proposed by Alcatel (2003) streams of individual traffic are carried from centrally located BRAS making multicasting of broadcast television unfeasible. VoIP services that the NAP provides or recognises can be guaranteed downstream priority, but third party voice services will be worse off than before as priority traffic uses capacity, hence VoIP traffic is competing with other data services for the remaining resources.



**Figure 4,** Migration path of service differentiation in DSL based residential networks

The third step is characterised by required upgrades of both CPE and DSLAM equipment to support two-way service differentiation. In this scenario, service differentiation is based on setting up separate virtual channels for each service and assigning services to specific ports on the CPE. Service differentiation is then transparent to the applications and performed through virtual channels in the network rather than at packet level. Both the CPE and DSLAM then prioritise voice and video virtual channels before data. This solution can support multicasting and therefore enables Video on Demand (VoD), IP television (IPTV), and VoIP. This scenario is the preferred situation of many NAPs as it gives them control over the network resources and provides a competitive edge to traffic they select by ensuring transmission priority. Competing third party service providers have to offer services through low priority data services. While this does not necessarily affect transmission in the local loop for customers that have not subscribed to ILEC voice or video services, it may limit third party competitiveness in the aggregation network.

The fourth and last scenario is based on two way content based service differentiation. Here either the end devices or CPE must define the priority class of packets and forward them accordingly. This can be implemented according to DS, where the packet QoS class is identified through a label in the IP header. Here the NAPs resume the role of pure transmission provider in a public garden scenario, leading according to traditional economic theory to fair service competition as well as service variety and lower prices for end customers. While most ILECs tend to prefer vertically integrated business models, gated garden business models (sometimes also referred to as "Open Access")

are also gaining support through municipal, energy utility, and alternative broadband projects (Larsen, 2006; Tadayoni, 2005). However, more research is needed on implementation of this scenario within DSL based access networks.

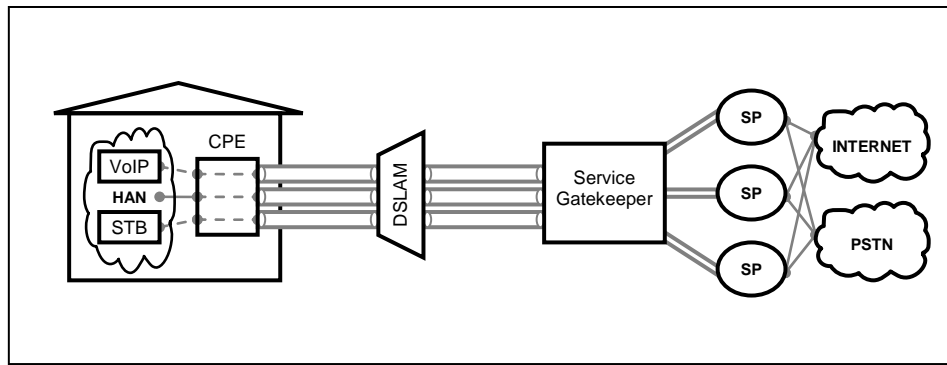
## **7. Implications of Migration Strategies**

To predict the most likely path of migration from one must consider the current network, and whether decision making is driven by competition, the profit-maximizing aim of a monopoly supplier, or the social welfare maximizing aim of a regulator. In the case of currently regulated ILECs their preferred migration strategy can be assumed to be one of profit maximisation and the goal of market control. In the absence of regulatory intervention, European ILECs have attempted to maintain vertically integrated business models and update their infrastructures to support new video services based on service differentiation (step 2 and 3 of Section 6)<sup>3</sup>.

While ILECs move towards multimedia service provisioning does not directly limit third party service providers from offering competing services, it may influence their success. Independent of the technical specifications, a network access provider that also participates in service provisioning is likely to discriminate against competing service providers (Moen, and Riis, 2003). Nuechterlein (2005, p. 172) counter argues that there is no strong empirical basis for these concerns. Regardless, there are examples of independent third party voice and video services provided over DSL, but their success when offering substitute services to those of ILECs has not been great (Tadayoni, 2006a ; 2006b). For the case of broadband telephony services, Davidsen and Johansen (2006) highlight the disruptive nature of VoIP and the need for new business models that add intermediary Internet Service Providers into the value chain. In principle their arguments boils down to the nature of payment for broadband networks and services: i.e., should NAPs provide multipurpose transmission services at a fixed charge that fully compensates their infrastructure expenses or should they partly get their revenue from services.

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<sup>3</sup> On a pan European scale, the French incumbent French Telecom is planning to roll out it's "MaLigne TV" IPTV service across its key European markets in 2006 (TVinternational, 2006). On a national level the Danish incumbent TDC has revealed plans to offer a nationwide IPTV service using Microsoft middleware (TVinternational, 2006).



**Figure 5,** “Open Access” service delivery platforms

In contrast to vertically integrated business models, recent broadband initiatives in the Nordic countries (Larsen, 2006) and in the US (Lehr, Sirbu, and Gillett 2004) have been deploying new Fibre-to-the-Home access networks based upon “open access” service delivery platforms. These networks are conceptually similar to the content based service differentiation presented as step 4 in Figure 4, but additionally put the NAP in the position of service gatekeeper as illustrated in Figure 5. This approach has the virtue of service competition, lower barriers to entry, and greater flexibility for customers. The down side is the strong situation of the NAP that in an unregulated environment can set monopoly prices or demand revenue sharing from service providers.

While there have not been reported examples of open access using gatekeepers in DSL infrastructures, unbundling regulation ensures competitive access to legacy copper infrastructures (Nuechterlein, 2005). However, these remedies are aimed at ensuring network access competition and do not affect service provisioning. Slowly regulators are addressing the issue of potential anti-competitive behaviour at service level and as an example the Danish regulator in 2005 revoked previously forced PSTN requirements from broadband access provisioning (Ingeniøren, 2005). This and other measures open the market to local service competition and also to alternative service providers such as Skype (2006) that reportedly use peer-to-peer technology to reduce infrastructure investment and offer free voice services globally (Baset, and Schulzrinne, 2004 ; Sigurdsson, 2006).

## 8. Conclusions

This paper has presented a number of migration strategies for implementing multimedia services in converged multipurpose residential broadband networks. Evidence shows that despite social benefits of competitively neutral “public garden” access networks, incumbent operators primarily maintain vertically integrated business

models and approach service differentiation as a means of facilitating their introduction of new multimedia services. The most likely approach that these operators will introduce is based on providing either one way or two way priority to real-time traffic. The consequence is a competitive edge, primarily useful for resource demanding video content. The analysis indicates that independent third party service providers aiming at competing with incumbents by offering substitutive traditional services over “best effort” connections will face competitive challenges while alternative providers such as Skype that apply new business models or cost efficient technologies can have a competitive edge. The situation is different in emerging broadband initiatives that choose “open access” where they place themselves as gatekeepers and do not compete on service level. In both cases regulators are faced with new challenges when moving from access regulation to stratified service provisioning level.

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