USE CASES AND ARCHITECTURES FOR HYBRID ACCESS

February 15th 2016
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## 2 Acronyms and Terminology

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<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>BBF</td>
<td>Broadband Forum</td>
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<tr>
<td>CGNAT</td>
<td>Carrier Grade NAT</td>
</tr>
<tr>
<td>FTTH</td>
<td>Fibre To The Home</td>
</tr>
<tr>
<td>HAG</td>
<td>Hybrid Access Gateway</td>
</tr>
<tr>
<td>HG</td>
<td>Home Gateway</td>
</tr>
<tr>
<td>HGI</td>
<td>Home Gateway Initiative</td>
</tr>
<tr>
<td>HHG</td>
<td>Hybrid Home Gateway</td>
</tr>
<tr>
<td>IETF</td>
<td>Internet Engineering Task Force</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution (4G)</td>
</tr>
<tr>
<td>HN</td>
<td>Home Network</td>
</tr>
<tr>
<td>MPTCP</td>
<td>Multipath TCP</td>
</tr>
<tr>
<td>NAT</td>
<td>Network Address Translation</td>
</tr>
<tr>
<td>POS</td>
<td>Point Of Sale (terminal)</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission Control Protocol</td>
</tr>
<tr>
<td>ToD</td>
<td>Time of Day</td>
</tr>
<tr>
<td>UDP</td>
<td>Unreliable Datagram Protocol</td>
</tr>
<tr>
<td>(U)HD</td>
<td>(Ultra) High Definition</td>
</tr>
<tr>
<td>UI</td>
<td>User Interface</td>
</tr>
<tr>
<td>USB</td>
<td>Universal Serial Bus</td>
</tr>
<tr>
<td>xDSL</td>
<td>ADSL or VDSL</td>
</tr>
</tbody>
</table>

### Hybrid Access

**Simultaneous provision of both fixed line and wireless Broadband access**

### Hybrid Home Gateway

An enhanced Home Gateway with both fixed and mobile broadband interfaces that can be used simultaneously. It provides traffic steering and muxing/demuxing as well as the other functions required for hybrid access e.g. management and diagnostics.

### Hybrid Access Gateway

A new network node that routes downstream traffic to the fixed and/or wireless access according to various policy rules, and can reconstruct upstream flows.

### Highspeed Broadband

A Broadband Service that is faster than the typical VDSL speed available today, i.e. significantly more than 60 Mbps.

### Digital Divide

Where there are a significant number of premises with a very low ADSL rate, or no Broadband coverage, in a given region.
3 EXECUTIVE SUMMARY

In 2014, HGI began to discuss the business drivers and architectural approaches for Hybrid Access and the HG enhancements that would be needed to produce a Hybrid Home Gateway (HHG), i.e. one that included more than one access technology, typically wireline (xDSL) and wireless (LTE). As this work developed, similar activity has progressed in the BBF and the IETF. The main goal of this HGI document is to address the use cases and business requirements for Hybrid Access, and to investigate the technical alternatives and their implications for the HG and home environment.

The topics covered include the end to end architecture, fixed-mobile bonding mechanisms, traffic steering and the Home Network architecture and topology.

The intended audience for this document is:

- Service provider product managers for Broadband services and Home Gateways.
- Vendor product/development managers assessing high level business drivers for introducing new features on HGs.
- Network architects.
4 INTRODUCTION

There is increasing customer demand for ever higher speed broadband, coupled with regulatory pressure in some countries. The ideal solution would be ubiquitous fibre-to-the-home (FTTH), however both the huge cost and long deployment time has limited the extent to which this has been adopted. Consequently, copper continues to be used as the broadband medium into the home using xDSL, and soon, G.fast (although fibre may be pushed deeper into the network to support the latter). One option for a more rapid deployment of faster Broadband is to aggregate the existing fixed xDSL access with an LTE broadband access. This so-called Hybrid Access is the subject of this document. Hybrid Access can provide faster broadband in some areas, and address the ‘slow broadband’ problem in others i.e. where ADSL alone cannot provide a basic mix of Internet access and video streaming.

4.1 MAIN FACTORS MOTIVATING HYBRID ACCESS

The main drivers for hybrid access are:

- Increasing the rates available to customers with slow ADSL lines.
- Providing higher speeds than are generally available from VDSL2, in particular to broaden the footprint of HD and 4K video streaming services.
- Increasing bandwidth without having to install the new fixed infrastructure in the customer premises required by FTTH.
- To help meet regulatory targets for Broadband speed and coverage. In Europe, national and EU regulatory authorities are pushing to increase the coverage of broadband connections at a range of speeds.
- Reducing the “digital divide” by helping to ensure that ‘all’ premises can have a Broadband rate of at least several Mbps.

Hybrid technology can also be used to provide increased bandwidth to mobile devices while they are within the home - this can have both performance and cost benefits. When the mobile device leaves the home, it transitions to the macro wireless network.

4.2 THE HYBRID HOME GATEWAY (HHG)

The Hybrid Home Gateway adds LTE capability to a traditional Home Gateway, with both interfaces able to be concurrently active. This needs a new Home Gateway. There are alternatives which do not embed the LTE, e.g. a 4G modem on a USB dongle, or a separate box connected via Ethernet or Wi-Fi (sometimes known as a MyFi device), however even then the HG would need new capability e.g. to mux/demux traffic over the 2 access paths.

The network operator needs to implement traffic steering policies to support hybrid access. These may need to take into account the different properties of the 2 links (e.g. delay/jitter/packet loss). In most cases, this will require a new node, the Hybrid Access Gateway (HAG), in the operator’s network.
If the HHG has an embedded LTE interface, its location within the home can significantly impact the Hybrid Access performance; an external antenna may be required which will also involve some new internal wiring. Finally, the Hybrid Home Gateway needs unified management.

4.3 ASSUMPTIONS

The following assumptions have been made:

- Applications have no direct awareness of the hybrid access.
- In the integrated gateway (single box) model, the HHG is managed by a single business entity.
- The above, single business entity is in control of installing traffic steering policies at both the HAG and HHG.
- The user may or may not be allowed to specify policy preferences.
- The user has a single point of contact for problems on either of the access technologies.

4.4 STRUCTURE OF THIS DOCUMENT

This document examines the technical and operational implications of Hybrid Access.

In Chapter Error! Reference source not found., the main use cases for Hybrid Access are given. Chapter 6 provides the Business Requirements. Architecture and technology alternatives are discussed in Chapters 8 and 8. Some conclusions are drawn in Chapter 9.
5 Use Cases

5.1 Use Case 1: Increase Footprint of Basic Broadband Services

Where ADSL cannot provide sufficient bandwidth to meet the requirements of a service package, adding LTE may offer improved web and email access, possibly SD/HD video streaming or download, plus enhanced upload.

![Figure 1 – Increase Footprint of Basic Broadband Services]

5.2 Use Case 2: Increase Footprint of Highspeed Broadband

For the purposes of this document, highspeed is defined as a broadband service whose rate is significantly higher than the average speeds available on today’s real-world VDSL2 deployments, i.e. significantly more than 60 Mbps, probably 100Mbps+. There are various reasons for doing this; from the service perspective, this would allow more than one 4k video stream to be delivered, while still providing high-speed browsing and download. There is a competitive angle in that this service could be positioned as superior to either a VDSL only, or LTE only, broadband service.

However this does not necessarily require hybrid access to be provided across the entire footprint. VDSL2 alone can offer such rates to a subset of customers, i.e. those on shorter loops or where vectoring has been deployed. The idea here is to increase the footprint of this highspeed Broadband by augmenting VDSL2 with LTE where necessary.
5.3 USE CASE 3: INCREASE SERVICE AVAILABILITY

Most Broadband is designed as a mass market, residential service. There is typically no resilience in the access network, and outages do occur, due to planned maintenance as well as faults.
However Broadband is also being used by businesses, where the consequences of a service outage can be significant e.g. for POS terminals or booking systems. Further, there are new services in the residential sector, such as E-health, assisted living and security, where true 24/7 connectivity is required; this may even become an insurance company requirement.

The basic idea is that all services normally run over the fixed access. Connectivity is continually monitored, and when the fixed link goes down all, or a selected subset of, the services are diverted to the wireless path. If only a subset is diverted, then the other services will stop until the fixed link is re-established. Reversion to the fixed path is done automatically when the link comes back up.

5.4 USE CASE 4: FASTER SERVICE TURN UP

This use case addresses new broadband customers who require quick “turn-on” of broadband service. The operator can deliver an acceptable range of basic digital services (Web and email access, plus SD streaming and some upload capability) over the LTE path until the wired service becomes available. Drivers for this use-case include pressure from regulatory authorities for an operator to fulfil a specified target coverage rate within a given timeline. Note however that if a single access of either type meets all the user’s needs, that it is generally preferable to a hybrid service, as it is likely to be cheaper and easier for both the operator and user. Therefore it only makes sense to provide a hybrid enabled interim solution if it is also believed to be necessary in the long term. If this is not the case, then an interim standalone wireless solution may be more appropriate, which is simply removed when the wired solution becomes available.

Figure 4 – Faster Service Turn Up
6 BUSINESS REQUIREMENTS

There are a number of high-level, business requirements associated with Hybrid Access.

<table>
<thead>
<tr>
<th>No</th>
<th>Business Requirements for a Hybrid Home Gateway</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.1</td>
<td>The HHG SHOULD be able to be self-installed by the customer, for both the 1-box and 2-box cases</td>
</tr>
<tr>
<td>R.2</td>
<td>To facilitate installation and maintenance, the HHG SHOULD support end-user friendly diagnostic and performance tools for both the WAN and LAN, including inter-box communication</td>
</tr>
<tr>
<td>R.3</td>
<td>The QoE of services, in particular conversational services, delivered over the aggregate path SHOULD NOT be significantly worse than when using the fixed path alone.</td>
</tr>
<tr>
<td>R.4</td>
<td>The interconnection between the fixed and mobile parts of a two-box solution SHOULD be able to transport the peak rate of the wireless access product.</td>
</tr>
<tr>
<td>R.5</td>
<td>The HHG MUST be able to support an operational model in which the traffic steering policy is solely dictated by the operator.</td>
</tr>
<tr>
<td>R.6</td>
<td>The HHG SHOULD be able to support an operational model in which the user can at least partially specify the traffic steering policy.</td>
</tr>
</tbody>
</table>
| R.7 | The HHG MUST support the measurement of traffic volumes on each path in both the downstream and upstream directions.  
*Note: this is to allow the user to be made aware of traffic volumes (which may impact charging), and to support the Use Case where the volume can cause a change to the traffic steering policy.* |
7 SOLUTION CONSIDERATIONS

7.1 LOCATION OF COMPONENTS IN THE HOME

Today, the fixed line router/modems will typically be placed so as to provide the best Wi-Fi coverage, often near the centre of the home, although it might be positioned next to the main STB. In contrast, the optimum position for reception of 4G signals is usually close to a window. This may point to a 2-box solution. The connection of the fixed and mobile boxes could be via wired Ethernet, or a point to point Wi-Fi connection.

7.2 SELF-INSTALL

Most Home Gateways are self-installed, and it is in the operator’s interest to apply the same model to Hybrid Home Gateways. However there are some new issues: determining the above mentioned location of a single box solution, and how to provide the interconnection in the 2-box case. Remote assistance via a help-line, and in the limit, a technician visit, should also be available. A further complication is that fixed and mobile networks are generally managed using different standards (e.g. TR-069 for fixed, OMA DM for mobile) and possibly by different operators. Technical, and possibly business, agreements would be required for this joint system to operate correctly.

7.3 SELF-DIAGNOSIS

Self-Diagnosis refers to activities carried out by customers to troubleshoot connectivity and performance problems. It is in the operator’s interests for customers to carry out as much diagnosis as possible, augmented only when necessary by remote management. However it must be remembered that many broadband customers are not particularly technically sophisticated.

Hybrid Access presents a particular diagnostics challenge because of the 2 distinct paths, either (or even both) of which may be experiencing problems, and at least one of which, the LTE path, is inherently time varying over both short and long time scales. However self-diagnosis, although more difficult for hybrid access, remains highly desirable.

Simplicity and usability of the diagnostic UI are key to the success of this feature. Measurements may include specific parameters (e.g. level of Wi-Fi interference) as well as long term monitoring, for instance of error rates.

As noted above, there may be a conflict between the optimum position of the hybrid Gateway with regard to the the 4G antenna, and providing good in-home coverage of the Wi-Fi. Therefore tools which help the user to find the best compromise location are desirable.
7.4 Traffic Steering

7.4.1 Policy Based Path-Selection

Policy is the set of rules used to assign traffic to the fixed and/or mobile path. Operators may perform path-selection based upon one or more of the following factors: service, application, bandwidth-limits, physical layer type and Time-of-Day (ToD).

The customer must be able to influence path selection, either directly or indirectly, where it has an impact on the customer experience, or on charging. For example a games console user would want the lowest latency path, and so wish to pin this application to the fixed network. Another user might not want to stream HD video over the LTE network, if their LTE broadband services had a usage cap with high per Mbyte charges once the cap had been exceeded. Note that a typical cap is 10 Gbyte/month, which is equivalent to only 2.2 hours of video streaming at 10 Mbps (and even less - ~45 mins - of UHD).

Hybrid Access path selection can be done via one or more traffic steering policies. These need to take into account not just technical decisions, such as which path provides the better transport capabilities (rate, jitter, packet loss etc.), but also charging and capping; one path may be more expensive than the other, and there may be different volume caps which dictate a change in policy when a cap is reached.

Note that there are 4 paths to be selected – 2 in both the Upstream and Downstream - and it must be possible to select these paths independently, although it may not be appropriate to give the customer this very fine-grained control. Further, the selection takes place at different locations, in the network (at the HAG) in the downstream, and at the HHG in the upstream.

Path selection can be done in the following ways:

- per end-device
- per application (service)
- per application (service) per stream
- per packet,

Path selection is done on the basis of policies installed in both the HAG and HHG. Per packet selection is the most complex, as it may need near real-time feedback on the properties of the 2 paths in order to make the appropriate choice. Packet based steering could for example be used to load balance, or to only send ‘overflow’ traffic on the alternative path. Further details on traffic steering can be found in Section 8.6.

7.4.2 Data Cap (Service Limits) & Automatic Threshold Tracking

The Operator could provide Threshold Tracking to inform the user how close they were to the threshold of their data plan. When it gets close, a warning should be issued.
7.5 **USER IMPACT**

7.5.1 **TRAFFIC STEERING AND TARIFFS**

The operator needs to offer different options and related tariff plans. From the user’s point of view, the simplest approach to Hybrid connections is one fat pipe which provides more bandwidth than their fixed access. The user does not know whether their data is flowing through fixed or mobile connection, and has no way of influencing this choice. This corresponds to allowing the operator to fully manage the connection and the related QoS/QoE.

This scenario needs a single, unified tariff for fixed and mobile access, otherwise the customer bill would depend on the operator’s decisions about how much of the traffic should go through each path.

A more sophisticated approach can be taken with more experienced users who require specific paths for specific devices/applications/streams, for instance a games box owner. However traffic steering could still be managed by the operator who would offer a range of packages that took into account the different end customer needs. In this case, static steering for specific types of traffic would be agreed between operator and end customer.
8 TECHNOLOGY OPTIONS

8.1 BASIC NETWORK ARCHITECTURES

There are 3 basic network architectures for Hybrid Access:

1. End to end
2. HAG plus HHG
3. HHG only.

8.1.1 END TO END

In the end to end case, the 2 paths go between the end device and the service platform, e.g. the video server. This relies on multipath TCP to establish and control the 2 paths. Apart from hosting the second access technology, the HG plays no part in the procedure, e.g. does not do any muxing/demuxing or explicit path selection.

The advantage of this approach is that it does not require a new network element (the HAG), or any additional functionality in the HG. The significant downsides are that it only works with TCP based applications, path selection and load balancing are fairly rudimentary, and both the source and end device must support MPTCP; note however that this is supported by iPhones (for the Sirius OS and later).

As this solution is already deployed, there is no need to specify it here, however it is a useful benchmark against which to measure other solutions.

8.1.2 HAG PLUS HHG

Full-blown Hybrid Access involves both an HHG and a HAG, as shown in Figure 5. In the downstream the HAG allocates traffic to the appropriate path, with this function being performed in the upstream by the HHG. This architecture can also use MPTCP, although it does not have to. The MPTCP would run between the HHG and the HAG. The latter would normally act as an MPTCP proxy server and terminate the protocol, however if a given Web server did support MPTCP, the operator could set the proxy to act transparently, i.e. simply forward the traffic from that particular server in the normal way.
8.1.3 HHG ONLY

Figure 5 – Overall Architecture – HHG plus HAG

Figure 6 – HHG only
In this case, the 2 paths go between the HHG and the service platforms as shown in Figure 6. True multipath operation relies on MPTCP running between the HHG and an MPTCP capable server. The HHG terminates the MPTCP protocol, thereby avoiding the need to support it in the end devices. The main advantage of this approach is that is does not require a new network element (the HAG). However it only works fully with TCP based applications, although it can provide protocol agnostic support for the failover Use Case.

### 8.2 IN-HOME ARCHITECTURE

Hybrid Access can be realised in a single, integrated customer premises box, or in 2 boxes if the LTE modem is not embedded in the HG. The advantages of the 2-box solution include allowing better positioning of the LTE modem when an internal (as opposed to roof or window mounted) LTE antenna is used, avoiding change-out of the HG, and not loading the cost of each HG with an embedded LTE interface. While an LTE dongle is an alternative, it will almost certainly perform worse than an embedded LTE modem or a second box due to antenna limitations.

Note that an HG with an LTE dongle would be classified as a 1-box solution. A significant issue with the 2-box solution is how the LTE traffic gets to the HG; options include Wi-Fi, a new Ethernet cable, or even powerline/phoneline. The pros and cons of these 2 solutions are summarised below:

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<th>2 box</th>
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<tbody>
<tr>
<td><strong>Pro</strong></td>
<td>• More acceptable to the customer – general dislike of multi-box solutions</td>
<td>• Allows optimum positioning for Wi-Fi coverage and LTE reception</td>
</tr>
<tr>
<td></td>
<td>• Does not take up one of the existing LAN interfaces (Ethernet, USB)</td>
<td>• May not need HG change-out – but firmware upgrade still needed (mux/demux, path selection)</td>
</tr>
<tr>
<td></td>
<td>• Facilitates unified management and diagnostics</td>
<td>• Can be used by converged and non-converged operators</td>
</tr>
<tr>
<td><strong>Con</strong></td>
<td>• No standards for a Hybrid HG</td>
<td>• Customer dislike of multi-box solutions</td>
</tr>
<tr>
<td></td>
<td>• Totally new box (needs new hardware)</td>
<td>• May occupy one of the existing LAN interfaces (Ethernet, USB)</td>
</tr>
<tr>
<td></td>
<td>• Needs higher processing capability</td>
<td>• May need to use Wi-Fi as a WAN interface</td>
</tr>
<tr>
<td></td>
<td>• Compromises Wi-Fi coverage and/or received LTE signal strength</td>
<td>• Harder to provide unified management and diagnostics</td>
</tr>
<tr>
<td></td>
<td>• May need an external (to the house) antenna and new co-ax between the antenna and HG</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Only suited to a converged operator</td>
<td></td>
</tr>
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</table>
8.2.1 Use of Wi-Fi for Fixed Gateway to Mobile Modem Connection

In the 2-box case, Wi-Fi is by far the simplest interconnect solution. However potential drawbacks are in-house propagation impairments, which can lead to reduced bit rates and higher error rates, which may need to be taken into account in path selection. The new IEEE 802.11ac standard, or using the 5 GHz band may help, but have their own coverage issues.

8.3 Bonding

Bonding is the generic name for mechanisms that aggregate the traffic from different physical paths. A certain amount of overhead is inevitable according to the layer at which the bonding is carried out. Solutions at various layers (1,2,3 or higher) are subject to other constraints such as the amount of latency and jitter to be compensated, the number of flows, and the number of higher layer addresses to be managed. Bonding solutions should be hidden from the application layer. Note that in some regulatory regimes, there may be limitations as to the Layer at which bonding can be done e.g. operators may be precluded from offering bonded solutions above Layer 2.

8.3.1 Layer 2

A number of standardized algorithms for L2 bonding are available, e.g. MLPPP and Link Aggregation (IEEE802.1). One problem is that all the links at each end point need to share the same IP address, but will normally have different MAC addresses. Fixed and mobile access operators sharing the same IP address might also be difficult since they normally have their own IP address plans.

8.3.2 Layer 3

Bonding can be done at Layer 3; there is already at least one commercial example of such a service. This uses multiple (two or more) Broadband connections which can be from different providers and can use different technologies. At the customer end, each broadband line is connected to a router which runs proprietary software. Each router may contain the access technology for its particular broadband service, or it may be connected to a dedicated broadband modem via Ethernet. One router is designated the master and it is responsible for allocating IP packets to the various broadband uplinks, and reconstructing the packet streams in the downstream direction. The (two or more) connections converge on a hosted aggregation server in the network which forwards a single stream to the Internet in the upstream and is responsible for allocating packets to the different broadband connections in the downstream. The system can periodically adapt to changes in the speeds of the different links to determine how much data goes down each. However there are various warnings from one of the providers of such a service:
• “If the line performance fluctuates rapidly and to extremes, it is likely that sub-optimal bonding will be achieved. Most wireless technologies (3G, Wi-Max, Wi-Fi) and some cable connections can have highly fluctuating performance.
• The service has been designed to use broadband connections where the latency to the aggregation server is <80ms. The service can operate beyond that latency but performance may be sub-optimal.
• The service works best when lines of a similar latency are used. Packet resequencing and other methods may need to be used to provide optimal performance where line latencies are radically different.
• The service introduces a small overhead to each packet (approximately 25 bytes) which may require some services such as VPNs to have their MTU lowered.”

8.3.3 Layer 4
At the transport layer there are three standards available: TCP, UDP and SCTP. SCTP traffic is in fact negligible, since SCTP is just used for signalling over IP. A traffic study of TCP and UDP [http://www.caida.org/research/traffic-analysis/tcpudpratio/] showed that the vast majority of traffic is currently TCP; however the amount of UDP traffic could rise significantly in the future due to HD/4k streaming. There is an existing technique to use multiple TCP paths to increase throughput which is described in Section 8.4.

8.4 MPTCP Overview
MPTCP is specified in RFC 6824, although enhancements are still under way.

MPTCP provides functionality beyond that of regular TCP, in particular:

1. More than one IP address can be specified at each end of a connection, i.e. the MPTCP protocol implements the multi homing concept. MPTCP still uses ports.
2. The concept of session is maintained but multiple (sub) flows can be created per session, regardless of the associated IP address.

A Hybrid Gateway can host a MPTCP Session using 2 IP addresses, with data being sent over either the fixed or mobile path (“subflow” in MPTCP terms) according to the Hybrid Gateway’s steering policy. Subflows are aggregated at the destination end, including any reordering. Packets can be switched seamlessly between subflows. In the case of a VoIP call for instance, this allows call continuity when switching from fixed to mobile. Subflow creation and deletion are dynamic. The availability of the connection is increased since data can be transmitted on different subflows in the event of failure. Subflows are unidirectional, so that transmission can be asymmetric with regards to path selection and usage. However the use of asymmetric links might impair the user experience of conversational services. There may also be problems with subflows traversing middle boxes like [CG] NAT.

Port identifiers can be set the same for all subflows, so that the complexity of managing them is confined to the MPTCP layer, and the application layer can remain MPTCP-unaware. Implementing an MPTCP based solution only requires (software) changes to the end systems (Gateway and Web server).
The destination end could be a MPTCP-aware server (not widely deployed at the moment), or an MPTCP proxy in the operator’s network. This MPTCP proxy (e.g. in the HAG) could behave as an MPTCP server for Hybrid Gateways and as a regular TCP client towards MPTCP unaware servers. This would be an extra expense for the Operator but would allow them to tune hybrid traffic and provide user value.

8.4.1 MPTCP OPERATION

Policy based packet forwarding is not standardised as part of MPTCP. Packet forwarding policies need to be specified by the operator and configured in the Hybrid Gateway, for instance via remote management (TR-069).

Multipath Congestion Control attempts to optimise MPTCP performance over the entire set of paths. The biggest problem is common bottlenecks, i.e. bottlenecks that affect subflows that share a physical path. MPTCP enables any number of subflows to be dynamically created and deleted, not just the two of a normal hybrid access scenario. MPTCP can provide more bandwidth by using subflows over a larger number of physical paths.

The first step is to find a number of “Equal Cost” paths for MPTCP to use - this is a routing problem, not MPTCP’s. A joint congestion control algorithm can then be used. RFC6356 (“Coupled Congestion Control for Multipath Transport Protocols”) provides the multipath extension to the regular TCP single path congestion control. The algorithm uses estimates of loss rates and round-trip time (RTT) for each subflow, and then computes the target rate and the ramp-up parameters to configure the aggressiveness used in achieving the desired rate.

However, the goal of this algorithm is to set the multipath flow's aggregate bandwidth to be the same as a regular TCP flow would get on the best path available to the multipath flow, whereas the aim of Hybrid Access is to increase the bandwidth available to each user, not merely make it more reliable.

8.4.2 PROS AND CONS

The pros and cons of MPTCP are summarised in the below Table.

<table>
<thead>
<tr>
<th>Pro</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Defined (IETF RFC 6824, IETF RFC 6356)</td>
<td>• Current implementations do not exploit MPTCP’s full potential</td>
</tr>
<tr>
<td>• Implemented</td>
<td>• Simple implementations may not provide significant advantages over regular TCP</td>
</tr>
<tr>
<td>• Can be implemented end-to-end avoiding deployment of a new network element (HAG)</td>
<td>• Policies need to be created and tuned by the Operator. No standard to help.</td>
</tr>
<tr>
<td>• Works on a per application basis, so can perform dynamic, per application steering.</td>
<td>• Requires 2 IP addresses</td>
</tr>
<tr>
<td></td>
<td>• Jitter and latency will be greater than that of the highest of the 2 paths</td>
</tr>
<tr>
<td></td>
<td>• Only works for TCP</td>
</tr>
</tbody>
</table>
8.4.3 MPTCP Conclusions

MPTCP as currently specified is not sufficient for all Hybrid Access Use Cases – in particular there is a need for a better way of doing packet-based muxing, and its use is obviously limited to TCP-based applications. However it does have the major advantages of not requiring a new network element (the HAG), and already being deployed to some extent, although of course a HAG can still be used where it acts as an MPTCP proxy.

8.5 UDP

UDP does not support packet re-ordering, so a higher layer protocol is needed to do this. One solution could be RTP, since this provides a time stamp that could be used for this purpose. Another solution might be SCTP as this provides multi homing, session control, sequencing and reordering. However this would have a major impact on applications, and so would not be deployable in the near future.

8.6 Traffic Steering

8.6.1 Static Steering

The simplest traffic steering solution is based on static rules per flow type. Path assignment rules are statically configured in the Hybrid Gateway, as factory defaults or through remote management. Static steering rules can of course also be changed via remote management, and in advance of a service being used. A default route must be specified when a flow type is not recognised.

One issue is what to do when a traffic steering rule cannot be met. For example a static rule might specify that all YouTube and all Netflix traffic should go on the fixed path. However this might exceed the capacity of that path. Options include blocking one or more of the flows, or performing packet by packet steering to send the excess traffic on the mobile path. Note however that the latter may have charging implications which the user needs to at least be made aware of. It also begs the question of how the HAG knows that the available bandwidth has been exceeded; while this could of course be statically configured, it would need to be able to be updated (due to DLM or rate adaptation), and it requires the HAG to do per customer rate monitoring over an appropriate timescale.

Rules for static steering can be based on a wide variety of parameters; some examples are provided in the following.
8.6.1.1 **Per Device**

This Use Case involves the owner of a games machine (e.g. X-Box) who wants to play real-time games over the Internet. They would need all of the X-Box traffic (in both directions) to flow through the fixed path for minimum latency. The rule that would need to be configured in both the Hybrid Gateway and HAG could simply be to steer based on the IP address of the X-Box.

8.6.1.2 **Per Application (Service)**

This Use Case applies where a movie service allows both download and streaming. The streaming would need to go over the fixed path to minimise jitter and error rate, whereas downloads could be sent via LTE. In this case the IP address of the source would not be sufficient to distinguish the 2 types of traffic. While LTE download would protect the streaming, it can have cost implications, and so it might be better to do the download over the fixed path as well, if enough bandwidth was available. This would however need a dynamic rather than a static rule.

8.6.1.3 **Per Application (Service) Per Stream**

This is where a subscriber uses an operator-provided VoIP telephony / video telephony service as well as a 3rd party service like Skype. In this case, all audio-visual streams, regardless of the application, should flow over the fixed path to minimise latency, jitter and error rate.

8.6.1.4 **Per Packet**

Per packet steering could be achieved by means of a static rule without any concept of flow or application type. For instance, the rule could be that fixed percentages of packets should be sent to each path based on each path’s nominal bit rate.

8.6.2 **Dynamic Steering**

In the dynamic steering model the Hybrid Gateway and/or HAG makes packet-by-packet decisions about how to route data.

A simple example is where traffic up to a configured limit is sent on the fixed path, and only the excess traffic is sent over the mobile link. Rules could be made more sophisticated by specifying constraints on a per application basis, or by time of day. Another option is to steer based on bit rate, latency and jitter targets.

8.6.2.1 **Per Packet**

Decisions about which path to use will be taken packet by packet. At the far end, packets may need to be re-ordered. This will have an adverse impact on latency and jitter. As noted above, MPTCP supports re-ordering.
8.6.3 ADVANCED CASES

The above functionalities and associated rules can be combined. For instance, the X-Box and the movie service examples do not overlap and can be implemented at the same time. Other dynamic rules, which can be used in combination with any of the above, are given below.

8.6.3.1 OVERALL USAGE (MONTHLY MEGABYTE LIMIT)

In this case the user specifies a limit (n Megabytes) for a given traffic type over a specific path – usually the mobile path. When this limit is reached, any further download is only carried out via the fixed path, but only when capacity is available and other applications e.g. video streaming, would get priority.

8.6.3.2 TIME-OF-DAY (ToD)

There could be advantages in shifting traffic between the fixed and wireless paths based on time of day. For example, available access network bandwidth could be reduced at peak periods, and traffic could be shifted to the wireless path.

8.6.3.3 SYMMETRIC / ASYMMETRIC STEERING

Symmetric steering is appropriate for conversational services, for instance VoIP telephony should go via the fixed path in both directions to provide the same user experience to both communicating parties.

8.7 VOICE

The applicability of hybrid access to voice may not be obvious. However if an operator wishes to move their primary voice service away from the PSTN, then the availability of a residential Broadband service may not be sufficient. Having an alternative, LTE path as a backup could then be very useful.

Note that running a voice call on both paths simultaneously is strongly discouraged.

An issue regarding voice and hybrid access that need to be addressed is support for a lifeline voice service; this may require battery back-up (if not already present), and require providing location information to the emergency services.
9 SUMMARY AND CONCLUSIONS

Hybrid Access may be appropriate to address some or all of the following:

- Increase bit rates in areas which currently suffer from poor ADSL coverage i.e. help to address the digital divide, or meet regulatory targets.
- Provide higher rates in VDSL areas for enhanced service support, or as a competitive response.
- Increase service availability for critical applications, such as emerging Smart Home services, a post-PSTN voice service, and small businesses e.g. to provide POS connectivity.
- To provide at least an interim service before high-speed, wired connectivity becomes available in an area.

However there are a various choices that need to be made, in particular whether to adopt an HHG-only architecture, or full blown Hybrid Access which requires a new network element, the HAG; this is not just an architecture issue – there are also commercial (who owns and runs the HAG ?) and performance implications. A related question is whether the solution needs to support both converged, and separate fixed and mobile operators.

The main consideration in the customer premises is whether to adopt a single box architecture (HG with embedded LTE modem) or have a separate LTE device. In the latter case, the main issues will be the box interconnect, and the impact on management and diagnostics; note that the HHG still has to control the traffic steering in this case.

The following developments are needed:

- Operators need to develop their own traffic steering policies. This may involve the near real-time determination of the properties of the different accesses.
- There needs to be a standard mechanism for distributing these policies to the HAG and the HHG.
- Diagnostics and troubleshooting that take into account the dual access. Combined management of the fixed and mobile access is also highly desirable; these currently use different management systems.

Finally the following need to be taken into account by Service Providers:

- Providing sufficient LTE network coverage and capacity. For example, is capacity needed to support widespread HD streaming, or is Hybrid Access a more niche service, which might have little impact on mobile network capacity?
- Can video streaming be done successfully over a dual path, given the different transport properties of fixed and mobile networks?
- Any regulatory constraints with regard to the bonding mechanisms that can be used, for example some wholesale network operators may not be allowed to offer L3 bonding.
- The extent to which the end user is made aware of the dual access, and the control, if any, they are allowed with regard to path selection.
10 BIBLIOGRAPHY