

 **Analysys**
BSG
Broadband
Stakeholder
Group

Green Paper

Predicting UK Future
Residential Bandwidth
Requirements

May 2006

BSG Green Paper: Predicting UK Future Residential Bandwidth Requirements

FOREWORD

This Green Paper has been prepared by the Broadband Stakeholder Group (BSG) as a contribution to the growing public debate about the potential requirement for further investment in next generation access infrastructures in the UK.

Most observers agree that as the take-up of broadband services increases and as new rich media content, services and applications emerge, demand for bandwidth by households will grow. However, it is not clear by how much or how quickly this will happen.

To help focus the debate further, the BSG has developed a scenario-based analysis of bandwidth requirements for 2008 and 2012 based on a set of key assumptions. However, it recognises that, while this may provide an informed and reasonable forecast, the results must be read with some caution for a number of reasons:

- Making predictions about the uptake and demand for any new technology is fraught with difficulties and predicting demand for bandwidth is particularly challenging. Future bandwidth requirements will be dependent upon a wide variety of variables, some of which we know and can predict, others that we know but can't predict, and some that we simply don't know. The methodology developed in this study attempts to create a logical framework to address this uncertainty. However, the conclusions are likely to be imperfect at best when tested against future events.
- Many assumptions have been made about technology development and changes in behaviour. In particular, key assumptions have been made about the demand for high definition video, the development of compression technologies, the tolerable transfer times for large files and the use of local storage and intelligent personal video recorders (PVRs). Changing the assumptions made about these critical variables could significantly affect the results.
- A key assumption was the unconstrained availability of bandwidth at affordable cost. The study considered how different types of 'IT literate' households might behave in a situation where the bandwidth available to them was unlimited.

Methodology

A working group was formed drawing upon the expertise of the BSG's broad membership to develop and agree a methodology.

- The working group firstly identified potential applications and services based on the expected future availability of consumer electronics services and equipment and their likely use by different user types.
- The group then extracted the 'elemental data flows' required for the delivery of these applications and services and established a view on an acceptable level of performance for each flow in the short (2008) to medium term (2012).

- The resulting data was passed to independent consultants who established the bandwidth requirements of various types of households, based on their likely concurrent use of the assumed applications and services.

The results, as presented in the attached report, are now being opened up for wider comment. In this respect, it is important to stress what this report does and, more importantly, does not do.

It does:

- Provide a scenario-based analysis of potential bandwidth requirements for 2008–2012 based on a set of key assumptions.
- Examine requirements of example broadband enabled households by looking at the usage patterns of relatively IT-literate individuals.
- Break down the day into three-hour blocks to examine concurrency while minimising complexity.
- Focus on the major bandwidth-hungry applications.
- Assume that spending power is unconstrained in application usage

It does not:

- Come up with an average household usage profile that will allow estimation of national demand.
- Consider individuals when away from the home.
- Forecast broadband penetration.
- Provide a minute-by-minute analysis of usage.
- Specify every application used regardless of bandwidth requirements.
- Predict bandwidth requirements for applications that are yet to be fully developed or understood.

Most importantly, the Green Paper does not constitute a business case for the deployment of next generation access services by any party, public or private. No consideration was made of the commercial case for deploying such services or of the value to the UK economy of such services being available.

Results

Based on the methodology developed by the BSG working group, the calculations of bandwidth requirements for the different elemental flows (which were estimated from first principles and industry data) and the assumptions made about the use of potential services and applications, a set of results was generated for 11 different household types for 2008 and 2012, which constitute the 'early majority users' (i.e. the 34% of users after innovators and early adopters).

The headline results for this group of household types are that:

- By 2008, the bandwidth demand for the most bandwidth intensive households could reach 18Mbit/s downstream and 3Mbit/s upstream.
- By 2012, the bandwidth demand for the most bandwidth intensive households could reach 23Mbit/s downstream and 14Mbit/s upstream.

Sensitivity

The research concluded that bandwidth demand is dominated by applications and services built on video flows and large file transfers and the results are particularly sensitive to the assumptions made about the introduction of high definition video and consumer tolerance of delay in download times. There are a number of mitigating factors that could significantly reduce the bandwidth required to deliver these applications and services, such as:

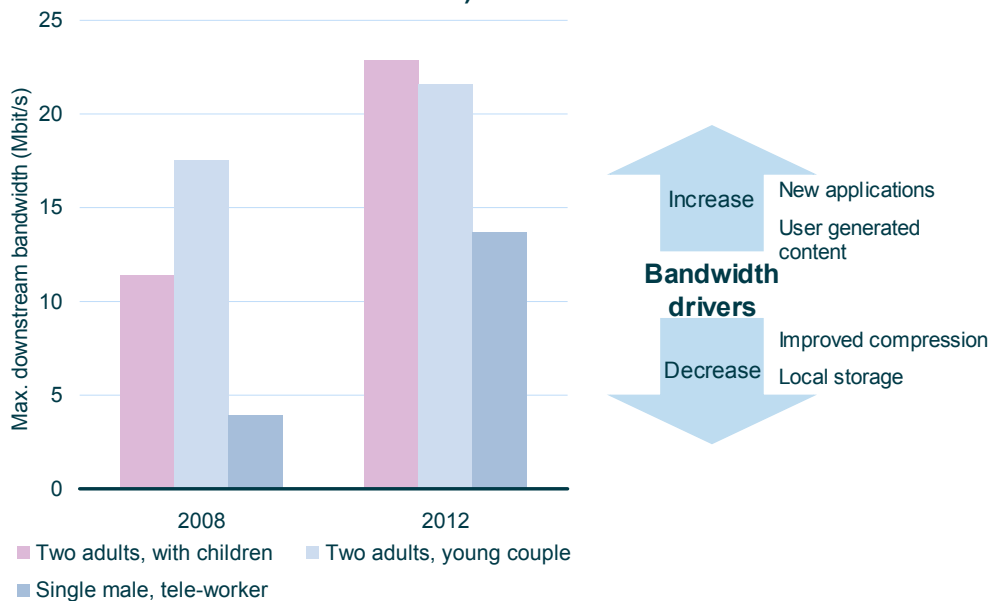
- Non-time critical applications could be delivered more slowly which could significantly reduce upstream bandwidth requirements.
- Advances in compression technology could lower the video bandwidth requirements.
- The use of high definition (HD) video flows might develop more slowly than was assumed.
- The development of hybrid solutions exploiting local storage and intelligent personal video recorders (PVRs) could temper the downstream time critical peak bandwidth requirements of some entertainment services.

However, there are a number of factors that could further increase bandwidth requirements:

- Innovation is likely to lead to the emergence of new unforeseen services that could increase the requirement for concurrent flows.
- The development of user-generated content (as has been seen in other markets, particularly Asia) could increase demand for upstream as well as downstream bandwidth.

These competing pressures have not been modelled explicitly, and clearly they could increase or decrease bandwidth use. However, given our best understanding of the likely technical developments and probable trends in human behaviour, we believe the headline forecast to be reasonable.

Maximum downstream requirements (three most bandwidth intensive households)



Next steps

We do not expect that there will be complete consensus about the validity of these results. Some will argue that the bandwidth estimates are too conservative, others that they are excessively high. As stated above, by changing the assumptions used in the study, it would be possible to generate quite different results.

Since the primary objective of this Green Paper is to stimulate further discussion on future demand for residential bandwidth in the UK, the BSG would welcome further comment, thoughts and ideas from all interested parties about additional factors that could have an impact upon these findings.

Antony Walker
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BSG Green Paper: Predicting UK Residential Future Bandwidth Requirements

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Annex A: estimation of elemental flow bandwidths

Annex B: detailed household results

By 2012 household bandwidth demand reaches 23Mbit/s downstream and 14Mbit/s upstream, but ‘time criticality’ of applications means that 3Mbit/s upstream may be sufficient

Total bandwidth demand

Household	2008 max. (Mbit/s)		2012 max. (Mbit/s)	
	up	down	up	down
A: Single adult, retired	0.03	3.8	0.9	7.9
B: Two adults, retired	2.7	3.8	3.0	11.4
C1: Single male, weekday	2.7	4.0	2.7	3.0
C1: Single male, weekend	2.7	3.8	2.7	7.5
C1: Single male, tele-worker	2.8	3.9	14.0	13.7
C1: Single male, entrepreneur	2.9	3.9	3.8	7.9
C2: Single female	2.7	4.0	2.7	3.0
D: Two adults, empty nesters	2.7	3.8	2.7	13.5
D: Two adults, young couple	2.9	17.5	14.1	21.6
E: Two adults, with children	2.8	11.4	13.7	22.9
F: Single parent	0.2	3.9	0.7	7.9

Time critical bandwidth demand

Household	2008 max. (Mbit/s)		2012 max. (Mbit/s)	
	up	down	up	down
A: Single adult, retired	0.03	3.8	0.4	7.9
B: Two adults, retired	0.03	3.8	0.6	7.7
C1: Single male, weekday	-	3.8	-	0.2
C1: Single male, weekend	0.1	3.8	0.4	7.5
C1: Single male, tele-worker	0.2	3.9	0.4	7.7
C1: Single male, entrepreneur	0.3	3.9	1.1	7.9
C2: Single female	-	3.8	-	0.2
D: Two adults, empty nesters	0.2	3.8	0.8	7.5
D: Two adults, young couple	0.0	3.9	0.8	8.3
E: Two adults, with children	0.3	11.4	0.9	22.9
F: Single parent	0.2	3.9	0.7	7.9

With less than 1Mbit/s upstream, large file transfers may be intolerable

- By 2012, bandwidth requirements reach:
 - 23Mbit/s downstream
 - 14Mbit/s upstream
- However, of the 14Mbit/s upstream, only 1Mbit/s is needed for time critical applications
 - taking a pragmatic view on tolerable transfer times for large files suggests around 3Mbit/s upstream may be sufficient for most users
- These results are strongly dependent on assumptions regarding SDTV and HDTV:
 - timing of MPEG-4 launch and availability of HDTV is key
 - improvements in compression techniques could lower bandwidth requirements but this is difficult to predict
- The size of large file transfers, and time taken to down/upload, is an important factor in both up and downstream requirements

A significant percentage of UK homes may not be able to receive such downstream speeds using current technology/networks

- The highest downstream demands are around 20Mbit/s and services of this speed are unlikely to be available to more than 50% of UK households with existing networks:
 - ADSL2+ cannot currently offer speeds in excess of 20Mbit/s beyond 1.5km from the exchange (in ideal conditions), although the performance of xDSL technologies may continue to improve between now and 2012
 - the cable networks can support similar speeds and cover around 45% of UK households
- Time critical upstream data requirements are likely to be within the range of xDSL technologies and the cable networks:
 - should demand for high-quality upstream video emerge (for example, through online gaming) the time critical element may increase rapidly
 - consumer tolerance to lengthy upload times for large files, and the impact this could have on the attractiveness of teleworking, will prove to be the key factors in whether available upstream speeds are sufficient

Local storage and intelligent PVRs could temper time-critical peak bandwidth requirements that are entertainment driven

- Many of the downstream bandwidth requirements are entertainment driven (e.g. through multiple streaming videos)
- Network operators and service providers could adopt a hybrid storage-based approach to lessen the reliance on high downstream bandwidths
 - the end-point in the UK is likely to be somewhere between ‘home storage’ (Sky+) and ‘home streaming’ (Homechoice, ntl/Telewest)
 - the first signs of this are emerging with Sky’s purchase of Easynet and the launch of PVRs by ntl/Telewest
- This does not affect *ad hoc* file transfers and some video content will still be streamed, such as promotional/marketing content from websites and educational content
- Under this hybrid approach, the entertainment based bandwidth requirements would be lower than forecast and demand on the core and access networks would be more under the control of the service provider
 - the upstream bandwidth demand will be unchanged

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Annex A: estimation of elemental flow bandwidths

Annex B: detailed household results

This study examines estimates bandwidth requirements in 2008 and 2012 for example households in the UK

- The Broadband Stakeholder Group (BSG) Research and Metrics Working Group has been examining bandwidth drivers in UK households for 2008 and 2012:
 - Analysys has been asked to consolidate the different opinions and views expressed by the members of the Working Group to provide a reasonable view of the future bandwidth requirements of UK households
 - this study considers a time-of-day analysis for example households (categorised by number and age of inhabitants) rather than estimating aggregate national demand
- The BSG has provided two key inputs to this work:
 - **applications expected to be used in 2008 and 2012:** the members of the BSG submitted lists of applications which were likely to be in use by households in 2008 and 2012. We have consolidated these lists into a single list of application categories (rather than individual applications, which would constitute a much longer list) used to inform the activities of our example households
 - **elemental flows:** each application can be thought of as a combination of data, audio and (streaming) video flows. The BSG has decided upon a list of approximately 30 such ‘elemental’ flows, which have been examined in detail during this study and form the basis for estimation of bandwidth requirements by application

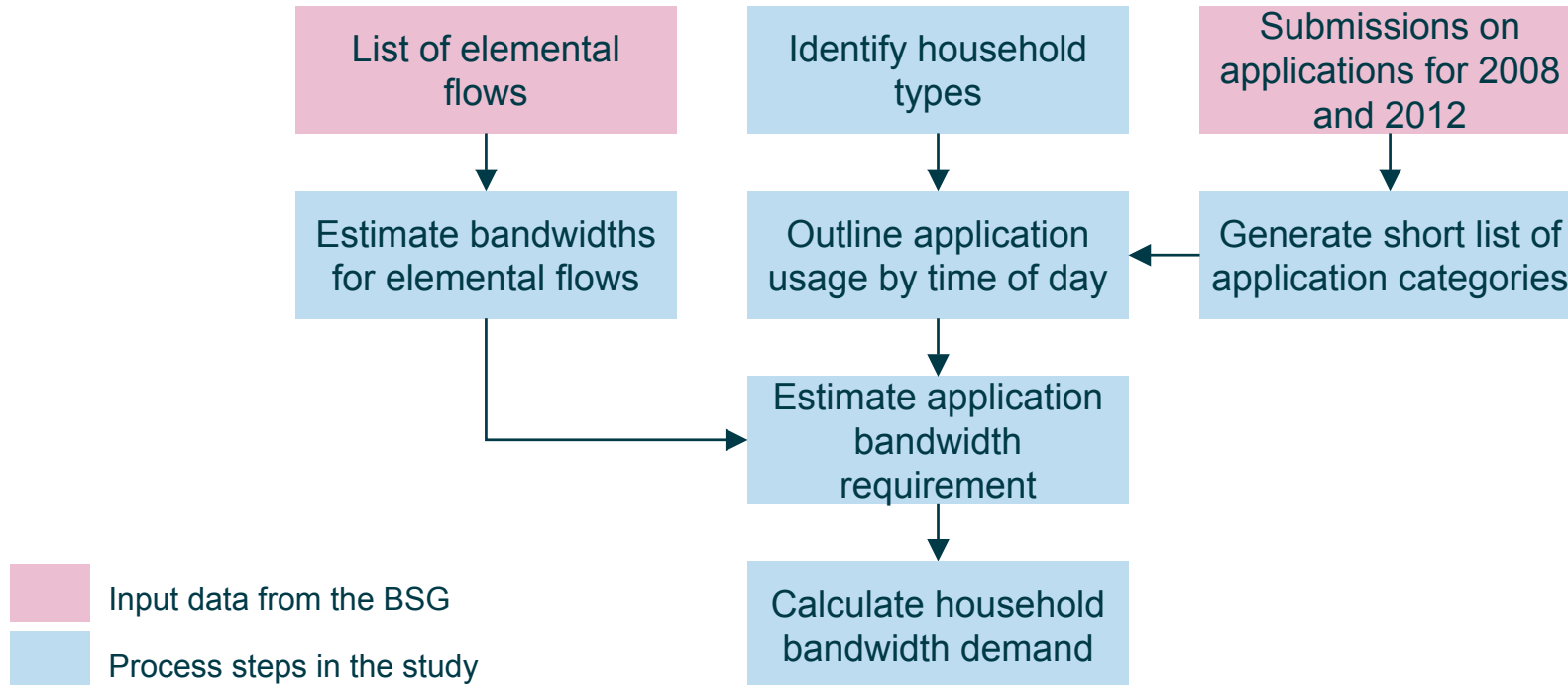
The scope of the study has been agreed with the BSG and provides a framework for a consistent scenario analysis

- This project does:
 - ▶ carry out a scenario-based analysis of bandwidth requirements for 2008 and 2012 based on a set of key assumptions*
 - ▶ examine requirements of example broadband enabled households by looking at the usage patterns of IT-literate individuals
 - ▶ break the day down into three-hour blocks to examine concurrency while minimising complexity
 - ▶ provide a relatively conservative view of demand
 - ▶ focus on the major bandwidth-hungry applications
 - ▶ assume that spending power is unconstrained in application usage
- This project does not:
 - ▶ come up with an average household usage profile which will allow estimation of national demand
 - ▶ consider individuals when away from the home
 - ▶ forecast broadband penetration – we consider ‘early majority’ users (the 34% of consumers after ‘innovators’ (2.5%) and ‘early adopters’ (13.5%))
 - ▶ consider a minute-by-minute analysis of usage
 - ▶ specify every application used regardless of bandwidth requirements
 - ▶ predict bandwidth requirements for applications which are yet to be fully developed/understood⁺

** for example, we assume that consumers will still wish to have access to streaming content even though local storage solutions (such as PVRs) will be widely available*

⁺ for example, virtual reality or gaming which requires a high-level of high quality streaming video content

The process for the study is built around the consensus view of the BSG



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We consider seven household types, which cover over 85% of UK households and include a mix of individuals

	<i>Number (000s)</i>	<i>%</i>	<i>Comment</i>
A: one adult, retired	3210	12.9	The least IT-literate category
B: one man & one woman, retired	2500	10.0	
C1: single male, under 65	2320	9.3	Assuming men retire at 65
C2: single female, under 60	1300	5.2	Assuming women retire at 60
D: two adults, no children	5610	22.5	Incl. empty nesters, young professionals and the middle aged
E: two adults, with children	5120	20.6	Incl. adults with young children only, older children only and a mix
F: single parent	1400	5.6	
Total	21 460	86.1	

Excluded from the study are all other households (3+ adults) with or without children and households over 60/65 but not retired

Source: Office for National Statistics, Census 2001

Note: We have assumed that the percentage distribution of households will be the same in 2008 and 2012 as it was in 2001

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Annex A: estimation of elemental flow bandwidths

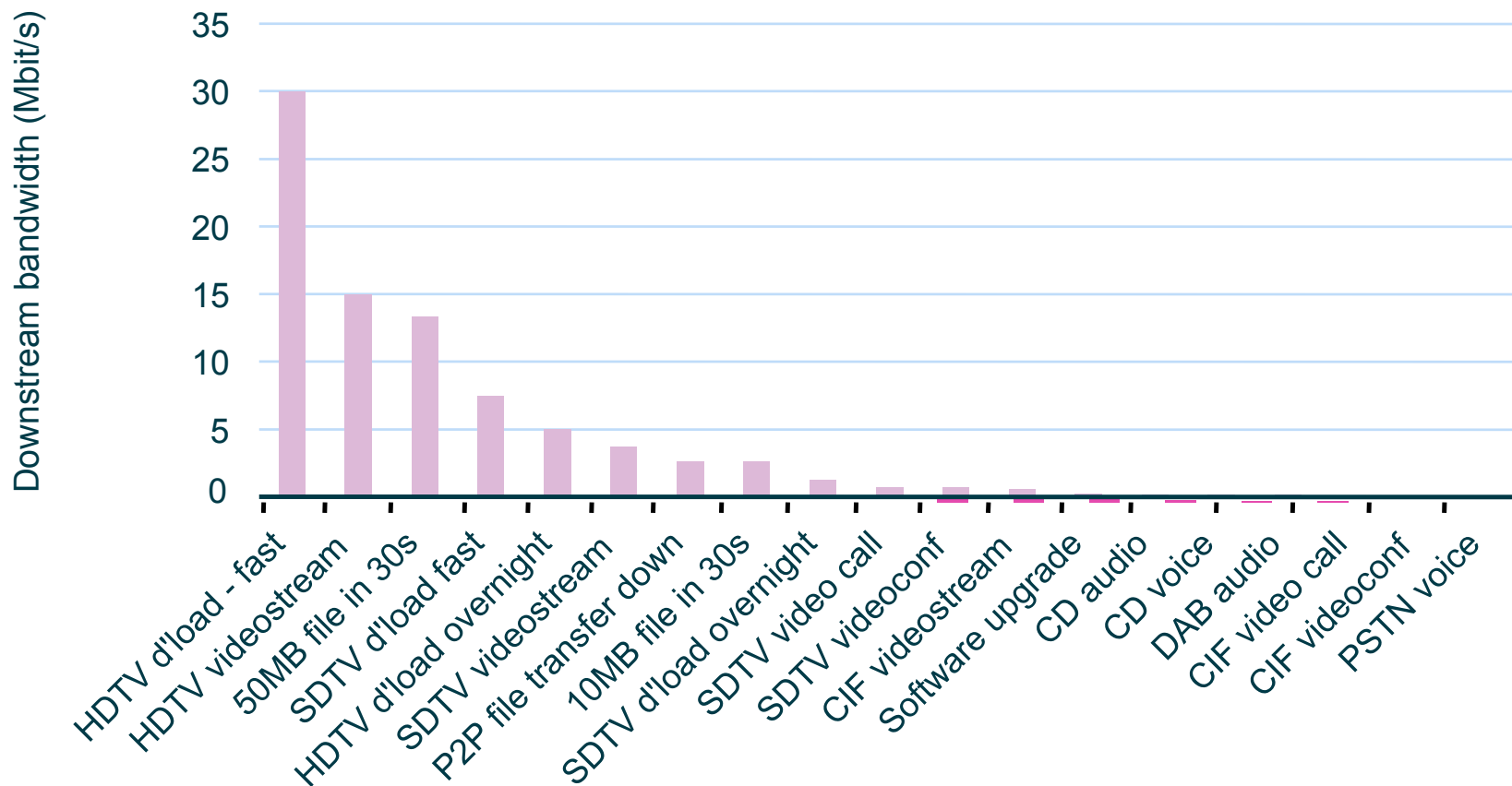
Annex B: detailed household results

Bandwidth requirements have been estimated from first principles and industry data

- We have combined industry data and first principles to estimate bandwidth requirements for each of the elemental flows:
 - the underlying assumptions for these are contained in the final report
- We have assumed that, in 2008, MPEG-2 is used for compressing videostreams and that MPEG-4, which is approximately twice as effective, is used in 2012:
 - SDTV is assumed to require 3.5Mbit/s in 2008 and this falls to 1.75Mbit/s
 - HDTV is assumed to take 15Mbit/s in 2008, falling to 7.5Mbit/s in 2012
 - in reality, some HDTV using MPEG-4 will be available in 2008, as will some SDTV
 - this will not affect the overall results, merely the difference between 2008 and 2012
- Some flows are reliant on the time and file size assumed (e.g. large file transfer, faster than real-time video downloads and P2P file sharing) and these assumptions are examined in a sensitivity analysis at the end of this presentation

The BSG and Analysys have identified in the region of 30 elemental flows with current (2005) downstream bandwidth requirements shown below

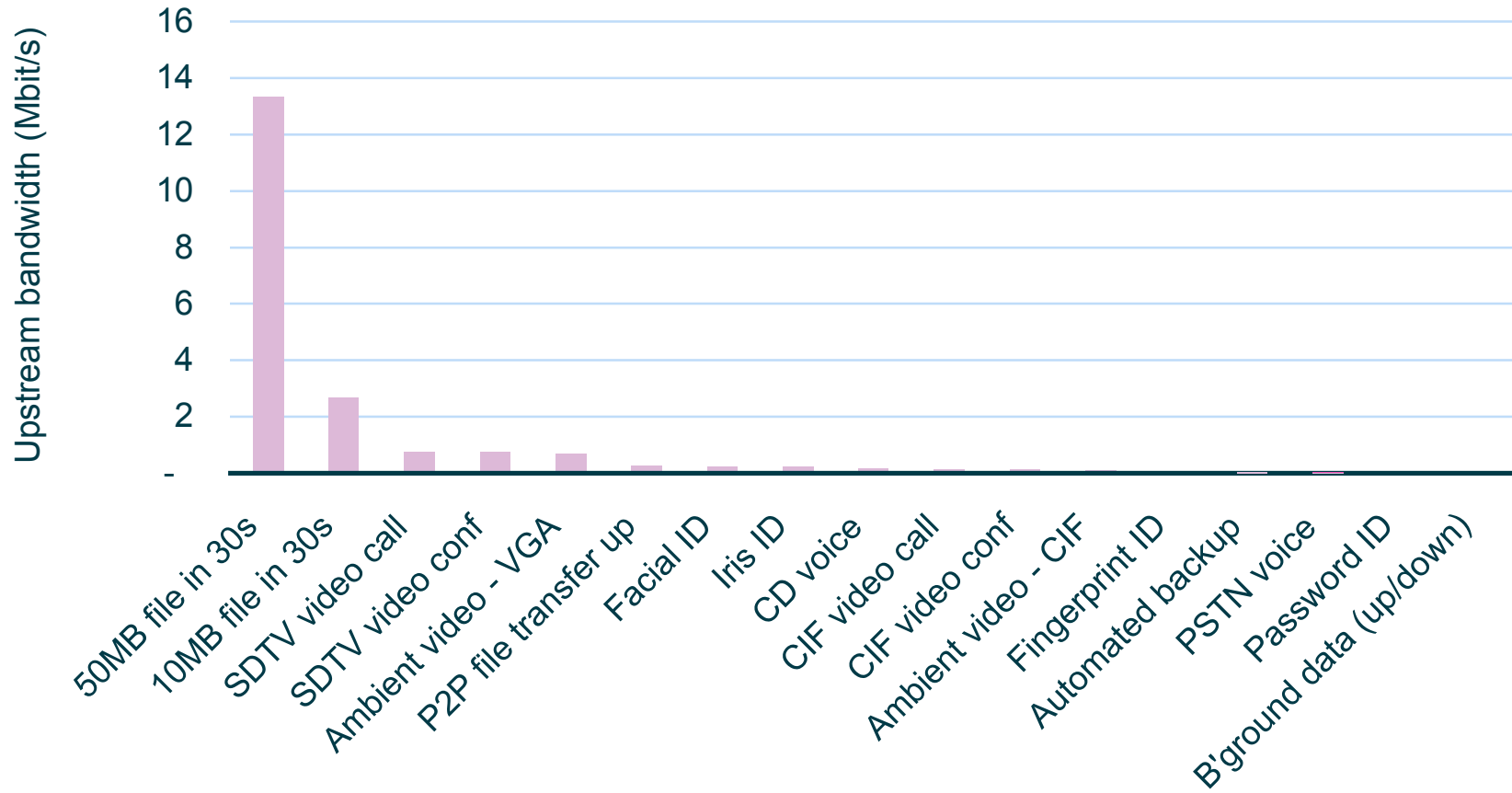
...



Source: BSG, Analysys

Note: not all elemental flows are assumed to have downstream components – in reality, all will but this will be minimal in, for example, automated back-up

... we have also estimated upstream bandwidth requirements, where these are significant



Source: BSG, Analysys

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Drawing on submissions to the BSG, we have arrived at a shortlist of application types which individuals may want to use [1]

- A number of submissions on likely applications to be used in 2008 and 2012 were discussed by the BSG Research and Metrics Group
- We have summarised these in a shortlist of applications of interest to residential users in 2008 and 2012
 - we have used this application list to structure the process of deciding which applications (and, therefore, underlying flows) are used by each household by time of day
 - we have not specifically calculated an average bandwidth required by each type of application (where bandwidth requirements can vary greatly) but have done so for each specific application
- For example, the *large file transfer* application type covers teleworking, user-initiated back-ups or transfers to remote servers, and receipt/transmission of large emails*
- The *electronic consumer services* application type includes e-banking, e-auctions, e-commerce and e-gambling*
- The list of application types, and applications considered, does not include estimation of the bandwidth required by applications which are not yet fully understood or defined: future applications may appear by 2008 and 2012 which are not yet in the latter stages of development or have yet to be developed

**Note: both of these application types are not limited to the examples listed here*

Drawing on submissions to the BSG, we have arrived at a shortlist of application types which individuals may want to use [2]

- Automated back-up
- Video Communication - High Quality
- Video Communication - Low Quality
- Large file download
- Small file download
- Electronic consumer services
- e-mail
- Monitoring – non-video
- Monitoring – video
- multimedia e-mail
- TV over BB - high quality
- TV over BB - standard quality
- TV over BB - low quality
- P2P file sharing
- Interactive TV upstream
- Online communities
- Playing online games
- Hosting online games
- File back-up - Fast
- File back-up - Slow
- Home learning
- Internet Radio - High Quality
- Internet Radio - Low Quality
- Telehealth
- VoIP
- Web browsing

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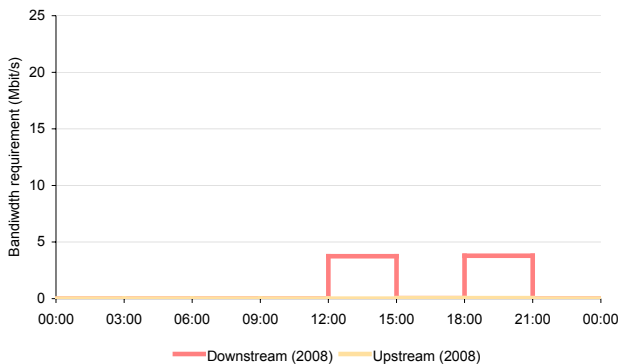
Conclusions

Annex A: estimation of elemental flow bandwidths

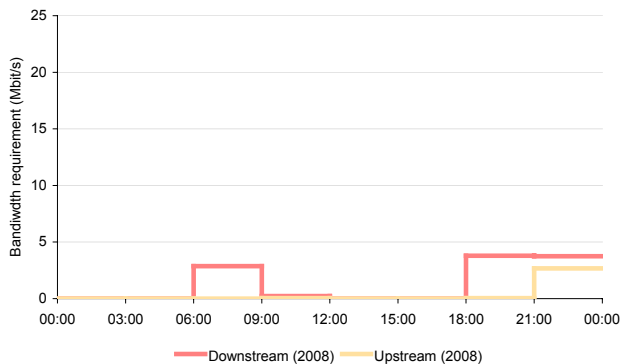
Annex B: detailed household results

2008 results by household [1]

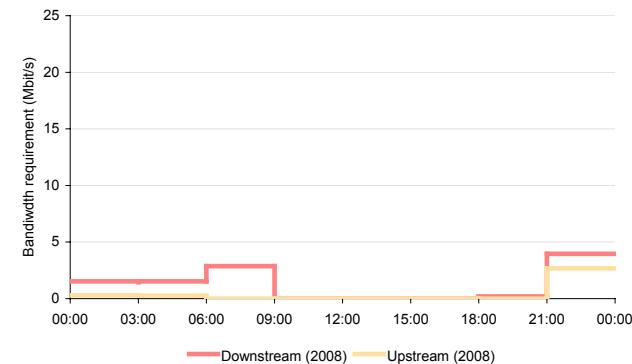
A: one adult, retired



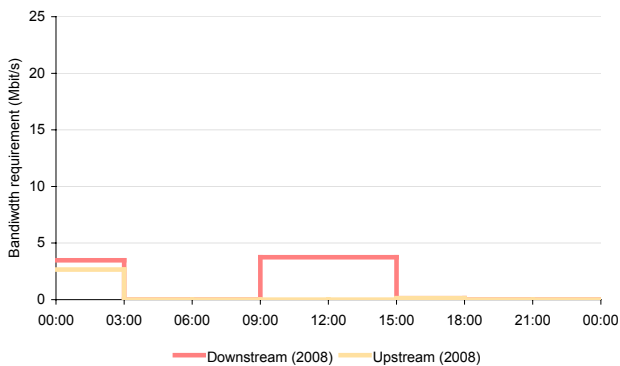
B: retired couple



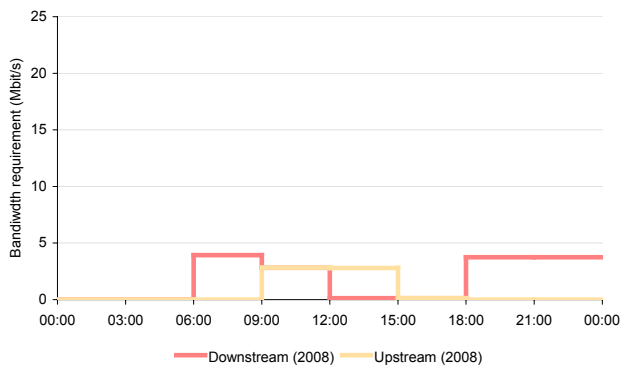
C1: single male, weekday



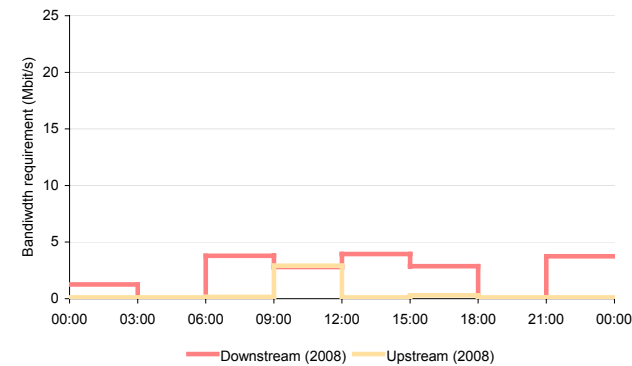
C1: single male, weekend



C1: single male, teleworker

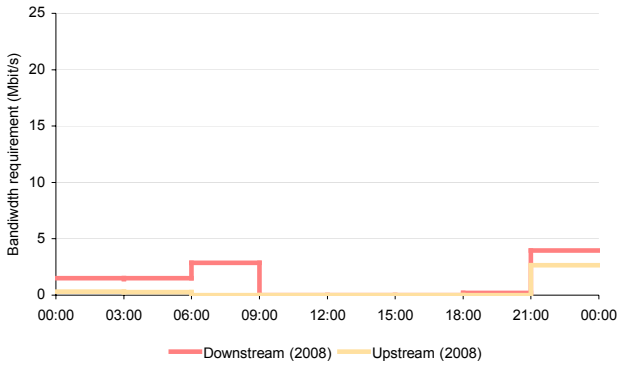


C1: single male, entrepreneur

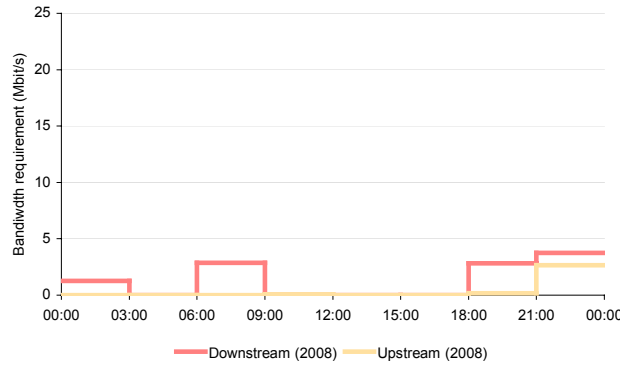


2008 results by household [2]

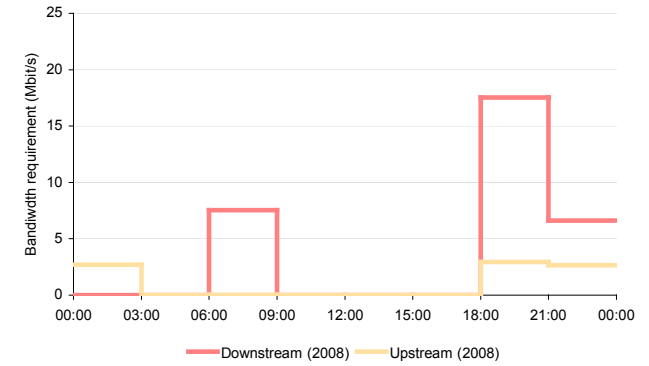
C2: single female



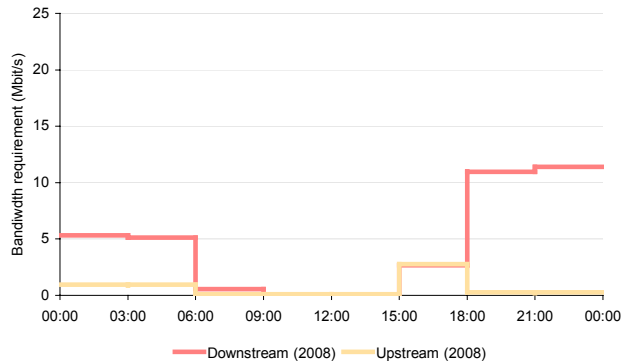
D: couple, empty-nest



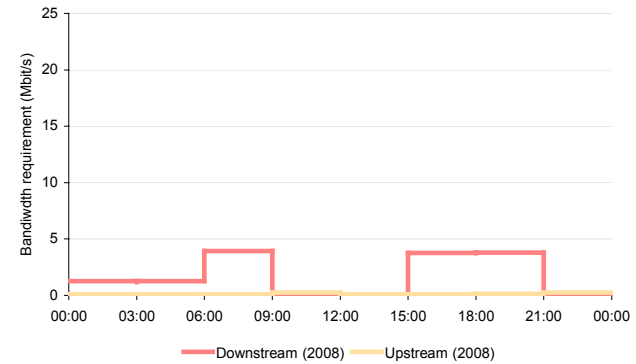
D: couple, no children



E: family

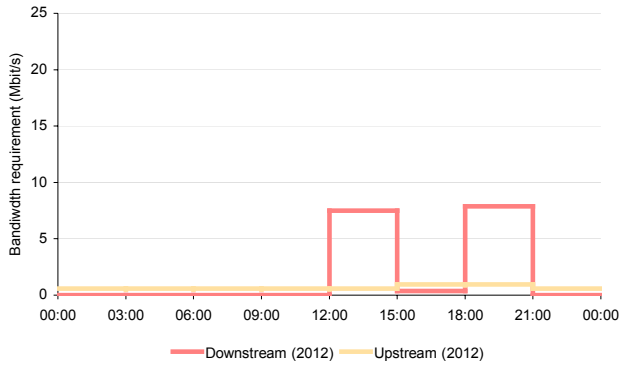


F: single parent

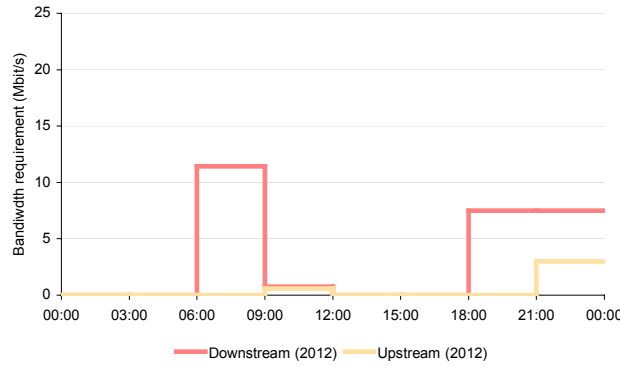


2012 results by household [1]

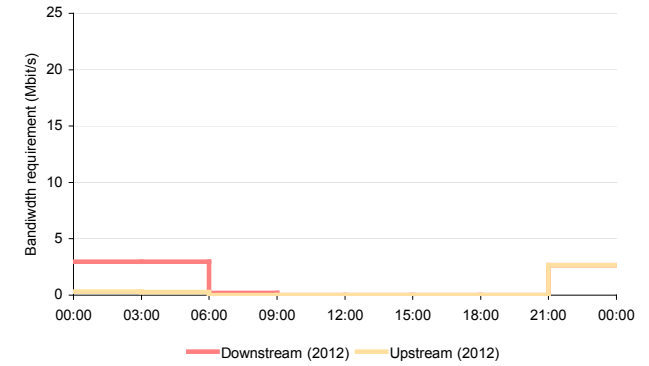
A: one adult, retired



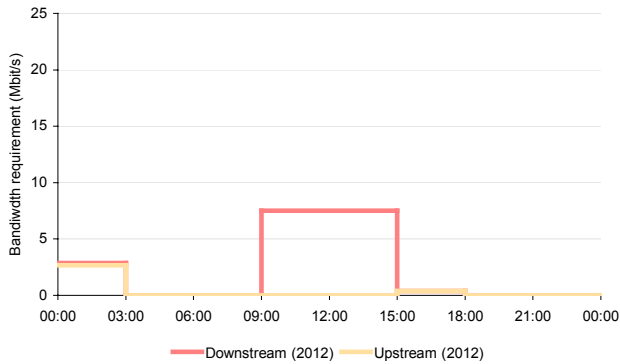
B: retired couple



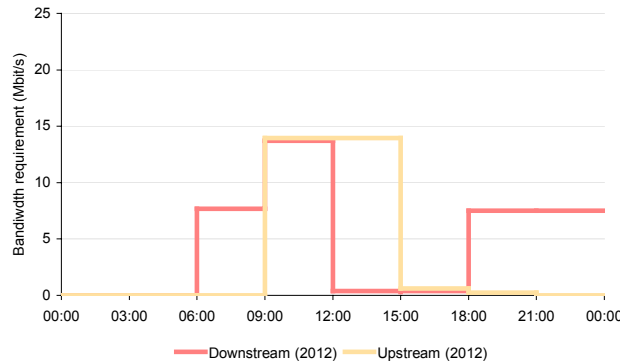
C1: single male, weekday



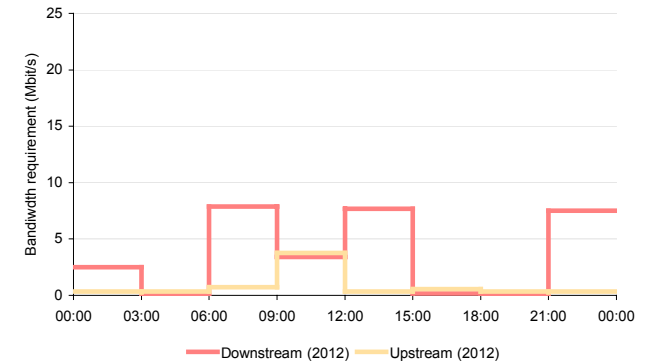
C1: single male, weekend



C1: single male, teleworker

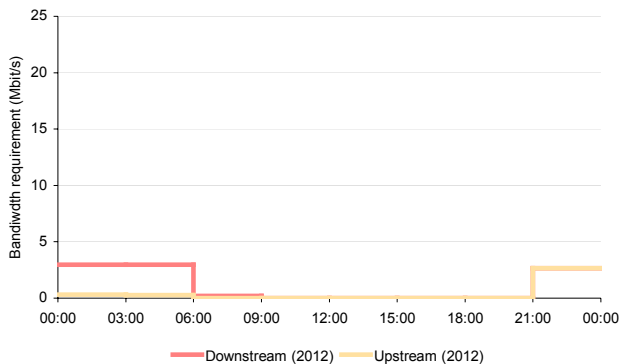


C1: single male, entrepreneur

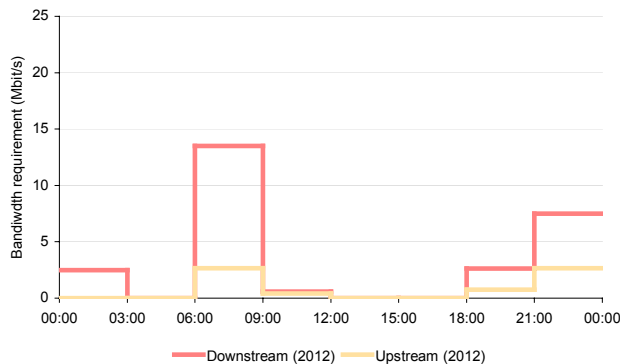


2012 results by household [2]

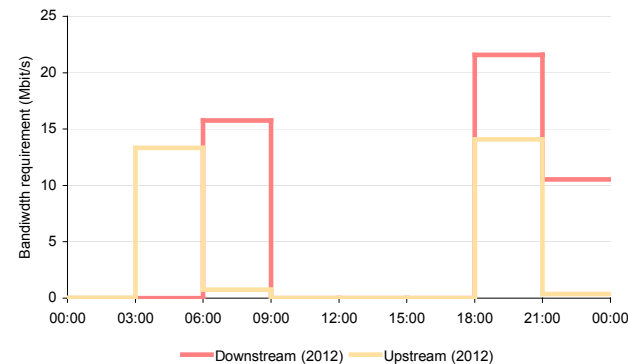
C2: single female



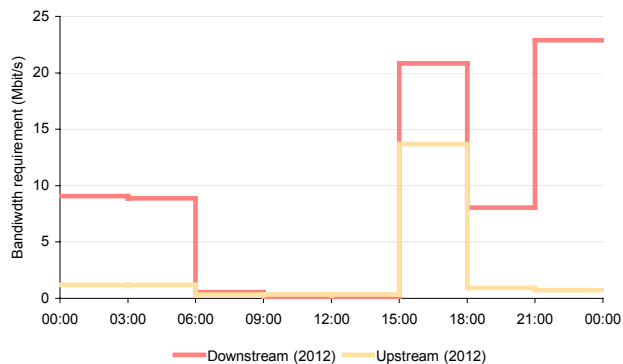
D: couple, empty-nest



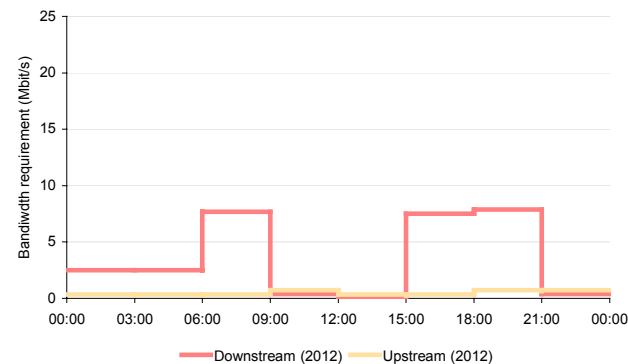
D: couple, no children



E: family



F: single parent

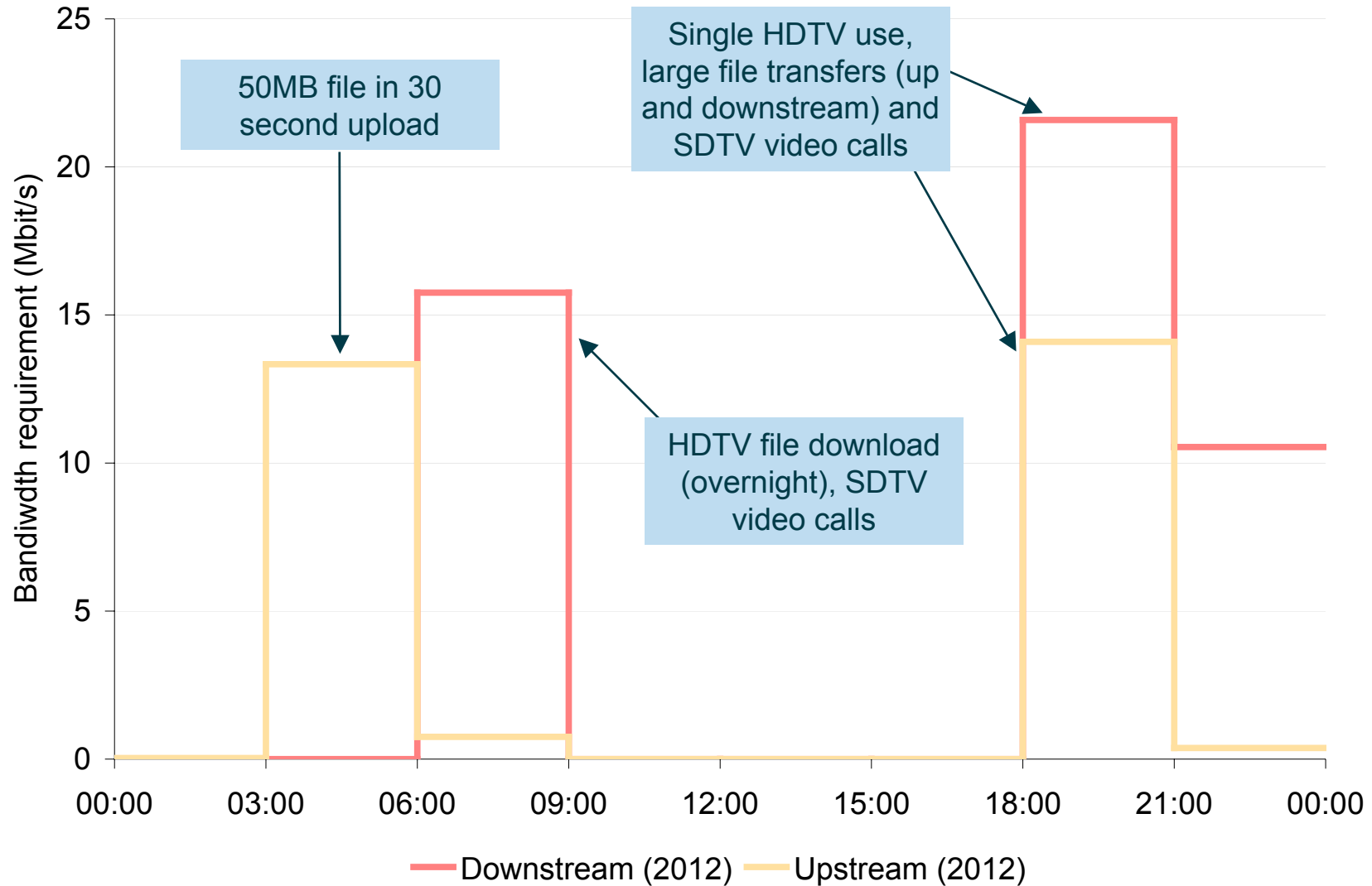


Example: couple, no children, 2012 – usage by time of day

2012	00:00	03:00	06:00	09:00	12:00
James	Online designing	Fast upload of latest designs at 50MB/30s	SDTV videoconference with design team in Beijing	No direct use – at work	
Charlotte	No direct use – in bed	No direct use – in bed	SDTV video call to new client	No direct use – at work	
Together	NA	NA	Download an HDTV movie for travel entertainment	NA	
Background	Automated hard disk back-up to remote storage facility	None	None	Home alarm system	
	12:00	15:00	18:00	21:00	00:00
James	No direct use – at work	No direct use – at work	Online CAD-CAM brainstorming session	SDTV videoconference with clients in the US	
Charlotte	No direct use – at work	No direct use – at work	Working from home – e-mailing, & SDTV video calls	Download materials to review on commute at 10MB/30s	
Together	NA	NA	HDTV	HDTV	
Background	Home alarm system	Home alarm system	None	None	

Further examples can be found in Annex B

Example: couple, no children, 2012 – results



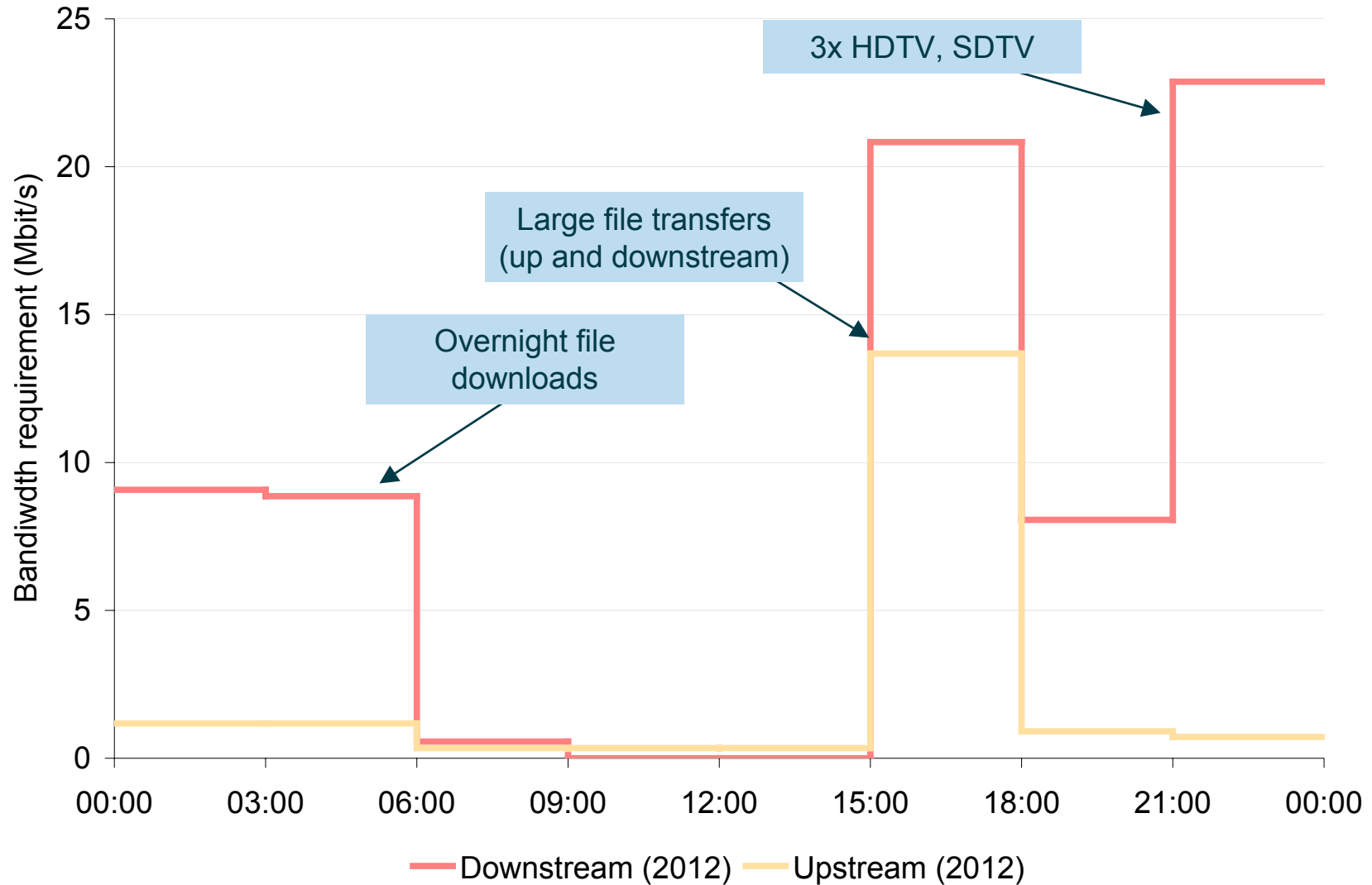
Example: family, 2012 – usage by time of day (am)

2012	00:00	03:00	06:00	09:00	12:00
Peter	No use	No use	Internet radio alarm clock CD quality	No use – out of the house	
Susan	Overnight HDTV Movie download	Overnight HDTV Movie Download	Internet radio alarm clock CD quality	No use – out of the house	
Edmond	Download Music & HDTV Movie	Download Music & HDTV Movie	Internet radio whilst getting up CD quality	No use – out of the house	
Lucy	Download Music & HDTV Movie	Download Music & HDTV Movie	No use	No use – out of the house	
Background tasks	Automated back-up of PC hard drive	Automated back-up of PC hard drive	In house CCTV uploaded to server	In house CCTV uploaded to server	
	In house CCTV uploaded to server	In house CCTV uploaded to server			

Example: family, 2012 – usage by time of day (pm)

	12:00	15:00	18:00	21:00	00:00
Peter	No use – out of the house	No use - Out of the house	HDTV VoD programme whilst making dinner	HDTV VoD	
Susan	No use – out of the house	No use – Out of the house	CD quality VoIP call	HDTV VoD	
Edmond	No use – out of the house	Background research for homework (50MB in 30s downstream)	Interactive Internet revision for exams	SDTV calls to friends	
Lucy	No use – out of the house	Upload graphics design homework at 50MB/30s upstream	SDTV calls to friends	HDTV VoD	
Background tasks	In house CCTV uploaded to server	In house CCTV uploaded to server	In house CCTV uploaded to server	In house CCTV uploaded to server	

Example: family, 2012 – results



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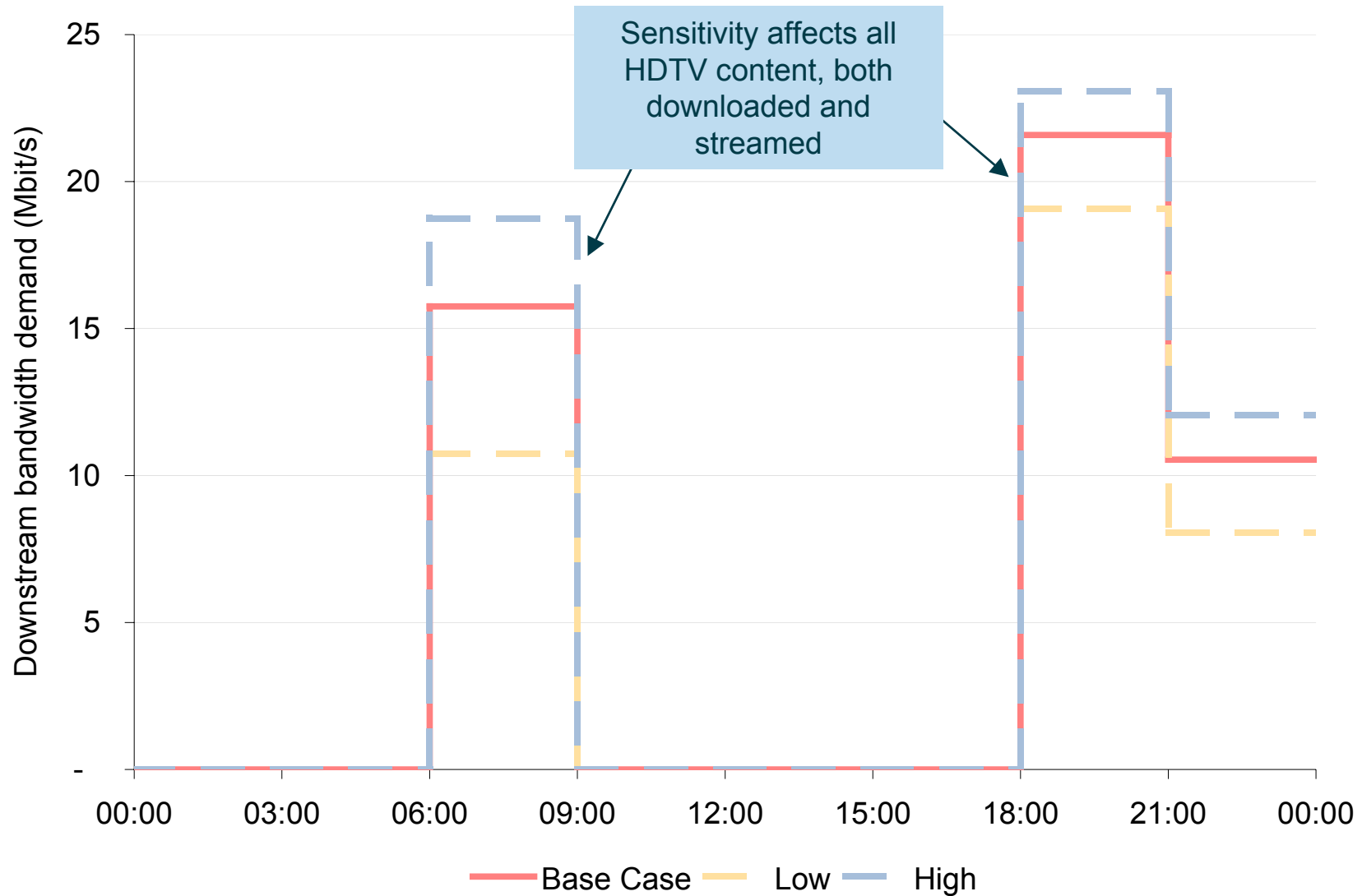
Annex A: estimation of elemental flow bandwidths

Annex B: detailed household results

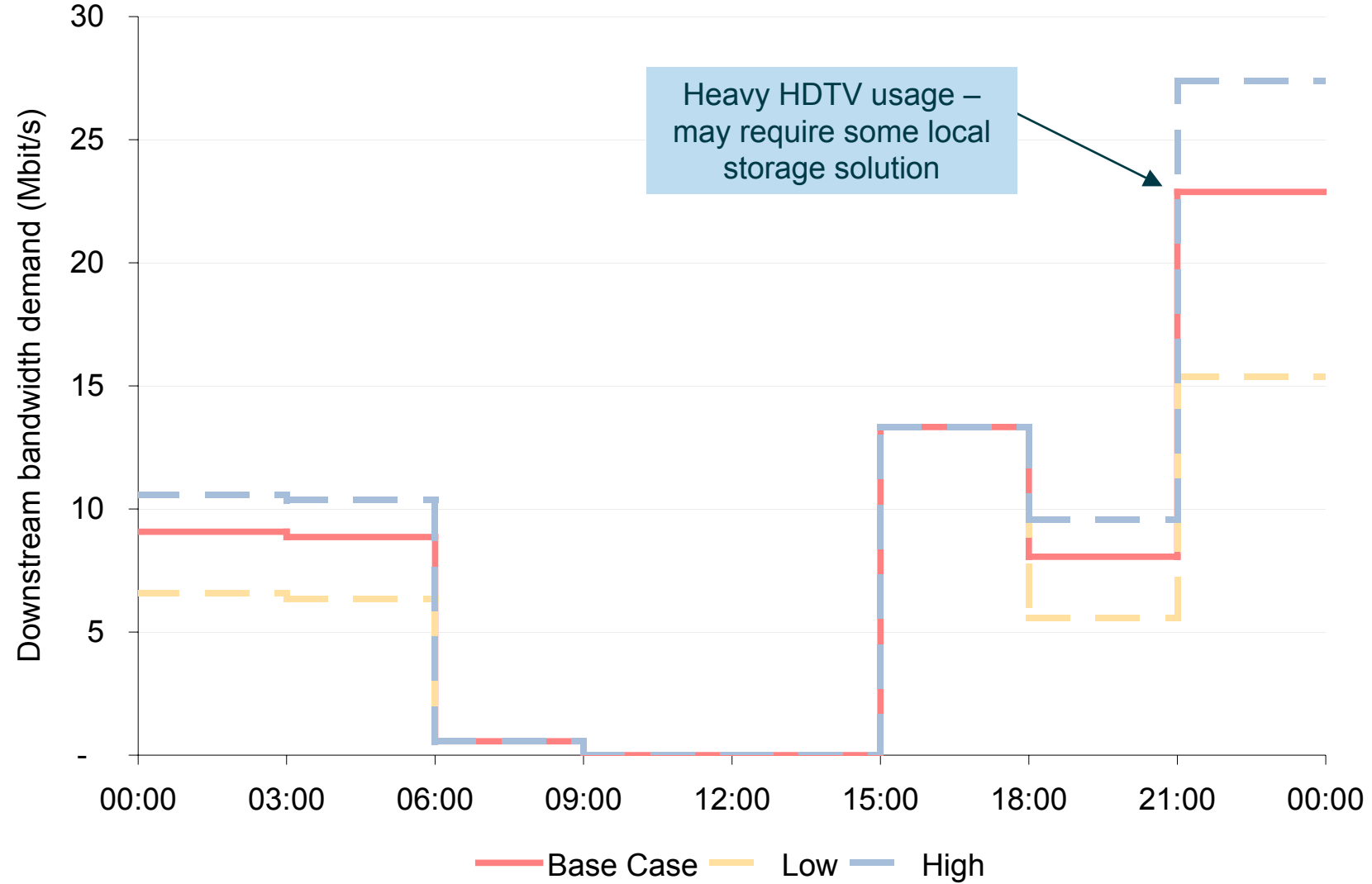
The sensitivity analyses examine the amount of bandwidth which is time-critical and the sensitivity of results to key assumptions

- In this section, we examine two areas of sensitivity in the results:
 - ▶ **time-criticality**: how much of bandwidth requirements are taken up by applications which are time-critical (e.g. streaming TV) and how much by those where delays are tolerable (e.g. large file transfers, P2P)?
 - ▶ **HDTV sensitivity**: what happens if HDTV content requires more bandwidth than estimated (as a result of more detail/motion) or lower bandwidth (through the introduction of improved compression techniques by 2012)?
 - this affects only the downstream requirements as, by 2012, we assume that upstream streaming video (e.g. video calls) is limited to SDTV quality

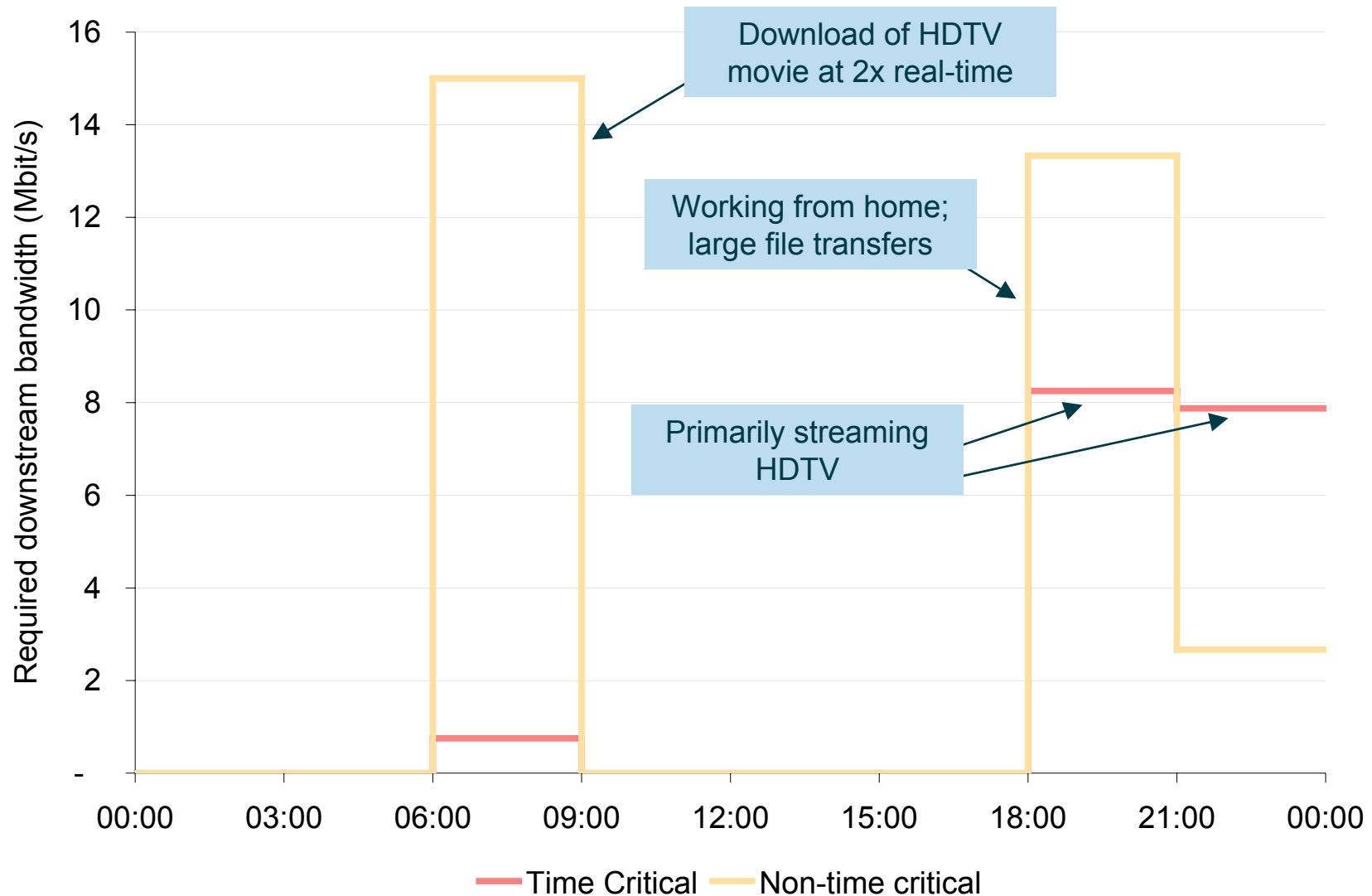
HDTV sensitivity: couple, no children, 2012



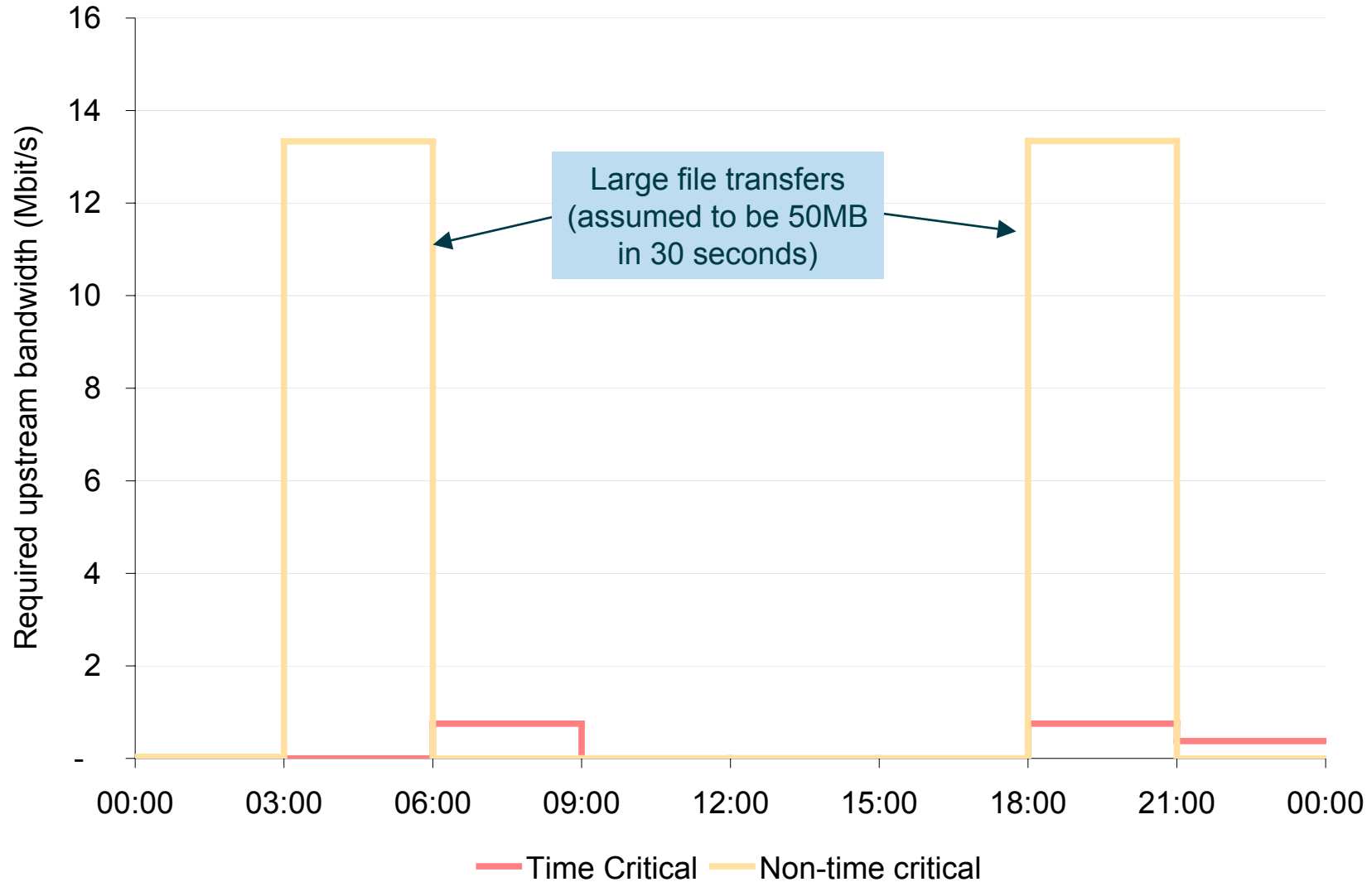
HDTV sensitivity: family, 2012



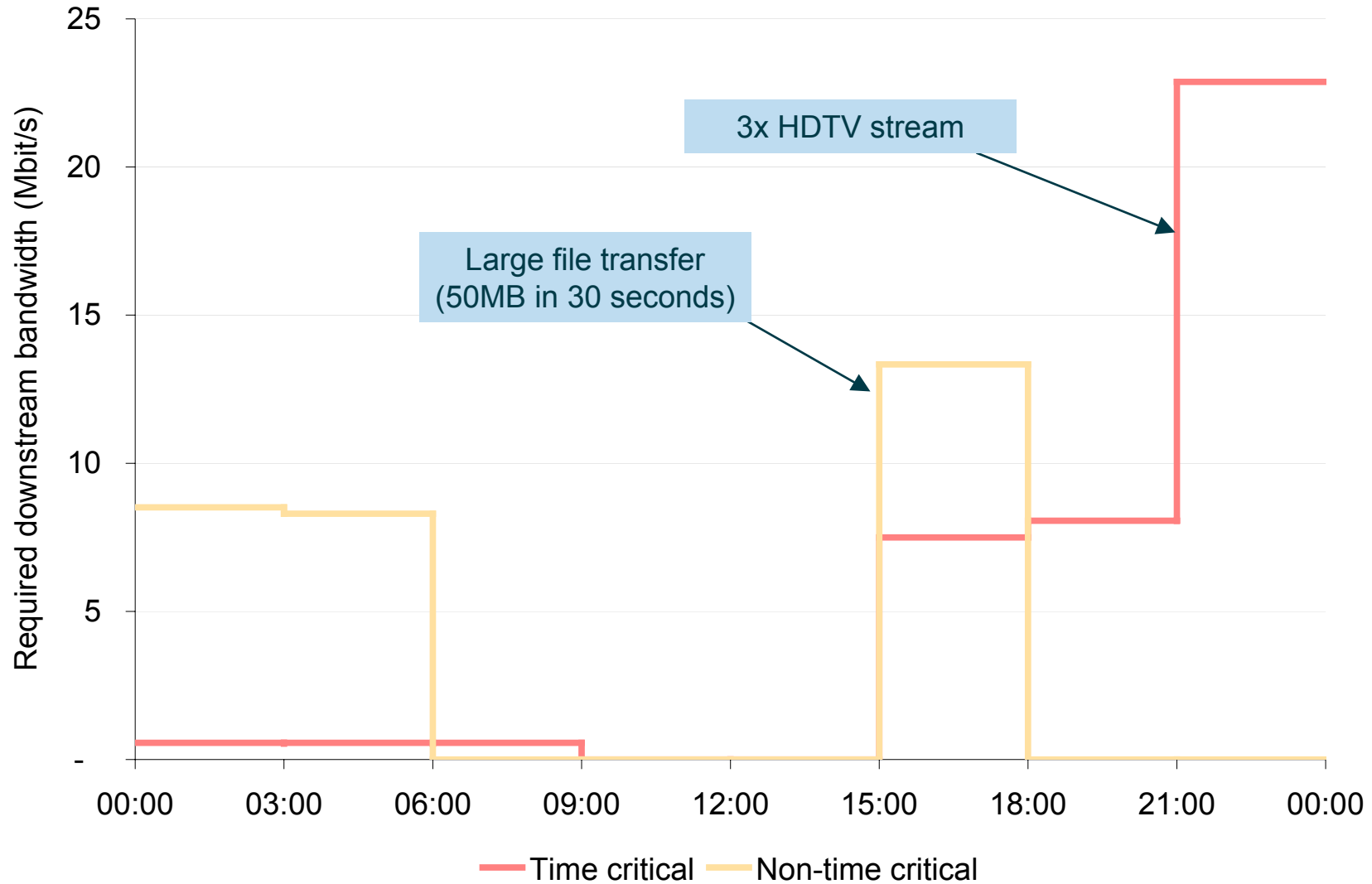
Time-critical downstream analysis: couple, no children, 2012



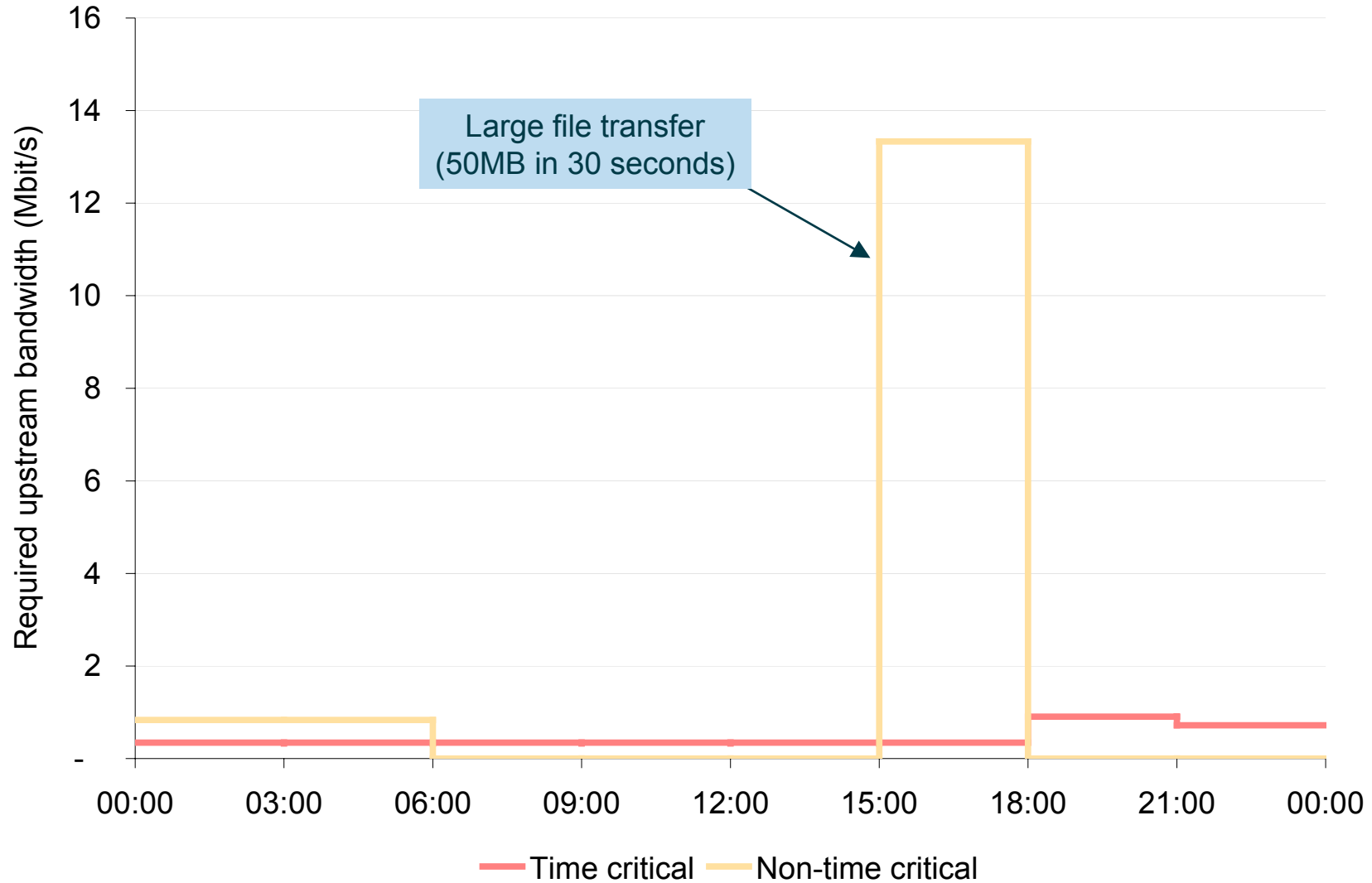
Time-critical upstream analysis: couple, no children, 2012



Time-critical downstream analysis: family, 2012



Time-critical upstream analysis: family, 2012



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Time critical downstream requirements are likely to be within the technical capabilities of ADSL2+, but not for all homes

- The highest downstream demands are around 20Mbit/s and services of this speed are unlikely to be available to more than 50% of UK households with existing networks:
 - ADSL2+ cannot currently offer speeds in excess of 20Mbit/s beyond 1.5km from the exchange (in ideal conditions), although the performance of xDSL technologies may continue to improve between now and 2012
 - the cable networks can support similar speeds and cover around 45% of UK households
- Time critical upstream data requirements are likely to be within the range of xDSL technologies and the cable networks:
 - should demand for high-quality upstream video emerge (for example, through online gaming) the time critical element may increase rapidly
 - consumer tolerance to lengthy upload times for large files, and the impact this could have on the attractiveness of teleworking, will prove to be the key factors in whether available upstream speeds are sufficient

Local storage and intelligent PVRs could temper time-critical peak bandwidth requirements that are driven by entertainment

- Many of the downstream bandwidth requirements are entertainment driven (e.g. three HDTV streams in the Family example)
- Network operators and service providers could adopt a hybrid storage-based approach to lessen the reliance on high downstream bandwidths
 - in June 2005 we discussed the distinction between ‘home storage’ (Sky+) and ‘home streaming’ (Homechoice, ntl/Telewest) and said that the likely end-point was to be somewhere between the two
 - the first signs of this are emerging with Sky’s purchase of Easynet and the launch of PVRs by ntl/Telewest
- This does not affect *ad hoc* file transfers and some video content will still be streamed, such as promotional/marketing content from websites and educational content
- Under this hybrid approach, the entertainment based bandwidth requirements would be lower than forecast and demand on the core and access networks would be more under the control of the service provider
 - the upstream bandwidth demand will be unchanged

Household bandwidth demand reaches 23Mbit/s downstream and 14Mbit/s upstream by 2012 – however, the time criticality of applications means that 3Mbit/s upstream may be sufficient

Total bandwidth demand

Household	2008 max. (Mbit/s)		2012 max. (Mbit/s)	
	up	down	up	down
A: Single adult, retired	0.03	3.8	0.9	7.9
B: Two adults, retired	2.7	3.8	3.0	11.4
C1: Single male, weekday	2.7	4.0	2.7	3.0
C1: Single male, weekend	2.7	3.8	2.7	7.5
C1: Single male, tele-worker	2.8	3.9	14.0	13.7
C1: Single male, entrepreneur	2.9	3.9	3.8	7.9
C2: Single female	2.7	4.0	2.7	3.0
D: Two adults, empty nesters	2.7	3.8	2.7	13.5
D: Two adults, young couple	2.9	17.5	14.1	21.6
E: Two adults, with children	2.8	11.4	13.7	22.9
F: Single parent	0.2	3.9	0.7	7.9

Time critical bandwidth demand

Household	2008 max. (Mbit/s)		2012 max. (Mbit/s)	
	up	down	up	down
A: Single adult, retired	0.03	3.8	0.4	7.9
B: Two adults, retired	0.03	3.8	0.6	7.7
C1: Single male, weekday	-	3.8	-	0.2
C1: Single male, weekend	0.1	3.8	0.4	7.5
C1: Single male, tele-worker	0.2	3.9	0.4	7.7
C1: Single male, entrepreneur	0.3	3.9	1.1	7.9
C2: Single female	-	3.8	-	0.2
D: Two adults, empty nesters	0.2	3.8	0.8	7.5
D: Two adults, young couple	0.0	3.9	0.8	8.3
E: Two adults, with children	0.3	11.4	0.9	22.9
F: Single parent	0.2	3.9	0.7	7.9

- By 2012, bandwidth requirements reach:
 - 23Mbit/s downstream
 - 14Mbit/s upstream
- However, of the 14Mbit/s upstream, only 1 Mbit/s is needed for time critical applications
 - taking a pragmatic view on tolerable transfer times for large files suggests around 3Mbit/s upstream may be sufficient for most users
- These results are strongly dependent on assumptions regarding SDTV and HDTV:
 - timing of MPEG-4 launch and availability of HDTV is key
 - improvements in compression techniques could lower bandwidth requirements but this is difficult to predict
- The size of large file transfers, and time taken to down/upload, is an important factor in both up and downstream requirements

Note: with less than 1Mbit/s upstream, large file transfers may be intolerable

Note: this study does not take into account network overheads

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Estimation of downstream elemental flow bandwidths [1]

- We assume throughout these calculations that all video applications are compressed by 50% in 2012 compared to 2008, through the universal replacement of MPEG-2 encoding by MPEG-4
- **Background data:** We assume a requirement rate of 1kbyte every 30 seconds, taking the form of a data packet communicating with a central control or monitoring system. The resulting bandwidth is 0.27kbit/s
- **Software upgrade:** Software upgrades may be either automatic or user-initiated. We have assumed an average upgrade file size of 15Mbyte, with a download time of 60 minutes, resulting in 0.033Mbit/s. This application is performed in the background and is sensitive to both the file size and the time taken to download the file
- **PSTN voice streaming:** Skype can maintain reasonable quality at 32kbit/s (we use this data rate)
- **CD voice streaming:** We take a high quality MP3 encoding rate of 192kbit/s. Though this does not yield true CD-quality sound, it is still of good quality*
- **DAB / CD quality audio streaming:** The MP3 encoding rate of 192kbit/s is used

**Music downloaded from iTunes Music Store, for example, is typically encoded at 128kbit/s. Online radio stations often run at lower bitrates, but the suitability of this depends on the type of content (e.g. sport commentary vs live concert)*

Estimation of downstream elemental flow bandwidths [2]

- **Webcam calls / conferences (CIF):** A common intermediate format (CIF, 352×288) quality image running at 30 frames per second (fps) with 16kbit/s of low quality audio requires 128kbit/s, using the most recent codecs.* We assume that, for videoconferences, a frame rate of 15fps is sufficient and that older codecs such as MPEG-2 are used in 2008, with newer ones such as MPEG-4 in use by 2012. This gives bandwidth requirements of 128kbit/s in 2008 and 64kbit/s in 2012
- **SDTV calls / conferences (VGA):** As for SDTV streaming, except we assume a refresh rate of 15fps and less movement, so the bandwidth requirements in 2012 are 0.75Mbit/s in 2008 and 0.38Mbit/s
- **Webcam (CIF) video streaming:** This differs from webcam calls and videoconferences in that we assume a higher frame rate (30fps compared with 15fps) and that the content contains more movement than a videoconference. This higher motion content lessens the effectiveness of the codecs and results in a multiple of 2.5 being applied to the bandwidth required for low motion content. When combined, these two factors give bandwidth requirements of 640kbit/s in 2008 and 320kbit/s in 2012
- **SDTV videostreaming:** We assume that SDTV at 30fps requires 3.75Mbit/s in 2008, falling to 1.88Mbit/s by 2012. In reality, the figure for streaming content may be lower than 3.75Mbit/s depending on the amount of motion in the content although this figure is sufficient for the majority of content
- **HDTV streaming:** HDTV requires up to 8–9Mbit/s using MPEG-4, although the exact rate depends on the amount of motion in the content. We take a rate of 7.5Mbit/s in 2012 and 15Mbit/s in 2008 (under MPEG-2) although it is likely that there will be some HDTV content in 2008, and this will be encoded using MPEG-4

*Source: *Codian (www.codian.com), a videoconferencing infrastructure product manufacturer*

Estimation of downstream elemental flow bandwidths [3]

- **File transfer:** We assume that the user wishes to downloading a 10Mbyte file in 30 seconds, resulting in a bandwidth requirement of 2.67Mbit/s. Similarly, for a 50Mbyte file in 30 seconds, we require 13.3Mbit/s. These bandwidth requirements do not change between 2008 and 2012 although they are heavily dependent on the underlying assumptions
- **P2P file transfer:** This elemental flow is similar to the large file transfer although the urgency of receipt is now as high. We therefore assume that the user would wish to download 60Mbyte (approximately an hour of music) in 30 minutes, resulting in a bandwidth demand of 268kbit/s

Estimation of upstream elemental flow bandwidths [1]

- Some of the upstream elemental flows have the same bandwidth requirements as the downstream versions. We have indicated where this is the case
- **Monitoring people / premises / utilities / appliances:** As for background data, we assume a required rate of 1kbyte every 30 seconds (0.27kbit/s), taking the form of a data packet communicating with a central control or monitoring system
- **Five channel webcam video (CIF):** Used for home monitoring via CCTV with the images uploaded to an off-site server. The number of channels (i.e. cameras) was agreed with the BSG. We have assumed a CIF quality videostream at 6fps with no audio (which requires 16kbit/s). This requires 112kbit/s for five channels (22.4kbit/s per channel)
- **SDTV videostreaming:** We assume that SDTV at 30fps requires 3.75Mbit/s in 2008, falling to 1.88Mbit/s by 2012. In reality, the figure for streaming content may be lower than 3.75Mbit/s, depending on the amount of motion in the content although this figure is sufficient for the majority of content
- **Five channel SDTV video:** For low motion SDTV content at 30fps in 2012, we have a requirement of 768kbit/s including audio (at 64kbit/s). Therefore, five channel SDTV quality CCTV style monitoring (low motion) running at 6fps, requires 0.69Mbit/s bandwidth
- **Background data:** As in the downstream case, we assume a rate of 0.27kbit/s taking the form of a data packet communicating with a central control or monitoring system

Estimation of upstream elemental flow bandwidths [2]

- **Automated back-up:** We assume that 15MB is transmitted in one hour, requiring 0.033Mbit/s in the background
- **Voice / videostreaming, calls and conferencing:** As for the downstream flows, namely:
 - **PSTN voice streaming:** 32kbit/s
 - **CD voice streaming:** 192kbit/s
 - **DAB / CD quality audio streaming:** 192kbit/s
 - **Webcam calls / conferences (CIF):** 128kbit/s in 2008 and 64kbit/s in 2012
 - **Webcam (CIF):** 640kbit/s in 2008 and 320kbit/s in 2012
 - **SDTV calls / conferences (VGA):** 0.75Mbit/s in 2008 and 0.38Mbit/s in 2012
- **File transfer:** As for the downstream flows; 13.3Mbit/s for 50Mbyte in 30 seconds and 2.67Mbit/s for 10Mbyte in 30 seconds
- **Password Identification:** We assume 1kbyte transmitted in 1 second, which implies a transfer rate of 8kbit/s
- **Biometric Identification:** We assume that the data needs to be transmitted in 1 second and that there are a number of sorts. For instance, an iris scan may be 30kbyte in size* and a facial scan 33kbyte in size⁺
- **P2P file transfer:** As for the downstream flow, 268kbit/s

*Source: American National Standards Institute

⁺ Source: International Civil Aviation Organisation

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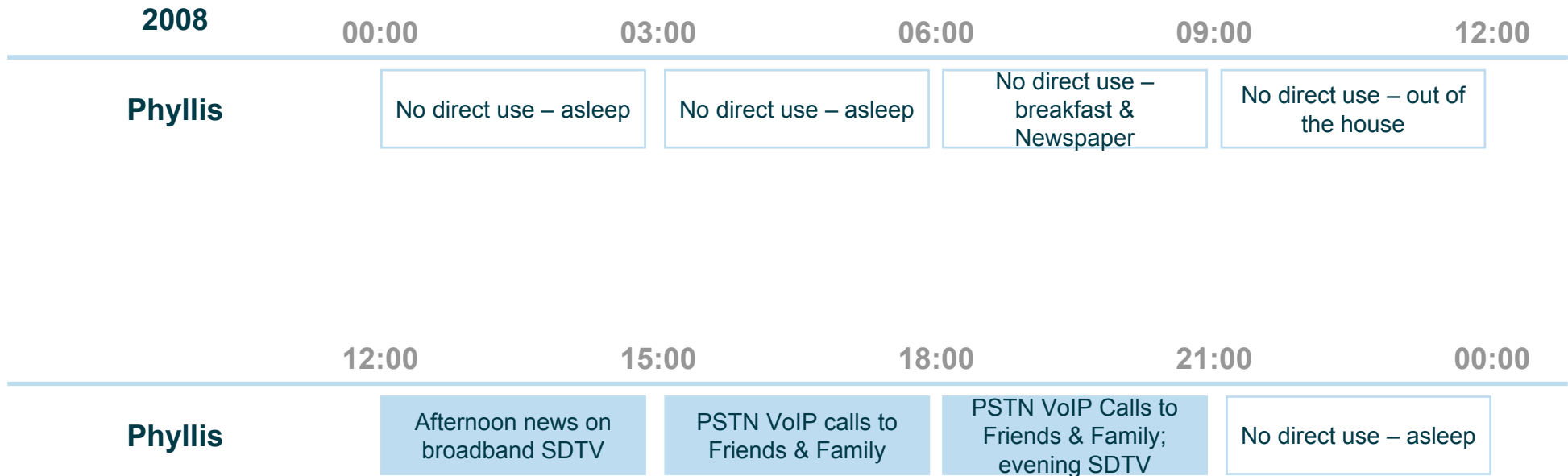
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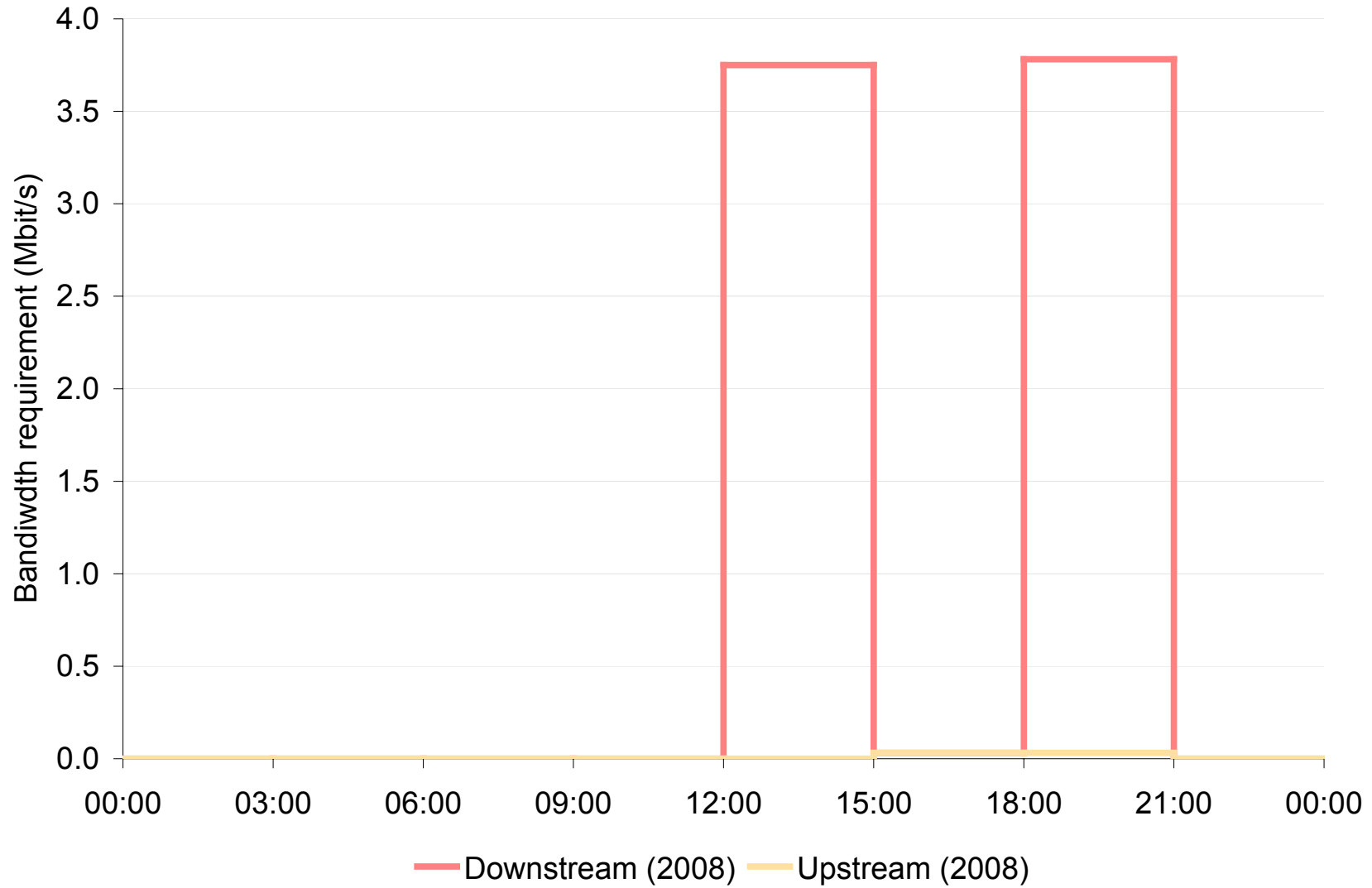
Annex A: estimation of elemental flow bandwidths

Annex B: detailed household results

Results: A – Single Occupant, Retired, 2008



Results: A – Single Occupant, Retired, 2008

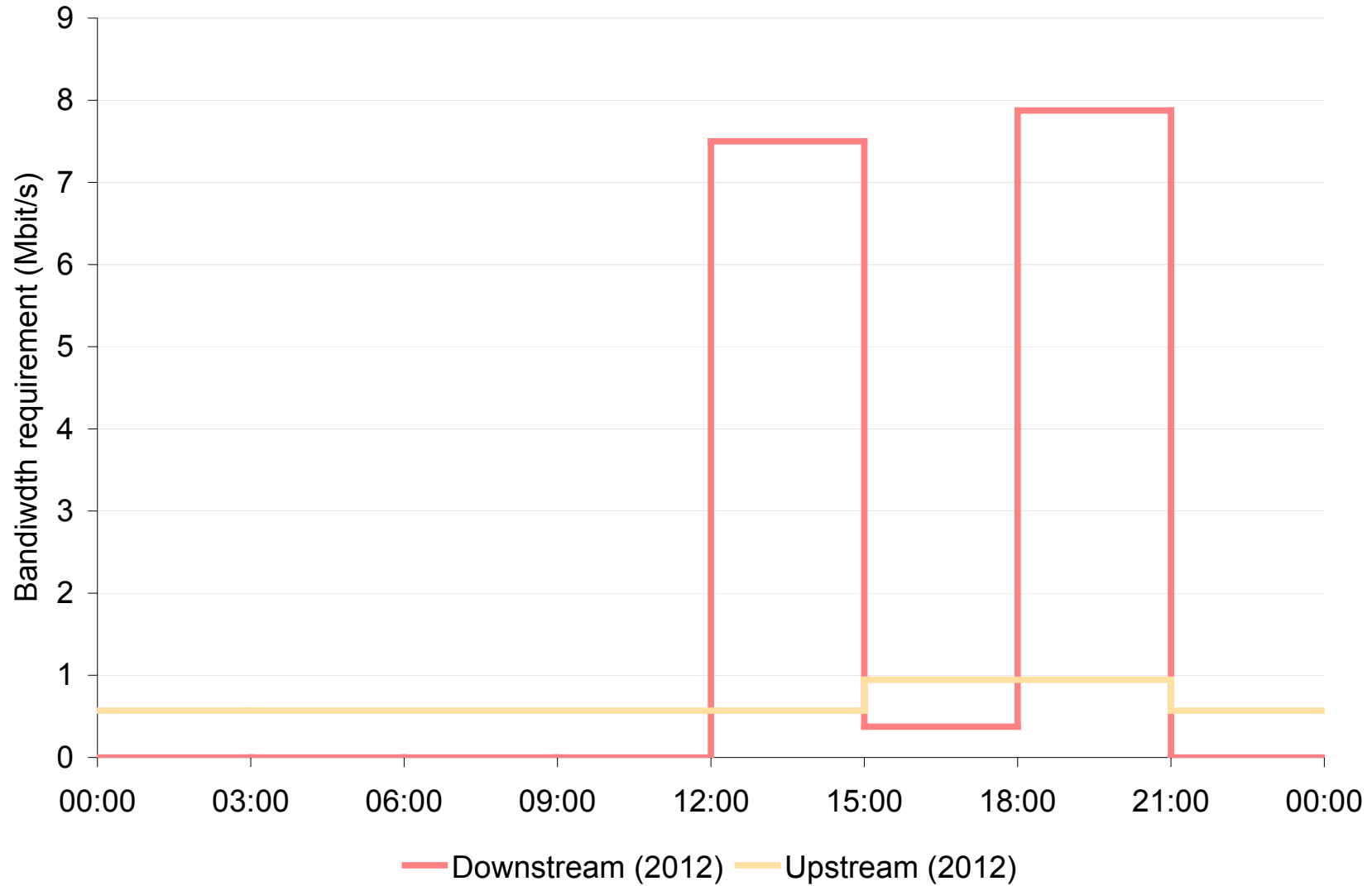


Results: A – Single Occupant, Retired, 2012

2012	00:00	03:00	06:00	09:00	12:00
Phyllis	No direct use – asleep	No direct use – asleep	No direct use – breakfast & Newspaper	No direct use – out of the house	
Background	Telehealth	Telehealth	Telehealth	Telehealth	
	12:00	15:00	18:00	21:00	00:00
Phyllis	Afternoon news on HDTV	SDTV Video Calls to Friends & Family	SDTV Video Calls to Friends & Family; evening HDTV	No direct use – asleep	
Background	Telehealth	Telehealth	Telehealth	Telehealth	

Telehealth uses the elemental flow for monitoring people and is assumed to be regular packets of information sent to a central location rather than detailed medical information

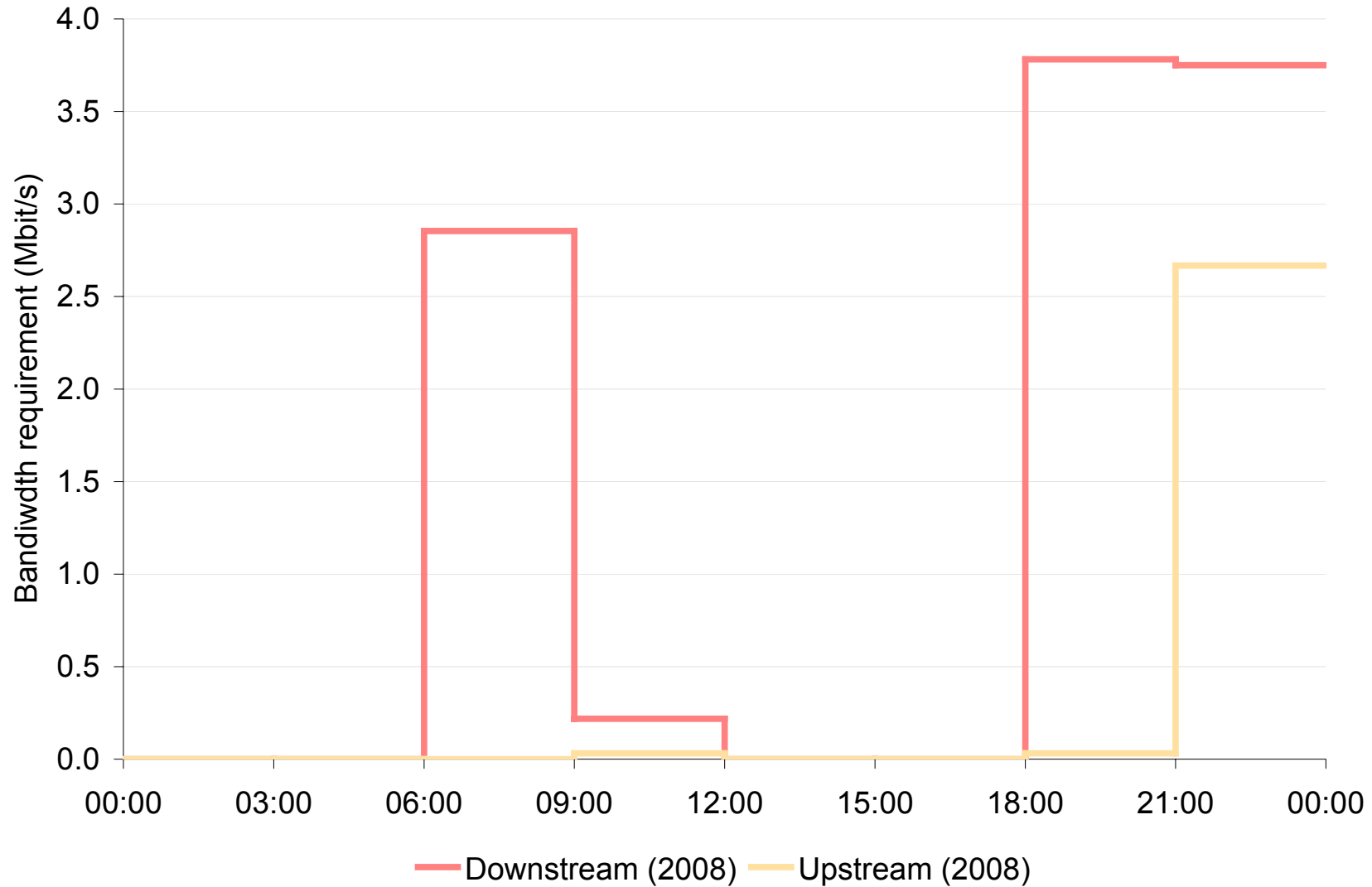
Results: A – Single Occupant, Retired, 2012



Results: B – One Man and One Woman, Retired, 2008

2008	00:00	03:00	06:00	09:00	12:00
Roger	No direct use - asleep	No direct use - asleep	Download grandson's holiday photos (10MB/30s)	No direct use – early round of golf	
Margaret	No direct use - asleep	No direct use - asleep	Online magazine	PSTN VoIP calls to friends & Internet radio	
Together	NA	NA	Internet DAB quality radio	NA	
Background	Non-CCTV monitoring of household	Non-CCTV monitoring of household	Non-CCTV monitoring of household	Non-CCTV monitoring of household	
	12:00	15:00	18:00	21:00	00:00
Roger	NA	NA	Internet Research – latest golf technology	Streaming SDTV	
Margaret	NA	NA	PSTN VoIP calls to family	Send grandson's holiday photos to friends (10MB/30s)	
Together	No direct use – out of house	No direct use – out of house	SDTV VoD movie	NA	
Background	Non-CCTV monitoring of household	Non-CCTV monitoring of household	Non-CCTV monitoring of household	Non-CCTV monitoring of household	

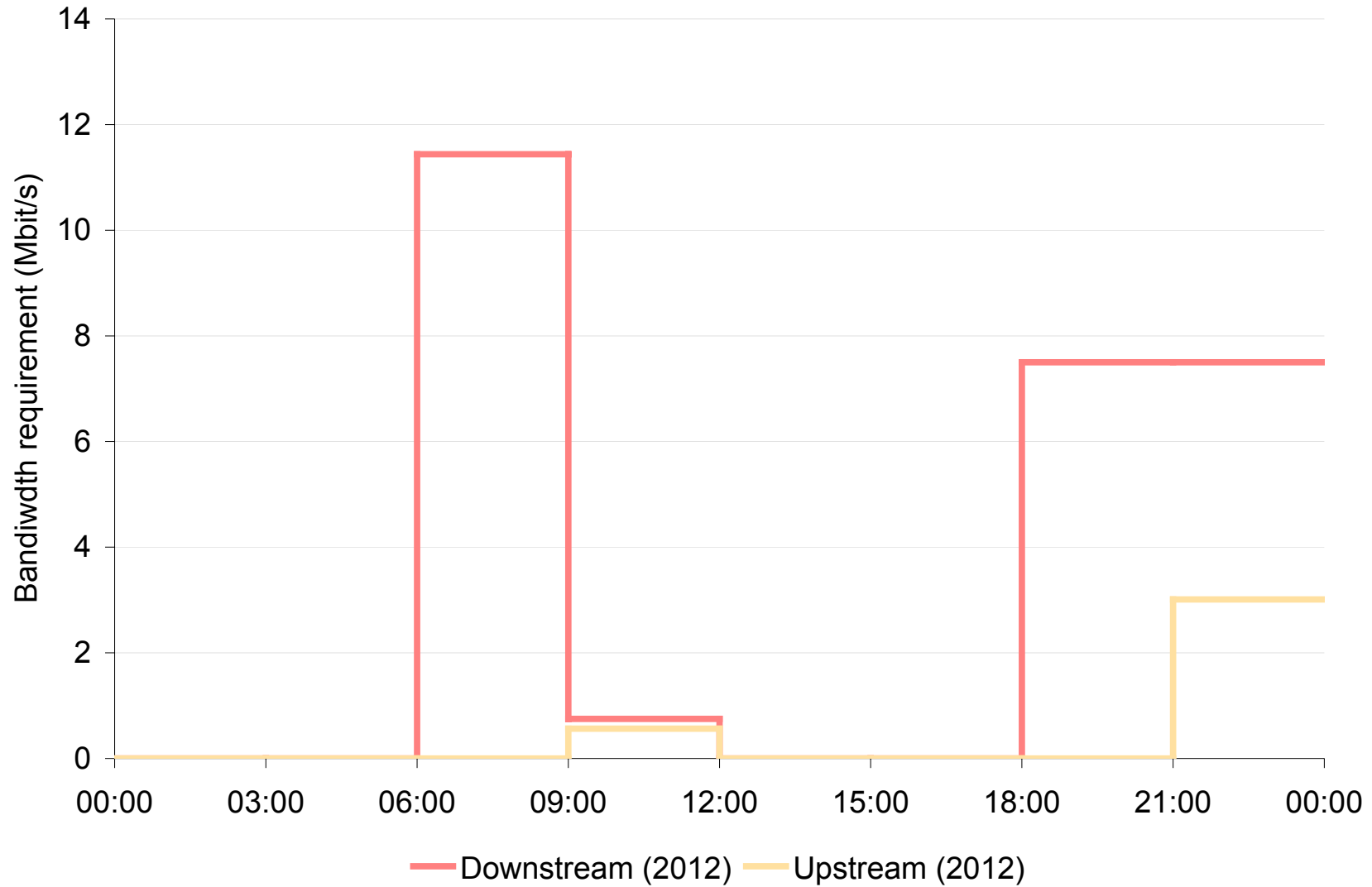
Results: B – One Man and One Woman, Retired, 2008



Results: B – One Man and One Woman, Retired, 2012

2012	00:00	03:00	06:00	09:00	12:00
Roger	No direct use - asleep	No direct use - asleep	Download SDTV video of granddaughter's wedding	No direct use – early round of golf	
Margaret	No direct use - asleep	No direct use - asleep	HDTV morning news	SDTV video calls to friends	
Together	NA	NA	Internet DAB radio	NA	
Background	Non-CCTV monitoring of household	Non-CCTV monitoring of household	Non-CCTV monitoring of household	Non-CCTV monitoring of household	
	12:00	15:00	18:00	21:00	00:00
Roger	NA	NA	Participating in online video (CIF) golf forum	HDTV	
Margaret	NA	NA	SDTV video calls to family	Send wedding video to friends	
Together	No direct use – out of house	No direct use – out of house	HDTV VoD movie	NA	
Background	Non-CCTV monitoring of household	Non-CCTV monitoring of household	Non-CCTV monitoring of household	Non-CCTV monitoring of household	

Results: B – One Man and One Woman, Retired, 2012

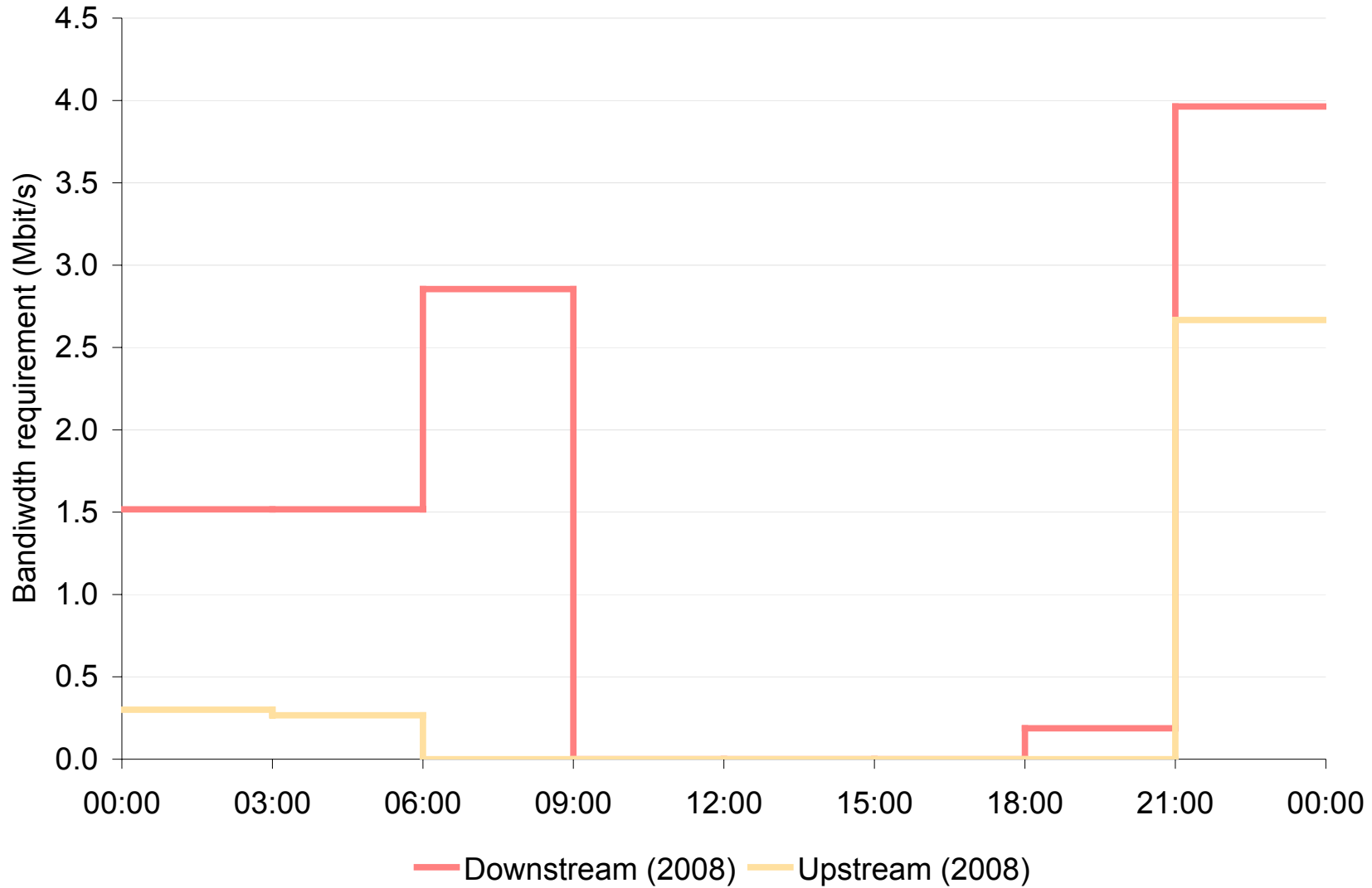


Results: C1 – Single Male, Working, 2008

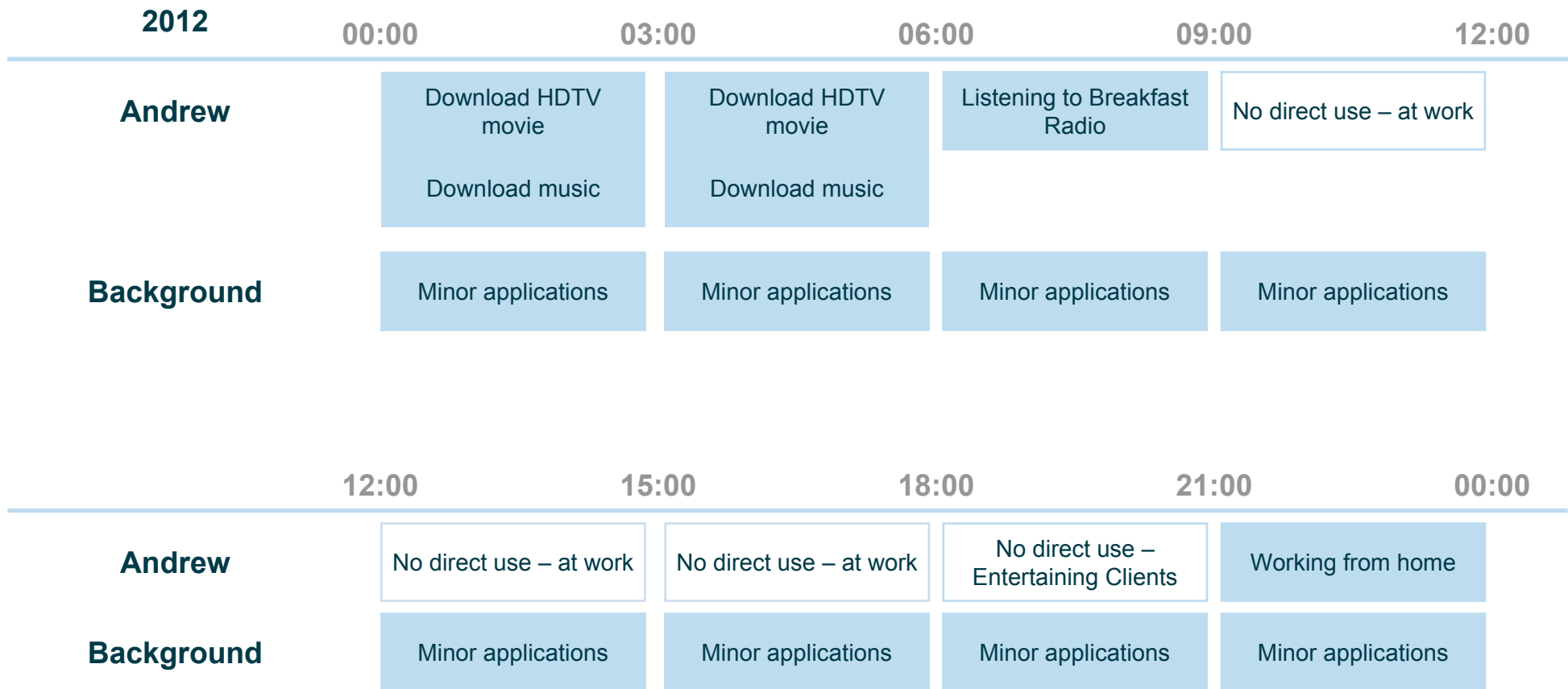
2008	00:00	03:00	06:00	09:00	12:00
Andrew	Download SDTV movie overnight Download music	Download SDTV movie overnight Download music	Listening to DAB breakfast radio Download materials to review on the tube (10MB/30s)	No direct use – at work	
Background	Minor applications	Minor applications	Minor applications	Minor applications	
	12:00	15:00	18:00	21:00	00:00
Andrew	No direct use – at work	No direct use – at work	Homework for Accounting exams DAB radio during homework	Upload Homework results to KPMG (10MB/30s) SDTV VoD movie	
Background	Minor applications	Minor applications	Minor applications	Minor applications	

Minor applications include updating antivirus software and filtering junk mail

Results: C1 – Single Male, Working, 2008

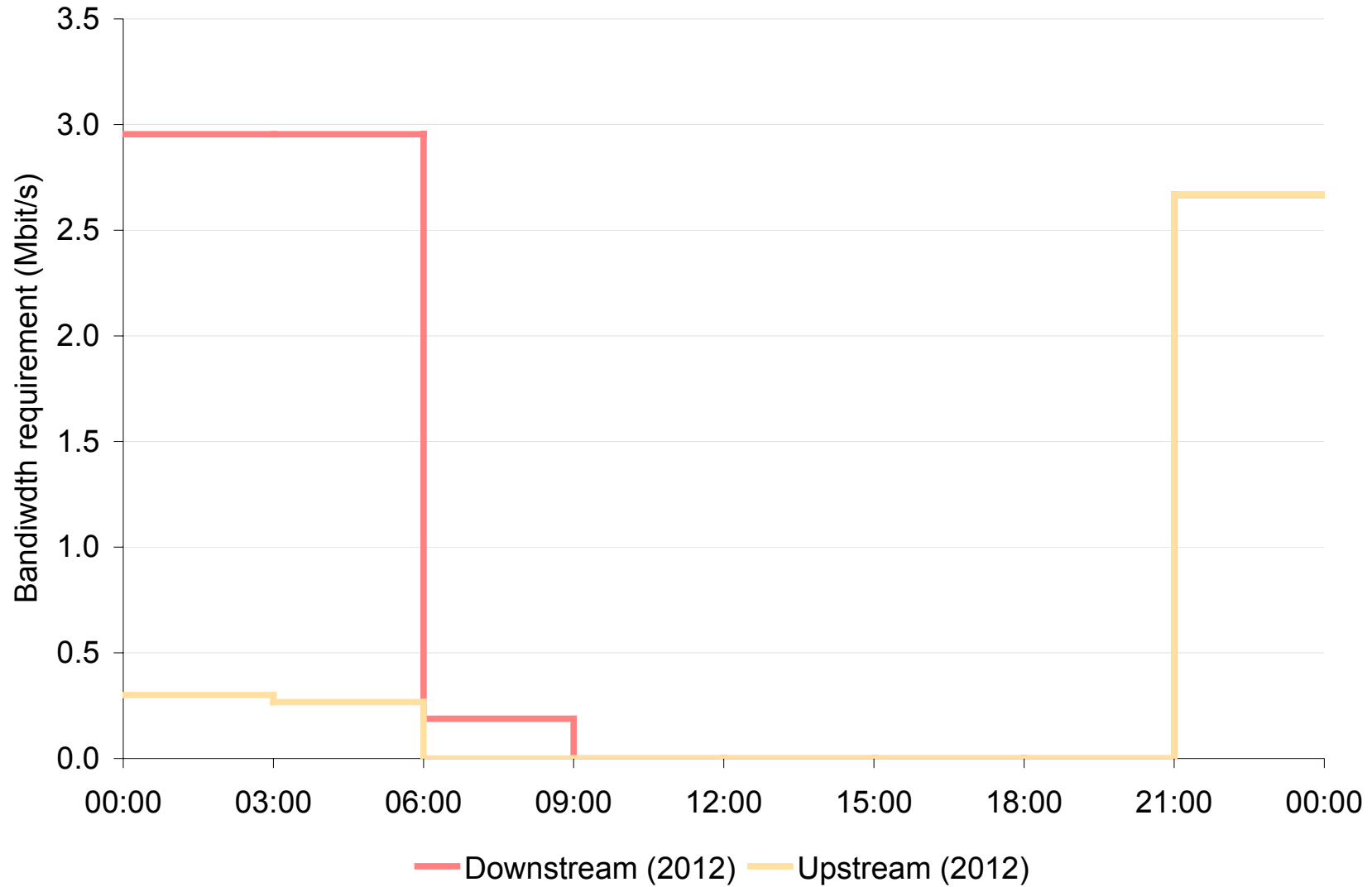


Results: C1 – Single Male, Working, 2012

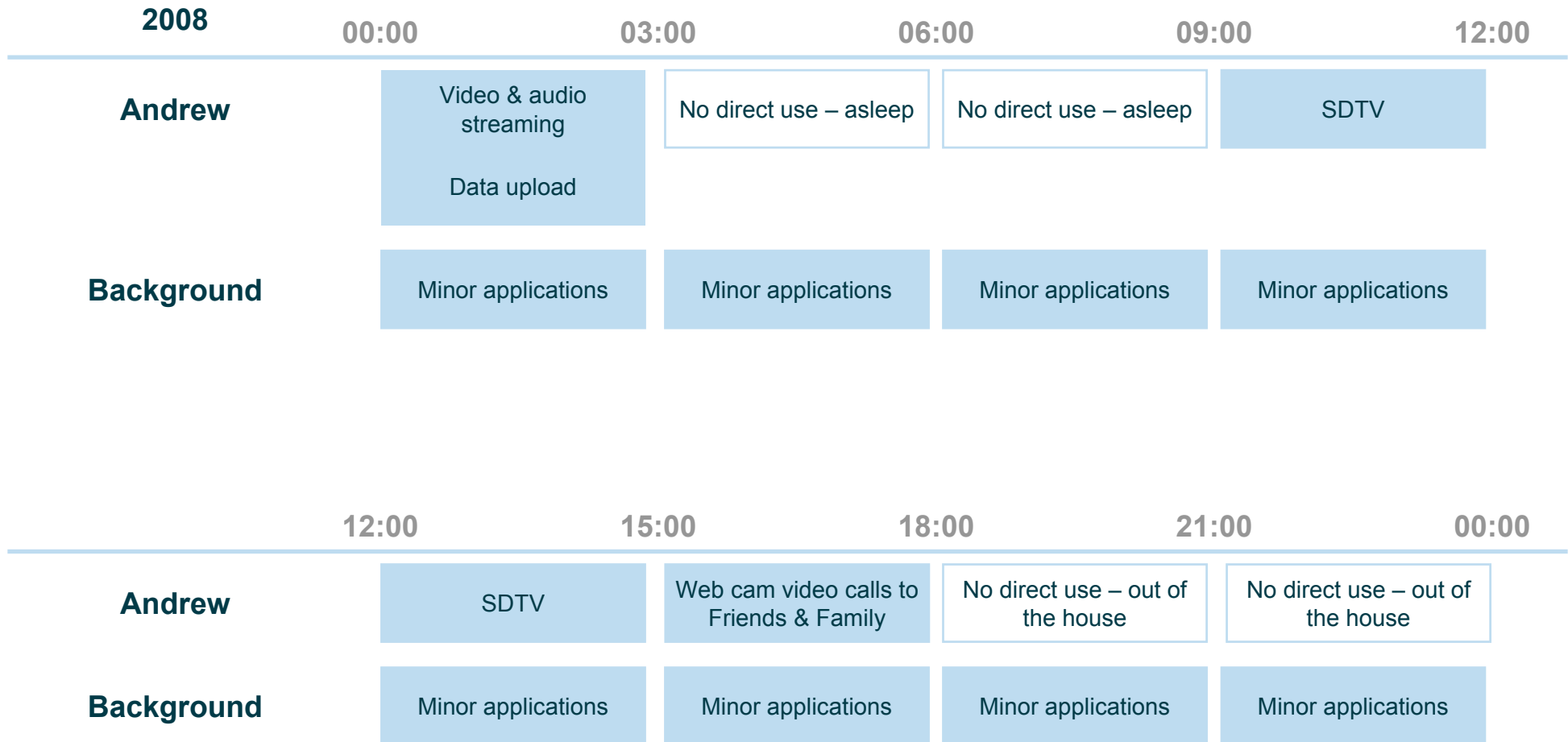


Minor applications include updating antivirus software and filtering junk mail

Results: C1 – Single Male, Working, 2012

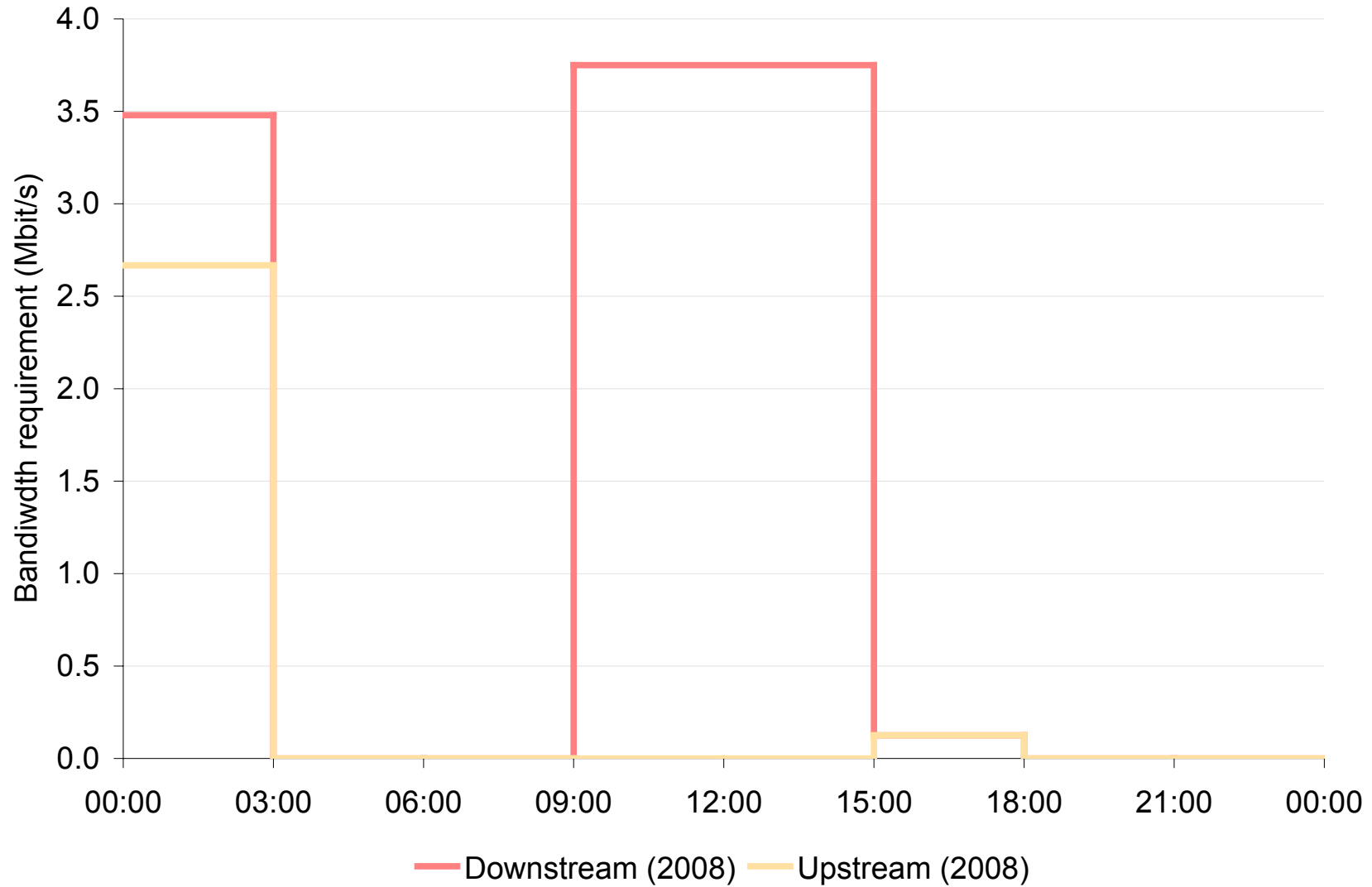


Results: C1 – Single Male, Working, Weekend, 2008

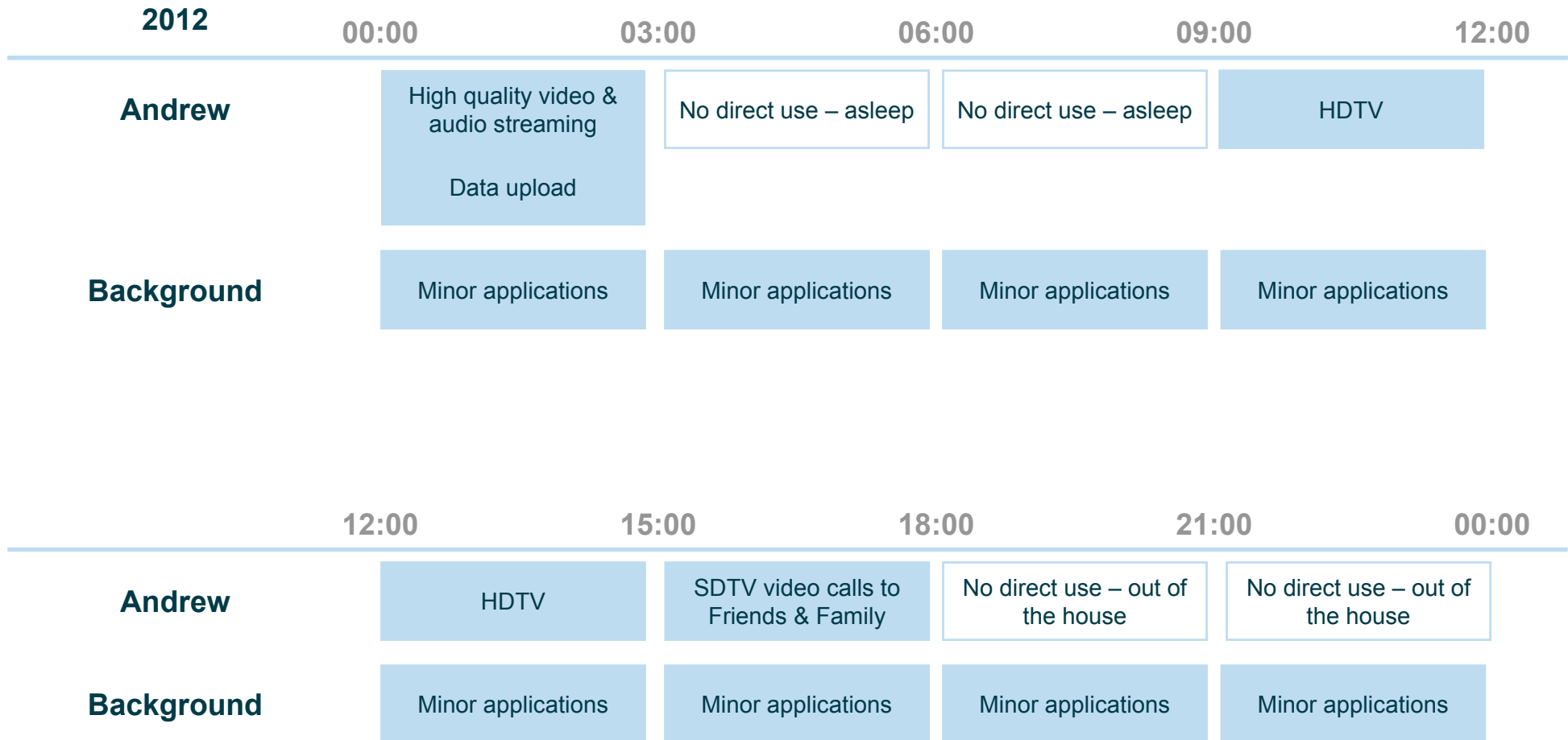


Minor applications include updating antivirus software and filtering junk mail

Results: C1 – Single Male, Working, Weekend, 2008

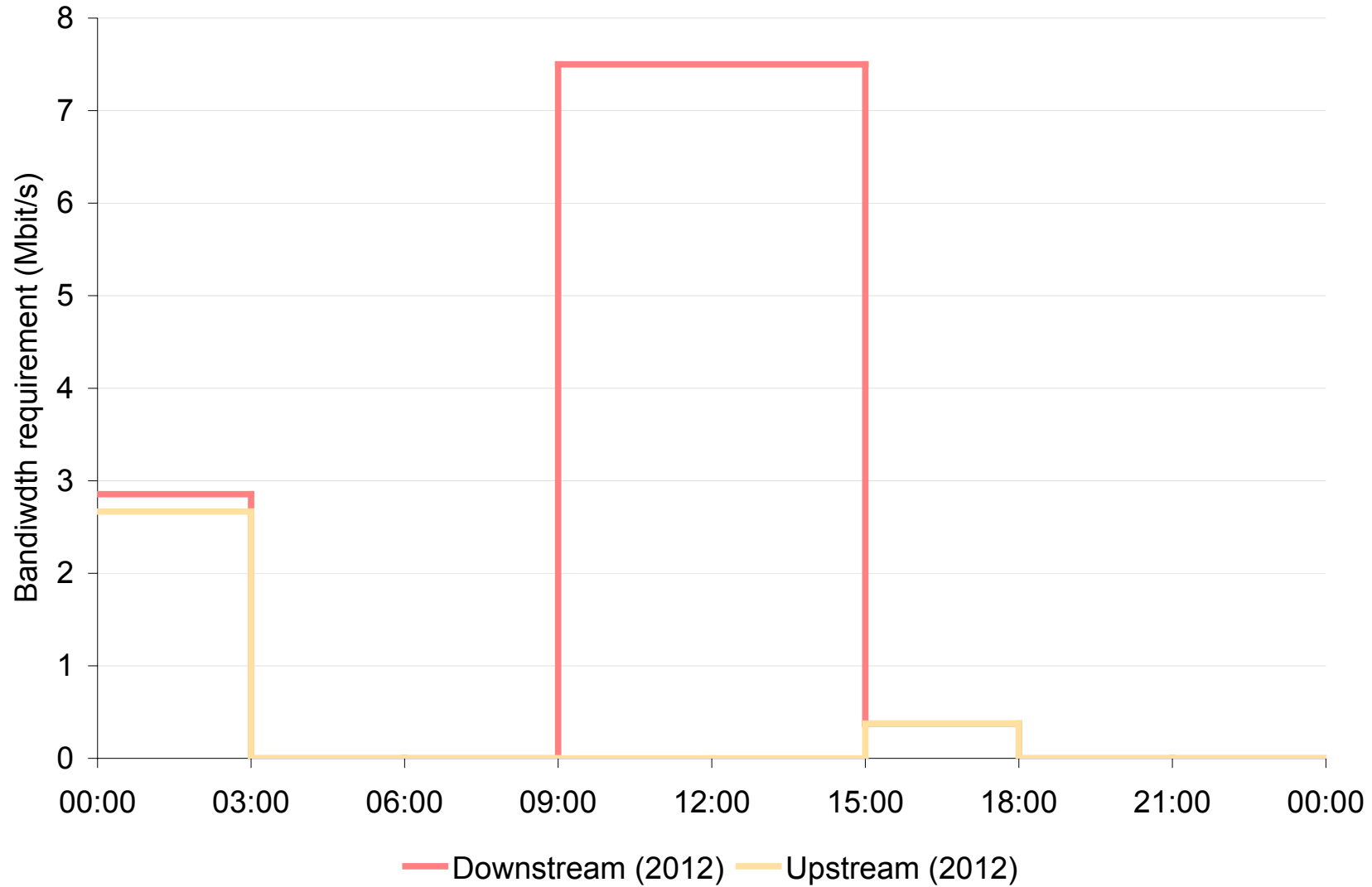


Results: C1 – Single Male, Working, Weekend, 2012

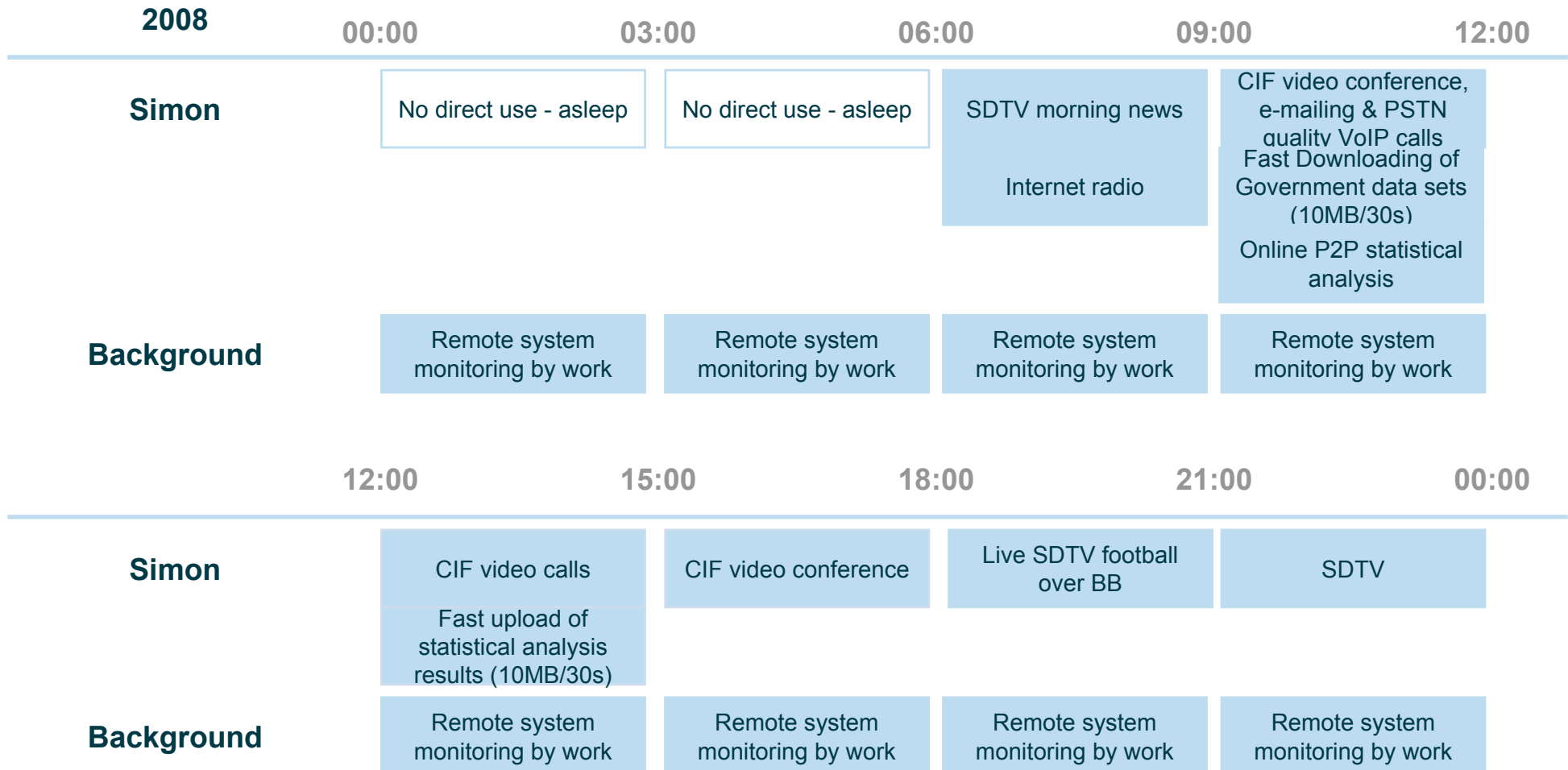


Minor applications include updating antivirus software and filtering junk mail

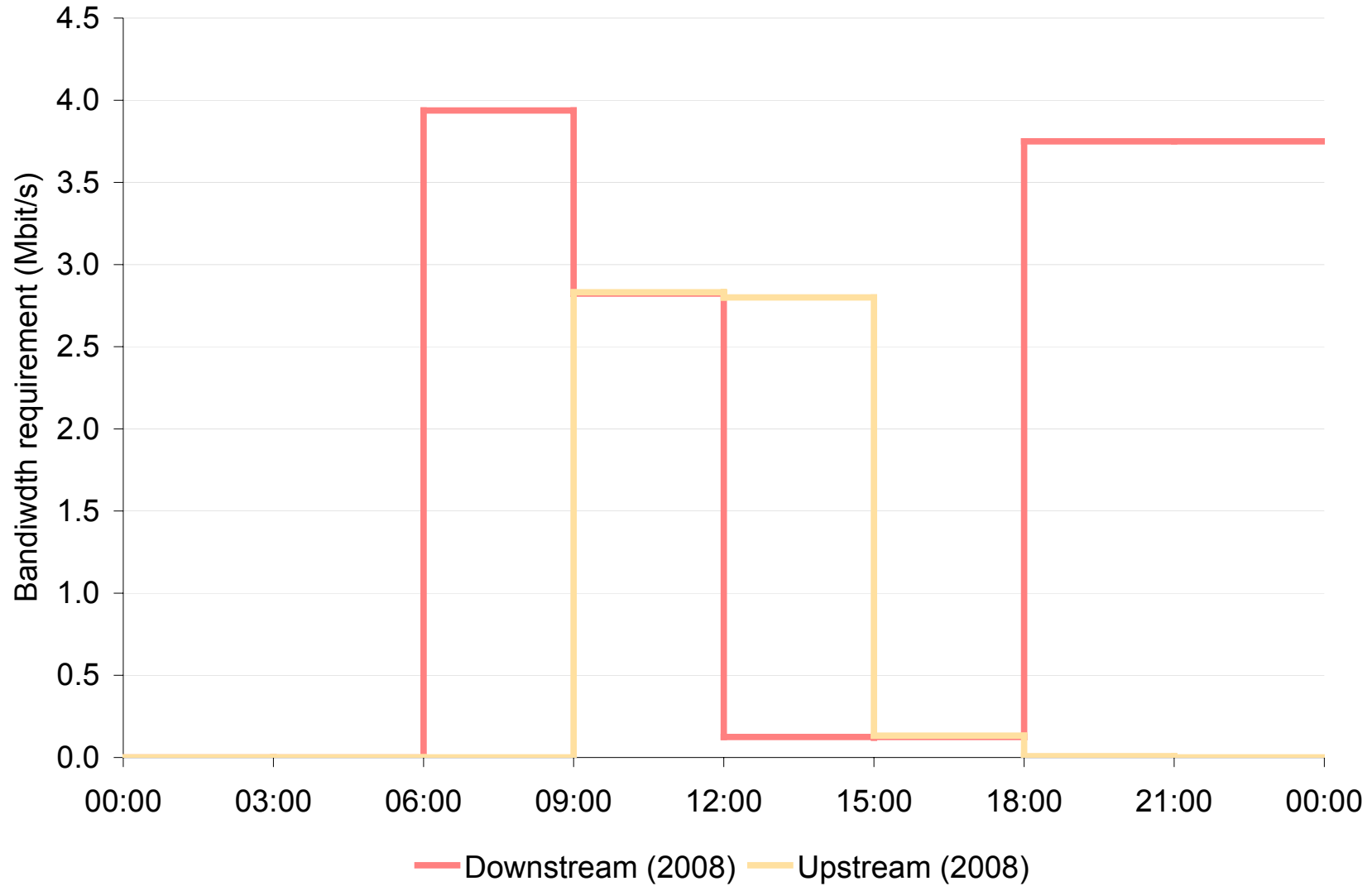
Results: C1 – Single Male, Working, Weekend, 2012



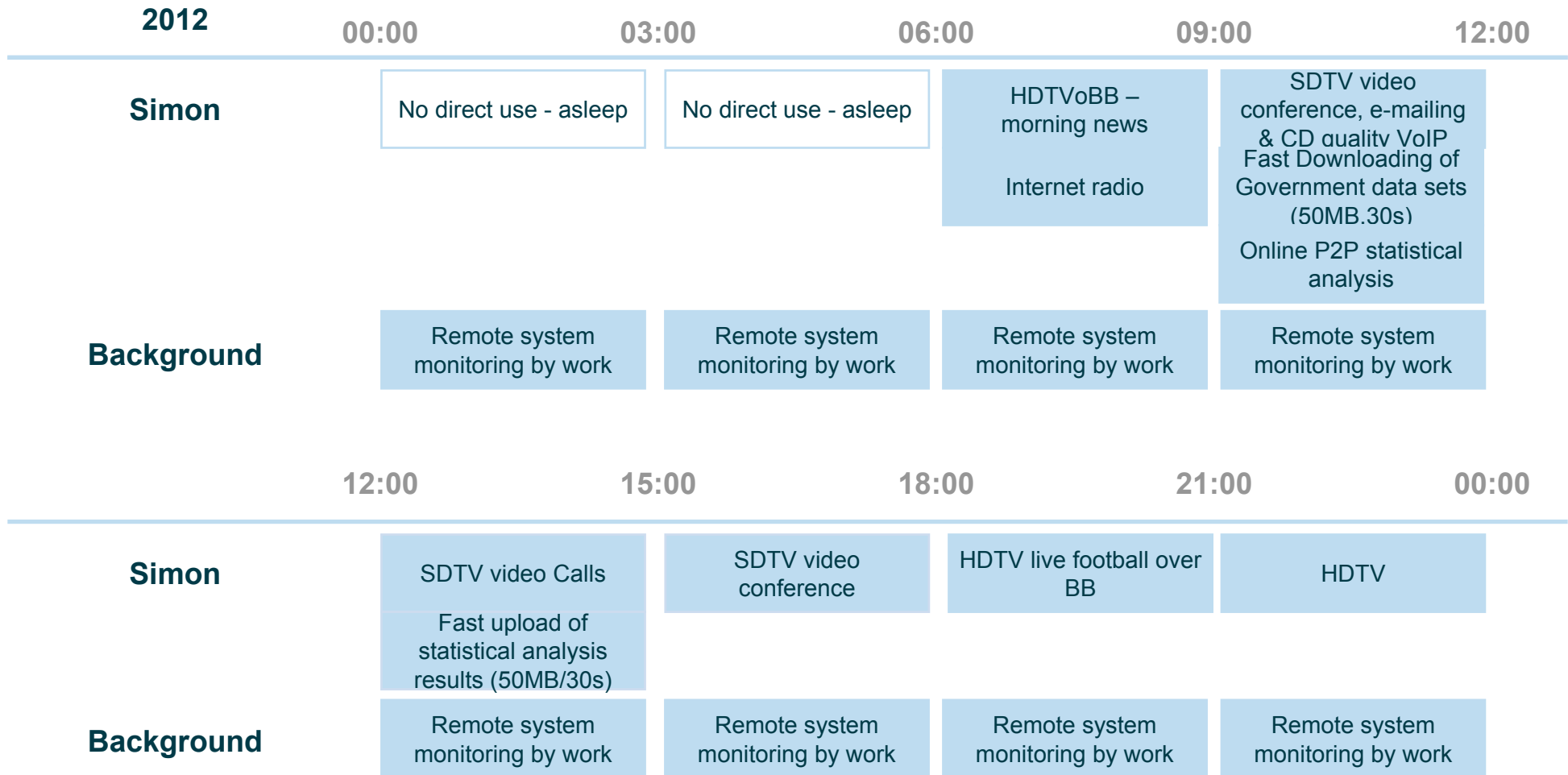
Results: C1 – Single Male, Teleworker, 2008



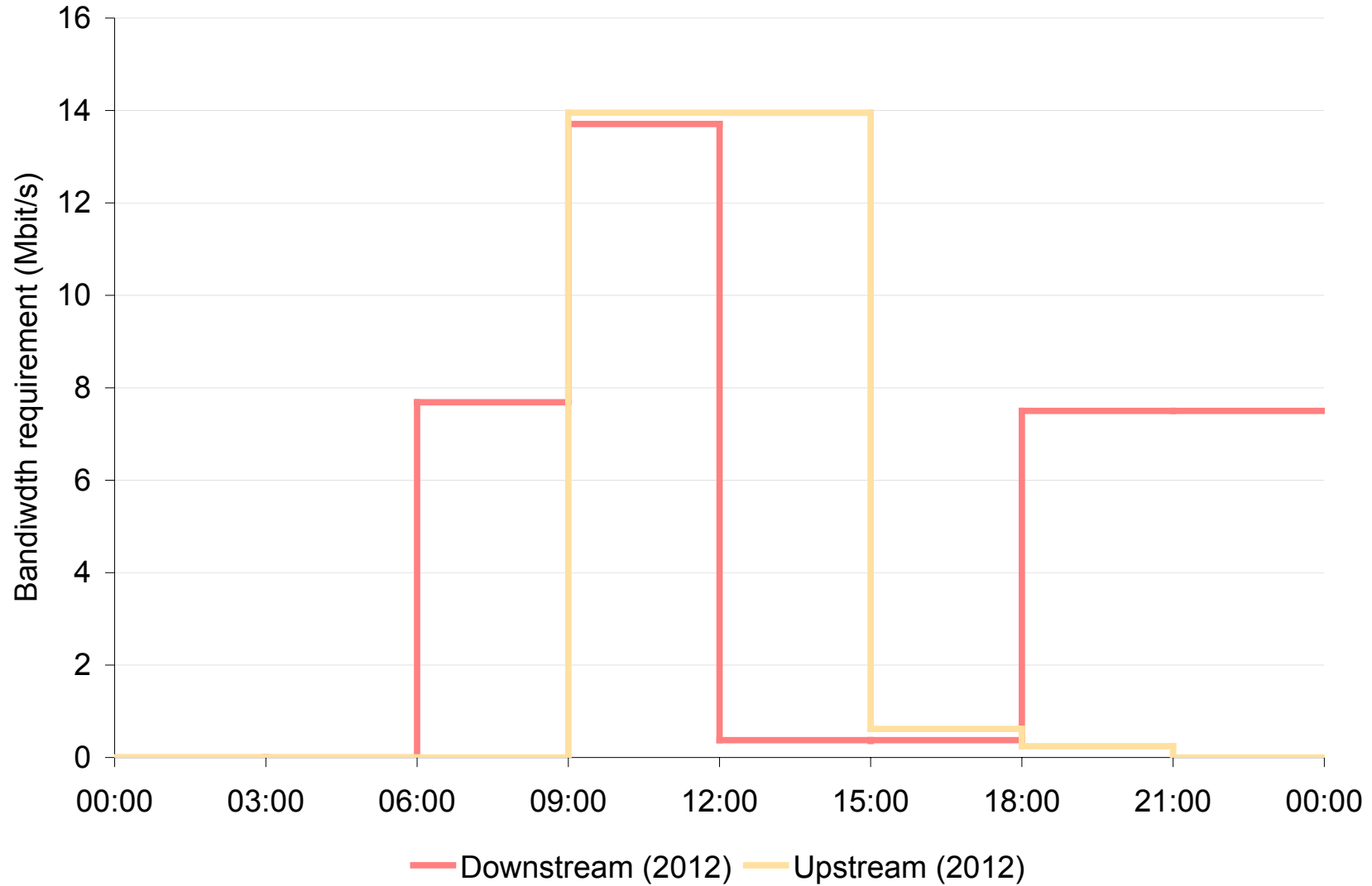
Results: C1 – Single Male, Teleworker, 2008



Results: C1 – Single Male, Teleworker, 2012



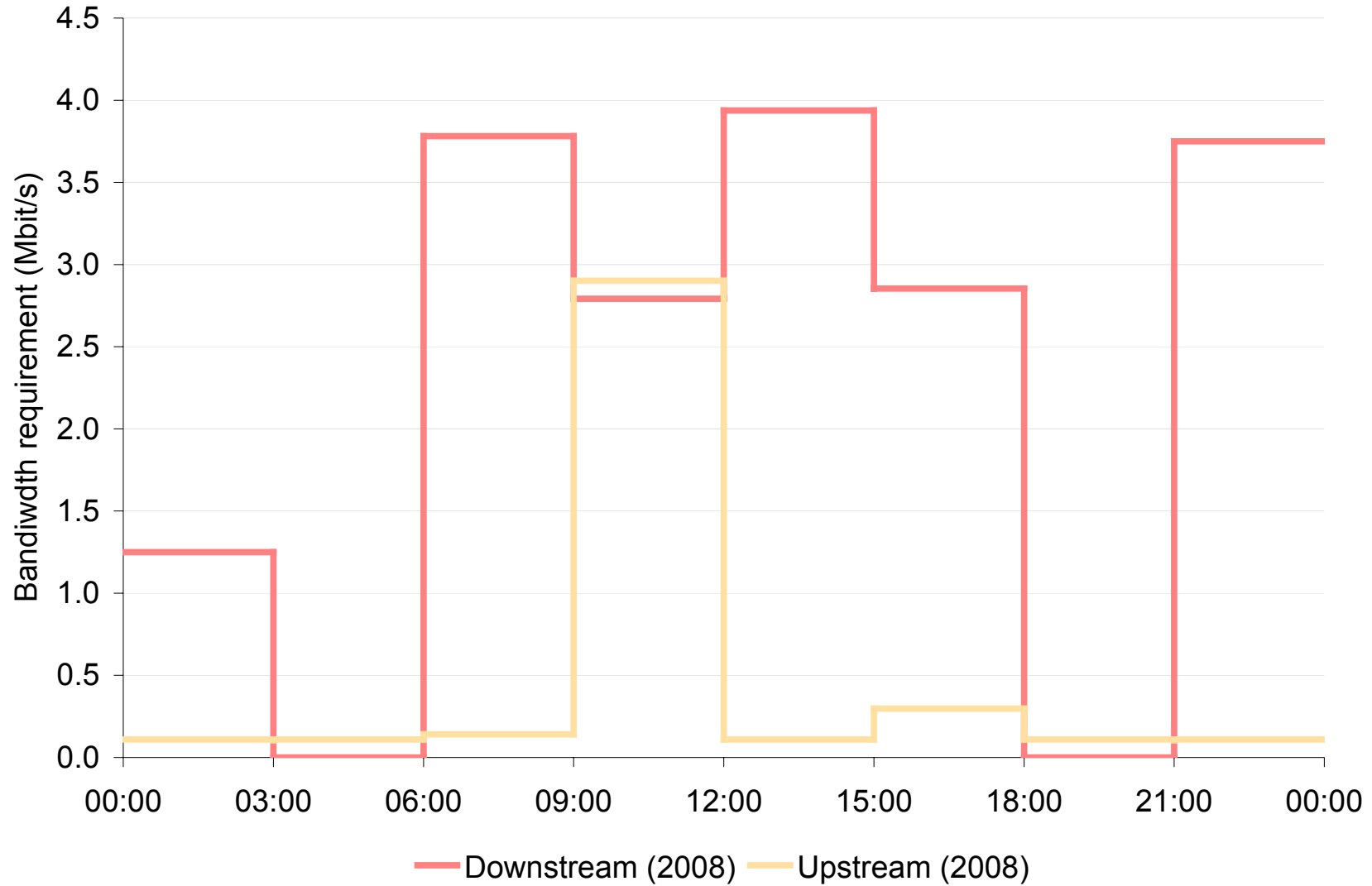
Results: C1 – Single Male, Teleworker, 2012



Results: C1 – Single Male, Home Entrepreneur, 2008

2008	00:00	03:00	06:00	09:00	12:00
Dominic	No direct use - asleep	No direct use - asleep	PSTN VoIP calls to clients in India SDTV – morning news	CIF Video calls with British suppliers E-mailing	
Background	CCTV monitoring home office	CCTV monitoring home office	CCTV monitoring home office	CCTV monitoring home office	
	12:00	15:00	18:00	21:00	00:00
Dominic	SDTV Internet DAB radio whilst doing admin tasks	Internet market research CD quality VoIP sales pitch calls	No direct use – at the gym and out to dinner	SDTV VoD movie	
Background	CCTV monitoring home office	CCTV monitoring home office	CCTV monitoring home office	CCTV monitoring home office	

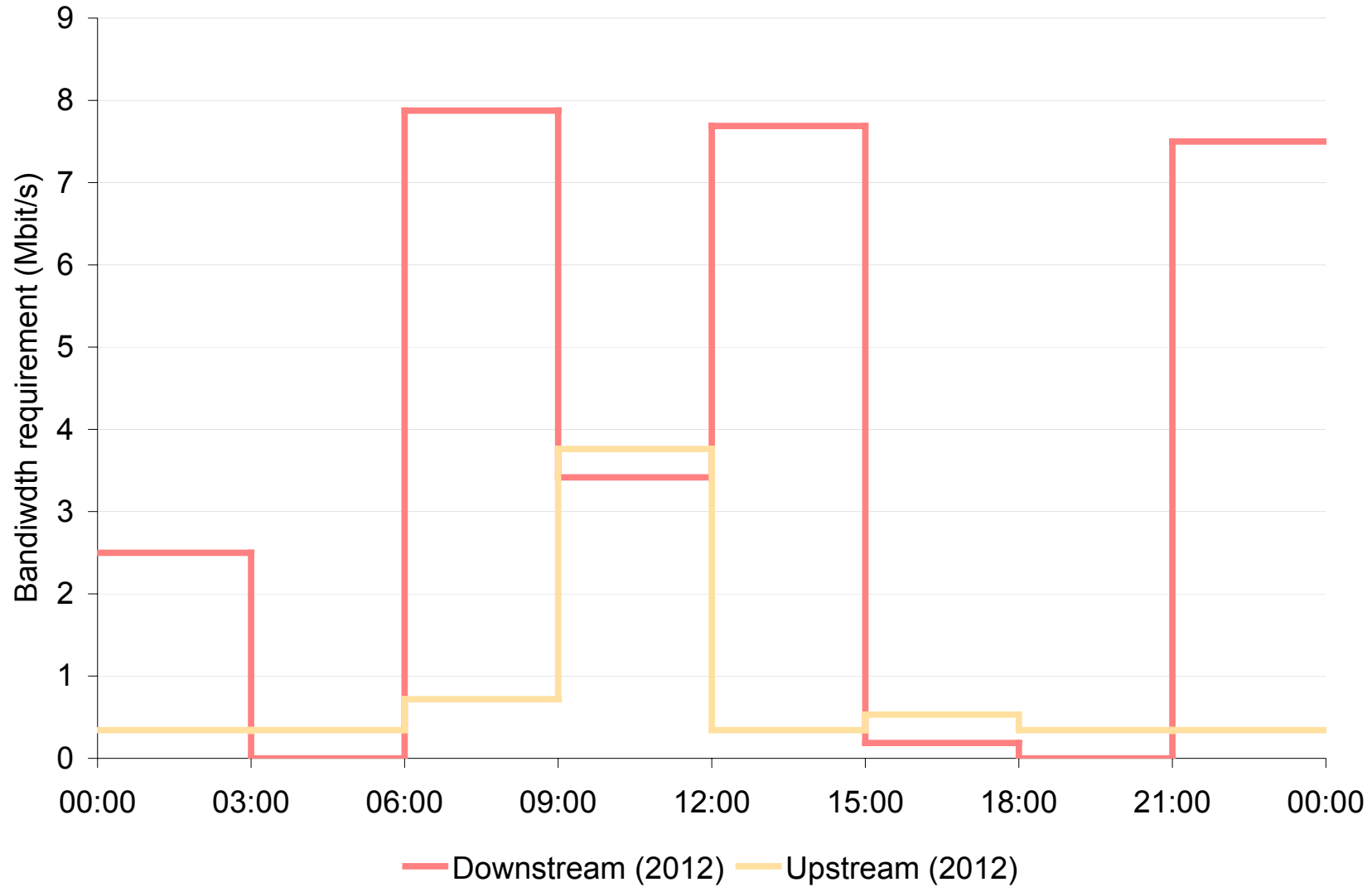
Results: C1 – Single Male, Home Entrepreneur, 2008



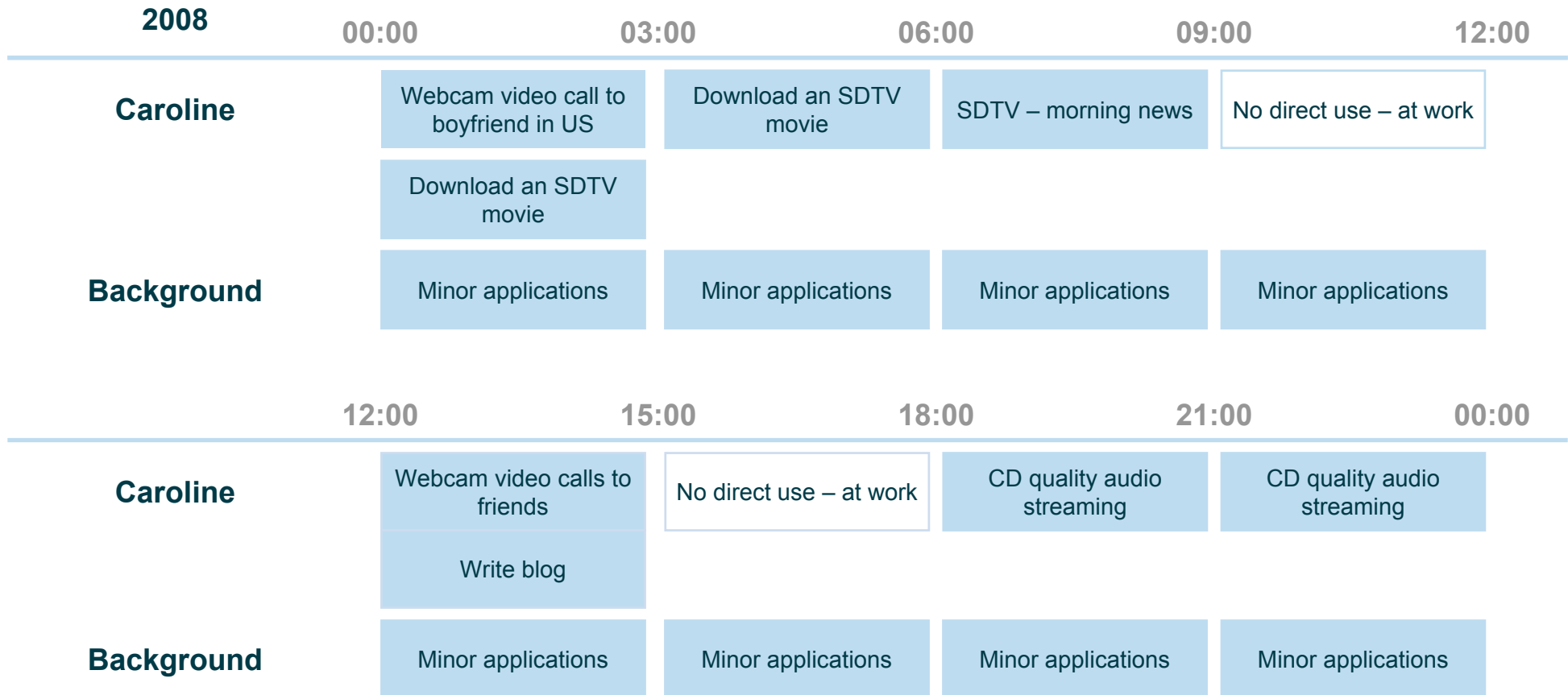
Results: C1 – Single Male, Home Entrepreneur, 2012

2012	00:00	03:00	06:00	09:00	12:00
Dominic	No direct use - asleep	No direct use - asleep	SDTV Video conference with clients in India HDTV – morning news	SDTV video calls with British suppliers E-mailing	
Background	CCTV monitoring home office	CCTV monitoring home office	CCTV monitoring home office	CCTV monitoring home office	
	12:00	15:00	18:00	21:00	00:00
Dominic	HDTV CD quality Internet radio whilst doing admin tasks	Internet market research CD quality VoIP sales pitch calls	No direct use – at the gym and out to dinner	HDTV VoD movie	
Background	CCTV monitoring home office	CCTV monitoring home office	CCTV monitoring home office	CCTV monitoring home office	

Results: C1 – Single Male, Home Entrepreneur, 2012

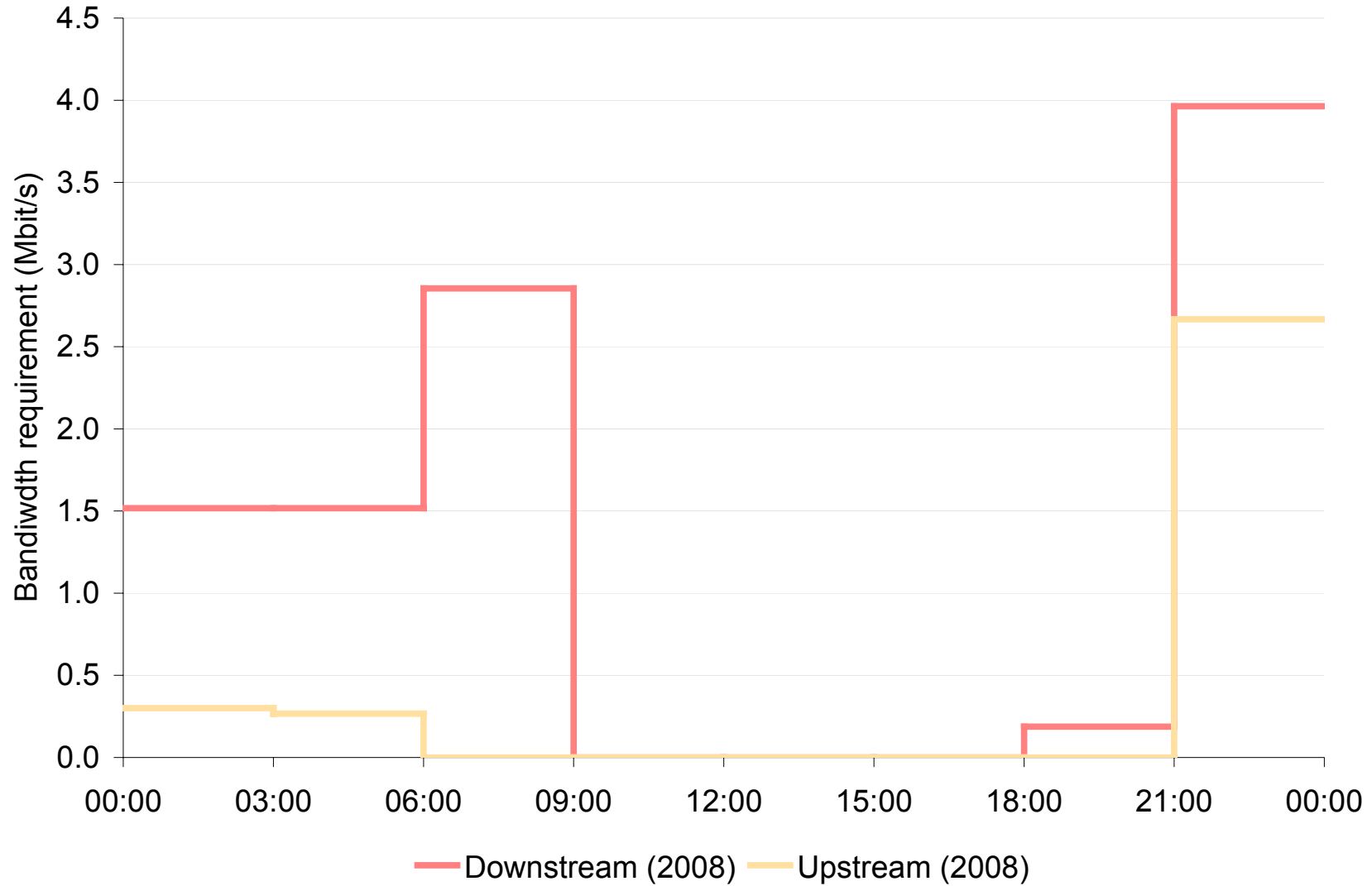


Results: C2 – Single Female, Working, 2008

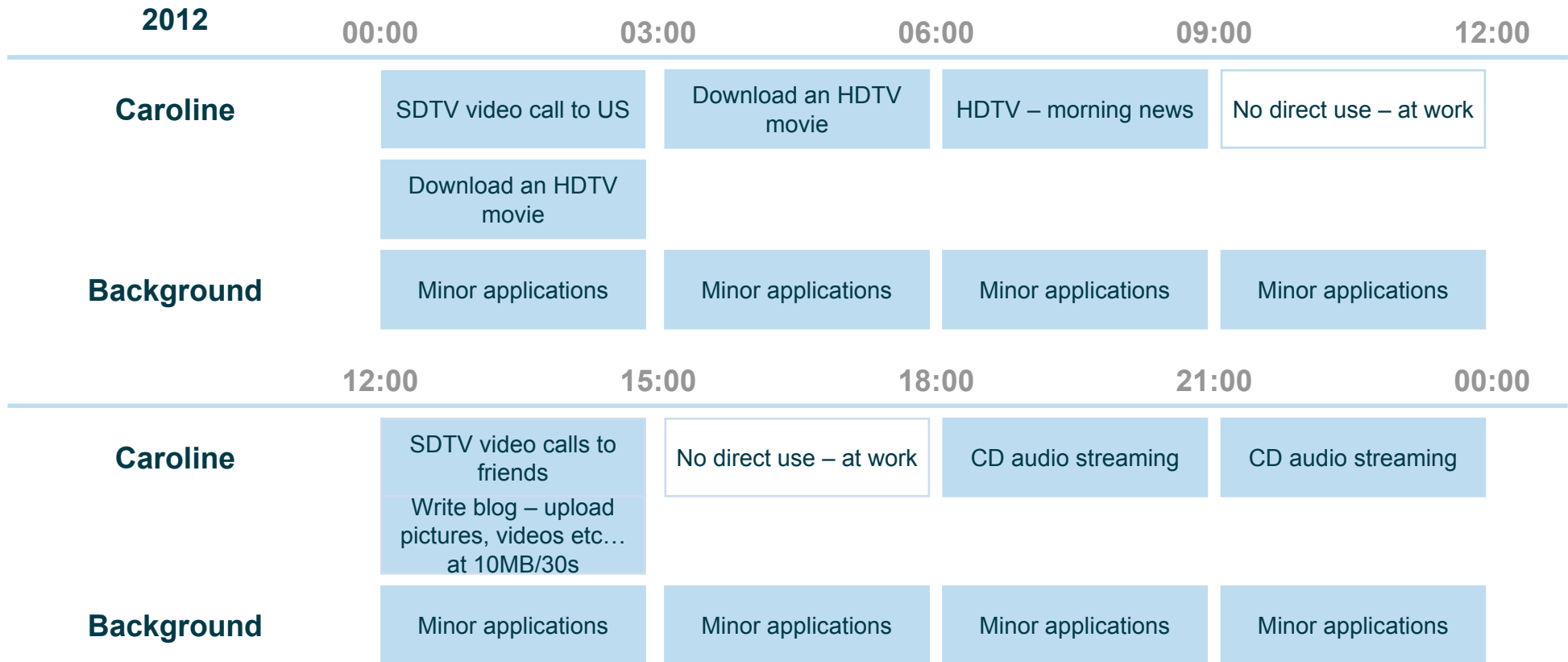


Minor applications include updating antivirus software and filtering junk mail

Results: C2 – Single Female, Working, 2008

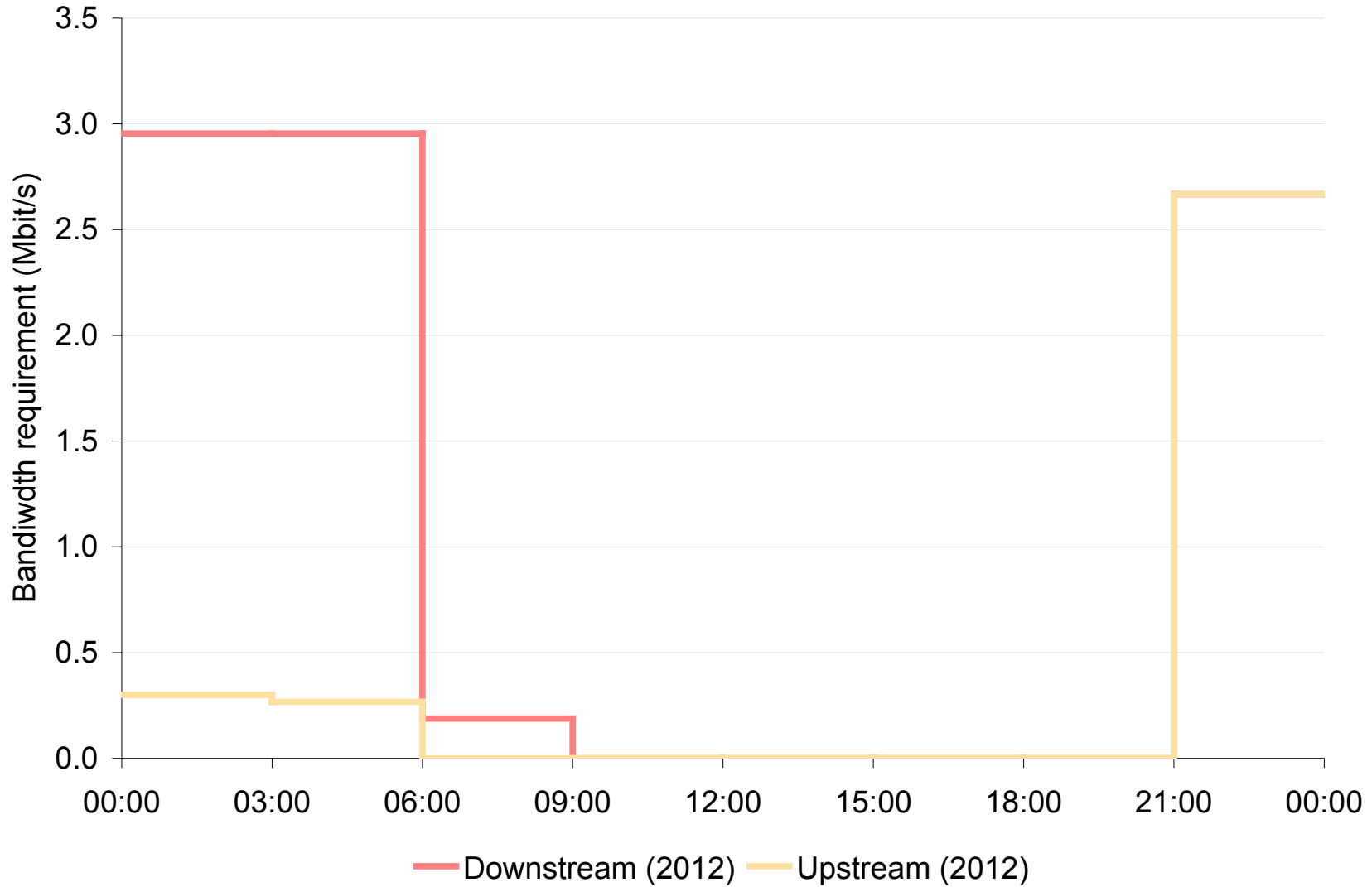


Results: C2 – Single Female, Working, 2012



Minor applications include updating antivirus software and filtering junk mail

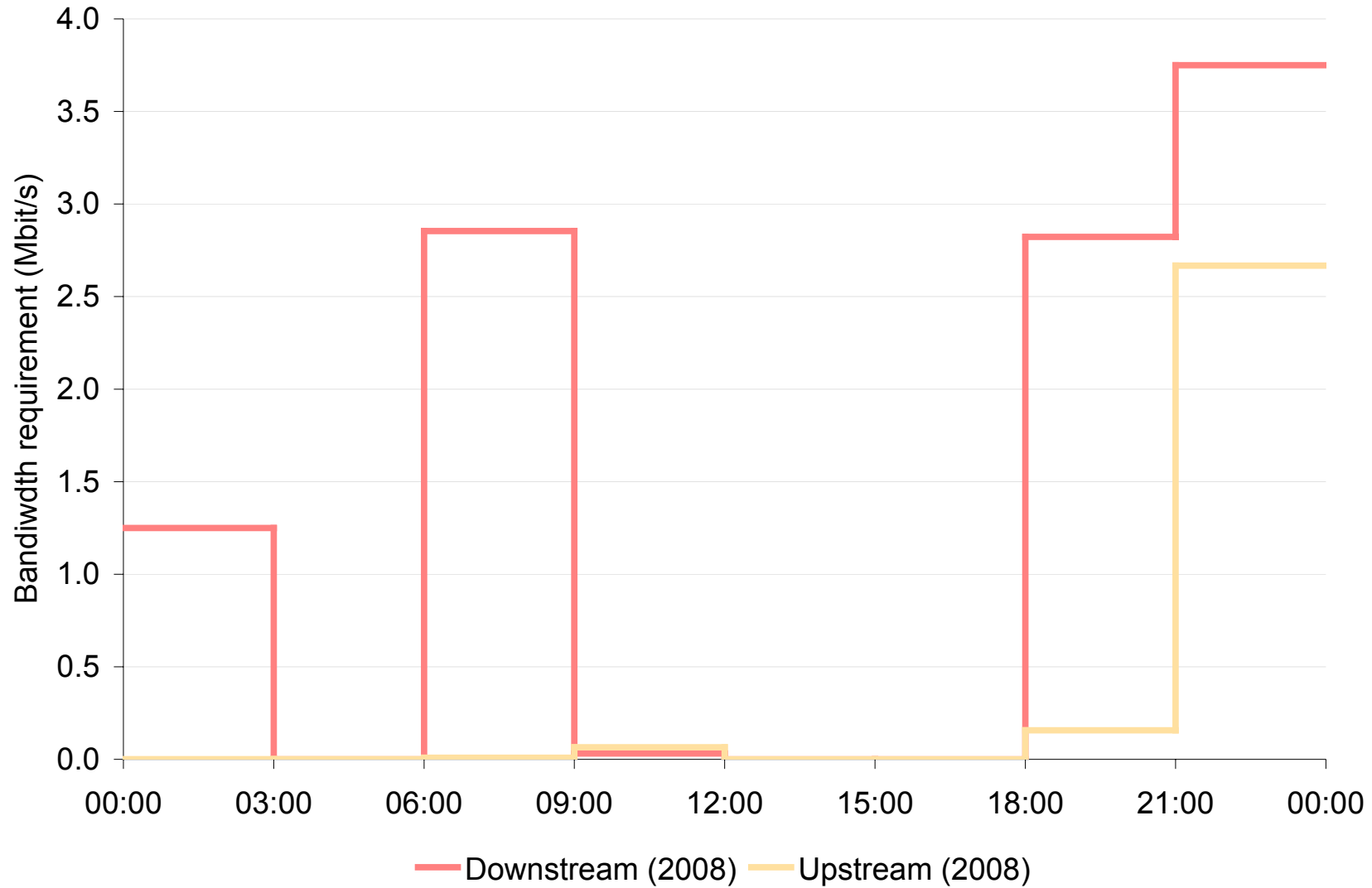
Results: C2 – Single Female, Working, 2012



Results: D – One Man and One Woman, Empty Nesters, 2008

2008	00:00	03:00	06:00	09:00	12:00
Raj	Download an SDTV movie	No direct use - asleep	Download latest copy of BMJ (e-subscription) at 10Mb/30s	No direct use – at the hospital	
Navdip	No direct use - asleep	No direct use - asleep	E-mail family in India	PSTN quality VoIP calls to friends	
Together	No direct use - asleep	No direct use - asleep	Internet radio	NA	
Background	Raj on call, BB monitoring of status at the hospital	Raj on call, BB monitoring of status at the hospital	Raj on call, BB monitoring of status at the hospital	Automated hard disk back-up to remote storage facility	
	12:00	15:00	18:00	21:00	00:00
Raj	No direct use – at the hospital	No direct use – at the hospital	Webcam (CIF) link to hospital – giving advice to junior doctor	SDTV VoD movie	
Navdip	No direct use – out of house	No direct use – out of house	Download evening class revision materials (10MB/30s)	Upload evening class homework (10MB/30s)	
Together	NA	NA	PSTN quality VoIP calls to sons	NA	
Background	Home alarm system	Home alarm system	Raj on call, BB monitoring of status at the hospital	Raj on call, BB monitoring of status at the hospital	

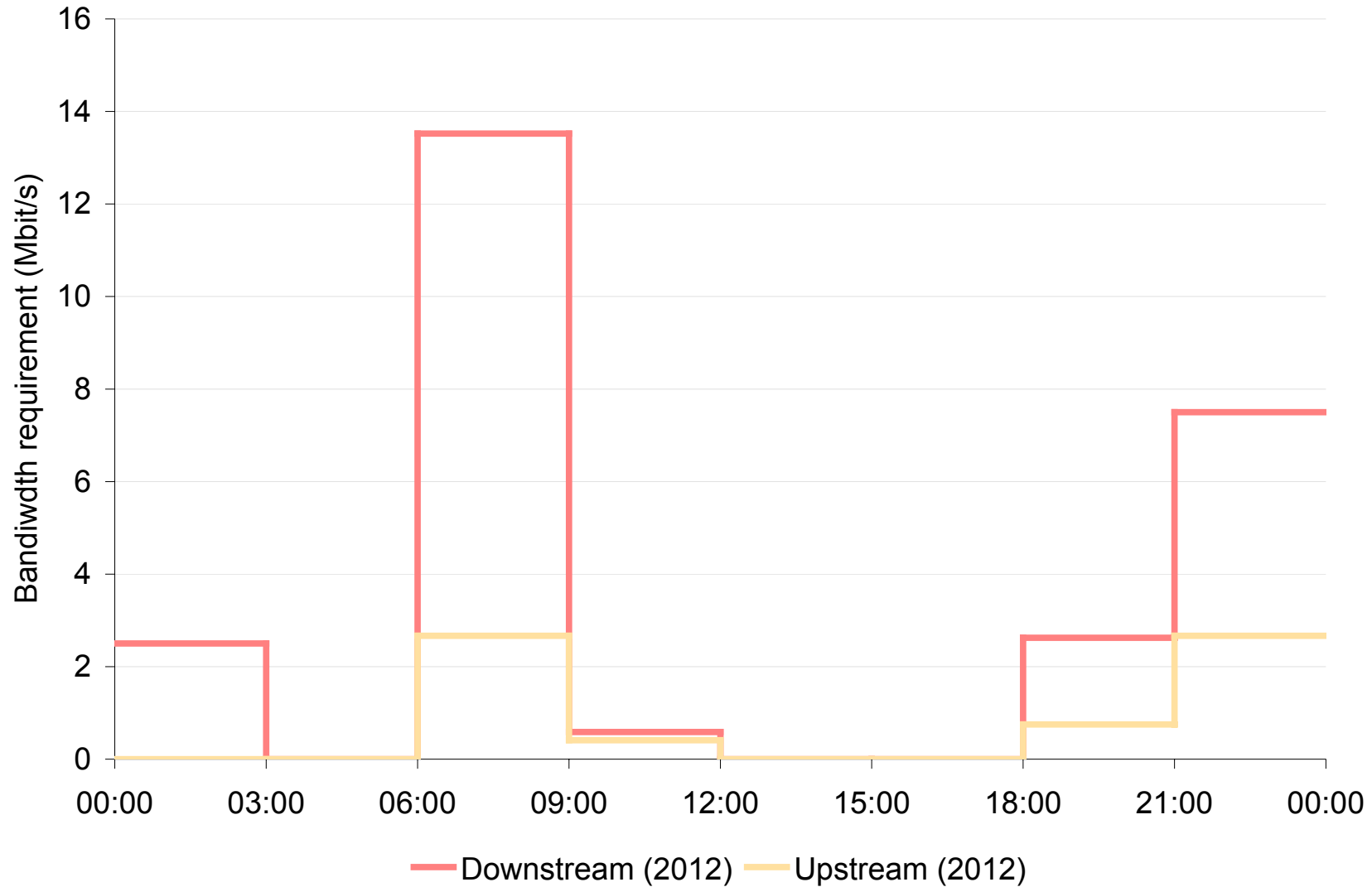
Results: D – One Man and One Woman, Empty Nesters, 2008



Results: D – One Man and One Woman, Empty Nesters, 2012

2012	00:00	03:00	06:00	09:00	12:00
Raj	Download an HDTV movie	No direct use - asleep	Download latest copy of BMJ (e-subscription) at 50MB/30s	No direct use – at the hospital	
Navdip	No direct use - asleep	No direct use - asleep	Rich e-mail family in India; download rich e-mail	SDTV video calls to friends	
Together	No direct use - asleep	No direct use - asleep	Internet radio	NA	
Background	Raj on call, BB monitoring of status at the hospital	Raj on call, BB monitoring of status at the hospital	Raj on call, BB monitoring of status at the hospital	Automated hard disk back-up to remote storage facility	
	12:00	15:00	18:00	21:00	00:00
Raj	No direct use – at the hospital	No direct use – at the hospital	SDTV video-conference with other doctors	HDTV VoD Movie	
Navdip	No direct use – out of house	No direct use – out of house	Streaming SDTV evening class video lecture	Upload evening class homework at 10MB/30s	
Together	NA	NA	SDTV video calls to sons	NA	
Background	Home alarm system	Home alarm system	Raj on call, BB monitoring of status at the hospital	Raj on call, BB monitoring of status at the hospital	

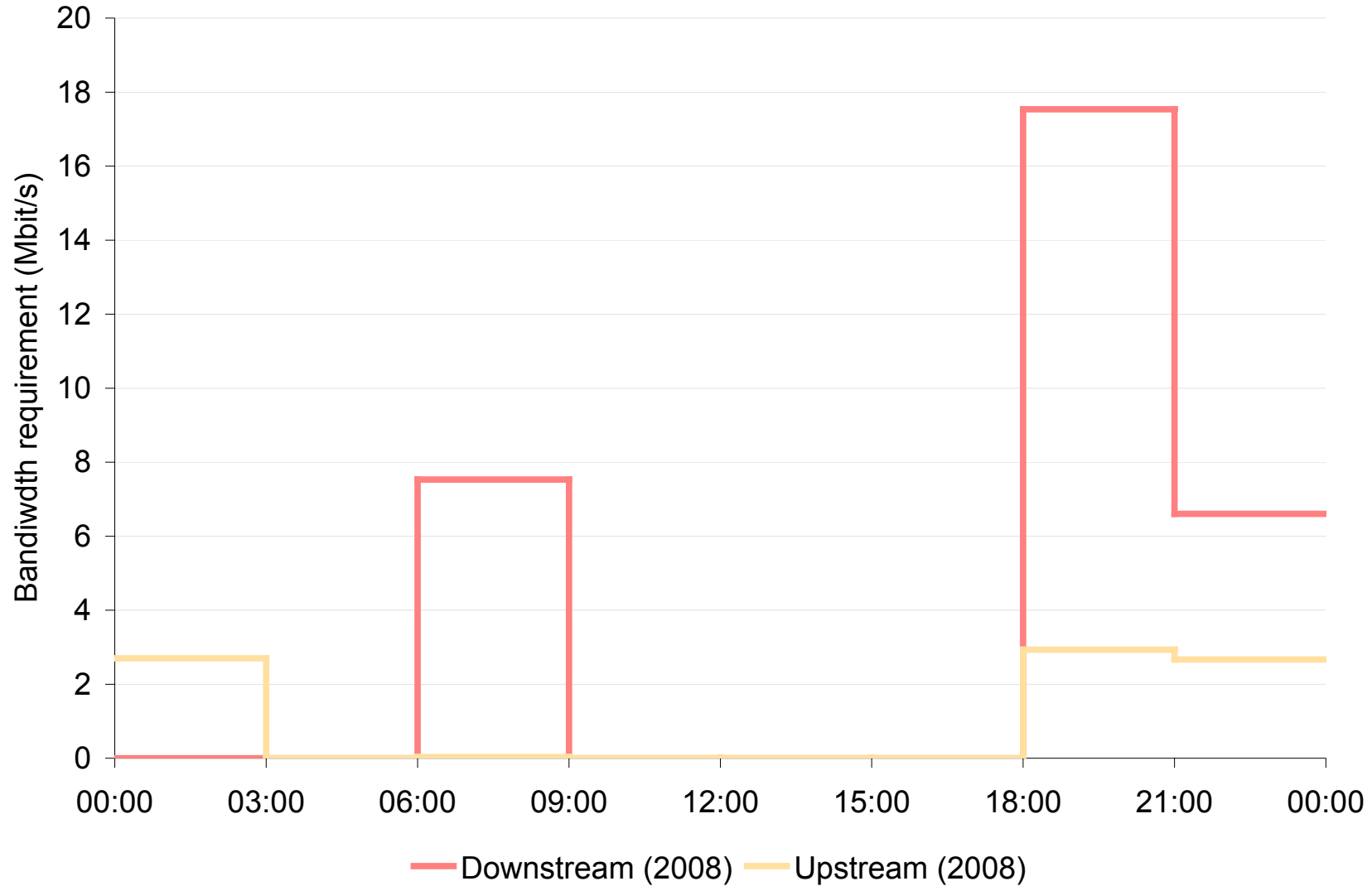
Results: D – One Man and One Woman, Empty Nesters, 2012



Results: D – One Man & One Woman, Young Professional Couple, 2008

2008	00:00	03:00	06:00	09:00	12:00
James	Uploading designs at 10MB/30s	No direct use – in bed	PSTN quality VoIP to colleagues	No direct use – at work	
Charlotte	No direct use – in bed	No direct use – in bed	PSTN quality VoIP to client	No direct use – at work	
Together	No direct use – in bed	No direct use – in bed	Download an SDTV movie for travel entertainment	NA	
Background	Automated hard disk back-up to remote storage facility	None	None	Home alarm system	
	12:00	15:00	18:00	21:00	00:00
James	No direct use – at work	No direct use – at work	Downloading graphics – ideas for designs (50MB/30s)	Online designing	
Charlotte	No direct use – at work	No direct use – at work	Download CD quality music	Download details of new case at 10MB/30s	
Together	NA	NA	SDTV	SDTV	
Background	Home alarm system	Home alarm system	None	None	

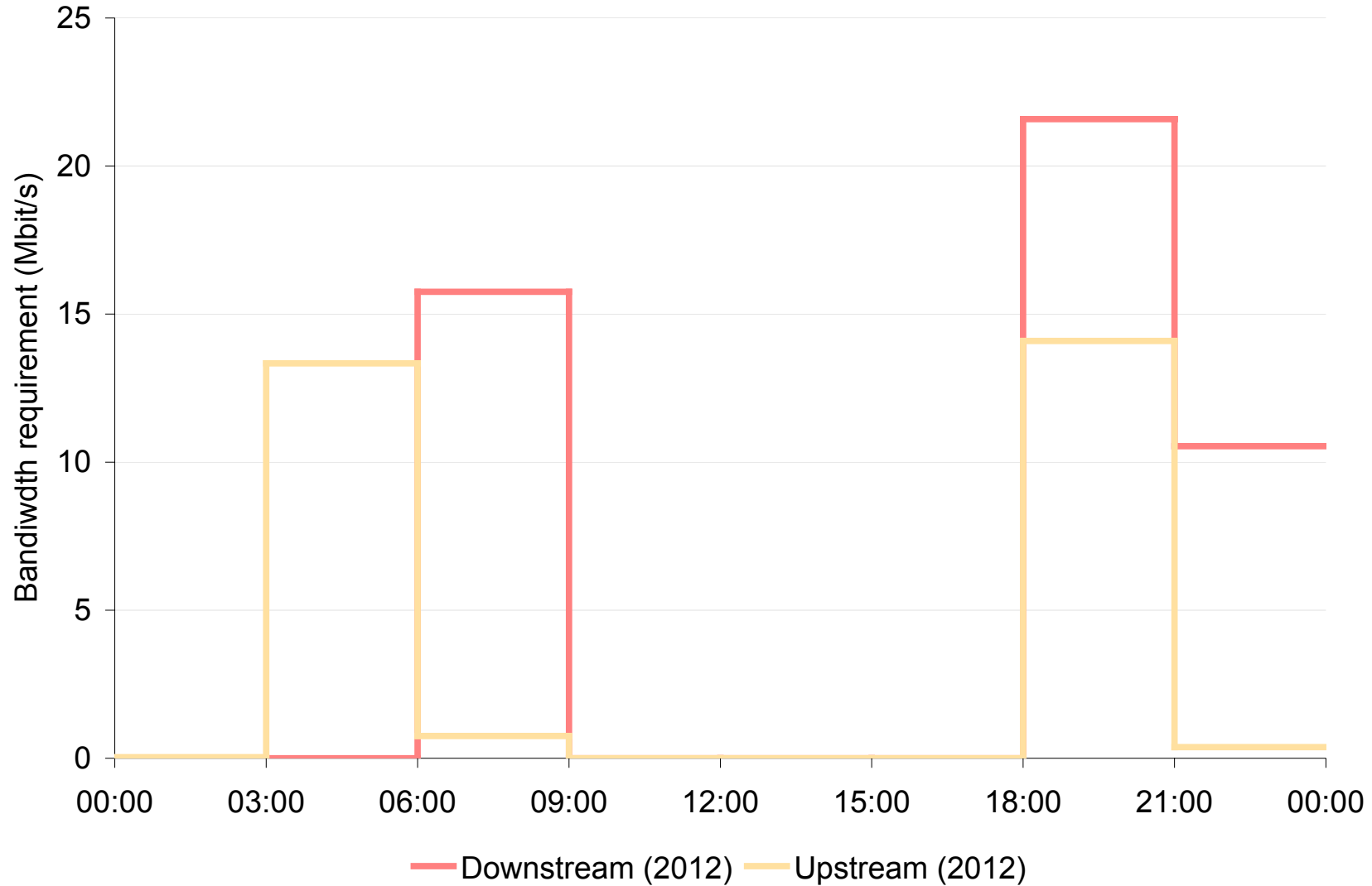
Results: D – One Man & One Woman, Young Professional Couple, 2008



Results: D – One Man & One Woman, Young Professional Couple, 2012

2012	00:00	03:00	06:00	09:00	12:00
James	Online designing	Fast upload of latest designs at 50MB/30s	SDTV video conference with design team in Beijing	No direct use – at work	
Charlotte	No direct use – in bed	No direct use – in bed	SDTV video call to new client	No direct use – at work	
Together	No direct use – in bed	No direct use – in bed	Download an HDTV movie for travel entertainment	NA	
Background	Automated hard disk back-up to remote storage facility	None	None	Home alarm system	
	12:00	15:00	18:00	21:00	00:00
James	No direct use – at work	No direct use – at work	Online CAD-CAM brainstorming session	SDTV Video conference with clients in the US	
Charlotte	No direct use – at work	No direct use – at work	Working from home – e-mailing, & SDTV video calls	Download materials to review on commute at 10MB/30s	
Together	NA	NA	HDTV	HDTV	
Background	Home alarm system	Home alarm system	None	None	

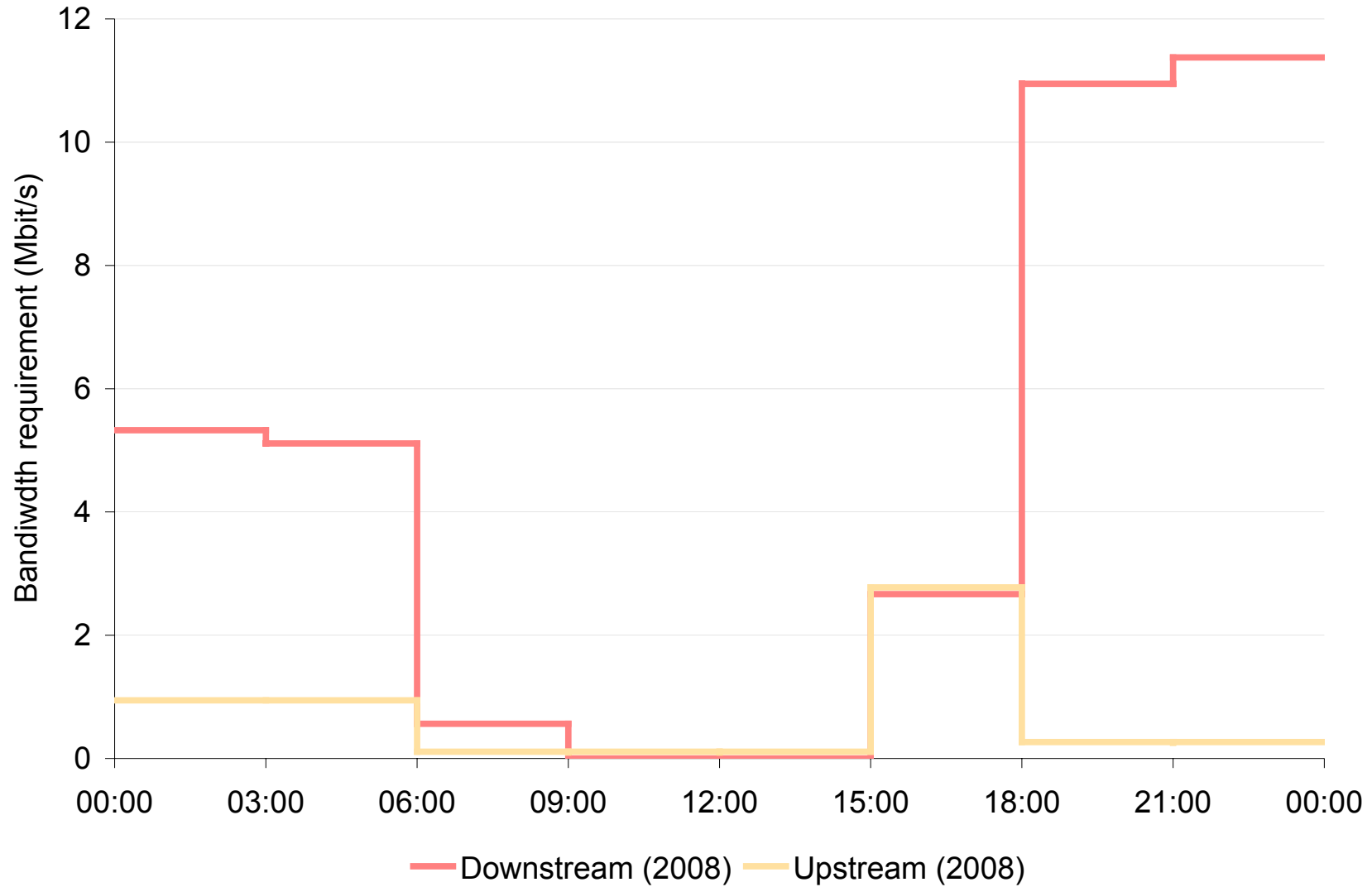
Results: D – One Man & One Woman, Young Professional Couple, 2012



Results: E – Family house, 2008

2008	00:00	03:00	06:00	09:00	12:00
Peter	No use	No use	Internet radio alarm clock	No use – out of the house	
Susan	Overnight SDTV movie download	Overnight SDTV movie download	Internet radio alarm clock	No use – out of the house	
Edmond	Download music & SDTV movie	Download music & SDTV movie	Internet radio whilst getting up	No use – out of the house	
Lucy	Download music & SDTV movie	Download music & SDTV movie	No use	No use – out of the house	
Background tasks	Automated back-up of PC hard drive	Automated back-up of PC hard drive	In house CCTV uploaded to server	In house CCTV uploaded to server	
	In house CCTV uploaded to server	In house CCTV uploaded to server			
	12:00	15:00	18:00	21:00	00:00
Peter	No use – out of the house	No use – out of the house	SDTV VoD programme whilst making dinner	SDTV VoD	
Susan	No use – out of the house	No use – out of the house	PSTN quality VoIP call	SDTV VoD	
Edmond	No use – out of the house	Homework research	Interactive Internet revision for exams	Webcam (CIF) calls to friends	
Lucy	No use – out of the house	Upload graphics design homework at 10MB/30s	Webcam (CIF) calls to friends	SDTV VoD	
Background tasks	In house CCTV uploaded to server	In house CCTV uploaded to server	In house CCTV uploaded to server	In house CCTV uploaded to server	

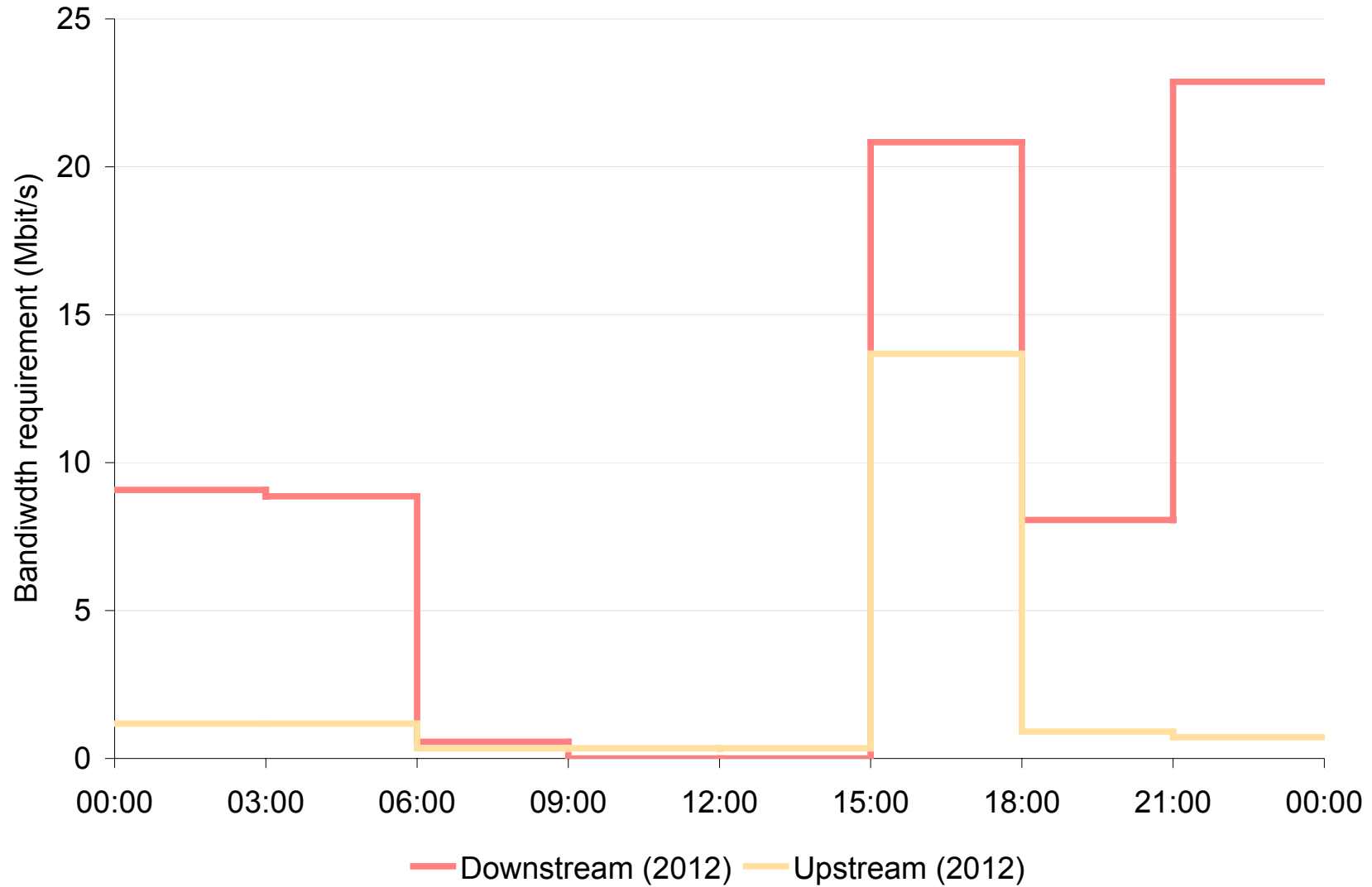
Results: E – Family house, 2008



Results: E – Family house, 2012

2012	00:00	03:00	06:00	09:00	12:00
Peter	No use	No use	Internet radio alarm clock CD quality	No use – out of the house	
Susan	Overnight HDTV Movie download	Overnight HDTV Movie Download	Internet radio alarm clock CD quality	No use – out of the house	
Edmond	Download Music & HDTV Movie	Download Music & HDTV Movie	Internet radio whilst getting up CD quality	No use – out of the house	
Lucy	Download Music & HDTV Movie	Download Music & HDTV Movie	No use	No use – out of the house	
Background tasks	Automated back-up of PC hard drive	Automated back-up of PC hard drive	In house CCTV uploaded to server	In house CCTV uploaded to server	
	In house CCTV uploaded to server	In house CCTV uploaded to server			
	12:00	15:00	18:00	21:00	00:00
Peter	No use – out of the house	No use - Out of the house	HDTV VoD programme whilst making dinner	HDTV VoD	
Susan	No use – out of the house	No use – Out of the house	CD quality VoIP call	HDTV VoD	
Edmond	No use – out of the house	Homework research (50MB in 30s downstream)	Interactive Internet revision for exams	SDTV calls to friends	
Lucy	No use – out of the house	Upload graphics design homework at 50MB/30s upstream	SDTV calls to friends	HDTV VoD	
Background tasks	In house CCTV uploaded to server	In house CCTV uploaded to server	In house CCTV uploaded to server	In house CCTV uploaded to server	

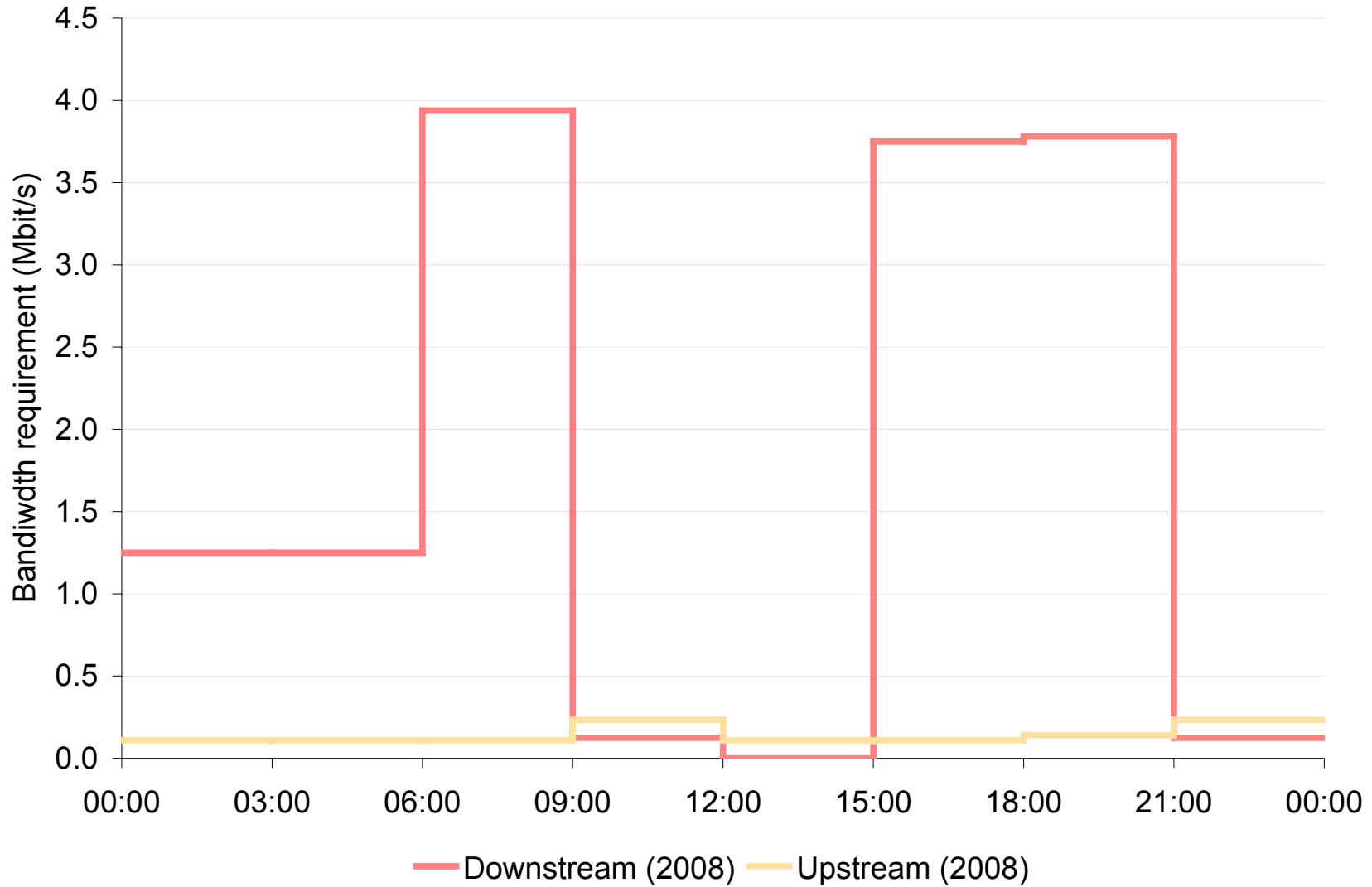
Results: E – Family house, 2012



Results: F – Single Parent, 2008

2008	00:00	03:00	06:00	09:00	12:00
Penny	Download an SDTV movie	Download an SDTV movie	Listening to breakfast DAB radio	CIF quality video phone to friends	
Lottie	No use	No use	SDTV VoD cartoons	No use (at school)	
Background	Webcam CCTV	Webcam CCTV	Webcam CCTV	Webcam CCTV	
	12:00	15:00	18:00	21:00	00:00
Penny	No use (out of the house)	Internet shopping	SDTV VoD	CIF quality video phone to friends	
Lottie	No use (at school)	SDTV VoD for homework use	VoIP conversations with friends	No use	
Background	Webcam CCTV	Webcam CCTV	Webcam CCTV	Webcam CCTV	

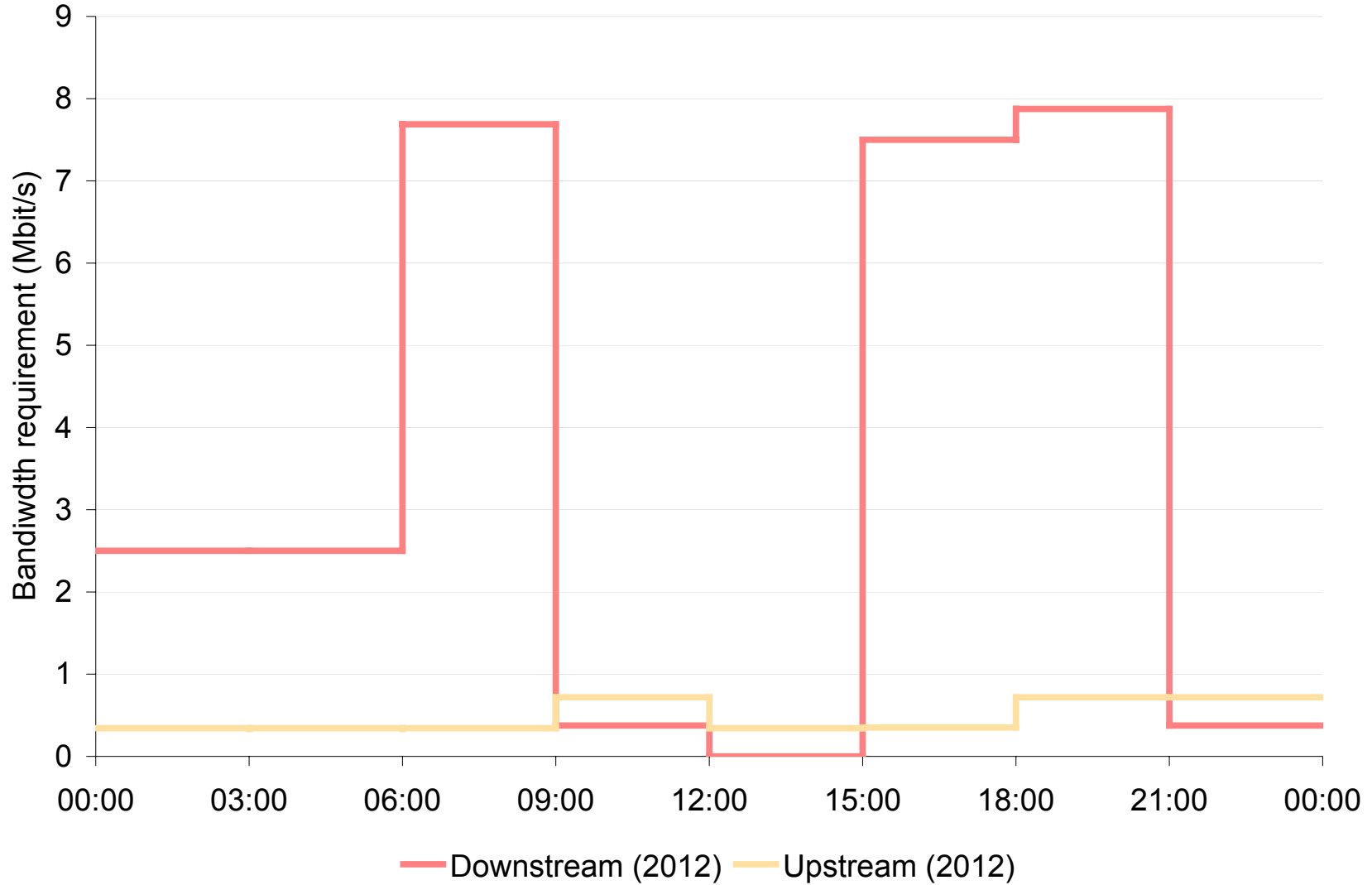
Results: F – Single Parent, 2008



Results: F – Single Parent, 2012

2012	00:00	03:00	06:00	09:00	12:00
Penny	Download HDTV Movie	Download HDTV Movie	Listening to breakfast DAB radio	SDTV quality video phone to friends	
Lottie	No use	No use	HDTV cartoons	No use (at school)	
Background	Good quality webcam CCTV	Good quality webcam CCTV	Good quality webcam CCTV	Good quality webcam CCTV	
	12:00	15:00	18:00	21:00	00:00
Penny	No use (out of the house)	Internet shopping	HDTV VoD	SDTV quality video phone to friends	
Lottie	No use (at school)	HDTV VoD for homework use	SDTV quality video phone with friends	No use	
Background	Good quality webcam CCTV	Good quality webcam CCTV	Good quality webcam CCTV	Good quality webcam CCTV	

Results: F – Single Parent, 2012



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