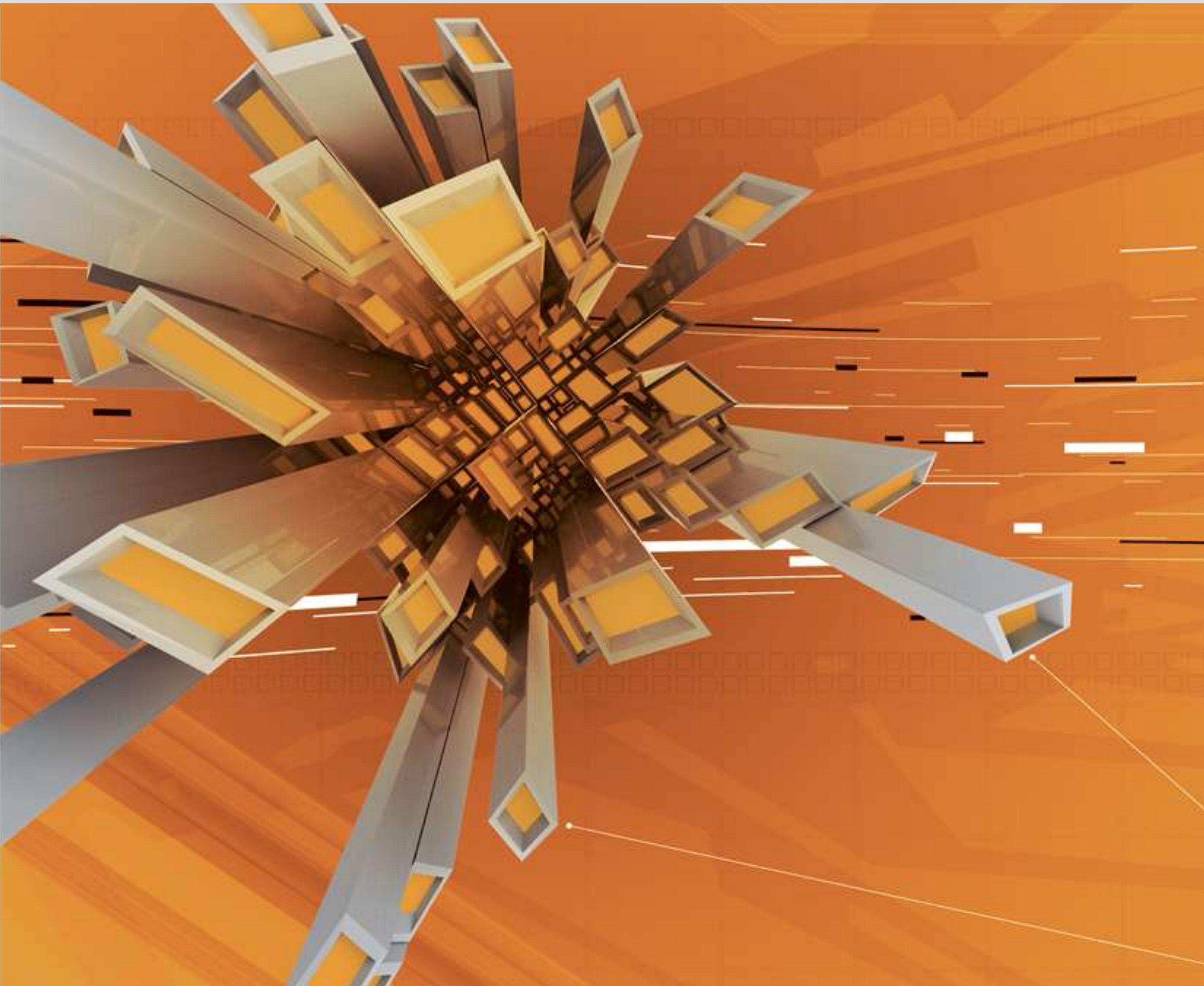
PA Consulting Group

Ofcom

The Likelihood and Extent of Radio Frequency Interference from In-Home PLT Devices

DRAFT - 13th November 2009



1 Executive summary

Power Line Telecommunications (PLT) is the collective term for various forms of communication over wiring used for supplying electricity (termed the 'mains' wiring throughout this report). The most recent developments in PLT devices address the consumer market for in home connectivity as an alternative to WiFi or cable. It is these in-home PLT devices that are the specific focus of this study. In-home PLT devices are growing in popularity and, in particular, their use in BT Vision installations in the UK has made the UK one of the biggest users of in-home PLT devices in Europe.

PLT devices operate at HF frequencies and, while they are unintentional radiators, there is evidence of interference to other HF users which has resulted in a number of complaints to Ofcom. While most of these complaints have been resolved, Ofcom is concerned that the problem may grow as the number of PLT devices deployed increases over time.

Ofcom has asked PA to assess the likelihood and impact of RF interference from in-home PLT devices over the next 5 to 10 years.

RF interference from PLT devices may reach HF spectrum users via a number of routes. For the purpose of this study we have split these into the following two categories:

- **Radiated emissions directly from the PLT user's home -** The mains wiring of the house where the PLT device is being used will act as an antenna and radiate the signal injected into the mains wiring by the PLT device. Depending on the distance between the PLT user and victim receiver, a victim receiver may suffer interference from these radiated emissions.
- **Interference from an "infected" powerline** - As the consumer unit of a typical house does not specifically filter out PLT signals, the PLT signal injected into the mains wiring within the home will potentially be conducted into the mains wiring external to the house. This mains connection external to the home will be shared by a number of other households. Interference could therefore be caused by radiated emissions from wiring nearby to the victim receiver that shares a mains connection with the PLT user and has been "infected" with the PLT signal.

In the case of both of these routes we have concluded that, provided uptake increases in line with our market forecasts, there will be a high probability of interference to HF users by 2020 if PLT device features do not change from those currently implemented. However, within this timescale additional interference mitigation features such as power control and smart notching should have been implemented in PLT devices and will be enough to reduce interference to negligible levels for most HF users. The exception to this is the safety critical aeronautical bands which we recommend are notched by default rather than smart notched.

While power control and smart notching are already part of the product roadmaps of the PLT vendors that we spoke to as part of this study, we recommend that these features are mandated to ensure their timely implementation in PLT devices.

Document control

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A	"Work in progress" draft for discussion with client	[✂] s.40	[✂] s.40	16-10-09
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Table of contents

2 Study aims and our approach

This section provides the context for the study, introducing PLT devices and their potential to cause interference to other radio spectrum users. It then states Ofcom's objectives for conducting the study and the specific questions answered.

2.1 In-Home PLT devices are increasingly being deployed in the UK

Power Line Telecommunications (PLT) is the collective term for various forms of communication over mains electrical wiring. The most recent developments in PLT devices address the consumer market for in-home connectivity as an alternative to WiFi or cable.

Power Line Telecommunications (PLT) is the collective term for various forms of communication over wiring used for supplying electricity (termed the 'mains' wiring throughout this report). This has been used for many years by the electricity companies themselves for monitoring and control of the electricity networks. This was originally at very low frequencies for simple control such as switching street lights or metering tariffs according to the time of day. Around the 1980s SCADA control systems appeared and used frequencies up to 148.5kHz with two-way communication. There are very few radio users at such low frequencies so radiated energy from these PLT systems was rarely if ever a problem.

The most recent developments in PLT have two significant differences from the earlier systems described above. Firstly they are aimed at end users outside the electricity company, i.e. the consumer market for in-home connectivity as an alternative to WiFi or cable, with some devices now on the market for less than £35. Secondly the frequencies used are much higher in order to support data rates comparable with Ethernet LANs and VDSL broadband systems. In particular the use of PLT in 'BT Vision' installations in the UK has made the UK one of the biggest users of in-home PLT devices in Europe.

The focus of this study is on in-home PLT devices, which provide a network within the home, rather than access PLT devices, which provide a data connection to the home. Figure 1 shows the distinction between the use of PLT in-home and for access to the home.

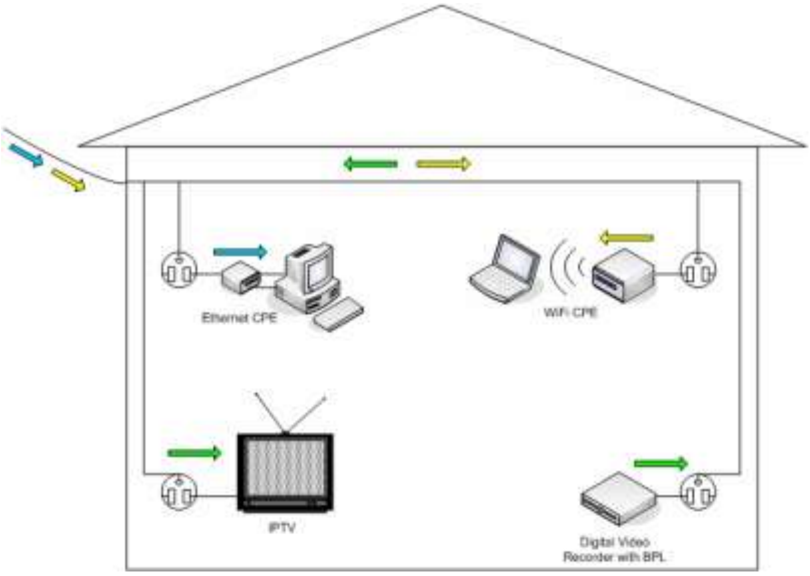

Figure 1 Distinction between In-home and Access PLT (In-home shown green. Access shown blue and yellow)

2.2 PLT device emissions have the potential to cause interference

PLT devices operate at HF frequencies and can act as unintentional radiators, effectively using the electricity supply wiring as an antenna. There is a significant body of evidence of interference to other HF users including amateur radio users and shortwave broadcasts.

The electrical power network is designed for distributing power from a small number of sources to a very large number of loads at 50Hz. The impedance of the network at the high frequencies used by PLT is uncontrolled and often time-varying as electrical devices are switched on and off. In addition, the live and neutral conductors are not always close together, which exacerbates far-field radiation effects. Fundamentally, with PLT, the power network is being used for something for which it was not designed.

When PLT devices send their signal into the mains wiring it propagates not only to the target device but throughout the mains circuit, being stopped usually only by a transformer or, over longer distances, by line attenuation. Typical PLT devices propagate for a range of several hundred metres. Typically there will be many homes on one circuit such as a street or a block of flats. The PLT signal from one home will therefore propagate through many others. Small offices within an office block may be similarly affected.

While the PLT standards mandate encryption to prevent accidental or intentional interception of data by devices that are not part of the same network, this does not stop the signal energy from propagating and therefore causing radio frequency interference. Measurements made on PLT deployments by Ofcom have shown significant rises in noise level at up to 300 metres from the power line or installation when PLT equipment is operating [1, 2, 3]. Given that most receivers are likely to be close to an electricity supply power source, the potential for widespread interference is clear.

The frequency range used by currently available PLT devices is approximately 2-30 MHz. This frequency range is also used by many licensed radio users in the UK including, among others, short wave broadcasting, amateur radio and professional users such as aviation, maritime and military communications. The amateur radio and shortwave listener communities have, in particular, documented instances of interference from in-home PLT devices.

2.3 Study objective - What is the likelihood and extent of interference from PLT in a 5-10 year timescale?

The objective of this project is to understand the likelihood and extent of radio frequency interference caused by increased use of PLT devices and evolutions of the technology. A quantitative analysis of expected interference will provide input to any future debate on Ofcom's regulatory duties in this area.

As noted above, there is evidence of interference from PLT devices to other HF users. This has resulted in a number of complaints to Ofcom and while most of these complaints have been resolved, Ofcom is concerned that the problem may grow as the number of PLT devices deployed increases over time.

Ofcom therefore asked PA to determine the likelihood and impact of RF interference from in-home PLT devices over the next 5 to 10 years. In looking at future trends for interference into other services, as well as potential device takeup, it has been important to take account of developments in the specifications for the PLT devices. Specifically there are plans to increase data rates and to introduce more advanced features to mitigate against the likelihood of interference to other services.

Ofcom provided the following guidance as to the study approach to be followed:

- A study of the relevant trends, developments and roadmaps of PLT devices, covering new and emerging technologies and standardisation activities;
- A study of the options for home networking, including wired Ethernet, WiFi and PLT based approaches, in order to understand under what circumstances PLT networking becomes attractive (or necessary) to users;
- A review of scenarios covering possible future deployment densities of PLT devices;
- A modelling activity, to simulate and quantify the interference effects of PLT devices for each scenario.

The study has been a forward-looking research study. While Ofcom are engaged in ongoing European standardisation and regulation work in relation to PLT devices, the project scope explicitly excluded providing advice on EMC regulations and their interpretation in relation to PLT.

2.4 Our approach

PA's approach comprised four key stages.

- ***Start-up and data gathering -*** Conducting desk research and discussions with PLT industry bodies to confirm device characteristics and trends and gathering existing information on PLT interference to avoid duplicating previous work. In addition holding stakeholder discussions with existing HF users to understand previous experience of PLT interference and victim receiver characteristics.
- ***Developing usage and density scenarios -*** Defining how and where in-home PLT devices are used and forecasting likely future densities for in-home PLT devices.
- ***Interference modelling -*** Examining the impact interference mechanisms between the PLT devices and victim systems in the relevant frequency bands and performing statistical modelling to determine the likely extent of harmful interference based on forecast device density.
- ***Sensitivity analysis and mitigation -*** Finally, conducting sensitivity analysis on the results by varying a number of assumptions and commenting on the viability of potential methods to mitigate against PLT interference.

An overview of our approach is given in Figure 2 with a detailed description given in Appendix D:.

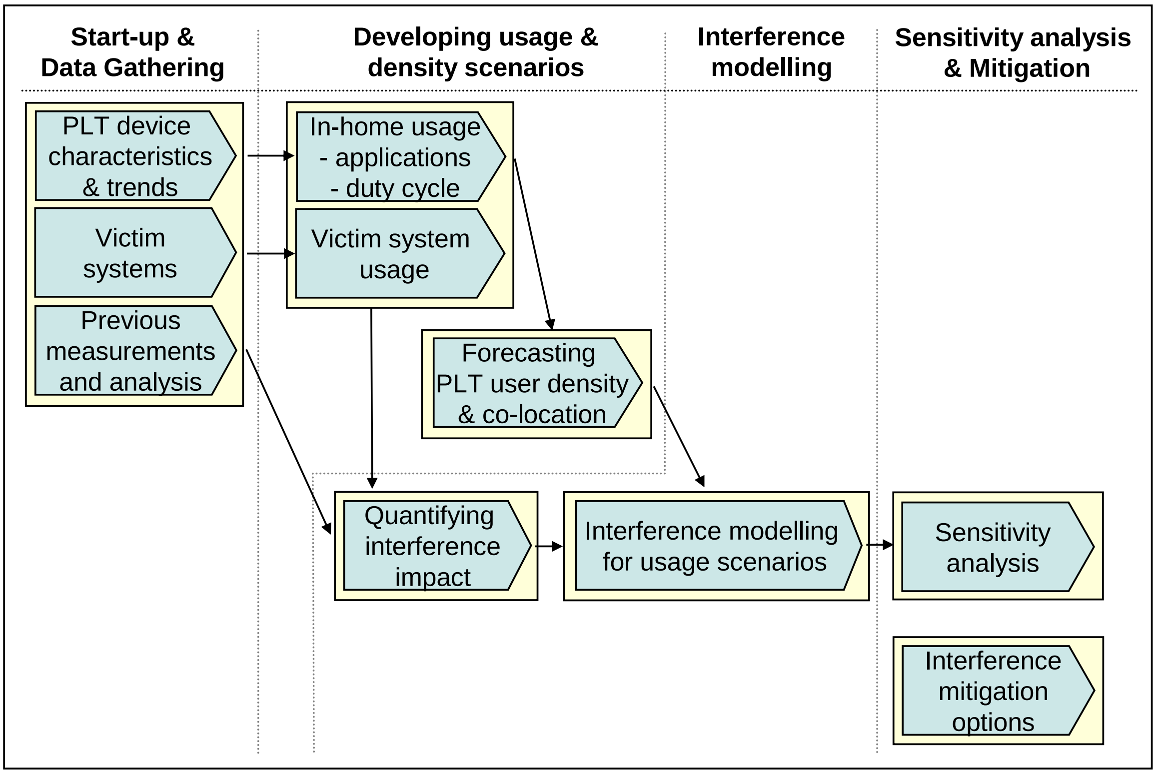

Figure 2 - PA's approach to this study

2.5 Report structure

This report is structured to present an independent and balanced assessment of this topic, with a logical flow in line with the approach described above.

- Section 3 - Overview of our findings for each interference mechanism and top level assumptions on PLT devices and victim receivers.
- Section 4- Detailed review of PLT devices both now and over a 5 -10 year timeline. Our market estimates for PLT devices are also presented.
- Section 5 - Detailed assumptions for each victim receiver type assessed.
- Section 6 - Description of our assessment of the likelihood of interference radiated directly from PLT user's homes.
- Section 7 - Detailed description and results from our main interference modelling activity, the development of a Seamcat model to quantify interference to ground based HF users via radiated emissions from PLT devices over small areas.
- Section 8 - Assessment of interference from PLT devices via an "infected" mains connection (as opposed to interference from radiated emissions directly from the PLT user's home).
- Section 9 - Summarising conclusions and recommendations for follow up by Ofcom.

A number of Appendices provide additional detail to support the conclusions of the main document.

3 If action is taken to ensure that mitigation techniques are implemented, the probability of interference to the majority of HF users up to 2020 is low

As PLT devices have the potential to cause interference via a number of mechanisms, this section introduces how we have categorised interference from PLT and our top level findings for each of these categories.

3.1 Interference via all of the assessed routes is manageable but requires action

Interference from PLT devices may reach victim receivers via a number of routes. For the purpose of this study, as shown in Figure 3, we have split these into the following two generic categories:

- **Radiated emissions directly from the PLT user's home** - The mains wiring of the house where the PLT device is being used will act as an antenna and the signal injected into the mains wiring by the PLT device will be radiated.
- **Interference from an "infected" powerline** - The PLT signal injected into the mains wiring within the home will potentially be conducted into the mains wiring external to the house. Interference could therefore be caused by radiated emissions from wiring nearby to the victim receiver that shares a mains connection with the PLT user.

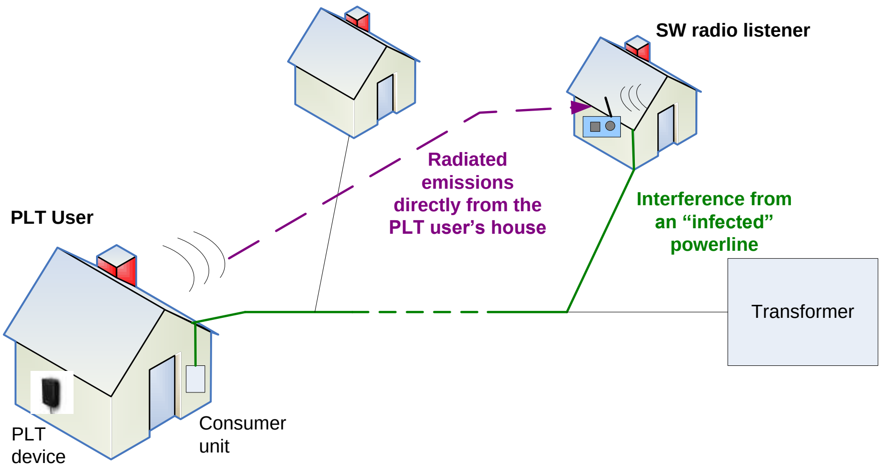

Figure 3 - Categories of interference mechanisms from PLT devices

In the case of both of these routes we have concluded that, if uptake increases in line with our market forecasts, there will be a high probability of interference to HF users by 2020 if PLT device features do not change from those currently implemented. However, based on our discussions with PLT suppliers, within this timescale additional interference mitigation features such as power control and smart notching should have been implemented in PLT devices and will be enough to reduce interference to negligible levels for most HF users. The exception to this is the safety critical aeronautical bands which we recommend are notched by default rather than smart notched.

While power control and smart notching are already part of the product roadmaps of the PLT vendors that we spoke to as part of this study, we recommend that these features are mandated to ensure their timely and consistent implementation in PLT devices.

3.1.1 Radiated emissions directly from the PLT user's home are manageable but require action

Current in-home PLT devices operate in the HF band; radiated emissions from these devices will propagate and potentially cause interference via a variety of mechanisms. These are discussed further in section 6.1 but for the purpose of this study have been divided into the following four categories:

- Cumulative effect of radiated emissions to ground based HF users over large areas
    - Via ground wave
    - Via sky wave
- Cumulative effect of radiated emissions to airborne HF users
- Cumulative effect of radiated emissions to ground based HF users over small areas

Cumulative effect of radiated emissions to ground based HF users over large areas - We have concluded that PLT interference from a cumulative ground wave effect over large areas is unlikely using GRWAVE[1] to confirm this. By scaling results from a previous NATO study [5] to our own market forecasts for PLT devices we have also concluded that there is no significant threat of PLT interference from a cumulative effect of sky wave over large areas.

Cumulative effect of radiated emissions to airborne HF users - We have considered interference to airborne HF users based on a study of the effects of PLT within ITU-R [6] scaled to our own market forecast for PLT devices. This has shown that both power control and notching need to be applied to the aeronautical bands to bring interference to manageable levels.

Cumulative effect of radiated emissions to ground based HF users over small areas - Given that the two effects above are relatively clear from previous studies, the main focus of our analysis of radiated emissions from PLT devices has been the probability of interference from the cumulative effect of radiated emissions to ground based HF users over small areas. Our simulation results show that across the three classes of victim receivers examined, interference from PLT devices is

[1] GRWAVE is a software implementation of the ITU standard for ground wave propagation, ITU-R P.368-7 [4].

manageable but does require action to mandate interference mitigation features in a timely manner. Table 1 summarises results from our simulation model across the three victim receiver types examined (details are given in Section 5) with the probability of interference categorised as follows:

- Negligible <1%
- Low 1-5%
- Medium 5-20%
- High >20%

	2010	2015	2020
Shortwave listener	Low probability of interference if power control mandated Negligible probability of interference if smart notching added.	Medium probability of interference with power control alone Negligible probability of interference if smart notching is added	Medium probability of interference with power control alone Negligible probability of interference if smart notching is added
Amateur radio	Low probability provided default IARU notches are applied Negligible probability of interference if power control is added	Low probability provided default IARU notches are applied Negligible probability of interference if power control is added	Low probability provided default IARU notches are applied Negligible probability of interference if power control is added
Aeronautical groundstations	Medium probability if power control is mandated Negligible probability provided notching is applied	High probability of interference with power control alone Negligible probability provided notching is applied	High probability of interference with power control alone Negligible probability provided notching is applied

Table 1 - Summary of modelling results

3.1.2 Power control will mitigate interference from an "infected" mains connection

Interference from an "infected" mains connection can be encountered:

- Outdoors via overhead powerlines
- Indoors via radiated emissions from the wiring of the victim receiver's house due to the house sharing a mains connection with a PLT user

Section 8 illustrates that the likelihood of interference via both routes, but in particular via the second, will grow to a significant level the next 5 to 10 years if no action is taken. However, power control, which is planned to be included in PLT devices by mid 2010, should significantly reduce the risk of interference via both of these routes to low levels.

It should be noted that there is uncertainty over interference via both of these routes due to a lack of data on the filtering effects of consumer units for PLT signals. Further measurements to confirm this effect in UK homes are recommended.

3.2 Inputs to our interference assessment

To assess the potential for interference from PLT devices via each of the routes discussed in section 3.1 we first needed to understand the following two inputs:

- PLT device technical characteristics and uptake, both now and over a 5 to 10 year timeline
- Technical characteristics of existing HF users

During this study we have contacted stakeholders from the PLT industry to understand the current state of PLT standards, the likely future direction of these, technical characteristics of PLT devices and PLT product roadmaps in particular for interference mitigation features. Details of our findings in these areas along with our market forecast for PLT devices are given in Section 4.

In summary, in each of the interference scenarios above we have assumed the following characteristics for PLT devices:

- Transmit power -58dBm/Hz as defined by UPA which is the dominant standard in the UK
- Default notching of IARU bands
- Notch depths of 30dB
- Power control available from mid 2010
- Smart notching available from Q3 2010

During this study we have also engaged with existing HF spectrum users to check our assumptions in terms of victim receiver characteristics. We have concentrated on the following three victim receiver scenarios:

- Shortwave Listener
- Amateur Radio user
- Aeronautical Ground station

In section 5 we give details of how these victim receivers were selected and the technical characteristics that we assumed for each.

A full list of the organisations that we contacted during the study is given in Appendix A: and we thank them for their contributions.

4 Applications, market forecast and technical characteristics for PLT devices

To analyse interference from PLT devices we require an understanding of the technical characteristics of PLT devices, where they are used and how many PLT devices we expect to have deployed over the 5 to 10 years. This section presents an introduction to PLT devices on the market today, our market forecast for uptake of PLT devices in the next 5 to 10 years and the technical characteristics of PLT devices now and in the future.

4.1 Applications of in-home PLT devices

There are two main types of PLT devices for consumer applications (as opposed to internal use by electricity utilities). These are Access PLT, also called broadband over powerline or BPL, and in-home networking. Access PLT is not commercially deployed in the UK and is not in the remit of this study, so we focus on in-home networking applications.

In-home networking, PLT devices inject a high frequency data signal, typically in the frequency range of 2-30MHz, into the consumer's existing mains wiring. At any power outlet in the house this data signal can then be filtered and recovered from the underlying 50Hz mains via a second PLT device thus providing a data connection between rooms without having to install dedicated network cables.

Figure 4 - Examples of PLT devices on the market

These devices are increasingly being used in the UK and Ofcom estimate that there are currently approximately 750,000 pairs of PLT devices in the UK [7]. In-home PLT products are also becoming more widely available from retailers with typical search results for PLT products returning:

- 40 at DABS
- 25 at Amazon
- 15 at PC world

The chipsets for the majority of these products come from Intellon and DS2 with big brands such as Netgear and Belkin amongst those offering in-home networking PLT devices. The commonest data rates on offer are 14Mbps, 85Mbps and 200Mbps but recently Belkin devices at 1Gbps have also become available in the UK.

Depending on the target application, in-home PLT devices come in various forms such as:

- Single Ethernet connections
- Ethernet hubs
- Combined devices giving the option of networking via power line or coaxial
- PLT with a WiFi access point
- PLT combined with an ADSL modem
- Part of a multimedia package such as BT Vision

By far, the largest source of in-home PLT devices in the UK is from BT Vision installations rather than from retailers. BT Vision provides a video-on-demand service to consumers via their BT broadband connection and includes a pair of Comtrend in-home networking PLT devices to allow the subscriber to extend their BT broadband connection to the location of their TV. Smart grid applications for monitoring energy usage are gaining interest in the electricity industry. Currently PLT standards for monitoring energy usage and controlling home heating or air conditioning systems, such as Homeplug Command and Control, operate at low data rates in the CENELEC frequencies (9 - 149 kHz) and are unlikely to cause interference. Future standards, such as Homeplug Green PHY, that expand smart grid applications to include monitoring throughout a utility company's infrastructure are considered to be beyond the scope of in-home networks and so outside the scope of this study.

In-home networking PLT devices currently on the market generally target:

- In-home networking of IT equipment such as sharing a broadband connection around the home or connecting a printer and PC.
- Distribution of audio visual signals around the home in particular for IPTV applications.

Throughout this study we assumed PLT usage scenarios based on the two applications listed above. A fuller description of PLT usage scenarios and their position relative to competing technologies is given in Appendix E:. These usage scenarios have been used throughout this study when considering:

- Market forecasts for PLT devices
- Proximity of PLT devices to victim receivers
- Duty cycles of PLT devices incorporating the correct split between the number of devices in idle mode and those transmitting data.

4.2 Expected uptake of PLT devices

To model interference from PLT devices over the next 10 years, PA needed to understand how many PLT devices would be deployed over this timescale. We therefore produced a model to estimate the expected consumer market uptake of PLT devices from now until 2020. A full description of the market model is given in Appendix F: and summarised in this section.

Our market estimates have been derived as follows:

- From PLT device shipment figures and our discussions with stakeholders we understand that approximately 3% of UK households currently have a PLT device, with BT Vision dominating this figure.
- From section 4.1, we have assumed that the increase in uptake of PLT devices will depend on two main markets; IPTV with PLT distribution (i.e. BT Vision) and Home networking (i.e. retail sales).
- We have assumed that the uptake of PLT-distributed IPTV will be driven by:
    - The number of UK homes with broadband
    - The positioning of IPTV relative to other TV packages available via cable or satellite
    - The propensity for IPTV providers to supply their package with alternative distribution.
- We have examined uptake of competing technologies such as WiFi, statistics from market surveys on in home networking, number of homes with broadband connections and uptake of IT equipment such as PCs to understand the uptake of home networks over the next 10 years.
- We have estimated the total number of PLT devices that will be deployed by combining our estimates from the IPTV and home networking markets and allowing for a limited overlap between these two markets.

Our model includes a low, medium and high uptake for PLT devices based on the following scenarios:

- ***Low Scenario*** - We assume that BT Vision has reached its maximum market share and continues to grow slowly allowing for the fact that the number of homes with broadband and therefore potential BT Vision customers will increase. In the home networking market PLT continues to struggle to differentiate itself against WiFi and takes a low share of this market.
- ***Medium Scenario*** - We assume that BT Vision continues to increase its market share slightly behind BT's own market forecast to allow for the below-forecast uptake that has been seen up until now. In the home networking market we assume that PLT devices slowly increase their market share but remain a minor player in this market due to the lack of convergence of standards and continuing dominance of WiFi.

- ***High Scenario*** - We assume that BT Vision reach their previous target of 2-3 million customers by 2011 and continue to grow at a similar rate over the subsequent years. In the home networking market we assume that PLT steadily increases its market share to 20%. Again, even in a high scenario, we do not anticipate PLT dominating the home networking market in the next 10 years due to absence of a single standard, no obvious cost advantage (especially as interference mitigation solutions are implemented) and the current dominance of WiFi.

The low, medium and high scenarios are driven by our assumptions on the proportion of UK broadband households that by 2020 will have IPTV and the proportion of the home networking market that PLT devices will have captured. These assumptions are shown Table 2.

	Low	Medium	High
Proportion of broadband homes with PLT-distributed IPTV	10%	20%	30%
Proportion of home networking market using PLT	2%	10%	20%

Table 2 - Assumptions on PLT uptake for 2020

Based on these assumptions our model estimates the uptake of PLT devices as shown below. The number of UK households with PLT devices is shown in Figure 5 and the proportion of UK households with PLT is shown in Table 3.

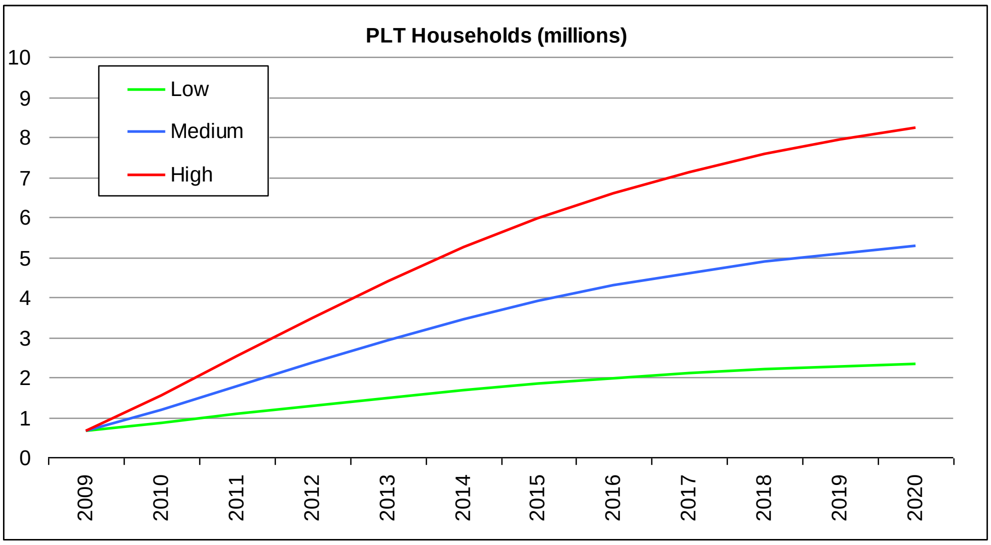

Figure 5 - Estimated number of UK households with PLT devices up to 2020

	2010	2015	2020
Low scenario	4%	8%	9%
Medium scenario	5%	16%	21%
High scenario	7%	25%	33%

Table 3 - Estimated proportion of UK households with PLT devices up to 2020

Figure 6 to Figure 8 translates the estimated number of PLT households into the density of PLT households that can be expected in open rural, rural, suburban and urban areas across the UK.

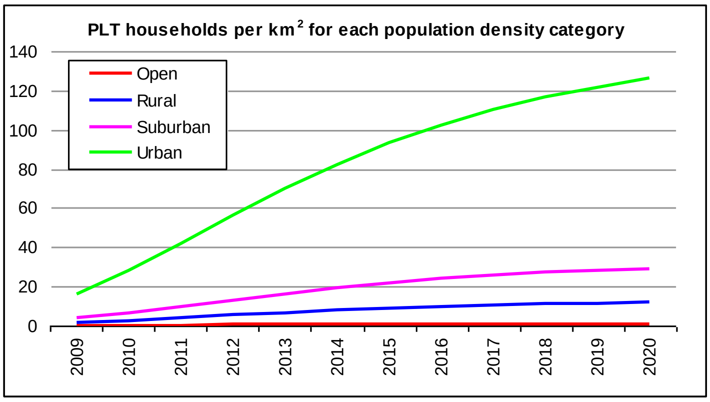

Figure 6 – Estimated density of PLT households for medium scenario

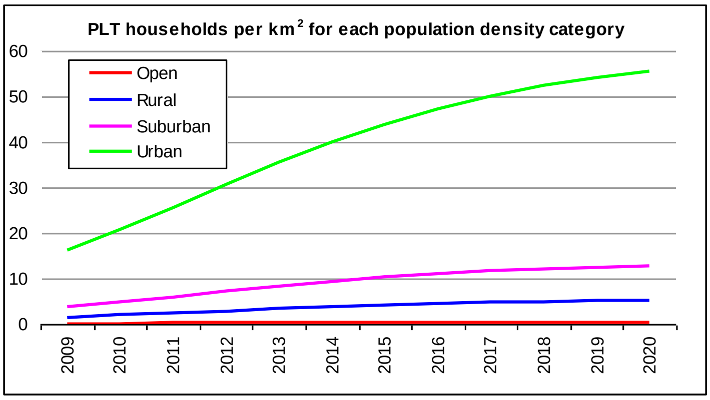

Figure 7 – Estimated density of PLT households for low scenario

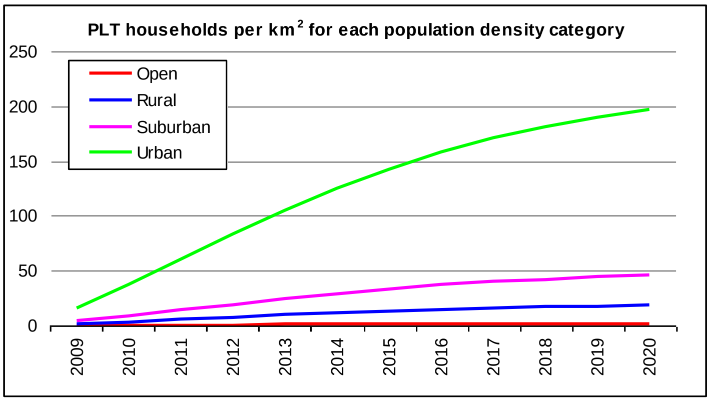

Figure 8 – Estimated density of PLT household for high scenario

4.3 Technical characteristics of PLT devices now and in the future

4.3.1 Current PLT standards

There are three industry standards widely used in in-home PLT devices on the market today; Homeplug, Universal Powerline Alliance (UPA) and High Definition Powerline Communication (HD-PLC). Of these UPA is understood to be the most common in the UK due to the widespread usage of the Comtrend powerline adapters in BT Vision installations. An overview of these three standards and their evolution is given in Figure 9.

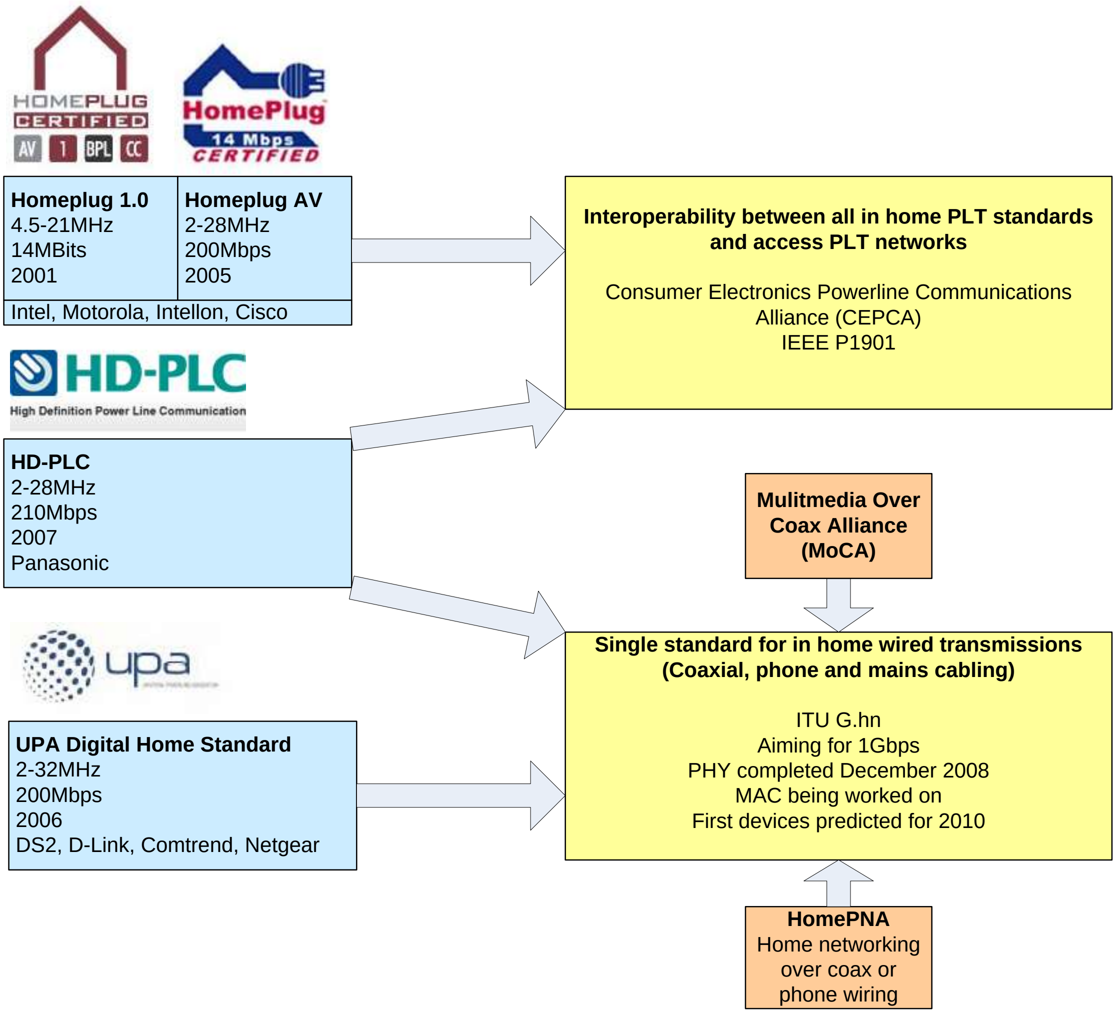

Figure 9 - Overview of the standards landscape for in-home PLT devices

The latest generations of each of today's three main standards are very similar and have the following features:

- OFDM waveform
- Data rates around 200Mbps
- Operate from 2 to 30MHz +/- 2MHz

- Apply default notches to the IARU bands of 30 to 40dB in depth

There are some differences between the standards such as sub-carrier spacing and operation in idle mode and these are detailed in Appendix G:. In terms of interference, the main differences are:

- Transmit power for UPA is -58dBm/Hz whereas Homeplug operates at -50dBm/Hz in the US and -55dBm/Hz in Europe
- UPA uses a token passing MAC which means the device has a 30% duty cycle in idle mode. In contrast Homeplug AV has a 1.25% duty cycle in idle mode due to its TDMA based MAC.

4.3.2 Future PLT standards

As shown in Figure 9 there are two new standards in development. These are:

- IEEE P1901 which aims to define protocols to ensure interoperability between existing standards
- ITU G.hn which creates a completely new in-home networking standard to replace the existing three PLT standards and combines PLT with networking via coaxial and telephone cables

From our stakeholder discussions there is no sign of these two routes converging and support from PLT vendors and existing standards is split between the two. This lack of a single industry standard may affect the market uptake of PLT devices and continue confusion amongst consumers and operators over the technology.

The future direction of PLT standards is discussed in more detail in Appendix H:. While future PLT standards look set to be based on OFDM waveforms in a similar way to today's technology, the following two main developments are anticipated:

- Higher speed devices operating above 30MHz
- Improved interference mitigation.

4.3.3 Higher speed devices operating above 30MHz

One trend that does look set to continue across the standards is development of higher data rate devices. This will require wider bandwidths and means that we can expect PLT devices to be expanding their operating frequency range to above 30MHz.

Indeed, 1Gbps PLT devices have already been recently entering the UK market in Belkin products based on a Gigle chipset. This chipset combines Homeplug AV with a proprietary technology that uses spectrum as high as 300MHz. These devices do not represent an official extension of the Homeplug or UPA standards but give an indication of how higher data rate future PLT devices may operate.

Notably the transmit power of the Gigle chipset is much lower above 30MHz at -80dBm/Hz compared to -50dBm/Hz below 30MHz. This reduced transmit power above 30MHz has been selected to ensure that the radiated emissions from PLT devices using this chipset fall below the CISPR guidelines and are fully EMC compliant. Interference mitigation techniques are not currently applied by Gigle above 30MHz as interference is not anticipated due to the reduced power level. Whether there is still a possibility of interference from a large number of devices into the existing radio systems operating above 30MHz could be the subject of further work.

The proposed ITU G.hn standard includes the option of operation up to 200MHz. However, as with the Gigle chipset the transmit power is greatly reduced above 30MHz.

4.3.4 Improved interference mitigation

From discussions with stakeholders the two main interference mitigation features on PLT device manufacturers' roadmaps are:

- Dynamic power control estimated to be available Q2 2010. This will adjust the power between two PLT devices to the minimum level to get the required data rate and will provide an overall reduction from the current situation where maximum transmit powers are used constantly.
- Smart notching estimated to be available Q3 2010. This will detect the presence of victim systems that PLT devices may cause interference to and applies a notch as appropriate.

Smart notching has been investigated within ETSI with guidelines for signal detection and notch depth published in 2008 [8]. Plugtests, carried out in 2007 by ETSI using Sony and DS2 smart notching demonstrators, have shown the feasibility of smart notching and have given the encouraging results that shortwave radio stations were received as well when smart notching was activated as when there were no PLT devices active [9]. It is worth noting that the IP for smart notching via this route is owned by Sony and so there would be an additional cost to PLT vendors if this feature was mandated. However, it is quite usual in standards like 3GPP that vendors will own IP that is essential to implementing that standard. In this case ETSI have arrangements with such vendors that they will licence their IP at a fair cost so that royalty fees do not prohibit other vendors from implementing the standard. Something similar could perhaps be done for smart notching in PLT. Alternatively vendors could use a different approach such as for example using a database of victim receiver systems and applying notches based on knowledge of the PLT device's location.

Transmissions during idle time are also a concern and ITU G.hn is currently looking at power saving solutions which will reduce transmissions and interference particularly in idle mode.

4.3.5 Summary of in-home PLT features now and in the future

In Figure 10 we summarise the roadmap of features that we anticipate in PLT devices. When modelling interference from PLT devices over the next 5 to 10 years, we have considered the impact of the interference mitigation features that are planned to be available in these timescales.

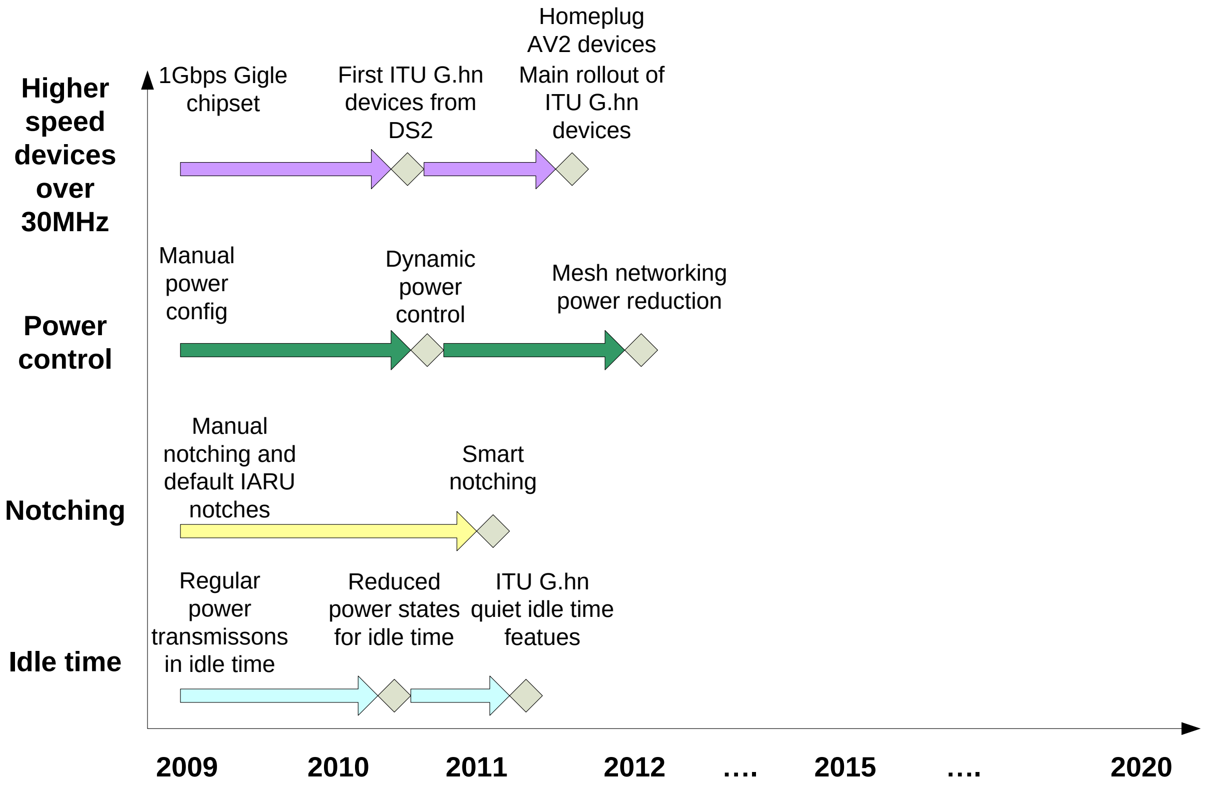

Figure 10 - Roadmap for PLT devices over the next 5 to 10 years

5 Victim receivers

This section introduces the existing HF spectrum receiving equipment which may suffer interference from PLT devices; these are termed "victim receivers". Throughout this study we have focused on three victim receiver types. This section discusses our selection of these three victim receiver types and the technical characteristics we have assumed for each of these from our stakeholder discussions.

5.1 2 - 30 MHz radio frequency usage in the UK

PLT devices operate in a range of approximately 2 to 30MHz, depending on which standard is selected. This frequency range is used by other radio and wired communication systems and where the frequencies overlap there is potential for interference. The main wired system at risk from PLT usage is broadband to the home being delivered via VDSL.

The 2 to 30MHz range is used by radio systems that require long range communications. Long range in this context means over-the-horizon paths that cannot be achieved reliably with VHF or higher frequencies. In the UK these users are:

- Short wave broadcast
- Amateur Radio
- Aeronautical
- Marine (Coastal waters)
- Military and Diplomatic
- Scientific Research including Radio Astronomy
- Analogue Cordless Phones

In addition Citizens' Band (CB) radio is a licence-exempt use at 27MHz, on the basis of being a secondary user in spectrum that is primarily allocated to the MoD.

The frequencies involved are illustrated in Figure 11.

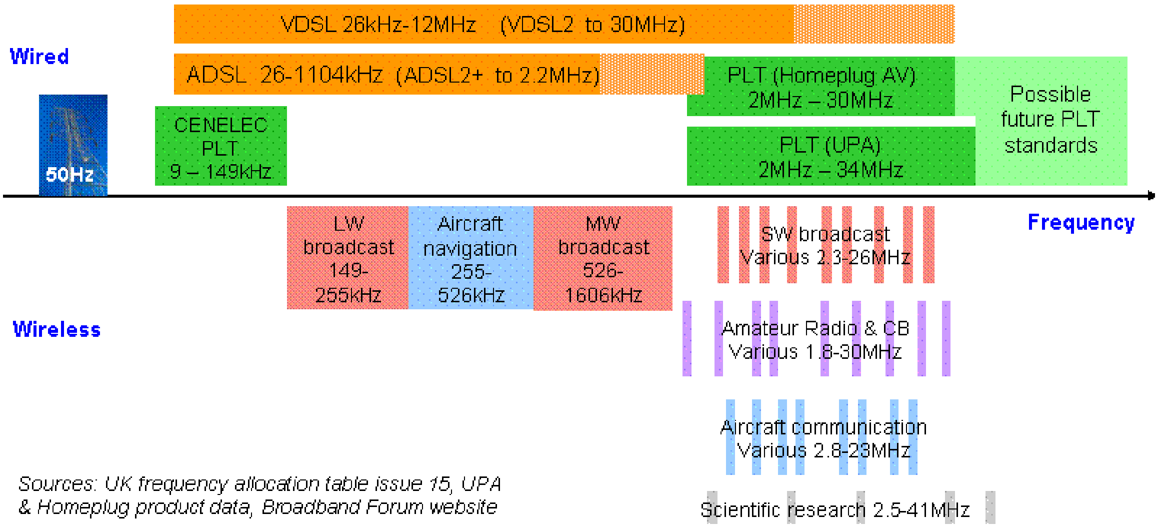

Figure 11. Wired and wireless spectrum usage

As discussed in section 4.3.3, there are currently PLT devices on the market that operate above 30MHz and this trend is set to continue in future standards. However, victim receivers above 30MHz have not been considered as these were agreed to be outside the scope of this study.

5.2 Selection of example receivers and focus of this study

In the initial prioritisation we considered the following potential 'victim receivers':

- ***Shortwave broadcasting*** has already been the subject of a number of other studies examining potential interference from PLT. However due to the international protection agreements in place we have decided to include this in the modelling.
- ***Amateur radio*** is a relatively high priority as most of the complaints about PLT received by Ofcom have come from this user group.
- ***Aeronautical ground stations*** have an important safety role and so is a high priority.
- ***HF maritime land stations*** no longer exist in the UK, and MF (up to 3MHz) is used in coastal waters only[2]. Distress calls are being migrated from MF to VHF or UHF for monitoring by satellite and aircraft in all waters for which the UK is responsible. Maritime land stations were therefore not modelled.
- ***Defence and diplomatic users*** are few and from our discussions with MOD there have so far been no reports of PLT causing interference with defence HF systems in the UK. In addition defence users have been the subject of a detailed study carried out recently by NATO. They have therefore not been modelled in this study.
- ***Scientific research*** at HF appears to be mostly radio astronomy. This uses specialised receivers and antennas, and use various techniques to mitigate noise in order to observe signals well below

[2] Source: Maritime and Coastguard Agency, October 2009

the existing noise floor. This type of use is sufficiently far removed from most other uses of HF in the UK that it was not modelled. We note also that radio astronomy requirements in relation to PLT have been the subject of a recent ITU report [6].

- ***Analogue cordless phones*** use HF for historic reasons and only operate over a very short range. They are being phased out and so were not modelled.

Three victim user types were therefore selected for detailed modelling:

- Shortwave listener - a listener to (usually foreign) broadcast radio stations. Programme content rather than technology is important.
- Radio amateur – technically literate and has passed exams to obtain licence. Has probably invested significant time and money.
- Aeronautical ground station professional user - full-time trained operating staff with expert technical back up. Controlled environment with funding available. This user type will also act as a proxy for other professional HF users.

In addition to radio systems, the potential for interference from PLT to DSL services was considered though not modelled in detail as with the other victim receiver types.

5.3 Victim receiver characteristics and proximity to PLT

From discussions with user representatives and examination of equipment data we have drawn up profiles of the three victim user types. These are described in this section.

5.3.1 Shortwave listener

Devices being interfered with	Consumer grade multi-band AM receiver. Migration to DRM is starting but small market share and slow uptake
Correlation with PLT use	Similar locations and probably similar hours

5.3.2 Radio Amateur

Devices being interfered with	Various types in use, but most common is a multi-band SSB transceiver
Correlation with PLT use	Similar locations and probably similar hours

5.3.3 Professional User (aeronautical ground station)

Devices being interfered with	Multi-band SSB transceiver
Users & Locations[3]	Easyjet are known to use HF for operations management and are understood to have ground stations at Luton and East Midlands airports. Airliners use HF in the air and on the ground. In the case of foreign airliners they will be communicating over a long range to their home country whilst on the ground in the UK. The only HF ground station used by NATS is in Ireland and so outside Ofcom's area of jurisdiction. It is in a rural area with no major urban areas nearby.
Correlation with PLT use	Assume 24 hour, 365 day use possible. Immediate area probably has little or no PLT. Suppression of nearby mains cables may be possible

[3] Source: Civil Aviation Authority, October 2009.

Based on our discussions with various HF user stakeholders, the three victim receivers have been specified in the model as described in Table 4.

Victim User Type	Shortwave Listener	Radio Amateur	Professional User
Rx sensitivity	-115dBm	-118dBm	-116dBm
Rx noise bandwidth	4kHz	2.2kHz	3kHz
Antenna type	0.5m vertical whip	G5RV horizontal dipole	Equivalent to G5RV
Source of noise level	ITU-R BS.703 (3.5uV/m)	ITU-R P.372, Residential	ITU-R P.372, Business
Frequency 1	2.3MHz	3.5MHz	3.0MHz
Antenna gain at f1	-3dBi average	+2dBi average	+2dBi average
Noise level at f1	-78dBm	-84dBm	-78dBm
Frequency 2	7.1MHz	7.1MHz	9.0MHz
Antenna gain at f2	-4dBi average	+1dBi average	+1dBi average
Noise level at f2	-89dBm	-94dBm	-92dBm
Frequency 3	26MHz	28MHz	23MHz
Antenna gain at f3	-5dBi average	0dBi average	0dBi average
Noise level at f3	-101dBm	-111dBm	-104dBm

Table 4 – Victim receiver characteristics

The above figures have been arrived at by the following methods:

- Receiver sensitivity - comparing published performance data, or standards for the broadcast receiver, and adjusting where necessary to give the RF power level into 50Ω needed to obtain a 12dB signal to noise ratio (SNR).
- Receiver noise bandwidth – published performance data, or standards for the broadcast receiver.

- Antenna type – examination of example broadcast receivers; discussions with amateur radio representatives; professional users assumed to have equivalent antenna performance to radio amateurs' equipment.
- Frequencies – for each user type, the lowest and highest bands within the range 2 to 30MHz as given in UK frequency allocation table, and a band near 7.75MHz (the geometric mean of 2 & 30MHz).
- Antenna gain – average gain as determined by modelling the selected antenna in EZNEC [10].

  Note that the antenna types used have broadly omni-directional characteristics. This is appropriate given that each user will either have portable equipment or be receiving transmissions from a wide range of azimuths. We are aware that some better equipped amateurs use Yagi style directional antennas with rotators. It is also possible that some professional users may have a similar arrangement.

  As these directional antennas are presumably aligned towards the wanted transmission, the effect will be to attenuate PLT emissions from azimuths outside the main lobe, whereas those in the main lobe will be amplified to the same extent as the wanted signal. Such configurations will therefore be less prone to interference than the omni-directional antennas that have been modelled.
- Noise level – sources as described in the table.

5.4 Potential interference with ADSL and VDSL

During our stakeholder discussions there have been some suggestions that PLT may cause interference to ADSL and VDSL services. However, we were unable to find evidence to support and quantify these claims. We also note that Ofcom has not as yet received any complaints of PLT devices causing interference to xDSL services. However, we recommend that Ofcom monitor this area to see if the situation changes as the UK migrates to ADSL 2 and VDSL.

Most xDSL deployed in the UK so far is ADSL. This has a maximum frequency of 1.1MHz and so does not overlap with the spectral mask of PLT devices. BT has recently announced that 40% of the population can now receive ADSL 2+ [11]. This operates up to 2.2MHz so has a slight overlap with in-home PLT devices. However, this overlap is too small for most users to have noticed any impact on data rate that might be due to PLT devices.

The real impact will only be seen if and when VDSL is rolled out as this operates up to 12MHz or 30MHz for VDSL2. The first trial deployments of VDSL were taking place during this study and results were not available at the time of writing. ETSI have conducted a "Plugtest" of VDSL alongside current in-home PLT devices, which showed that some level of interference could be created. The worst case was when the mains and telephone (i.e. VDSL) cables were tied together over a length of 40m. In this instance the PLT signal was picked up on the VDSL cable at -121dBm/Hz, which represents a 19dB degradation in the signal to noise ratio and would reduce the VDSL capacity to around 1% of its nominal level. However reducing the parallel cable run to 5m and separating the cables by just 1cm cut the pickup to -135dBm/Hz which would give a VDSL capacity around 60% of nominal. It is therefore sensitive to being in close proximity to mains cables carrying PLT, with a rapid improvement achieved by a small separation of the cables.

If PLT is proven to couple into telephone cabling at a significant level then headline data rates will suffer and complaints to Ofcom may follow. As there are no commercial deployments of VDSL in the UK as yet, we recommend that Ofcom work closely with BT to monitor any potential interference issues in this area.

6 Radiated emissions directly from the PLT user's home are a concern over the next 5 to 10 years and will require action

This section considers interference via the first of the two main interference mechanisms introduced in section 3; interference caused by radiated emissions directly from the PLT user's home. There are a number of propagation effects at HF to consider when examining the potential routes of interference from radiated emissions directly from the PLT user's home. We have concluded that the biggest causes for concern are interference to aeronautical users, both when airborne and on the ground, and interference to SW radio listeners. In both of these cases the likelihood of interference is significant over a 5 to 10 year timescale but can be brought to manageable levels if power control and appropriate notching are mandated.

6.1 HF propagation creates multiple radiated emission effects

As described earlier, the mains wiring of a house where in-home PLT devices are being used will act as an antenna and generate radiated emissions. This section reviews propagation at HF and the resulting potential routes whereby PLT devices may cause interference to existing users of the HF spectrum.

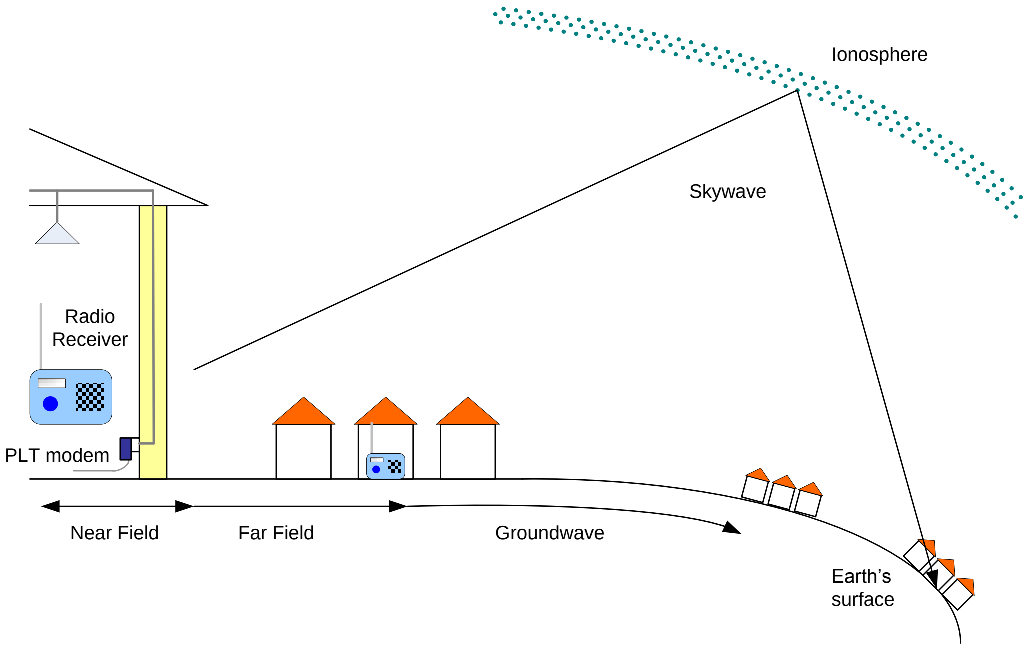

Figure 12. - Variation of propagation mode with distance

As shown in Figure 12, there are four regions around the PLT wiring to be considered for propagation purposes:

- Near field propagation occurs within approximately one radian wavelength (λ/2π) of the radiating element. This is direct magnetic field coupling similar to a transformer and not a travelling wave. Consequently normal radio propagation models do not apply.
- Line of sight far field propagation occurs beyond the near field boundary and consists of a propagating electromagnetic wave. This is characterised by the received power falling in proportion to the square of the distance, or -20dB/decade.
- Ground wave propagation starts from a certain distance into the far field, as the wavelengths at PLT frequencies are long relative to the height above ground of the propagation path. The electromagnetic wave develops from a space wave into a surface wave travelling along the earth-air boundary. The power in this propagation mode falls with the fourth power of distance, or -40dB/decade. The distance at which this change occurs depends on the electrical characteristics of the ground.
- Sky wave is an anomalous propagation mode that gives HF radio many of its useful long-range characteristics. Energy radiated at an angle upwards from the earth remains as a space wave rather than a surface wave. Upon reaching the ionosphere it may be reflected back towards the earth. In this case the wave will reach the earth again at a level much higher than the ground wave at the same point due to the lower rate of attenuation with distance. This effect is critically dependant on the characteristics of the ionosphere which in turn are dependant on factors including direction, time of day, time of year, phase of the sunspot cycle and recent solar flares.

There have been many reports published over the last 8 years or so looking at radio interference effects of PLT. We have drawn on these throughout this report as listed in the references given in Appendix C:. Based on these previous studies and propagation effects at HF, we have concluded that that there are four main mechanisms of interference from radiated emissions directly from and PLT user's home to consider. These are:

- Cumulative effect of radiated emissions to ground based HF users over large areas
    - Via ground wave
    - Via sky wave
- Cumulative effect of radiated emissions to airborne HF users
- Cumulative effect of radiated emissions to ground based HF users over small areas

Our conclusions for interference via each of these routes are given in sections 6.2 to 6.5.

6.2 The cumulative ground wave effect over a large area is unlikely to cause interference

Ground wave propagation causes an attenuation that increases at 40dB per decade of distance and whose absolute value is dependent on factors including frequency, ground conductivity and E field polarisation. There is concern that as the number of PLT devices deployed increases, the ground wave signals will accumulate and cause interference even though the PLT devices may be distributed at long distances from victim receivers.

However, we anticipate that in the ground wave mode the interference effect will be dominated by devices closest to the receiver and that the cumulative effect of an even distribution over a wide area is negligible. The reason for this is because with a constant PLT device density, the number of devices at any distance from the victim receiver increases linearly with distance whilst the power received decreases with fourth power of distance i.e. -40dB/decade. The net result is that for each doubling of distance the additional power contribution falls with a third power. Therefore the increase in number of devices as the deployment area grows is vastly outweighed by the path loss for those extra devices.

This is illustrated by the program GRWAVE which is a software implementation of the ITU standard for ground wave propagation, ITU-R P.368-7. If we consider a wide area deployment of PLT devices as a series of concentric rings each with a uniform density of PLT devices, we can use GRWAVE to calculate the powers resulting at the centre point from each ring in turn. The cumulative effect as the deployment spreads out from the centre can then be seen by summing the power from each ring. This is illustrated in Figure 13.

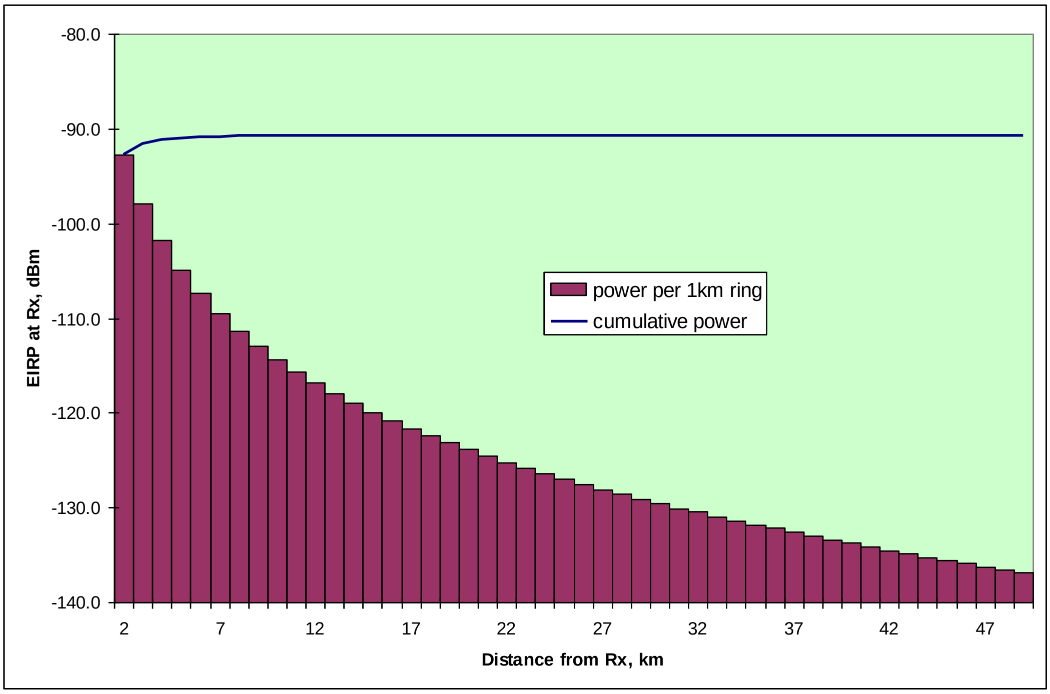

Figure 13. Cumulative effect of ground wave propagation

The maroon vertical bars represent the power at a receiver in the centre originating from each of the concentric rings with radii at 1km intervals from 2 to 50km. The blue line represents the cumulative power as each ring is successively added outwards from the centre[4]. The first ring at 2km radius contributes -92.7dBm. The second ring adds 1.1dB to this. All the other rings out to 50km combined add just 0.9dB. We therefore do not anticipate that the cumulative groundwave components contributed from PLT devices spread over large areas will have a significant interference effect. Instead interference from radiated emissions will be dominated by the PLT devices local to the victim receiver and this is discussed further in section 6.5.

6.3 Interference from a cumulative sky wave effect over a large area is only significant in quiet rural areas

Sky wave propagation occurs due to the action of the ionosphere as a mirror to reflect radio waves back to the surface of the earth. The earth itself can then reflect the radio wave back upwards to create multiple 'hops'.

The effect of this on HF radio coverage is that, beyond the range at which the ground wave mode has attenuated the signal into the noise, the signal strength can increase due to the ionospheric reflection. Beyond that area the signal level falls again, and then rises at still further range due to the second hop and so on.

Due to the distances involved, typically hundreds or thousands of km, the attenuations are large. However these long distances also create large coverage areas. Considering incoming interference to a receiver, a potentially large number of PLT devices may be in the area that can propagate via sky wave to the receiver. This tends to offset the high attenuation when considering the cumulative effect of a wide area deployment of PLT.

As described in Appendix J:, sky wave propagation is difficult to predict and will vary with time of day. We have therefore based our evaluation of cumulative sky wave effects on previous work in this area.

NATO has carried out a detailed assessment of likely received power levels from PLT emissions via sky wave at various locations, convolving the path loss with the population density over a large area and scaling to allow for an arbitrary market penetration of 0.05 per capita [5]. We have taken these results and re-scaled to allow for our own market forecasts.

In our medium market uptake we estimated that 21% of UK households will have PLT devices by 2020. In the UK there are on average 2.7 persons per household, meaning that the NATO assumption of 0.05 per capita is equivalent to 13.5% of households, at the lower end of our forecast range. If we scale this up to 21%, the radiated power levels will increase by 2dB over those in the NATO report.

NATO's predicted PLT emissions for locations at Bodo, Winnipeg and Augsburg show that in nearly all cases the statistical spread was over 20dB. Therefore an adjustment of 2dB to the results is not

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[4] The calculation assumed a PLT power of -58dBm/Hz, in a 2.2kHz bandwidth and a density 51.5 devices per km^2 corresponding to our market forecast for suburban areas. The frequency was 8MHz, the effective antenna gain of the house wiring -24dBi, the receiver antenna gain 0dBi, and the ground conductivity 14mS/m representing the Midlands.

considered particularly significant in these forecasts and the NATO results are taken as still valid for this study. The wide spread of received power levels is down to the highly variable nature of the ionosphere and the parameters that influence it.

The threshold that NATO used to judge whether interference was occurring was based on the PLT emissions being "in the range of 10 to 1 dB below the ITU-R Quiet Rural noise curve". It is estimated that around 1% of the UK population live in areas of the type that could expect to have "Quiet Rural" noise levels, the other 99% live in areas that can expect higher ambient noise levels. We therefore consider that the threshold used, whilst appropriate for military use, is unduly pessimistic for most of the UK's population.

The Rural noise level is also plotted on the NATO graphs. This shows that in Augsburg, which of the three locations is likely to be the most similar to the UK, the upper end of the spread of received powers exceeds the Rural noise level by around 5dB worst case with the median values around 5-10dB below the Rural noise level. Although not plotted on the results in the NATO report, the ITU-R noise levels for Residential and Business areas exceed the Rural area by 5dB and 10dB respectively.

The conclusions are therefore that sky wave propagation from a widespread deployment of PLT devices can significantly increase the radio noise floor in quiet locations. However the reason they are quiet is that there are few homes or businesses in the area, and so few people are affected by the rise in noise floor. In the areas where most homes and businesses are located there will be a rise in noise floor though this will only be apparent at times and frequencies where the sky wave conditions create a sufficiently low path loss to another populated area. This is likely to be a very minor effect in Business/Urban areas but will occur often enough to be noticeable in Rural areas.

6.4 Notching and power control is required to protect airborne HF users

Nearly all users of HF are located at or close to ground level and hence the ground wave and sky wave modes apply for cumulative effects of wide area PLT deployments. The exception is aircraft whilst in flight. They are clear of the ground and so do not have the impact of nearby PLT devices. However they have line of sight to a large area and so free-space propagation can occur from potentially a large number of distant PLT devices.

A detailed analysis of this effect was carried out by J.Stott of the BBC [12] which concluded that significant interference to aircraft at any height was possible. This had the caveats that at the time the standards for in-home PLT networking and the antenna gain of home wiring at high elevations were unknown.

A recent study by ITU Working Party 1A has carried out a similar analysis incorporating the current UPA standard and results of measurements from flight tests [6]. We have just two comments to add to this work:

- The assumed PLT device density of 250 per km2 is higher than our market forecast even for urban areas. At our estimated 126 PLT devices per km2 by 2020 for a medium uptake and urban scenario, the power at the aircraft receiver would drop by 3dB. The impact of this is that PLT devices examined by ITU would just meet the criteria for a 0.5dB rise in the noise floor across most of the HF band provided power control and notching of the aircraft bands were both implemented. However, from 10-15 MHz the PLT device power would need to be reduced by a further 0.5dB to meet the interference criteria. As a transmit power of -55dBm/Hz is given for the PLT device we assume these findings apply to European Homeplug AV devices.

- If Homeplug AV devices raise the noise floor by 0.5dB that implies their contribution is 9dB below the existing noise floor. UPA devices have an output power of -58dBm/Hz and so 3dB lower than the level assumed in the ITU results. UPA with power control and notching would therefore be expected to meet the interference criteria also.

It is therefore recommended that power control and default notches are mandated for the aeronautical bands to protect these safety critical services.

6.5 Interference to ground based HF users is manageable but requires action

As discussed in sections 6.2 and 6.3, the cumulative effects of the long range HF mechanisms of sky wave and ground wave are not thought to present a significant threat of interference. The main source of interference to ground based HF users will be the PLT devices local to the victim receiver i.e. within the same town.

Previous studies have measured radiated emissions from a single home using PLT devices. However, we were unable to find previous studies that examined the cumulative effect of multiple PLT devices located close enough to a victim receiver to contribute significantly to interference. The main focus of our simulation work has therefore been to further investigate this effect.

Interference caused by radiated emissions will increase with the number of homes using PLT devices within a particular range of the victim receiver and will still reach the victim receiver regardless of whether that victim receiver shares the same mains circuit as all the PLT users or not. To simulate this effect we have modelled large numbers of PLT devices randomly distributed around a victim receiver. The observed interference level at the victim receiver was calculated via a link budget calculation for the path between each PLT device and the victim receiver. This link budget has been based on the injected power of the PLT device, the antenna gain of home wiring, a suitable propagation model between the PLT, victim receiver performance and interference threshold.

Section 7 gives details of the interference modelling approach and results. Table 5 gives an overview of these results with the probability of interference categorised as follows:

- Negligible <1%
- Low 1-5%
- Medium 5-20%
- High >20%

	2010	2015	2020
Shortwave listener	Low probability of interference if power control mandated Negligible probability of interference if smart notching added.	Medium probability of interference with power control alone Negligible probability of interference if smart notching is added	Medium probability of interference with power control alone Negligible probability of interference if smart notching is added
Amateur radio	Low probability provided default IARU notches are applied Negligible probability of interference if power control is added	Low probability provided default IARU notches are applied Negligible probability of interference if power control is added	Low probability provided default IARU notches are applied Negligible probability of interference if power control is added
Aeronautical groundstations	Medium probability if power control is mandated Negligible probability provided notching is applied	High probability of interference with power control alone Negligible probability provided notching is applied	High probability of interference with power control alone Negligible probability provided notching is applied

Table 5 - Summary of results from Seamcat modelling[5]

Overall these show that if PLT devices remain unchanged from today there is a high likelihood of interference to most HF users. However, this interference is manageable and, if introduced on time, power control and smart notching should bring the likelihood of interference to negligible levels. Consideration should be given to mandating the introduction of power control and smart notching to ensure that these are deployed in PLT devices in the required timescales indicated in Table 5. Aeronautical groundstations give the most cause for concern and notching of the aeronautical bands is recommended to protect these safety critical services.

[5] Note that these results are for the low frequency end of the potential interference range and hence represent a worst case as the interference signals do not propagate as far at higher frequencies.

7 Modelling results show that interference from PLT is manageable but requires action

The main analysis of interference from radiated emissions directly from PLT user's homes has been carried out using a Monte Carlo simulation modelling tool, SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool). This chapter describes our approach to simulating interference via SEAMCAT, our assumptions and our results across the three victim receiver types examined. Our simulation model shows that interference from PLT is an issue for most HF users both now and in the future. However, planned interference mitigation techniques from PLT device vendors will bring the probability of interference to negligible levels in most cases. It is recommended that these planned features are mandated to ensure that they are deployed in a timely manner. The most concerning case is that of aeronautical groundstations and we recommend that notching is mandated in these safety critical bands.

7.1 Model structure and methodology

For this study we have built up models to represent a low, medium and high frequency operation for each of the three victim receiver types:

- Shortwave radio
- Amateur radio
- Aeronautical ground station representing professional users.

UPA PLT devices have been simulated with the following characteristics:

- Transmit power -58dBm/Hz
- 30MHz bandwidth from 2-32 MHz.

Based on our discussions with various HF user stakeholders, the three victim receivers have been modelled as described in section 5.3 and in particular using the parameters listed in Table 4.

To complete the link budget calculation between the victim receiver and PLT devices, the model also requires:

- Antenna gain of mains wiring to translate the power injected into the mains by the PLT devices into EIRP.
- Propagation model for radiated emissions from PLT devices.

To complete the interference calculations we required an understanding of:

- Interference criteria for victim receivers

- Duty cycle of PLT devices.

Our assumptions in these areas are discussed in the remainder of this section.

7.1.1 Antenna gain of in home wiring

Theoretical analysis of the average antenna gain of house wiring is difficult due to the wide variety of installations. We have therefore instead based our antenna gain for PLT devices on practical measurements reported in the following two sources:

- The NATO study summarises these emission level measurements and recommends an antenna gain of -30dBi with a variation of ±5dB to ±10dB due to variations in the wiring [5]. On more detailed examination of the NATO report, most in-home measurements were in the -20 to -30dBi range.
- Recent measurements of UPA and Homeplug PLT devices in Canada give an average antenna gain of -24dBi [13].

We have therefore assumed an antenna gain of -24dBi with a variation of ±5dB to ±10dB in our model.

7.1.2 Propagation model

The existing propagation models built into Seamcat are not specified at frequencies below 30MHz. PA therefore developed a custom model based on a information from several sources. As discussed in section 6.1 and illustrated in Figure 12, there are four relevant propagation modes. Of these sky wave has been evaluated separately in section 6.3. Similarly aircraft in flight are analysed separately in section 6.4.

For the remaining scenarios the custom propagation model has been derived to cover the following effects:

- Near field
- Far field
- Ground wave

A number of previous studies [5, 13] have measured the radiated emissions from mains wiring using PLT devices to within 3m of the mains wiring. This is within the near field for frequencies below 16MHz. The majority of such measurements show signal strength to distance relationships, known as distance conversion factor, of around -20dB/decade in both the near and far field. This matches the free space path loss “inverse square law” that we would expect for far field radiation.

At distances beyond the far field the propagation changes to a surface wave phenomena at the earth/air boundary. This has distance conversion factor of -40dB/decade. The distance at which this change occurs is where the ground wave path loss intersects the free space loss and is described in detail in appendix J.3.

In our custom propagation model we have therefore applied a distance conversion factor of -20 dB/decade up to the ground wave transition distance and then applied a distance conversion factor of -40dB/decade. A more detailed description of our propagation model is given in Appendix J:.

7.1.3 Interference criteria

The HF noise floor from natural and man-made sources is usually higher than thermal noise of a HF receiver and so devices operating at these frequencies are normally limited by the background noise level rather than receiver sensitivity. An increase in the background noise floor will result in a corresponding decrease in SNR for HF users. Typically for type approval receivers must budget for a 3dB increase in background noise. This interference margin has also been discussed for SW radio receivers. Throughout this study we have therefore assumed that interference will occur if the equivalent AWGN interference signal resulting from PLT devices is at the same level as the background noise and hence gives a 3dB increase.

Arguably PLT devices may not have the same interference impact on a narrowband receiver as an AWGN interference signal. In-home PLT devices are based on an OFDM waveform and have a relatively flat wideband spectrum. If a PLT signal is received by a wideband victim receiver then, based on the contribution of a large number of uncorrelated sub-carriers making up the PLT signal, the interference signal will be Gaussian in nature. However, if the PLT signal is received in a narrow bandwidth the interference effect may not be the same as with a Gaussian interference source.

In a narrow band the PLT signal will still have a flat spectrum but may not be Gaussian in nature as it will be made up of a small number of sub-carriers that will display the characteristics of the underlying modulation scheme.

In addition, PLT devices transmit regular beacon signals when in idle mode. This is part of both the Homeplug and UPA standard although there are different duty cycles associated with each (see Appendix G:). This “bursty” transmission may have a more detrimental effect on the receiver particularly when multiple beacon signals of many PLT devices are summed.

We were unable to find any previously published studies evaluating the interference impact of a wideband PLT signal being received in a narrowband victim receiver. However, as described in Appendix L:, the UWB community has examined this issue and based on their results we have assumed a worst case scenario throughout this study that the effect of PLT radiated emissions is similar to an impulsive noise source of interference. We have applied a correction factor to our original interference criteria of a 3dB rise in the background noise floor to allow for this impulsive noise effect.

As detailed in Appendix L:, this gives our final interference criterion:

$$\frac{I}{N} = -2dB$$

7.1.4 Interference from Idle time versus continuous transmission

Our model repeatedly calculates the instantaneous interference signal observed at the victim receiver over a large number of events. We have used our market forecasts from section 4.2 to set the density of PLT devices around the victim receiver for each victim receiver type. However, in a given instant not all deployed PLT devices will be transmitting and the transmit duty cycle will vary depending on how many devices are in idle mode compared to transmitting data. We have applied the following assumptions with regard to idle time:

- We assume that the transmit power of an idle PLT device is the same as for one transmitting data. From our lab tests (see Appendix I:) and our discussions with stakeholders, we understand that there is no difference in the peak power transmit level of a PLT device during idle time compared to continuous data transmission. Therefore a PLT device will generate as much interference in an instant during the "on" time of its idle mode duty cycle as it will in the "on" time of its data transmission mode.
- We have assumed that the probability of a PLT device transmitting is 58% which is the weighted average duty cycle that combines the duty cycles of PLT devices in idle mode and data transmission mode according to the expected proportion of devices in each mode at peak usage times (see L.2).
- We assume in our baseline model that the idle time transmissions across PLT devices are uncorrelated. As the UPA idle sequence is based on a token passing sequence this should be largely uncorrelated between networks. The beacon signals used by Homeplug AV in idle mode are synchronised to the 50Hz AC mains supply but we understand that each network beacon has an offset relative to the AC line cycle zero crossing and that this differs between networks. However to allow for the possibility that idle sequences may be synchronised our sensitivity analysis has examined the worst case scenario of when all idle mode devices are synchronised.
- We have already accounted for any worsening of interference due to the PLT devices transmitting in short bursts when in idle mode by assuming the worst case scenario of impulsive noise and adjusting the I/N as discussed in 7.1.3.

7.2 Baseline simulation results

The results in this section assume a medium market uptake, 58% duty cycle and a fixed protection radius as appropriate to each of the victim receiver types. We call is our baseline case. A sensitivity analysis is later performed in 7.3 to understand how the results from this baseline are affected by changes in the market uptake, duty cycle and protection radius.

7.2.1 Interference is dominated by the nearest PLT devices

In the simulation model, we can vary the distance between interfering transmitters and the victim receiver using two parameters:

- Number of active transmitters per simulation run

- Density of interfering transmitters given in devices per km²

Figure 14 shows the interference signal received at a SW radio victim receiver as the number of PLT devices is increased. The density of PLT devices was kept constant, at the density estimated for 2010 in the medium suburban scenario by our market model, for each of the results shown. Keeping the PLT density fixed but increasing the number of active PLT devices has the effect of increasing the area around the victim receiver that contributes to the interference signal.

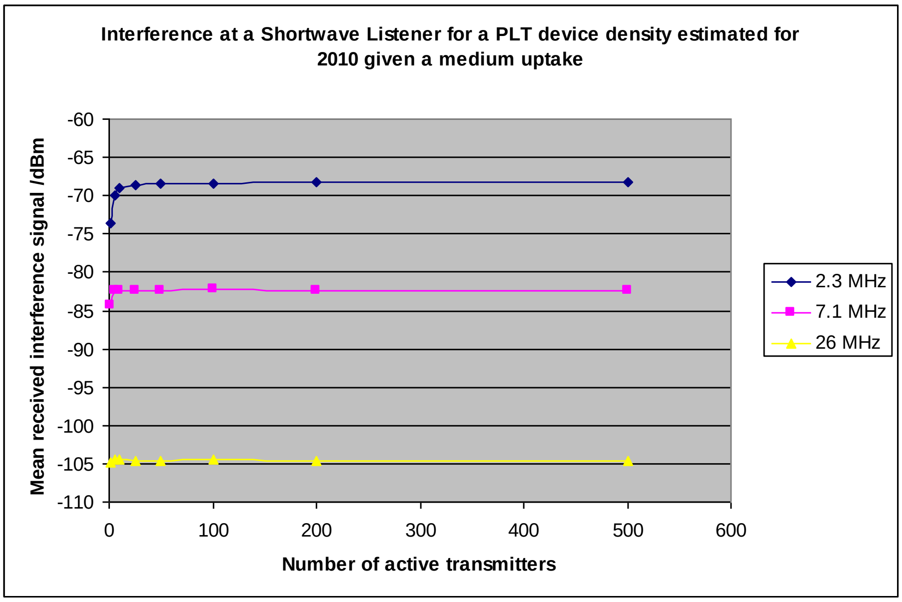

Figure 14 – Total interference experienced as a function of the number of PLT devices

Figure 14 shows that the interference observed by the shortwave victim receiver type is dominated by a few PLT devices at close range. This is the case at low, medium and high frequencies. This effect is most prominent at the highest frequency as the transition in path loss from -20 dB/decade to -40 dB/decade occurs at shorter distances as the frequency increases.

In each instance the interference is stable for a number of active PLT devices of 100 or more, so for the remaining simulations we have set the number of active devices to 100. We have observed the same effect at different device densities and, although a higher device density does generally mean that more active transmitters must be simulated before the interference reaches a stable level, we have observed at device densities up to 200 devices per km² that the interference level is stable by 100 active transmitters.

7.2.2 Probability of interference by victim receiver type

The remaining graphs in this chapter show the probability of interference at the victim system as the power of the interfering PLT sources is varied. The slope of the probability curve is due to a number of factors including (a) the random distribution of interferers around the victim and (b) the variation in the effective gain of the PLT interferer (for example due to the orientation of the in-house wiring with respect to the victim).

For each of the three victim receiver types we first examine the probability of interference for a low, medium and high shortwave broadcast band from 2-30MHz using a medium market uptake estimate for 2010. This shows if particular frequency bands are likely to suffer more than others. We then look at the potential for interference over the next 5 to 10 years. This is based on the victim receiver at a fixed frequency but PLT device density changed in line with our medium uptake market forecasts for 2015 and 2020.

For each of the graphs we have marked:

- Transmit power for today's UPA devices. The 17dBm PLT power marked corresponds to the UPA power spectral density of -58dBm/Hz in a 30MHz bandwidth. We have used UPA as our baseline as this dominants the UK PLT market via BT vision today.
- Potential PLT power reductions due to interference mitigation features including:
    - 22dB reduction for power control. According to a recent submission to CISPR 22 by Koch [14], the introduction of power control to PLT devices is estimated to reduce the transmit power by 22dB. From discussions with PLT vendors should be available by mid 2010.
    - 30dB reduction for fixed or smart notching. We understand that PLT devices can generate notch depths up to 40dB. However, we have reduced this to 30dB to allow for intermodulation from neighbouring bands which may increase power in the notch. This effect has been highlighted as a concern amongst victim receivers [15] and in our own observations of PLT devices we have seen variability in notch depth (see I.2). Currently the IARU bands are notched by default and smart notching is in development and planned to be released Q3 of 2010.

For each of the three victim receivers we have assumed the following protection distances and environments:

- ***Shortwave listener, protection distance 1m, suburban***. We have assumed that it will always be feasible to move a SW radio at least 1m away from mains causing interference and that SW radios will be used largely in domestic settings in suburban areas.
- ***Amateur radio user, protection distance 5m, suburban.*** We have assumed that amateur radio antennas will be mounted external to the building and can be at least 5m from the source of interference. We have also assumed that amateur radio sets will be used in domestic suburban areas.
- ***Aeronautical ground stations, protection distance 100m, urban.*** We have assumed that a professional user such as this will be protected by a protection distance of 100m but could be located in built up urban areas.

Interference to SW Listeners is manageable via power control and smart notching

Figure 15 shows that the effect of interference to a SW listener is worst at the lowest frequency band. This is because far field propagation at -20dB/decade will exist for the largest distance at low frequencies. There is a high probability of interference in all cases if PLT devices do not change. However, the introduction of power control would mitigate interference to shortwave listeners in the short term at least.

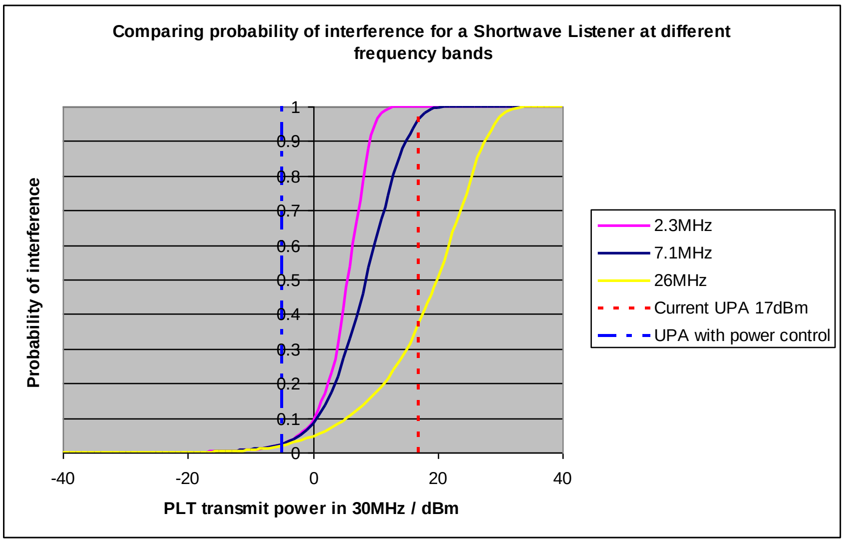

Figure 15 - Probability of interference for SW radio listeners against PLT power for 2010

Figure 16 shows that while power control provides a short term solution, in the longer term additional mitigation features will be needed. If smart notching was applied this would potentially reduce the PLT transmit level by another 30dB and bring the probability of interference to negligible levels. We therefore recommend that power control and smart notching is mandated to mitigate interference to shortwave listeners.

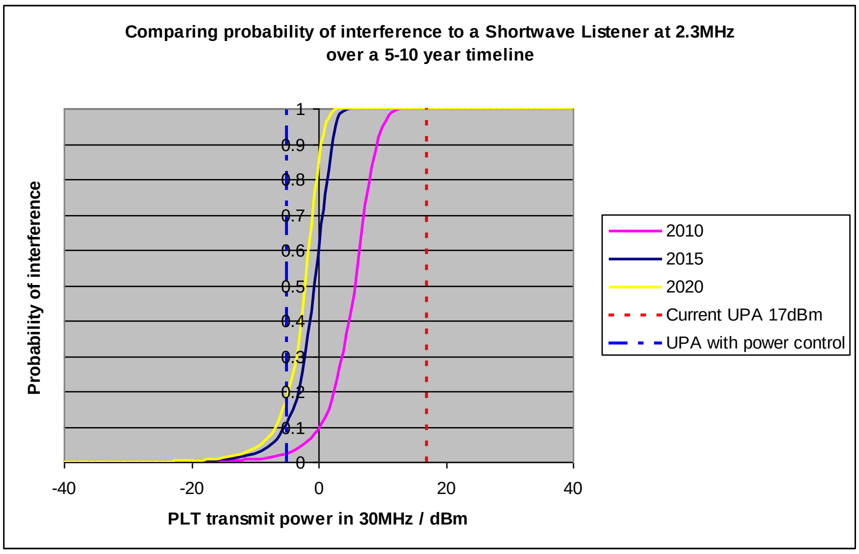

Figure 16 - Probability of interference to a shortwave listener over a 5 to 10 year timeline

Existing IARU notches are sufficient to maintain a low likelihood of interference to Amateur Radio users

Amateur radio bands are already notched by default in most PLT devices on sale today. However, it is worth noting that there will be certain level of earlier devices already deployed which may not include these. Figure 17 shows that, taking this notching into account, the probability of interference for an amateur radio user across a range of frequency bands is low in the short term. The introduction of power control would further reduce the probability of interference to negligible levels.

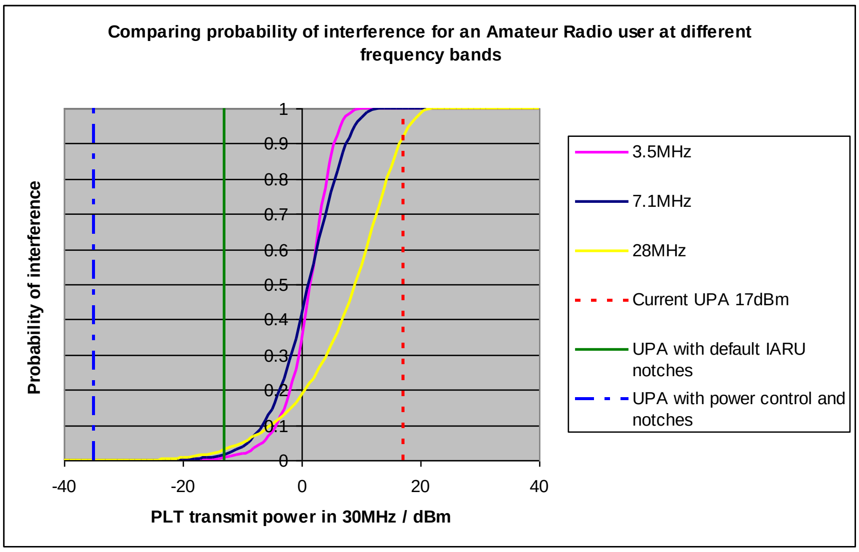

Figure 17 - Probability of interference for Amateur Radio Users against PLT power for 2010

As shown in Figure 18, the current notching of the amateur radio bands is enough to ensure a low probability of interference out to 2020. Again, this situation only improves with the introduction of power control. We therefore do not anticipate that any specific action to mitigate interference in the amateur radio bands.

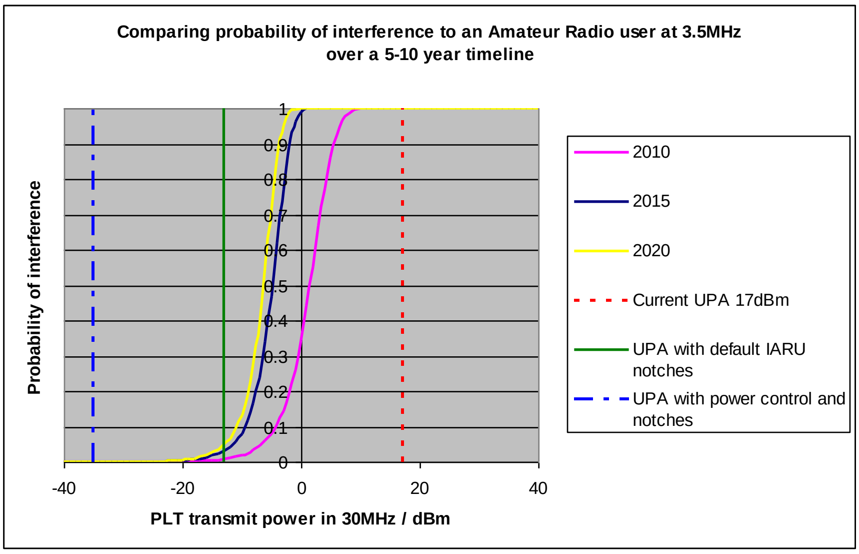

Figure 18 - Probability of interference to an amateur radio user in a 5 to 10 year timescale

Power control and notches in the aeronautical bands are required to protect safety critical aeronautical ground stations over a 5 to 10 timescale

Figure 19 shows that the probability of interference to aeronautical ground stations is high if PLT devices do not change from those currently deployed. The introduction of power control will improve the situation significantly but additional notching is needed to bring interference to negligible levels in the short term across all frequency bands.

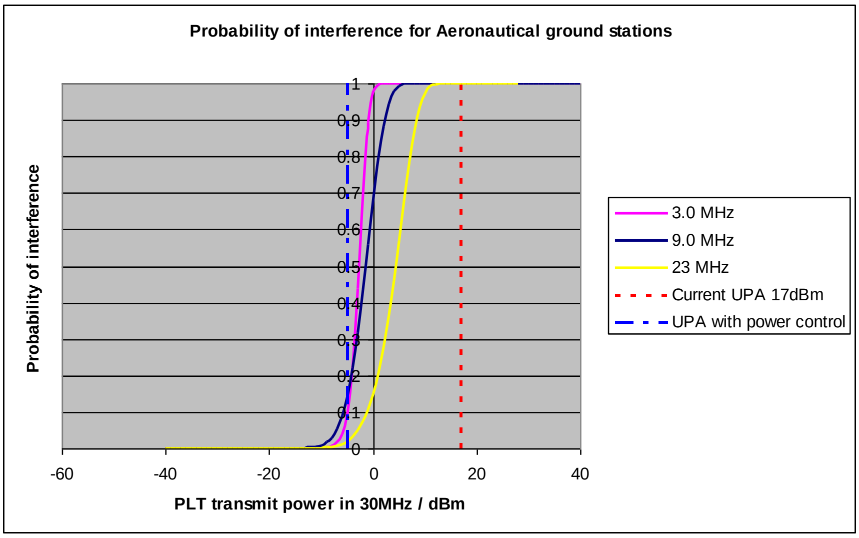

Figure 19 - Probability of interference for Aeronautical ground station against PLT power

Figure 20 shows that the interference problem continues to grow in the medium and long term and that power control will not be sufficient. Smart notching could be used as with the shortwave listener case. However, as aeronautical ground stations provide a safety critical service and section 6.4 has already found a significant threat to airborne HF users we recommend the notching of all aeronautical bands in PLT devices.

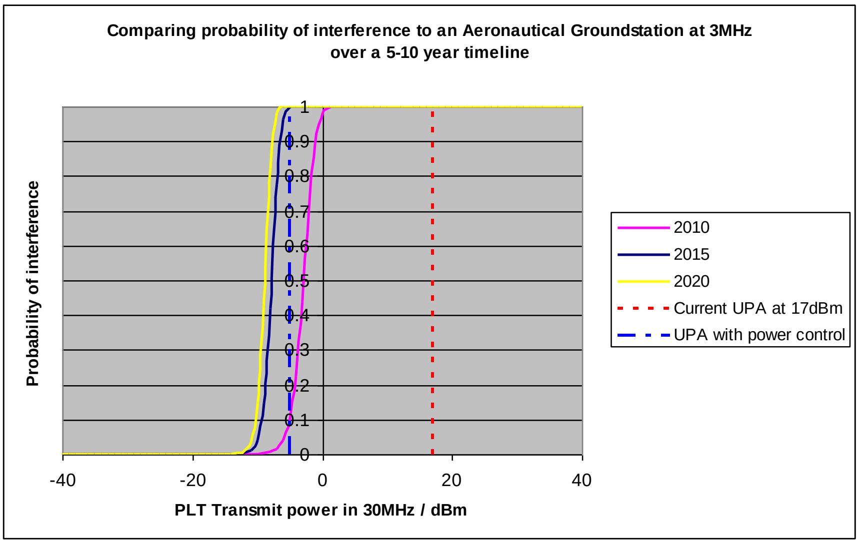

Figure 20 - Probability of interference to an aeronautical groundstation over a 5 to 10 year timescale

It is noticeable that these curves switch from no interference over a reduced power range compared with Figure 15 and Figure 17. The reason is that the relative statistical variation in the range of the PLT interferer from the victim receiver is much reduced because of the larger exclusion zone.

7.2.3 Comparison across users shows that aeronautical ground stations give the most cause for concern

Figure 21 compares the probability of interference across the three victim receiver examined. This shows that the target transmit power for PLT devices to minimise interference is in a similar range for each of these three victim receivers. The aeronautical ground station case gives the most cause for concern as unlike the amateur bands is not already notched.

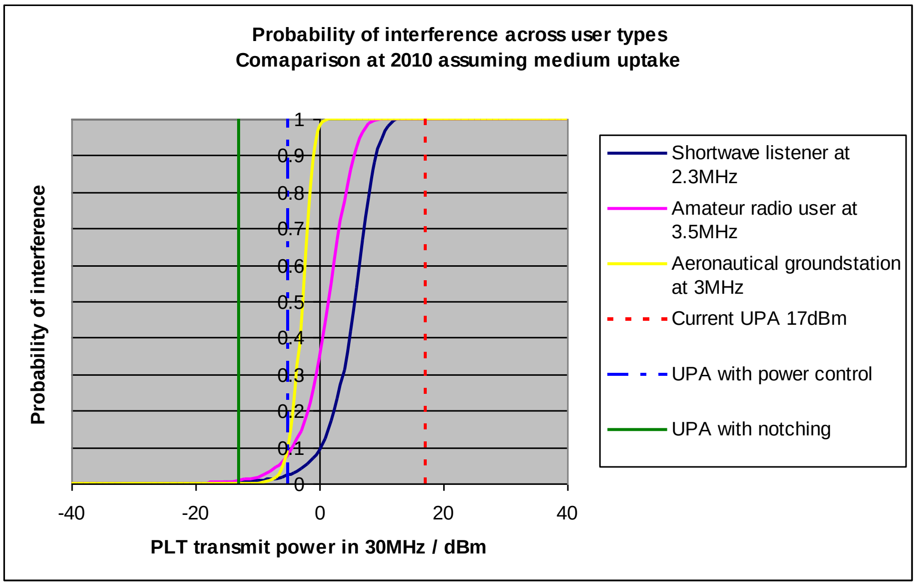

Figure 21 - Comparison of probability of interference across victim receivers

7.3 Sensitivity analysis

The results in section 7.2 assume a medium market uptake, weighted average duty cycle of 58% and a fixed protection radius. In this section we investigate the difference between the worst case and best case scenarios for these parameters to understand how sensitive these results are to our baseline assumptions.

7.3.1 Market uptake

Our market forecast described in 4.2 produces low, medium and high scenarios depending on how fast we believe PLT uptake will be and the proportion of the home networking market that we believe PLT devices will win. Figure 22 shows how the long term risk of interference varies depending on the market uptake scenario applied. As an example of a typical victim receiver we have used an amateur radio scenario for this simulation. This shows that interference mitigation options applied should allow for approximately an extra 3dB reduction in transmit power to cover the worst case scenario. The interference mitigation options already recommended in section 7.2 will already deliver this additional factor and so this result does not change our previous conclusions.

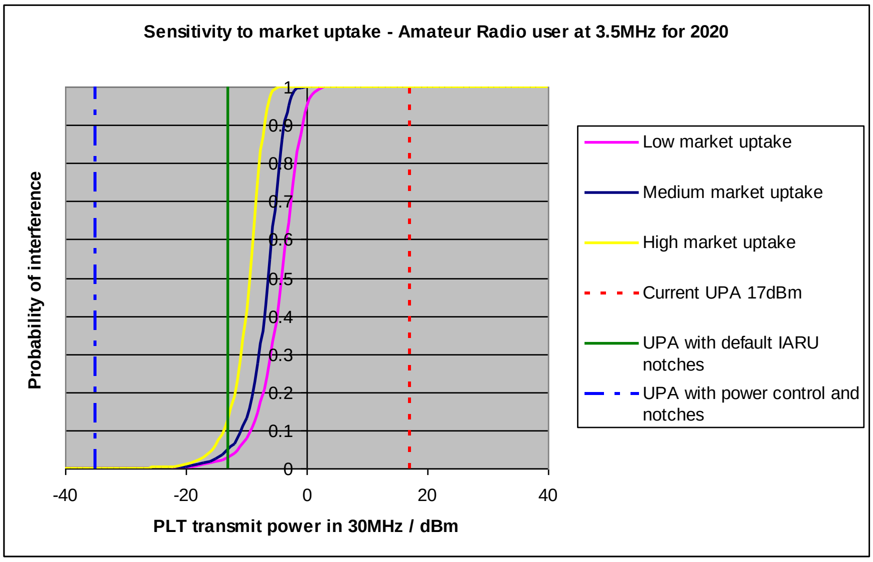

Figure 22 - Sensitivity to market forecast

7.3.2 Idle time

As discussed in section 7.1.4, our baseline simulation model allows for PLT devices in idle mode by taking a weighted average between the duty cycle for a PLT device in idle mode and one transmitting data which gives a duty cycle of 58%. However, in a worst case scenario all idle signals may be synchronised and generate periodic bursts of interference.

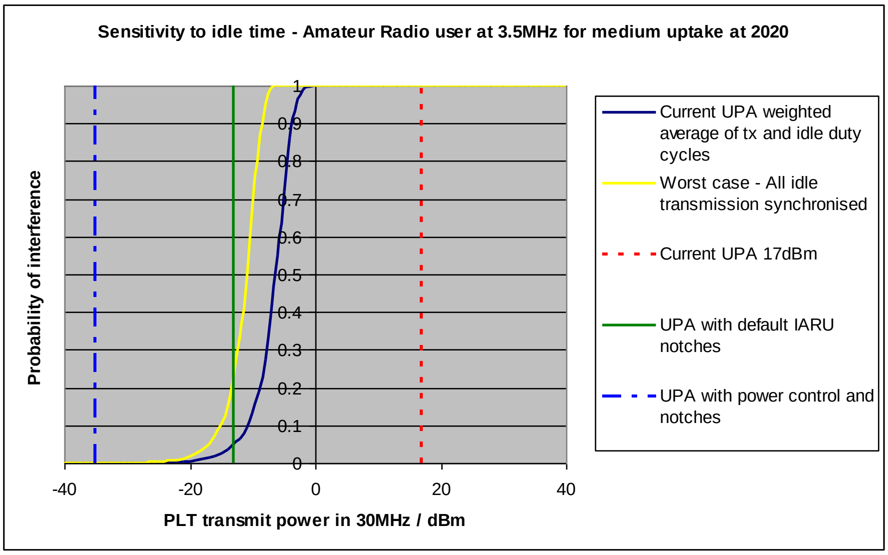

Figure 23 - Sensitivity to idle time

Figure 23 illustrates the difference in likelihood of interference between this current case and worst case scenario and shows that this doesn't vastly change the target transmit power for PLT devices to bring interference to minimal levels. This result does not therefore change our previous recommendations for interference mitigation.

7.3.3 Protection radius

Of the three victim receivers examined the aeronautical groundstation gives the most cause for concern in the next 5 to 10 years. We have recommended notching of aeronautical bands but another option might arguably be to extend the protection radius around this type of victim receiver.

Figure 24 examines the effect of applying a larger protection radius to the aeronautical groundstation using the medium market uptake for 2020. This shows the protection radius would need to be extended beyond 400m to bring the likelihood of interference from PLT devices with power control to low levels. We conclude that notching of the aeronautical bands will be more practical than extending the protection radius to these levels. In addition, as discussed in section 6.4, notching of aeronautical bands will be required mitigate interference to airborne HF users anyway.

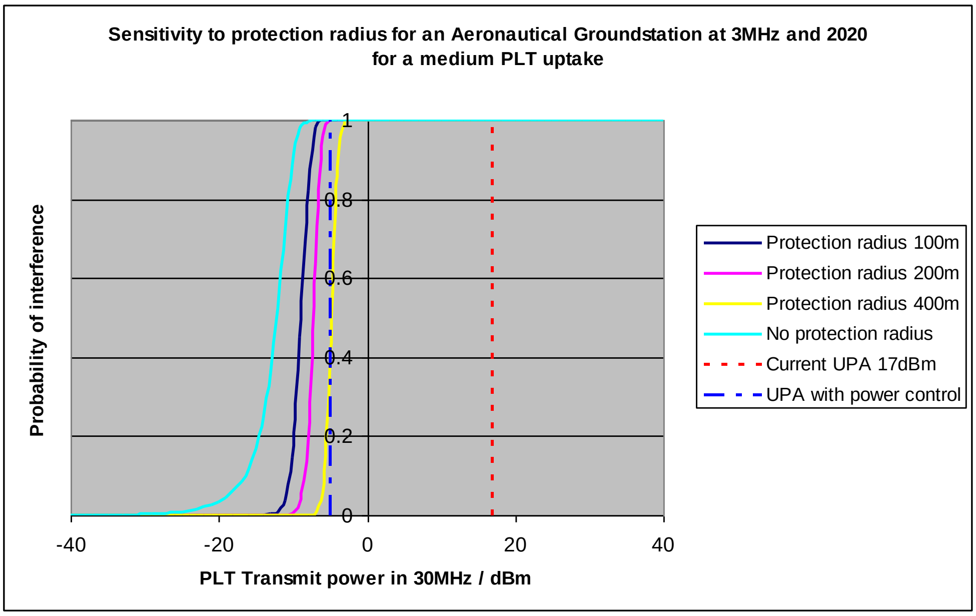

Figure 24 - Sensitivity to protection radius

8 Interference from an "infected" mains connection

This section considers interference via the second of the two main interference mechanisms introduced in section 3; interference from an "infected" mains connection. This is split into interference radiated from overhead cables and interference conducted close to a victim receiver and then radiated in the victim receiver's location. In both cases the probability of interference is linked to the probability of the victim receiver having a mains connection "infected" by a PLT device. In both cases we also conclude that power control is required in PLT devices to bring the likelihood of interference to negligible levels for the predicted uptake of PLT over the next 5 to 10 years.

8.1 We have examined mechanisms for interference from an "infected" power line

As discussed in section 3, during this study we have divided interference from PLT devices into interference via radiated emissions directly from the PLT user's home and interference resulting from the victim receiver being nearby to a power line that is "infected" with a PLT signal.

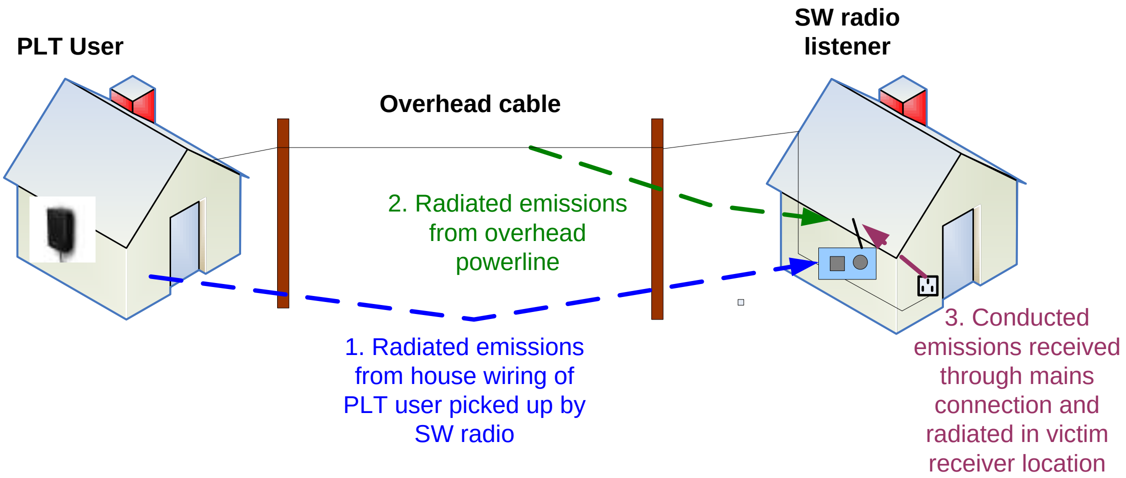

Figure 25– Different Routes of Interference from PLT devices

Figure 25 recaps on the difference between these two interference mechanisms and further sub divides interference from an "infected" power line as follows:

1. Radiated emissions from the PLT user's house. The mains wiring of the house where the PLT device is being used will act as an antenna and radiate the signal injected into the mains wiring by the PLT device. This has been discussed in detail in sections 6 and 7.

2. Radiated emissions from nearby overhead power lines (due to an "infected" mains connection). If no filtering is applied at the consumer unit in the PLT user's home then the conducted emissions from the PLT device will continue to be transferred into mains wiring external to the house. In the case where overhead cabling is used to provide power to the PLT user's home, our tests have shown that the overhead cable will continue to radiate emissions from the PLT device and cause interference to a SW radio located nearby to the overhead power line (see appendix I.5).

3. Conducted emissions received via the mains connection and then radiated close to the victim receiver (due to an "infected" mains connection). As discussed above, the conducted emissions from PLT devices may continue to be transferred into the mains network external to the house. Depending on the attenuation of the mains cabling between homes, these conducted emissions may be transferred into the mains wiring of neighbouring homes sharing the same mains transformer and phase. The mains wiring of this neighbouring home will also act as an antenna and radiate the received conducted PLT emissions. If the victim receiver, such as a SW radio, is being used in a neighbouring property it is possible that it may suffer PLT interference radiated from its own mains wiring.

The remainder of this chapter evaluates interference related to mechanisms 2 and 3 i.e. those caused by an "infected" powerline external to the PLT user's home.

8.2 Radiated emissions from nearby overhead power lines require mitigation via power control

To illustrate the likelihood of interference via radiated emissions for nearby power lines, Table 6 provides the link budget for the example scenario shown in Figure 26 where a Shortwave Radio Listener is located 5m from an overhead power line that is carrying interference from a PLT device being used in a house down the street. This calculation works back from the interference criteria at the victim receiver to estimate the minimum cable length that could be tolerated between the PLT device and the victim receiver for no interference to occur.

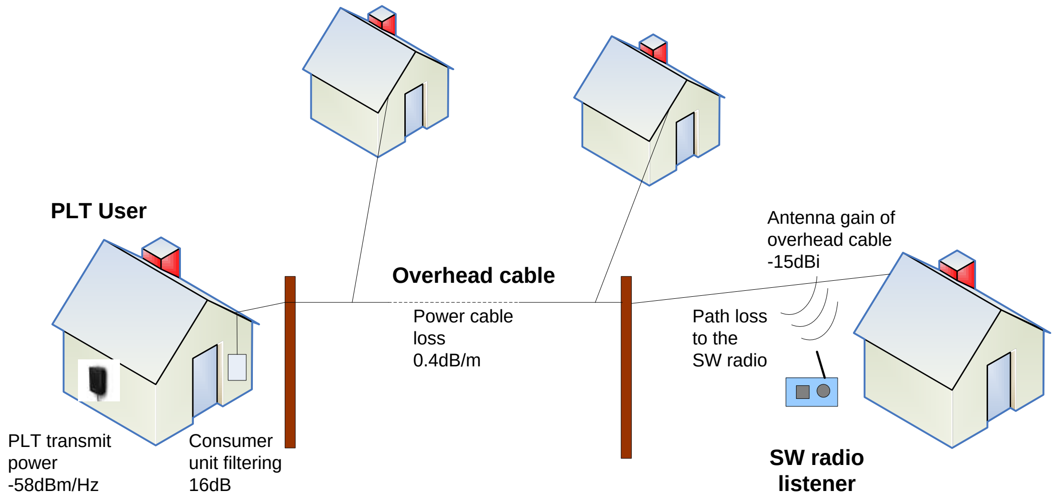

Figure 26 - Example scenario for interference from overhead cable

Link Budget Component for SW radio in 4KHz Bandwidth at 7.1MHz		Value
Background noise at victim receiver		-89 dBm
+ Acceptable I/N at victim receiver		-2dB
Maximum permitted PLT interference level received by the SW radio		*-91dBm*
- Victim receiver antenna gain		-(-4dBi)
+ Propagation loss for 5m		18dB
- Overhead cable antenna gain		-(-15dBi)
Maximum permitted PLT power in the overhead cable 5m from the victim receiver		**-54dBm**
Original PLT injected power -58dBm/Hz in 4kHz		-22dBm
- Loss from PLT user's consumer unit		-(16dB)
PLT power injected into overhead cable from PLT user's house		**-38dBm**
Minimum loss allowed in the overhead cable between PLT user's home and victim receiver location if no interference is to occur		16dB
Minimum cable length from PLT device to victim receiver location (cable loss 0.4dB/m as per assumptions)		**40m**

Table 6– Example link budget for SW radio victim system suffering PLT interference via overhead power lines

Assumptions in this calculation include the following:

- The victim receiver is a Shortwave Radio Listener with a 4kHz bandwidth operating at 7.1MHz with an antenna gain of -4dBi with background noise used for broadcast planning as described in 5.3.1.
- Assumes a UPA PLT device operating with a transmit power of -58dBm/Hz.
- The interference criteria is set so that the PLT device does not raise the background noise floor by more than 3dB and allowing for the fact that the PLT signal in a narrow band is non Gaussian (see Appendix L:).
- The distance between the victim receiver and the overhead power line is at least 5m.
- The distance conversion factor at close range and 7.1MHz is 25.5dB/decade based on recommendations by NATO [5] who estimates a distance conversion factor of 23dB/decade at 5MHz and 29dB/decade at 10MHz.

- The effective antenna gain of an overhead power line is -15dBi based on recommendations by NATO [5].
- Filtering loss of a home consumer unit is 16dB. It should be noted that there is little data available on this subject. The best source we found was a draft report from ITU-R study group 1A who are currently examining the impact of PLT devices on radio communications below 80MHz [6]. Even in this report there is significant variation between the optimistic and pessimistic measurements of the filtering effects of consumer units reported to the ITU-R group. Our 16dB assumption is based on an average of these reported measurements.
- The attenuation of power cables is 0.4dB/m as used in an analysis by Koch submitted to CISPR 22 to inform discussions regarding PLT devices [14].

Table 6 shows that having one PLT device with 40 meters of cable between it and a shortwave radio victim receiver could cause interference via the overhead cabling. If more than one house sharing the same mains circuit uses PLT devices then the interference signals will add in the overhead cable and the minimum required separation to avoid interference will potentially increase. However, the increase in the interference signal level will be partially cancelled by the cable loss between houses. For example, if two adjacent houses with 10m of overhead cable between them both used PLT devices the increase in interference would be 1.5dB rather than 3dB. We conclude that in the example above interference would occur if one or more PLT user's homes were on the same overhead cable circuit and within 30m of the victim receiver.

Table 6 shows the link budget for this interference scenario assuming that no interference mitigation is applied. If we assume that power control is incorporated into PLT devices shortly, in line with the expected PLT roadmap, then the average power reduction of 22dB delivered by this would more than provide the required loss between the PLT device and victim receiver of 16dB. It is therefore anticipated that the introduction of power control will greatly reduce the likelihood of interference via this route.

8.3 Conducted emissions received via the mains connection and then radiated close to the victim receiver will require mitigation via power control

Table 7 estimates the minimum cable distance there would have to be between a PLT device and the home where a victim receiver was being used to avoid interference via conducted emissions received through a shared mains connection. This scenario is shown in Figure 27.

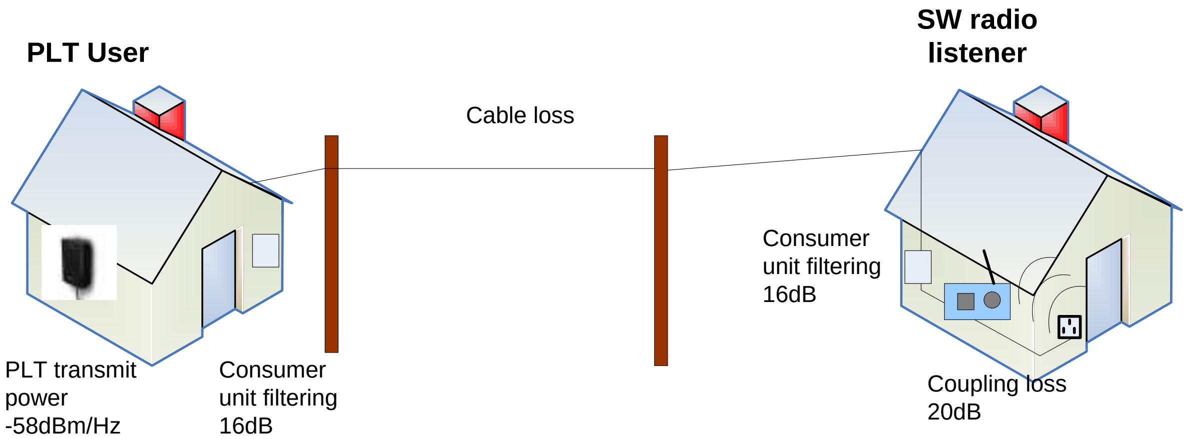

Figure 27 – Example Scenario for interference via conducted emissions and radiated in victim location

Link Budget Component for SW radio in 4KHz Bandwidth at 7.1MHz		Value
Background noise at victim receiver		-89dBm
+ Acceptable I/N at victim receiver		-2dB
+ Coupling loss between mains in victim receiver location and the victim receiver		20dB
+ Loss from victim receiver's consumer unit		16dB
Maximum permitted PLT power entering the victim receiver consumer unit		**-55dBm**
Original PLT injected power -58dBm/Hz in 4kHz		-22dBm
- Loss from PLT user's consumer unit		-(16dB)
PLT power injected into external mains cable		**-38dBm**
Allowed loss between the PLT device and the victim receiver's mains wiring		17dB
Minimum separation between PLT house and shortwave listener's house		**42.5m**

Table 7 - Example link budget for a SW radio suffering from PLT interference radiated from the mains wiring in the house where the SW radio is located

In Table 7 we have assumed the following:

- The victim receiver will be at least 1m from any mains wiring.
- At 1m we assume near field coupling loss effects of 20dB between the victim receiver and the mains wiring. Field trial measurements at 1m from PLT devices were not available to confirm the near field effects of PLT devices. However, this coupling loss is in line with field strength measurements made for in home PLT devices by the Communications Research Centre Canada (CRC) at 3m which, translated to EIRP, are approximately 24dB down on the injected transmit PLT power [13].
- Filtering loss of a home consumer unit is 16dB based on measurements reported to ITU-R (see section 8.2).
- PLT device is a UPA device with a transmit power of -58dBm/Hz
- The attenuation of power cables is 0.4dB/m based on CISPR 22 discussions [14].

This shows that if any houses sharing the same mains circuit are within 42.5m of the victim system and using PLT then the victim system is likely to suffer interference. Similarly to the overhead power line case, if more than one household is using PLT and is connected to the same mains circuit the PLT interference level in the mains will increase and potentially the minimum required separation between the victim receiver and the PLT users will also increase.

Also similarly to the overhead power line case, the required loss between the PLT and shortwave listener's house of 17dB would be provided by the introduction of power control in PLT devices.

8.4 The probability of interference via "infected" mains power line will become significant by 2020 if power control is not introduced

In sections 8.2 and 8.3 we have seen examples of the minimum cable length required between a typical victim receiver and the PLT user to avoid interference if they are sharing the same mains circuit. The overall likelihood of interference in both cases will depend on the probability that the victim receiver shares a mains circuit with a PLT user in the first place.

For sensitive aeronautical users we assume that the antenna would be more than 40 – 42.5m from residential areas and so would be unlikely to suffer interference via either of the two mechanisms described in sections 8.2 and 8.3.

For amateur radio and shortwave radio listeners we assume that these devices will be used in areas close to the user’s house and so interference from overhead powerlines will depend on the likelihood that the victim receiver’s location is supplied electricity via an overhead powerline and shares a mains circuit with a neighbouring house within 40m of cable length which is using PLT.

The number of adjacent houses within 40m of cable from the victim receiver will vary between house type from flats and terraced house closely spaced at one extreme to farm houses at the other extreme. From Appendix M: we assume that the average low voltage cable length per household is 20m and so on average a victim receiver will suffer interference if any of the four neighbouring houses around it (i.e. two at 20m each to the right and two at 20m each to the left) have a PLT device in use. It is worth noting that although the example link budgets worked through were specifically for a shortwave radio listener the difference for an amateur radio user at a similar frequency would be approximately 3dB due to the improved antenna gain but reduced bandwidth. This would give a difference in required cable length of 7.5m which based on our estimate of 20m would still mean that it would suffer interference if any of the 4 neighbouring houses (i.e. two either side of the amateur radio user) were using PLT devices as in the case of the shortwave listener. In addition, most PLT devices apply at least a 30dB notch to amateur radio bands by default which would remove the risk of interference.

We assume that the 4 neighbouring houses are on the same mains circuit as the victim receiver. This is based on Appendix M: which shows 57 households on average share the same transformer giving 19 households on average sharing the same phase mains supply. It is therefore feasible that all four neighbouring houses could be sharing the same mains supply as the victim receiver.

Based on the medium uptake curve of our market model detailed in section 4.2, we anticipate that 21% of households will have PLT devices by 2020. Therefore the probability that at least one of its four neighbours uses PLT will be:

$$1-(0.79)^4 = 0.61 \qquad \text{Equation 1}$$

Also based on Appendix M:, we estimate that 22% of households in the UK have electricity supplied via an overhead cable. The probability of one of the victim receiver’s four neighbours using PLT and the victim receiver being supplied via an overhead cable would therefore be 13%.

This shows that based on the example scenario given in section 8.2, a significant proportion of victim receivers would experience interference from PLT via overhead cables by 2020 if the uptake of PLT continues to grow in line with our market forecast.

A similar logic can be followed for the likelihood of interference from the mechanism described in section 8.3. However, in this case interference will occur regardless of whether the victim receiver’s home is supplied electricity via an overhead or underground cable. The probability of interference to victim receivers in this case would therefore be much higher at 60%.

Table 8 summarises the resulting probability of interference when a similar logic is applied using the market forecasts for 2010 and 2015. These results illustrate the potential scale of interference via PLT emissions conducted via cabling external to the home and we recommend that consideration is given to filtering at the consumer unit to isolate in-home PLT networks from the remainder of the distribution network. Further measurements and research into these interference mechanisms are also recommended as we found a lack of previous studies in this area. In particular the filtering loss of consumer units and the average PLT signal transferred to external mains cables is relatively unknown.

	2010	2015	2020
Interference from an overhead cable	4%	11%	13%
Interference from victim receiver's own mains	19%	50%	61%

Table 8 - Probability of interference from an "infected" mains power line over a 5 to 10 year timeline (based on baseline/medium takeup scenario)

As mentioned earlier, interference via this route will be significantly reduced if power control is introduced inline with the current roadmap for PLT devices. It is therefore recommended that power control is mandated to ensure that it is implemented in the forecast timescales.

9 Conclusions and recommendations

This study has examined the likelihood and extent of RF interference from in-home PLT devices over the next 5 to 10 years via two main routes; radiated emissions directly from the PLT user's home and interference from an "infected" powerline. In the case of both of these routes we have concluded that, provided uptake increases in line with our market forecasts, there will be a high probability of interference to HF users by 2020 if PLT device features do not change from those currently implemented. However, our results also indicate that interference mitigation techniques currently being developed by PLT device vendors and being discussed in international standards bodies will be sufficient to reduce this interference to negligible levels for most HF users. The exception to this is the safety critical aeronautical bands which will require notching by default.

Our conclusions across each of the interference mechanisms investigated can be summarised as follows:

- ***Cumulative effect of ground wave over very large areas*** - The likelihood of interference from PLT devices via this route is low as the observed interference signal at the victim receiver is dominated by the closest PLT devices.
- ***Cumulative effect of sky wave over very large areas*** - Based on results from NATO, the likelihood of interference from PLT via the cumulative effect of sky wave is low. The exception to this is in quiet rural areas.
- ***Cumulative effect of line of sight interference to airborne HF users*** - Based on results from the ITU, there is a significant chance of interference to these HF users. Both power control and notching are required to bring PLT signals below the interference threshold.
- ***Cumulative effect of radiated emissions to ground based HF users*** - The likelihood of interference via this route varies with the HF victim receiver type. As IARU bands are already notched by default by most PLT on sale today, the probability of interference is low over the next 5 to 10 years. It is worth noting that earlier PLT devices did not include IARU notches and may need to be updated. For shortwave listeners, the introduction of power control will keep the probability of interference low in the short term. Over the next 5 to 10 years smart notching is required in addition power control to keep the likelihood of interference low. Aeronautical ground station users in urban areas provide the most concern of the three groups examined. These safety critical services will require both notching and power control to bring the likelihood of interference to low levels for the next 5 to 10 years.
- ***Interference from an "infected" powerline via an overhead cable*** - The likelihood of interference via this route is low to medium from now up to 2020 if PLT devices do not change. However, the introduction of power control is likely to significantly reduce interference via this route to negligible levels. It should be noted that there is uncertainty over the filtering effects of UK consumer units which will affect this conclusion.

- ***Interference from an "infected" powerline via interference conducted close to the victim receiver*** - The likelihood of interference via this route is medium to high from now up to 2020 if PLT devices do not change. However, the introduction of power control is likely to significantly reduce interference via this route to negligible levels. It should be noted that there is uncertainty over the filtering effects of UK consumer units which will affect this conclusion.

Based on these conclusions we recommend the following:

- ***The maximum transmit power of PLT devices should be harmonised***. Our conclusions are based on the UPA standard with a transmit power of -58dBm/Hz. However, currently PLT product manufacturers can vary the transmit power of PLT chipsets and the Homeplug AV standard operates at the higher level of -55dBm/Hz. This ambiguity makes future interference levels difficult to predict and will vary with whichever devices become dominant. Our results indicate that interference is manageable based on a maximum transmit power of -58dBm/Hz.
- ***Power control and smart notching should be mandated***. Power control and smart notching are anticipated to be available in Q2 and Q3 of 2010 respectively. Our results show that these features need to be introduced in these timescales to keep interference at manageable levels and recommend that these features are mandated in PLT devices to encourage their inclusion in a timely manner.
- ***Notches in the IARU bands should be mandated***. Most PLT vendors already notch the IARU bands by default and our results show that this is enough to keep the likelihood of interference at low levels. We therefore recommend that notching of these bands is mandated to ensure that all PLT vendors follow this practice.
- ***Notches in the aeronautical bands should be mandated***. Our results show that notching and power control will be required to protect aeronautical bands from PLT interference over the next 5-10 years. Due to the safety critical nature of these bands we recommend that permanent notching rather than smart notching is applied. We have also assumed a protection radius of 100m in our analysis and this should be checked against current aeronautical ground stations.
- ***The filtering effects of UK consumer units should be measured***. Our results are based on measurements that exist of PLT signal loss through consumer units, and lead us to recommend action on power control and notching. It would be prudent to test the filtering effects of a range of typical consumer units in the UK to ensure that consumer units with a lower filtering effect are not present in large numbers.
- ***Measurements of radiated emissions from in-home PLT devices deployed in the UK.*** We found a lack of measurements of radiated emissions specifically from in-home PLT devices. One such study has been carried out recently in Canada measuring emissions outside a single PLT home. However, it would be useful to repeat this in the UK at distances covering the near field, far field and ground wave propagation to understand any dependency on UK-specific wiring practices and to examine the effect as the number of PLT homes increases.

- ***Interference between PLT and VDSL should be monitored***. There have been suggestions of interference between VDSL and PLT devices. We recommend that Ofcom monitor this with BT as VDSL is deployed in the UK.

Appendix A: Acknowledgement of stakeholder input

We have contacted the following people and organisation for input to this study and we thank them for their contributions:

Standards Groups	
UPA (Universal Powerline Association)	Donald Pollock, Permanent Secretary
Homeplug Powerline Alliance	Rob Ranck, President

PLT device vendors	
Comtrend	Jonathan Lishawa
DS2	Jorge Marcos, Product manager for home networks Chano Gomez, Standards Santiago Vicent, Technical
Intellon	Purva Rajokotia, Director of Standards Chris Henningsen, Vice President, Marketing
Gigle	David Sorensen
BT Vision	Trevor Morsman

Victim Receiver Groups	
UKQRM	Richard Yarnall
EMCIA	Keith Armstrong, President of the EMC Industries Association
BBC	Cath Westcott, Senior Frequency Manager, Broadcast Networks at BBC World Service

Victim Receiver Groups	
RSGB	Colin Richards, EMC Committee Secretary
CAA	John Mettrop
MCA	Richard Rees, Spectrum & Technical Standards Unit, Maritime & Coastguard Agency
MOD	Ian Taft, Defence Spectrum Management
QinetiQ	Paul Arthur, Intelligence and Digital Security Anil Shukla, Centre for Propagation and Atmospheric Research
Individual	Voi Piotrowski

Appendix B: Abbreviations

ADSL	Asymmetric Digital Subscriber Line
CAA	Civil Aviation Authority
CISPR	Comité International Spécial des Perturbations Radioélectriques
	(Special international committee on radio interference)
DHS	Digital Home Standard
EIRP	Equivalent Isotropically Radiated Power
EMC	Electromagnetic compatability
ETSI	European Telecommunications Standards Institute
HD-PLC	High Definition Powerline Communications
HF	High Frequency
HomePNA	Existing wires home networking alliance
HPA	Homeplug Powerline Alliance
IARU	International Amateur Radio Union
IP	Intellectual Property
ITU	International Telecommunications Union
MCA	Maritime and Coastguard Agency
MoCA	Multimedia over Coax Alliance
MOD	Ministry of Defence
NATO	North Atlantic Treaty Organisation
OFDM	Orthogonal Frequency Division Multiplexing
PLT	Powerline Telecommunications
RF	Radio Frequency
RSGB	Radio Society of Great Britain
SSB	Single Sideband

SW	Short Wave
UPA	Universal Powerline Association
VDSL	Very high bit rate Digital Subscriber Line

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Appendix D: PA's structured approach to quantifying interference

PA’s approach to the study is detailed in this section. Our approach drew on information from the PLT industry and existing interference analysis to avoid duplicating previous work. We developed and documented usage scenarios for in-home PLT and forecast likely future device densities. We then performed statistical modelling and sensitivity analysis to determine the likely extent of harmful interference to other licensed systems.

This approach was adopted to ensure that Ofcom has a comprehensive report on the likelihood and extent of interference, based on a clear evidence base and taking account of all relevant effects. The statistical model that we have developed will be made available to Ofcom to enable further sensitivity analysis to be performed as PLT device specifications develop and equipment volumes grow in the future.

D.1 Overview of approach

PA’s approach comprised four key stages.

- Conducting desk research and discussions with PLT industry bodies to confirm device characteristics and trends and gathering existing information on PLT interference to avoid duplicating previous work
- Defining usage scenarios and forecasting likely future densities for in-home PLT devices
- In parallel, examining the impact interference mechanisms between the PLT devices and victim systems in the relevant frequency band and perform statistical modelling to determine the likely extent of harmful interference based on forecast device density
- Finally conducting sensitivity analysis on the results by varying a number of assumptions and commenting on the viability of potential methods to mitigate against PLT interference.

Details of individual tasks follow.

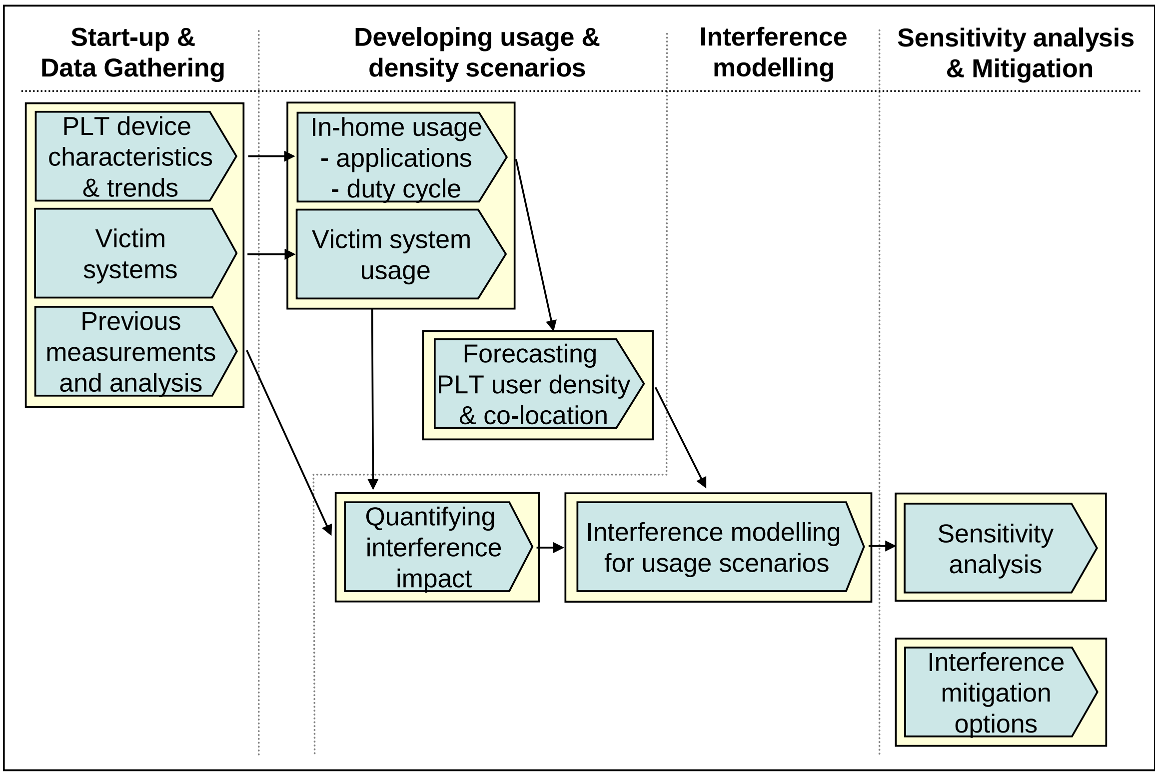


Figure 28 - Overview of PA approach

D.2 Description of study stages

D.2.1 Start-up and data gathering

The work began with a start-up meeting with Ofcom to confirm the approach to be taken to the study and to agree a number of key assumptions.

This included assumptions regarding the treatment of the different existing systems that could be subject to interference. The possible victims were derived from the list of users at the frequencies used by PLT.

We engaged with the PLT standardisation bodies and industry groups such as UPA and Homeplug to understand trends and likely roadmaps for PLT standards and devices. The study included a wider stakeholder consultation approach including PLT vendors and chipset providers, as well as bodies representing the potential victim systems. A list of all the stakeholders consulted is given in Section Appendix A:.

We avoided 're-inventing the wheel' by conducting a desk research exercise to collate existing sources of material on models and measurements for PLT interference. Examples included reports by the ECC [416], NATO [5] and Ofcom [1, 2, 3]. A list of all the reference documents reviewed is given in Section Appendix C:. Given the allowed scope for the study, this approach provided the necessary level of detail, without time-consuming activities such as widespread measurement of PLT devices or in-depth protocol level simulation of interference between PLT standards and the wide range of potential victim systems.

D.2.2 Defining the usage scenarios

The first input required for the modelling is a definition of how PLT devices will be used in the home. A series of usage scenarios were generated. Product literature was used as a guide, not only as this highlights the possible applications, but also as it will tend to influence the buyers as to how to use the products.

Examples of the usage scenarios at which current devices are being targeted include:

- Home IT networks e.g. PC to printer
- Small office IT networks e.g. between multiple PCs
- Home entertainment networks e.g. re-directing satellite, Freeview or IPTV services to a TV screen.

These applications for PLT tend to be alternatives to dedicated wired networks or wireless devices such as WiFi or AV senders. Future scenarios could extend to smart metering and energy monitoring devices, home monitoring and device control systems.

Usage scenarios and characteristics were also derived for victim receivers. In order to keep the scale of the work to a manageable level, one standard implementation for each of the potential victim service types was selected. For example Amateur Radio uses a variety of signal standards, but SSB voice is the most common in the 2-30MHz range, so this mode alone was evaluated for scenarios where Amateur Radio is the victim receiver. Stakeholders confirmed that SSB is also the most common modulation in aviation communications.

D.2.3 Forecasting PLT user density and co-location

Having identified the PLT and victim receiver usage scenarios, we then quantified their extent and likely density. The approach was forward looking as PLT is still at an early stage of adoption. The correlation between PLT users and victim receiver users was also considered because if they are usually co-located this will cause a much greater RF interference impact than if their distribution is random. The degree of co-location was considered for different victim system types.

Our market predictions are based on demographics of the user groups identified in the usage scenarios, and on comparison with other markets in similar technologies and/or geographies. Two approaches to uptake forecasting have been used. A bottom-up approach, using statistical analysis of current data as the basis for future forecasts provides a detailed segmentation of user profiles as well as adoption rates. A top-down methodology is used to calibrate the bottom-up calculations and serves as a common sense check. Where possible the development of analogous markets is taken into account insofar as technology take-up curves tend to exhibit a similar shape across different markets, varying mainly in timescale. In carrying out our forecasting, we focussed on the drivers and influencers, be they technical, commercial, competitive or regulatory, in order to determine likely development of the PLT market.

While we recognise that there is considerable uncertainty in the potential market, we provide an evidence base for our estimates as far as possible by looking at the take-up of:

- devices that could utilise PLT - for example percentage of homes with more than 1 PC, homes with multiple TV sets, Sky+ homes etc.
- devices that perform a similar function to in-home PLT, such as Wifi routers and video senders.

Having established an estimate of the addressable market for PLT devices, we derived a number of high-level scenarios that cover the different possibilities, rather than trying to figure out a detailed 'answer' on PLT demand. For example, the scenarios could be:

- very limited penetration, PLT achieves only a couple of percent of the market
- moderate penetration for use in WLAN-equivalent, competes with WiFi, but still only say 5-10% of market
- high penetration, used intensively by power monitoring, WLAN-equivalent, video senders etc.

D.2.4 Quantifying the impact of interference on victim systems

The nature of RF interference is such that is rarely clear-cut as to whether interference is occurring. Instead a more representative measure is the probability of successful reception or interference under particular conditions. This takes into account variability in factors such as propagation losses, antenna orientations, and the indeterminate nature of power wiring.

Determining whether interference is occurring is not only a matter of power levels however. Factors related to the standards and data rates such as the modulation scheme are also taken into account at this point. The question of what constitutes an acceptable level of interference will vary according to the application. For instance a Morse code signal can tolerate a much lower signal-to-noise ratio before it becomes unintelligible compared to a voice signal. The details of the signals of both the PLT system and the victim receiver have been considered in order to derive the extent of the RF interference.

The main PLT standards use OFDM modulation in which a large number of sub-carriers, each of narrow bandwidth relative to the whole signal, are modulated with data. This modulation is adapted to take account of channel conditions that vary with time and across the bandwidth of the transmission, and will typically vary from BPSK to multi-level QAM. The bandwidth of each sub-carrier is 20-24kHz compared to a typical bandwidth of 2-4kHz for the licensed radio systems in the frequency range of interest. It is therefore likely that the victim receiver will see part of one the PLT sub-carriers which will have a different interference effect to receiving the entire wideband PLT signal made up of many sub-carriers. The impact of this effect has been examined in detail and our modelling approach for interference from PLT to the victim receiver takes account of the impact of this effect.

For each potential victim system we defined acceptable levels of interference based on the structure of the PLT interference. The dominant PLT standards have been evaluated, although the similarities between them mean that a full analysis for one standard has been followed by a brief analysis of the effect of the differences in the other standard.

D.2.5 A statistical approach to interference modelling

All the factors listed above formed the input to the statistical model driven by the assumed user densities. The statistical model built aggregates PLT interference according to the usage scenarios and determines the proportion of the time or of instances of use where RF interference is experienced sufficient to disrupt normal use of the victim receiver.

After considering a number of alternatives, the model was built using SEAMCAT, an interference analysis tool developed by the European Radiocommunications Office (ERO).

Full details of the modelling approach taken are given in Section 7.

D.2.6 Sensitivity analysis

Our results expressed the interference impact as the probability of suffering RF interference for each of the scenarios identified. Subject to the details of the scenarios there may well be additional variables considered in the results such as separation distances.

The variation of the results with time will also be given. Time affects the results in two respects: firstly the take up of PLT is expected to increase in future, and there may well be increases or decreases in user densities for the victim receivers also; secondly technology evolutions will introduce new usage scenarios or make existing ones obsolete.

The sensitivity of the results to the various factors such as time, physical separation or usage scenario enable Ofcom to assess whether regulatory intervention is required, when and where, and the effectiveness of different possible forms of intervention.

D.2.7 Interference mitigation

We commented on the viability of different interference mitigation methods to overcome interference.

Examples could include regulatory action on emissions masks, perhaps with notches at specific frequencies used by particularly sensitive victim systems. An alternative approach could be a technical solution in the in-home wiring, such as a wideband filter in the vicinity of the electricity meter to prevent interference leaking down the power lines - something that could perhaps be deployed in conjunction with future smart metering technology.

D.3 Interaction with Ofcom

To deliver an effective outcome, PA secured the following contributions from Ofcom:

- Discussion and agreement of basic assumptions at the start of the project, including the relative focus to different victim system types
- Guidance on and access to previous Ofcom studies and a multitude of previous measurements and analysis that were helpful to the study
- Provision of contact details for key victim stakeholders.

Appendix E: In-Home PLT networking usage scenarios and competitive position

E.1 PLT usage scenarios

The scenarios described here have been used throughout this study when considering:

- Market forecasts for PLT devices
- Proximity of PLT devices to victim receivers
- Duty cycles of PLT devices incorporating the correct split between the number of devices in idle mode compared to those transmitting data.

PLT Home User Application 1

Name	**Broadband in every room**	**Source**
Description	Connecting the internet to one or more PCs that are not co-located with the modem. WiFi has it sown up at present but can PLT make inroads?	
User demographic	50/50 male/female, average age 41.7, price sensitive	Forrester "2008 Global Internet And Broadband Landscape"
Devices being networked	57% UK homes on broadband (2008) 68% EU-7 adults have a computer available at home, 9% of these have no desktops, 62% have 1, 22% have 2+ 6% of those with a PC +7% of those without intend buying a PC in next 6 months (Q2 2008)	As user demographic plus "European Consumers And Their PCs"
Data rates, duty cycles	Home usage. 70% of PC owners use it for photos, 36% manage finances, 14% connect to employer's network, 9% watch live TV + 4% record TV to HDD	Forrester "European Consumers And Their PCs"

PLT Home User Application 2

Name	Wired for sound and vision	Source
Description	Networking the PC, TV, stereo etc. Content stored on or streamed to one device being played on a different device e.g. MP3 files on PC played on HiFi, or BBC iPlayer to TV	
User demographic	Average age 41, income $77,000 (US survey Q1 2007)	Forrester "Home Networks Begin To Shift To Entertainment"
Devices being networked	Sharing a broadband connection is still the main motivation for setting up the network 93% desktop, 71% laptop, 52% printer, 37% game console, 28% DVR, 20% Media PC, 11% media gateway	"
Data rates, duty cycles	Share internet/printer/files/storage across PCs 82/61/57/31%, games console 37%, music to HiFi 29%, video to TV 24%, remote program DVR 15%, IPTV 11%	As user demographic

PLT Home User Application 3

Name	The home teleworker	Source
Description	A mini-LAN for the home office with PC, printer, modem etc. Non-work devices likely to be on same network	Forrester "Casual Home Workers Embrace The Digital Home"
User demographic	Forrester definition: bring work laptop home at least once a week	
Devices being networked	95% desktop PC, 91% laptop, 52% printer, 32% game console, 18% media centre PC, 15% DVR, 10% network storage	"
Data rates, duty cycles	Sharing across multiple PCs: 63% Internet connection, 39% printer, 32% files, 21% storage. 19% photos to TV, 15% music to HiFi	"

E.2 Competing technologies

The main competing technology highlighted in our discussions with stakeholders from the PLT industry is WiFi. PLT aims to be more reliable, provide a longer range and have an easier set up than competing WiFi products. However with a typical price range of £35 - £125 PLT devices are is slightly higher cost than the WiFi equivalent. Also at the moment PLT networks still require a network cable between the PLT adaptor at the mains socket and the end product requiring a network connection and so does not provide the mobility of WiFi.

Data networking over other wired media in the home such as coaxial and telephone cabling could also be seen as a competitor to PLT. However, from discussions with stakeholders there is a growing trend to provide a unified device that will support whichever in-home wired media is most readily available and provides the best performance. The emerging ITU G.hn standard for in-home networking provides a unified standard that will operate over telephone, coaxial or powerline cables and is an example of this trend.

Strengths and weaknesses of PLT against other in-home networking technologies can be summarised as follows:

- Strengths:
  - Easy setup. The setup of a PLT network aims to be as straightforward as plugging in the PLT adaptors and connecting a cable between them and the devices to be networked.
  - Longer range than wireless competitors particularly in older buildings with thick walls,
  - Reliability. Although the mains network is not the most suitable wired medium for transmitting data and will suffer from changing loads and reflection of signals, PLT devices aim to be more reliable than a wireless solution such as WiFi which may suffer from interference and congestion from other users of the unlicensed band.
- Weaknesses:
  - Price. In-home networking PLT devices are slightly more expensive than equivalent WiFi products.
  - Lack of mobility. PLT devices still require a connection to the mains and so do not offer the same mobility as alternatives such as WiFi.
- Opportunities:
  - IPTV. Service providers are increasing looking to provide triple play services to consumers consisting of voice, video and data. If IPTV is to be added to existing voice and video services a quick and easy method of sharing the broadband access point to other rooms in the home is attractive.
  - Smart metering. In a bid to be more environmentally friendly, enabling consumers to monitor their electricity consumption is becoming more topical and gaining interest with electricity suppliers.
- Threats:

- EMC testing. There is much debate over suitable type approval and EMC testing for in-home PLT devices. Changes to international standards in this area placing stricter limits on PLT devices could be a set back to the industry.
- Lack of a harmonised industry standard. The WiFi industry has already converged on a single industry standard but within the PLT industry there are still multiple rival standards causing confusion amongst consumers.

Appendix F: Modelling future PLT uptake in the UK

In this section we describe the market modelling that has been performed to predict the future density of PLT devices nearby to victim systems. The approach, assumptions and principles of model operation to perform sensitivity analysis are described.

F.1 The PLT device market model

PA has modelled the expected consumer market uptake of PLT devices in the home. The model provides Ofcom with a reasonable view of speed and extent of domestic uptake during the next 10 years. This uptake is modelled on the basis of available data, the uptake of analogous technologies / the development of analogous markets, as well as based on PA's experience.

We have employed our proprietary market / service model tool, which PA frequently deploys in such projects. This tool has been used to great effect for our clients in a variety of business and financial planning activities, technological deployments and regulatory activities such as in this case.

The market model is built in such a manner as to provide a market forecast output that feeds PA's in technical assessment of the likelihood of interference from PLT devices. This market forecast output is calibrated in terms of PLT device uptake density, relational to population. That is to say, the model determines the variation in the density of households that are likely to use PLT devices over the forecast period. The model forecasts a median scenario and in addition allows low- and high-scenario variations. The functioning of the model is explained in greater depth below. Input data is fully sourced and assumptions are fully documented.

F.2 Model inputs and data sources

PA made use of a number of input data sets in its market model. Some of these inputs are directly consumed by the model, such as in the case of retail shipment volumes to date. Other inputs are used in aggregate to inform or shape the forecast, such as the historic and forecast values for the uptake speed of home networks deployments. Input data includes the following.

- Office of National Statistics (ONS) data:
- PA sourced population by surface area data for England, Ireland, Scotland and Wales from each of the relevant government Statistics Offices. The degree of regionality in this data fluctuates from parish to borough level depending on the way in which the particular statistical office collates data. However, the model calculation of population density normalises all data.
- In addition to population by surface area data, PA similarly sourced population per household data from UK Statistical Offices. Furthermore we sourced data on the number of UK households in order to check the accuracy of population and population by household data sets.

- Business planning forecasts of the BT Vision service were taken into account, although PA applied its judgement in light of the large degree of variance between the previous iteration of the business plan and actual uptake to date.
- Equally, PA took into account both quantitative and qualitative statements by device manufacturers relating to current and expected sales forecasts, as well as expected product modifications and improvements.
- Numerous published primary and secondary market analysis studies, providing insight into the historic and forecast uptake of analogous technologies and markets. These include data on household PC, laptop and 2nd PC/laptop uptake, household broadband penetration, wired/wireless home-network uptake and household wLAN deployment as well as data on uptake of networked home audio-visual devices such as the 'Squeezebox'.

F.3 Model output – Density of households using PLT devices

PLT modems communicate between each other via the mains so it is reasonable to assume that any user will have a minimum of two such devices plugged in to form a network. Both UPA and Homeplug standards have protocols that allocate use of the channel between the modems in the network by means of time and/or frequency division. Put another way, on any given frequency no more than one modem in the network may transmit at any instant.

Considering the potential interference at a specific frequency it is therefore not the number of PLT modems but the number of networks that they are organised into that will determine the number of active devices at one time.

The applications for PLT identified in Section 4.1 will in each case tend to have all the PLT modems in a household networked together. Different households' networks will operate independently from each other. The number of households with PLT will determine the number of independent networks and hence the number of PLT devices transmitting (subject to activity factors) at a given time and frequency. Our market forecast has therefore been carried out to give the number of PLT equipped households in the UK.

One possible correction factor to this is that if market penetration of PLT reaches very high levels then supposedly independent networks may interact by means of reacting to each others' emissions as a noisy channel. How the PLT devices' self-organising protocols will react in this case is unknown at this time.

F.4 Assumptions and variables

In the interpretation of third-party data, as well as in forecasting PLT device uptake, it is necessary and routine practice to make a number of assumptions. The main assumptions are explained below.

F.4.1 Population density

Population density is calculated using statistical data for UK land mass and population. It is then grouped into four nominal density categories; (1) open space, (2) rural, (3) suburban, (4) urban. We have applied population density parameters as follows:

- Open space – between 0 and 50 people per square kilometre
- Rural – between 50 and 250 people per square kilometre
- Suburban – between 250 and 500 people per square kilometre
- Urban – more than 500 people per square kilometre

F.4.2 Population growth rate

We modelled an annual 0.7% increase in UK population size throughout the forecast period. Population growth is applied uniformly across the UK.

F.4.3 Household size

Population density is converted into household density, using the statistical data for population per UK household. Population density is converted into household density using the statistical data for the population per UK household. The estimate stands at 2.7 persons per household in 2009. PA has not varied the figure for persons per household over the forecast period, as there is no data available to suggest what further variance might occur.

F.4.4 Addressable market

PA determined an annual ceiling for the adoption of PLT devices. This ceiling was informed by the known and forecast deployments of broadband-enabled homes (suitable for IPTV services) and wired and wireless home-networks, both sourced from market analysis material.

F.4.5 Rate of adoption

Whereas the uptake curve starting point is determined by the known market shipments to date, and PA forecasts the end point as a function of analogous markets, the rate of adoption (of curve pitch) is determined by ‘p’ and ‘q’ values for the equation of the curve. PA’s market forecast module contains existing scenario-based uptake curves for low, medium and high scenarios. The ‘p’ and ‘q’ values are shaped using PA’s interpretation of third party data and our experience.

F.4.6 Clustering

Whereas population density is calculated within certain parameters using four categories (open space, rural, suburban, urban), this does not account for ‘clustering’. Clustering describes the prevalence for conurbation to be nuclear rather than dispersed evenly throughout an area. This pertains specifically to open space and rural areas. The model factors this in by capturing a proportion of both open space and rural dwellers as living in similar proximity to each other, as those in suburban areas.

F.5 Methodology

PA extrapolated market data from BT Vision shipments as well as PLT device retail / resell shipments in order to determine the installed base of households with PLT devices as at 2009. From this point forward, PA benchmarked the rate of uptake against the proliferation of wLAN units as well as home wired/wireless networks.

The rate of adoption of devices can be varied, but is currently set to a ‘medium’ scenario. This rate of adoption is expected to be faster than the rate of wLAN adoptions. This is because the market is already familiar with the purpose of home networking technologies, and the fact that PLT networks are currently easier to set up than a wireless network.

The market penetration ceiling is also scenario-based and also set to ‘medium’. Whereas market research against which PLT uptake is benchmarked will already include significant market events, the scenarios are predicated on the occurrence of certain situations as follows:

- ***Low Scenario*** - We assume that BT Vision has reached its maximum market share and continues to grow slowly allowing for the fact that the number of homes with broadband and therefore potential BT Vision customers will increase. In the home networking market PLT continues to struggle to differentiate itself against WiFi and takes a low share of this market.
- ***Medium Scenario*** - We assume that BT Vision continues to increase its market share slightly behind BT's own market forecast to allow for the below-forecast uptake that has been seen up until now. In the home networking market we assume that PLT devices slowly increase their market share but remain a minor player in this market due to the lack of convergence of standards and continuing dominance of WiFi.
- ***High Scenario*** - We assume that BT Vision reach their previous target of 2-3 million customers by 2011 and continue to grow at a similar rate over the subsequent years. In the home networking market we assume that PLT steadily increases its market share to 20%. Again, even in a high scenario, we do not anticipate PLT dominating the home networking market in the next 10 years due to absence of a single standard, no obvious cost advantage (especially as interference mitigation solutions are implemented) and the current dominance of WiFi.

The low, medium and high scenarios are driven by our assumptions on the proportion of UK broadband households that by 2020 will have IPTV and the proportion of the home networking market that PLT devices will have captured. These "forecast end point" assumptions for the low, medium and high scenarios are shown Table 9.

	Low	Medium	High
Proportion of broadband homes with PLT-distributed IPTV	**10%**	**20%**	**30%**
Proportion of home networking market using PLT	**2%**	**10%**	**20%**

Table 9 - Assumptions on PLT uptake for 2020

Appendix G: Characteristics of PLT devices currently deployed

This appendix discusses the technical characteristics of in-home networking PLT devices on the market today.

This chapter has particularly benefited from telephone interviews that we held with chipset vendors, PLT product manufacturers and standards organisations active in the PLT industry. We are grateful to the organisations who participated in these discussions.

G.1 Industry standards - Homeplug vs UPA vs HD-PLC

There are three industry standards widely used in in-home PLT devices on the market today; Homeplug, Universal Powerline Alliance (UPA) and High Definition Powerline Communication (HD-PLC).

Figure 29 – Certification marks of the three PLT industry groups for in-home networking (note these certification marks are copyright of the respective standards groups)

The HomePlug Powerline Alliance (HPA) was founded in 2000 and was the first PLT industry standards group to be formed. The US semiconductor vendor Intellon has always been heavily involved in the Homeplug standards but, unlike the other standards groups, is not the only semiconductor vendor in the HPA. Gigle currently produce Homeplug chipsets and STMicroelectronics and SPiDCom have both also announced that they plan to release Homeplug chipsets next year [17][18][19]. The alliance also has sponsors such as Intel, Motorola, Comcast, NEC and Cisco.

In November 2001 the HPA released Homeplug 1.0 with a peak data rate of 14Mbps. Alongside this the HomePlug logo was introduced so that consumers could readily identify interoperable products that had passed the alliance's certification program. This was followed by the high end Homeplug AV standard in 2005 which delivers 200Mbps and is aimed at high quality video and audio distribution.

Confusingly, there are PLT devices on the market that are marked with the Homeplug logo but provide 85Mbps rather than 14 or 200 Mbps. These devices are sometimes described as "Homeplug with Turbo" but this isn't an official standard published by the HPA. Homeplug with Turbo is instead an Intellon proprietary technology and extends Homeplug 1.0 by adding Turbo coding and a higher order modulation to give the increased data rate.

The second of the PLT industry standards groups, the Universal Powerline Alliance, was announced in 2005. This group was setup by the Spanish semiconductor vendor DS2 who had originally participated in the Homeplug standards. The aim of UPA was to develop a global universal PLT standard that was equally accessible to all semiconductor vendors. Although DS2 are currently the only semiconductor vendor in the UPA, the alliance is working to get other semiconductor vendors involved.

The UPA originally aimed to develop standards covering both in-home and access PLT devices. However, as the Open PLC European Research Alliance (OPERA) was also working towards a standard for access PLT devices around the same time, the UPA has focused more on PLT for in-home networking and interoperability between in-home and access PLT devices. The UPA Digital Home Standard (DHS) was approved in February 2006 and with data rates of 200Mbps is comparable to Homeplug AV.

UPA certified PLT devices dominate the UK market as DS2 chipsets are used in the Comtrend powerline adapters included in the BT Vision package. At September 2009, we understand that there were 750,000 pairs of these devices deployed in the UK.

The third industry standards group is based around Panasonic's High Definition Powerline communications technology (HD-PLC) which is a registered trademark of Panasonic. HD-PLC delivers 210Mbps and is comparable to Homeplug AV and UPA DHS. The HD-PLC alliance who promotes this standard, is based in Japan and was founded in September 2007.

The HD-PLC alliance claim in their description of HD-PLC that using a wavelet OFDM waveform, as opposed to FFT OFDM waveform, means that HD-PLC compliant devices have sharper roll off and deeper notches than other in-home PLT standards to minimise interference to other users.

Table 10 compares the technical characteristics of the various in-home PLT standards. Unfortunately, we were unable to obtain detailed technical specifications for HD-PLC. We are unaware of HD-PLC devices on sale in the UK and so have focused on Homeplug and UPA are these most important to understand from a UK perspective. ITU G.hn is included on Table 10 for comparison and will be discussed in section Appendix H: under future trends.

All in-home PLT standards use an OFDM waveform for the Physical layer. Both UPA and Homeplug operate over similar frequency ranges of 2-28MHz and 2-32MHz respectively. Interestingly, 30MHz is a breakpoint in EMC regulations and DS2 must reduce their transmit power above 30MHz by 30dB to ensure compliance.

	HomePlug V1.0	HomePlug 1.0 with Turbo (Intellon proprietary)	HomePlug AV	UPA Digital Home Standard	ITU G.hn
Frequency range	4.5 -21 MHz	4.5 – 21 MHz	2 – 28 MHz	2 – 32 MHz	2-50MHz, 2-100MHz or 100-200MHz
Number of usable sub-carriers	84	84	Between 275 and 1155 carriers are used.	1536	1966, 4014 or 4096
Sub-carrier spacing	200kHz	200kHz	24.41kHz	19.53kHz	24.41kHz
Maximum throughput	14 Mbps	85 Mbps	200 Mbps	200 Mbps	1 Gbps
Modulation scheme	DBPSK or DQPSK	16 QAM, 64 QAM, 256 QAM	BPSK to 1024 QAM	BPSK to 1024 QAM	Up to 4096 QAM
Forward error correction	Concatenated Viterbi and Reed Solomon	Turbo	Turbo convolutional code (TCC)	Reed-Solomon adapted for powerline	Low density parity check (LDPC)
Adaptive modulation and coding?	Yes	Yes	Yes	Yes	
Notching?	Notches at fixed frequencies to protect amateur radio bands	Notches at fixed frequencies to protect amateur radio bands	Notches at fixed frequencies to protect amateur radio bands	Programmable notches up to 40dB deep.	Notches at fixed frequencies to protect amateur radio bands Smart notching also required
MAC scheme	Prioritised CSMA/CA	Prioritised CSMA/CA	TDMA and CSMA	Token ring prioritised TDMA	
Central controller?	No	No	Yes	Yes	

Security	56 bit DES	56 bit DES	128 bit AES	168 bit Triple DES	
Range	Approx 200m	Approx 200m	Up to 700m	300m	
Transmit power	-50dBm/Hz	-50dBm/Hz	-50dBm/Hz for US -55dBm/Hz for Europe	-58dBm/Hz below 30MHz -88dBm/Hz above 30MHz	

Table 10 – Technical Characteristics across PLT device standards

The MAC is quite different between Homeplug and UPA. Homeplug AV uses a combination of Time Division Multiple Access (TDMA) and Carrier Sense Multiple Access with Collision Avoidance (CSMA / CA) for its MAC. All nodes in the network are synchronised to two cycles of the mains signal or 40ms. At the start of each frame a central node announces the allocated time slots for the next frame which will include contended and non-contended periods. In idle times, where no data is being transmitted, this schedule announcement or beacon signal from the central controller is the only transmission seen. The MAC in UPA is different and is based on a token passing TDMA scheme. Each node in the network can only transmit when it holds the token. However, this means that in idle times there are still a high number of transmissions on the network as the token gets passed from node to node. The result is that UPA devices are more likely to cause more interference in idle mode than Homeplug devices. In our lab tests, the difference in MAC between UPA and Homeplug was audible on a SW radio as an additional tone of approximately 1kHz (see appendix I.3).

Adaptive coding and modulation is facilitated by both standards to maximise data rates for a given cable or channel quality between two PLT devices.

It should be noted that these standards are technical specifications that have been agreed amongst vendors to ensure interoperability between PLT devices rather than conformance with EMC regulations. For example, the relevant alliances for both UPA and Homeplug have test facilities for performing Plugtests and supporting their certification programmes. However, EMC testing is outside the scope of Homeplug or UPA certification and is instead expected to be covered by the product manufacturer to obtain CE marking.

Recently 1Gbps PLT devices have been entering the UK market in Belkin products based on a Gigle chipset. This chipset combines Homeplug AV with a proprietary technology that uses spectrum as high as 300MHz. While these devices do not represent an official extension of the Homeplug or UPA standards it is worth noting their characteristics as these devices are available for use in the UK and so may potentially cause interference. We understand that the Gigle chipset uses a dual band modem which operates Homeplug AV from 2-28MHz and a Gigle proprietary technology from 50-300MHz.

Potential interference from the upper band of Gigle devices is not thought to be a problem as the transmit power above 30MHz is at the greatly reduced level of -80dBm/Hz as opposed to -50dBm/Hz below 30MHz. The reduced transmit power above 30MHz has been selected to ensure that the radiated emissions from PLT devices using this chipset fall below the CISPR guidelines and are EMC compliant.

G.2 Interference mitigation in current PLT devices

Both UPA and Homeplug have worked with the American Radio Relay League (ARRL) at various stages to ensure that interference to amateur radio users is minimised. The Homeplug standards include 30dB notches for the International Amateur Radio Union (IARU) bands and an additional amateur radio band at 5MHz. The UPA DHS specifies that programmable notches up to 40dB in depth must be provided and in practice most UPA manufacturers notch out the IARU bands by default. We have observed these notches in our own lab testing of PLT devices as shown in Figure 30 with further details given in Appendix I.2.

In terms of dealing with complaints outside these default notches PLT device manufacturers are given the following options:

- Amplitude mapping or power reduction
- Programmable notches

Both DS2 and Intellon allow PLT device manufacturers to customise the spectral mask of their chipsets by reducing the transmit power for particular group of sub-carriers via an amplitude map or masking out sub-carriers completely to generate a notch. Notably the DS2 chipset can be programmed once installed in the end-user's premise via a web based interface and this approach has been used to resolve a number of complaints in the UK.

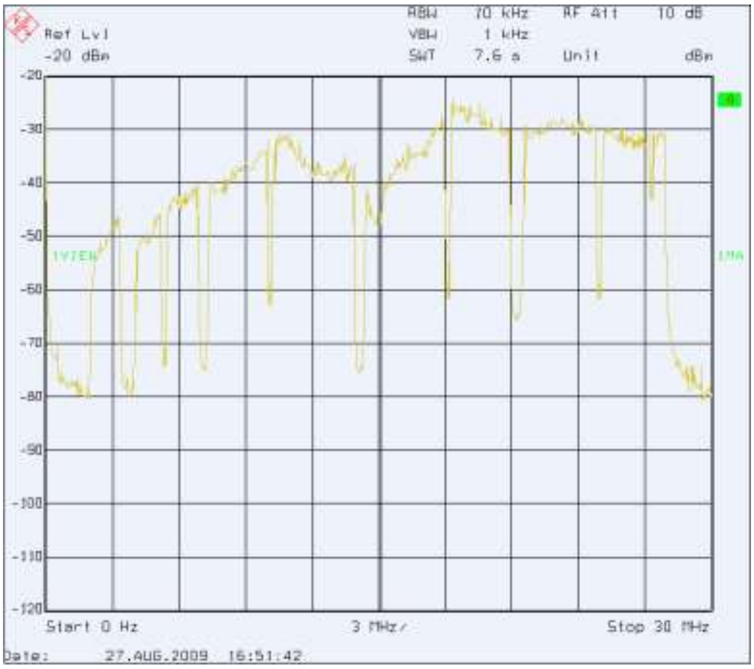


Figure 30 – Observed spectrum of a Belkin Homeplug AV PLT device

There are plans to improve the current approach to interference with smarter device features that automatically reduce power or add notches as interference is detected rather than relying on manual intervention by the regulator, service provider or user. These are discussed further in Section Appendix H:.

G.3 International regulation of PLT devices

There is much debate and concern around EMC testing for PLT devices. While it is not in the remit of this study to comment on this subject, it is useful to be aware of the relevant standards and differences between countries as these affect the characteristics of PLT devices.

In the US FCC part 15 applies to PLT devices [20]. This specifies radiated emissions limits for unintentional radiators below 30MHz. Conducted emission limits are not applicable to this category of devices. For in-home PLT devices these radiated emission limits equate to a power spectral density of -50dBm/Hz below 30MHz, which is used by the Homeplug standards. However, above 30MHz the radiated emission limits are much stricter and equate to a drop in power spectral density to -80dB/Hz.

The FCC has added specific subsection to part 15 to cover access PLT. Extra requirements for these devices include:

- Interference mitigation techniques such as power control and smart notching
- Notching of aeronautical and maritime bands
- Exclusion zones around aeronautical and maritime receiver stations such as coast guard stations

Currently, in- house PLT is classified separately to access PLT and so these extra measures do not yet apply to it.

In Canada Interference-Causing Equipment Standard 0006 (IECS-006) applies to PLT devices and has recently been updated so that it now specifies radiated emission limits from 1.705 – 960 MHz that are in line with the FCC Part 15 equivalent limits, clarifies that in-home PLT devices are subject to IECS-0006 and adds in-situ testing [21]. Notably, no conducted emission limits have been set above 1705kHz as this area still requires further study.

CISPR 22 gives international guidelines for ITE but is based on conducted emissions for unintentional radiators below 30MHz rather than the US approach of radiated emissions. CISP22 translates into European EMC directive as EN55022. There is much debate over how conducted emissions of PLT devices should be tested in both standards groups but as yet there has been no PLT specific changes to these standards. This has left standards with a certain degree of ambiguity which has given rise to considerable debate around EMC compliance of PLT devices currently on the market [15].

In 2001, the European Commission (EC) requested that work should start on a harmonised European standard for PLT devices. European regulators have been working towards setting specific limits and example suggested limits include the German NB30 and UK MPT1570 levels [5]. The general guidance from the EC in this area is based on recommendation 2005/292/EC from April 2005 which recommends removing unjustified regulatory obstacles to deploying and operating electronic communications networks over powerlines [22]. However, as yet there has been no agreement on a harmonised standard in Europe.

This general confusion and uncertainty over harmonised international regulations for PLT devices is potentially slowing the uptake of PLT devices. Service providers will not want to commit to including PLT devices in their service offerings while regulatory changes are still being debated that could demand the recall of deployed PLT devices and be a major set back to the PLT industry.

Appendix H: Future trends in PLT devices

This section discusses how the PLT landscape is likely to change in the next 5 to 10 years as a key area for the study is the future likelihood of interference as both devices change and devices may become more widespread in the market.

H.1 Industry standards

H.1.1 Convergence on a single standard for in-home PLT devices

As discussed in section G.1, there are currently 3 industry standards for in-home PLT devices. In the past we have seen that the uptake of technologies usually accelerates once the industry has converged on one standard due to the clarity amongst consumers and economies of scale that this brings. The WLAN industry converging on the IEEE 802.11 series of standards is an example of this. There have been similar efforts in the in-home PLT industry with two main future standards emerging; IEEE P1901 and ITU G.hn.

The main difference between ITU G.hn and IEEE P1901 is that ITU G.hn is a completely new PHY and MAC for in-home devices using telephone, power or coaxial cables whereas IEEE P1901 specifies mechanisms to ensure co-existence of existing in-home PLT industry standards.

The exact transmit power for ITU G.hn is still under consideration but for PLT devices will likely be -55dBm/Hz below 30MHz and -80dBm/Hz above 30MHz. The frequency range of ITU G.hn varies with medium and mode. For PLT devices 3 bands have been suggested as 2-50MHz, 2-100MHz or 100-200MHz. It is also likely to include improved interference mitigation features such as quieter idle times, smart notching and dynamic power control. Other technical characteristics of ITU G.hn are compared against existing standards in Table 10. It is worth noting while there are significant similarities between ITU G.hn and Homeplug AV the two standards are not compatible.

As shown in Figure 31, there is a split amongst the current in-home PLT industry standards groups between IEEE P1901 and ITU G.hn. It is difficult to see how this standards battle will play out. The HPA claim that 75% of in-home networking devices worldwide are Homeplug based and introducing a new PLT standard that is not backwards compatible with these doesn't make sense. However, UPA claim that at 200Mbps they dominate the market and are promising ITU G.hn chipsets by mid 2010. The UK is skewed towards UPA because of the BT Vision deployments but interestingly Freesat are HPA members and could significantly readdress this imbalance if Homeplug was used in Freesat set top boxes for interactive TV.

While this division in the in-home PLT industry still exists it is unlikely that PLT devices will enjoy the high uptake seen by competitors like WiFi.

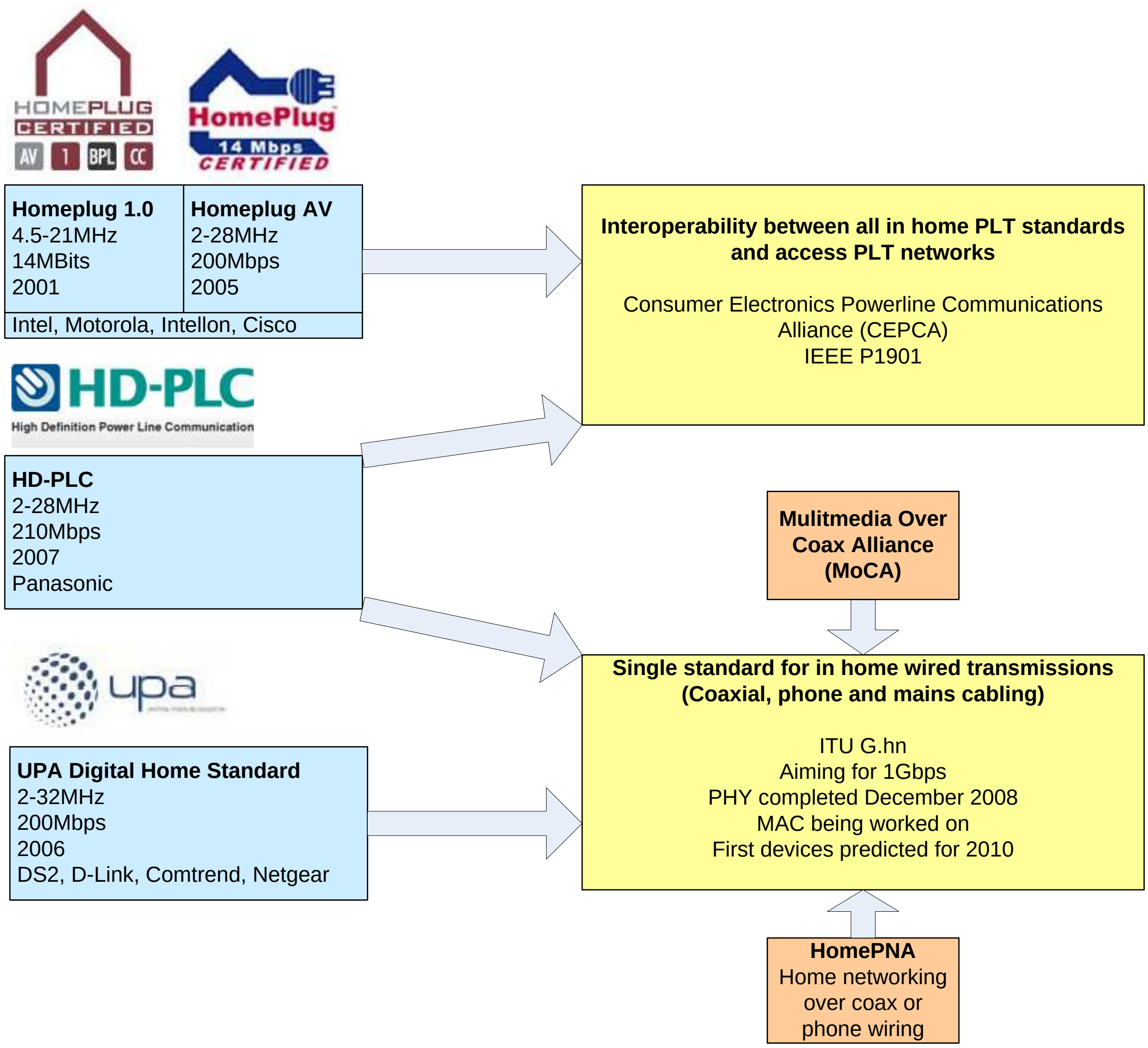


Figure 31 – Future direction of in-home PLT standards

H.1.2 The future of the Homeplug standards

The current roadmap for the UPA standard is very much to adopt ITU G.hn and so it is likely that any future UPA standards will look similar to ITU G.hn. However, the HPA support interoperability amongst multiple standards via IEEE P1901 and so will continue to develop Homeplug standards that

Current Homeplug standards efforts beyond those already deployed include:

Homeplug Command and control. This was released in October 2007 and is a low cost, low data rate (7.5kbps) variant of Homeplug that uses the CENELEC frequencies. This targets applications like control of heating, lighting, air conditioning and remote monitoring around the home. It also covers advanced metering applications and is linked to Smart Grid initiatives.

Homeplug BPL. This is for last mile broadband access to the home and so not in the remit of this study.

Homeplug GP or Green PHY. This takes Homeplug Command and Control further to cover more Smart Grid applications and uses higher data rates of 1-3.8Mbps. HPA is working with utility companies to understand the information they need from homes and how this fits with monitoring in the rest of their infrastructure. Homeplug GP will be interoperable with Homeplug AV and operates in a similar frequency range. This takes PLT networking outside the home which is something to track as it extends the range of interference.

Homeplug AV2. This will go higher in frequency to give data rates to fit a 600Mbps use case. Most HD steams require 20Mbps so the current Homeplug AV real data rate of around 30Mbps starts to get tight for use cases with multiple HD streams around the home. Homeplug AV2 will be compatible with IEEE P1901 and has the same MAC as Homeplug AV. The PHY is changing to use a higher frequency range and the HPA is examining the characteristics of transmitting at these higher frequencies at the moment. Transmit power is reduced by 30dB above 30MHz due to FCC part 15 limits.

H.2 Interference mitigation techniques in the pipeline

From discussions with stakeholders the two main features on PLT device manufacturers' roadmaps are:

- Dynamic power control estimated to be available Q2 2010. This will adjust the power between two PLT devices to the minimum level to get the required data rate and will provide an overall reduction from the current situation where maximum transmit powers are used constantly.
- Smart notching estimated to be available Q3 2010. This will detect the presence of victim systems that PLT devices may cause interference to and applies a notch as appropriate. For example, an ETSI working group has been studying detection of SW radio signals based on pick of the SW broadcast in the mains wiring. There is some concern over the feasibility of detecting victim signals using mains wiring due to sensitivity limits. This route also has cost barriers for vendors as the main IP is owned by Sony. Other approaches include using a database of victim receiver systems and applying notches based on knowledge of the PLT device's location.

Transmissions during idle time are also a concern and ITU G.hn are currently looking at power saving solutions which will reduce transmissions and interference particularly in idle mode. In particular, the ITU G.hn standard includes a synchronous MAC and scheduled hibernation for several cycles to reduce interference.

The synchronous MAC allocates timeslots to each user via a MAP frame which each PLT device listens for. Devices only transmit in their timeslot if they have data to transmit which is an improvement on UPA where a token is constantly passed between devices even if there is no data to transmit. Also if a device has no data to transmit it can inform the network master that it is going into hibernation mode. Whilst in this mode no data will be sent to this device. Data destined for the hibernating node will be buffered until the device wakes up.

H.3 Future international regulation of PLT devices

There have been multiple draft changes to CISPR 22 proposed to define limits specific to PLT devices but none of these have as yet been agreed upon.

The general theme of suggested changes are to:

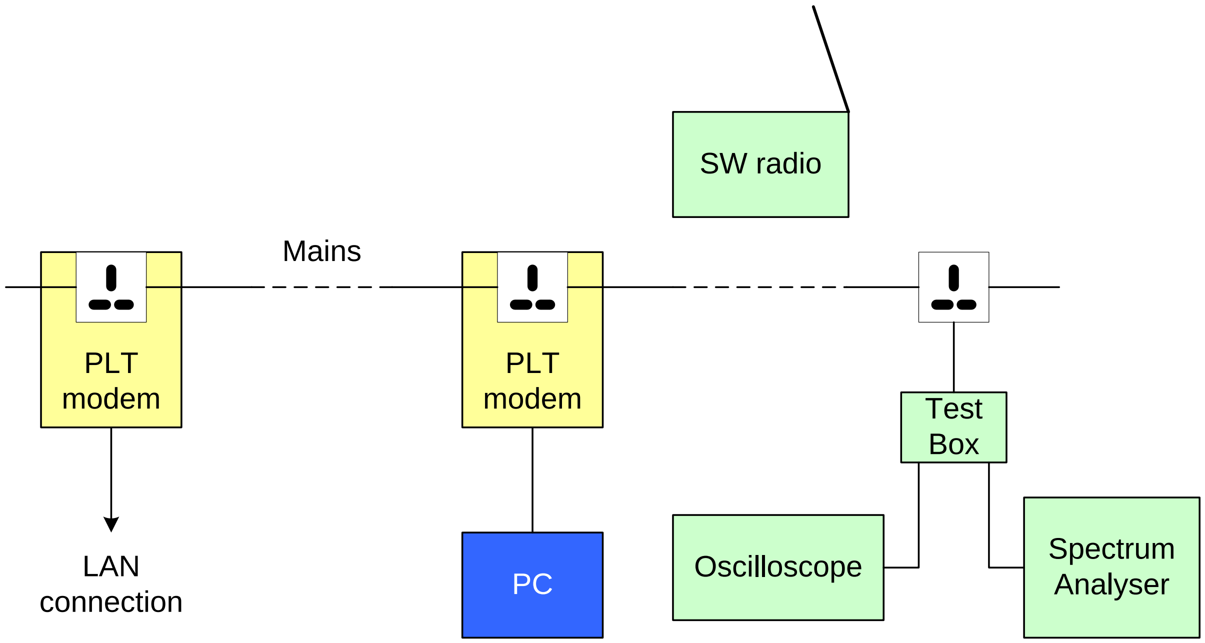
- Mandate notching of IARU bands
- Specify maximum PSD around -55dBm/Hz below 30MHz and -85dBm/Hz above 30MHz.
- Mandate interference mitigation features in PLT devices such as automatic power control and smart notching.
- Mandate lower transmissions by PLT devices in idle time

While most PLT devices currently notch IARU bands by default, we are not aware of any devices on the market which apply dynamic power control or smart notching.

From a standards viewpoint it is also worth noting that the reduction in transmit power above 30MHz across the standards makes achieving data rates higher than the current 200Mbps devices a challenge for PLT vendors.

Appendix I: PA observations of PLT devices

I.1 Lab test configuration



Initial test were carried out in the PA electronics laboratory. The test set up comprised the following main items:

- A pair of PLT modems
- A PC and LAN connection to provide traffic over the PLT modems
- A spectrum analyser and test box for sampling the high frequencies from the mains, with an oscilloscope for observation in the time domain
- A portable shortwave radio receiver

The spectrum analyser and oscilloscope monitored the conducted emissions carried on the mains wiring. The test box attenuated the 50Hz mains to a level that did not affect the sensitivity of the spectrum analyser. The radio monitored (qualitatively) the radiated emissions.

I.2 Spectral mask of Homeplug V UPA

The spectra of a pair of Belkin Homeplug AV PLT modems and a pair of BT Vision Comtrend 902 PLT modems were observed. The results are shown in Figure 32 and Figure 33 respectively.

The yellow traces are the spectra observed from the mains Live connection with the modems active. The blue and green traces in Figure 33 are the background mains noise with the modems off and the spectrum analyser noise floor respectively.

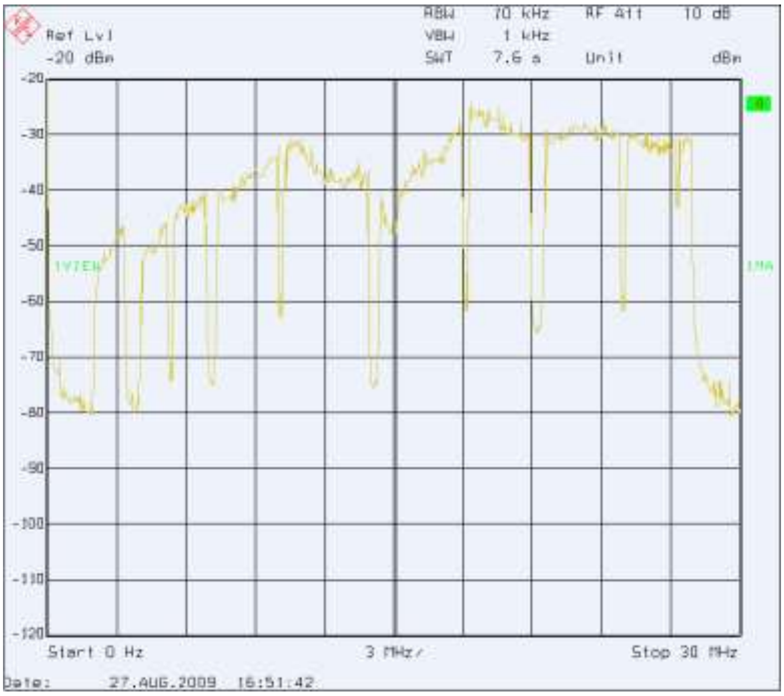


Figure 32 -Frequency response of Belkin Homeplug AV modem

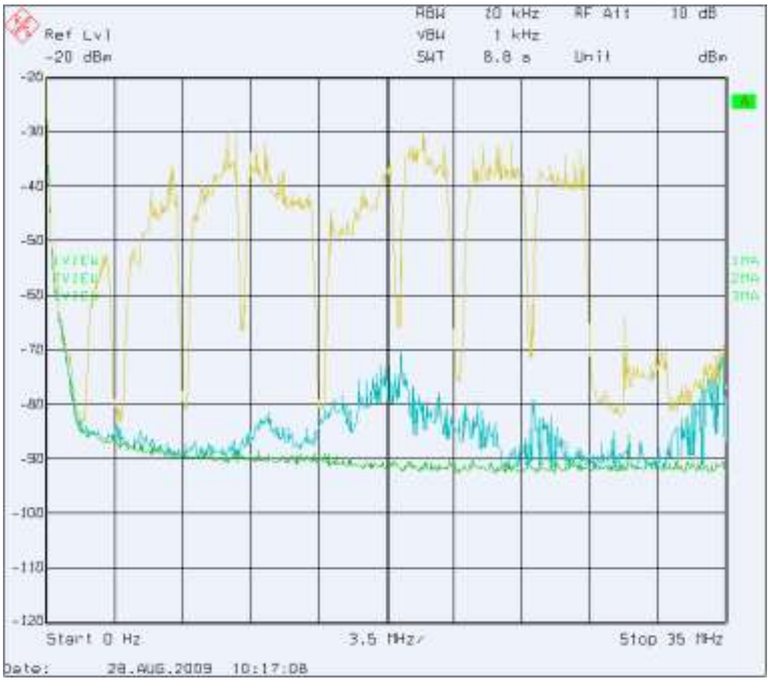


Figure 33 – Frequency response of the Comtrend 902 modem

The Homeplug specification has a power spectral density (PSD) of -50dBm/Hz whereas UPA operates at -58dBm/Hz. This matches the PSD plots that we captured. The variability with frequency can be attributed to two factors:

The mains wiring is designed to distribute power at 50Hz and is not optimum for signal transmission at MHz frequencies. There will be various resonances due to stubs and impedance discontinuities as a result

The filtering effect of the test box that is used to remove the 230V 50Hz component will also attenuate the low frequency end of the PLT band

Both devices have default notches at the IARU bands. The Belkin device has an extra notch at 5.3MHz which the Comtrend device is missing. The extra band is also used by amateur radio groups and but is not an official IARU band. We understand that some of the complaints about interference from Comtrend devices that Ofcom has received are in relation to this band. In these cases complaints have been resolved by adding the extra notch which is a straightforward procedure.

The notch at 21MHz was examined more closely on both modems as shown in Figure 34 and Figure 35.

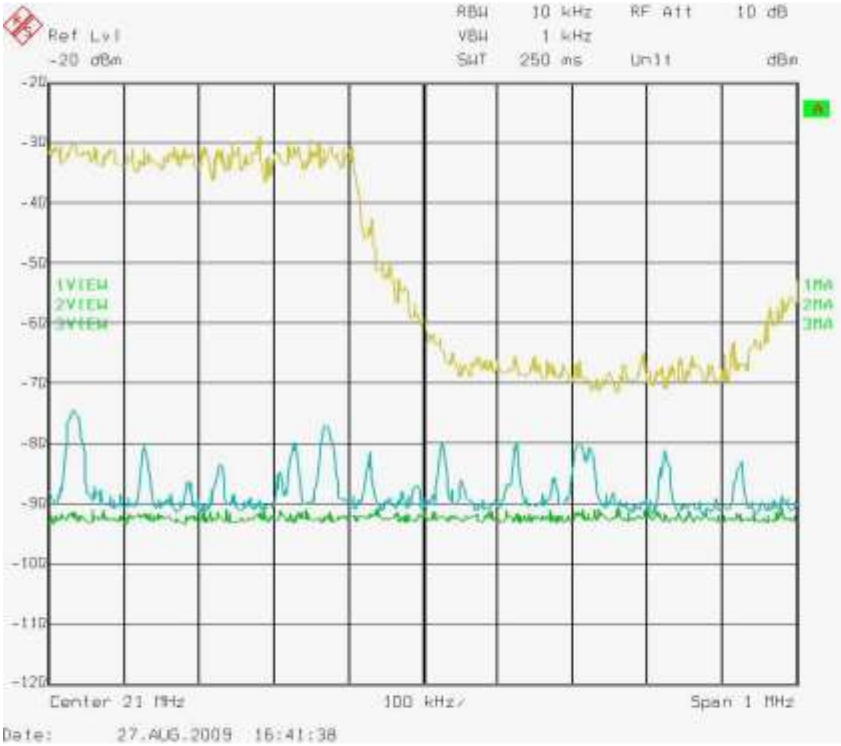


Figure 34. 21MHz notch on Belkin Homeplug AV modem

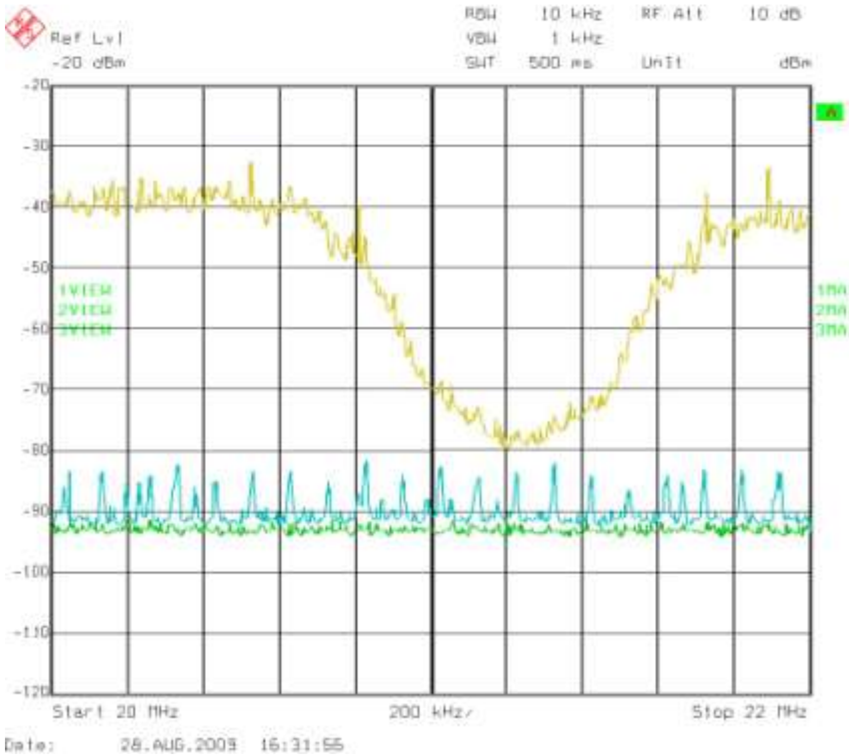


Figure 35. 21MHz notch on Comtrend 902 modem

The Homeplug modem had a noticeably sharper rolloff and broader bandwidth of the notch than the UPA (Comtrend) modem.

Both modems achieved a similar notch depth of 35-40dB. The limiting factor was not identified. Intermodulation in the mains wiring can cause the PLT spectrum to spread at a reduced level into the notches and to frequencies outside the intended frequency band. These tests were carried out in a building that had been professionally rewired a few years earlier so the wiring was assumed to be in good condition.

We also checked for differences in the spectra of the UPA and Homeplug devices when they were transmitting data compared to idle mode. No difference in the measured power spectra were observed between the two modes indicating that the transmit power level remains the same for PLT devices whether they are in idle mode or transmitting data.

I.3 Interference from Homeplug V UPA

To observe interference from PLT devices, a shortwave radio was placed on the laboratory bench where a UPA device was plugged in but not switched on. The radio was tuned to a channel with no audible radio signal before the UPA modem was switched on.

The UPA device was switched on and left in idle mode. A continuous tone of around 1kHz was audible on the SW radio. In addition a regular “click” could be heard at a rate of around 2 per second.

Observations of the UPA device in idle mode via an oscilloscope showed a regular burst of energy at a period of 972µs corresponding to a frequency of 1029Hz. These bursts were of duration 297µs giving a duty cycle of 31%. There were periodic longer bursts also observed.

A Homeplug PLT device was tested in a similar way and a "clicking" was also heard on the SW radio although not with the same underlying 1kHz tone as the UPA case. Observations via the oscilloscope showed that a beacon signal was transmitted in idle mode approximately every 40ms for a duration of 500µs. This duty cycle of 1.25% is much lower than UPA and may account for some of the difference in audible interference between the two PLT device types.

Our observations match the 40ms beacon rate used by Homeplug AV where the start of a beacon period is synchronised to the AC mains power signal and has a duration of two AC cycles. In a Homeplug AV network one device will always act as the central coordinator and produce a beacon signal at the start of each beacon period to announce the schedule for that beacon period to the other PLT devices in the network. This short beacon signal occurs regardless of whether data is being transmitted or not.

The difference in duty cycle between Homeplug and UPA can be explained by the difference in MAC schemes used. As mentioned, Homeplug uses a short regular beacon signal to announce scheduling. UPA instead operates on a token passing arrangement and so the token is continuously passed from one PLT device to the next even when there is no data to be sent.

I.4 Effect of PLT sub-carrier offset from victim receiver centre frequency

As discussed in section 7.1.3, the interference effect of an OFDM signal from a PLT device cannot be assumed to be the same as AWGN in a narrowband victim receiver. Nasri and Lampe [23] have examined a similar effect between MB-OFDM as used in UWB and narrowband receivers. Based on their conclusions the interference effect will depend on:

- Ratio of the sub-carrier spacing to the victim receiver bandwidth.
- Offset of the dominant OFDM sub-carriers from the centre frequency of the victim receiver.

In our lab tests we were unable to change the bandwidth of the PLT devices or the SW radio to verify the first conclusion. However, we did observe the cycle between least audible interference and most audible interference as the SW radio was tuned across half a the sub-carrier spacing of the PLT device as predicted by Nasri and Lampe.

Frequency on the SW radio (Tuning resolution of 5kHz)	Audible interference level	Homeplug sub-carrier number corresponding to tuned frequency
15.47 MHz	Low	633.7
15.48 MHz	High	634.1
15.495 MHz	Low	634.7
6.555 MHz	Low	268.5
6.57 MHz	High	269.1
6.58 MHz	Low	269.5

Table 11 - Observations of interference with offset of sub-carriers and victim receiver centre frequency

I.5 Observations of PLT devices in home scenarios

A pair of Belkin Homeplug AV PLT devices were tested in at three residential locations; two with underground cabling to the mains and one with overhead mains cables.

In the case with underground cabling:

- Interference 2m from the houses was not a problem when listening to a SW radio station
- On a clear channel, i.e. just listening for interference, PLT interference was observed up to 20m from the houses
- At one of the houses a low level of PLT interference was observed near the consumer unit of a neighbouring house on a clear channel indicating that the PLT signal was being passed from house to house

In the case with overhead cables:

- PLT interference was observed up to 75m from the house
- In particular interference was observed when walking underneath the overhead cable indicating that it was spreading interference from the PLT to the rest of the street.

Appendix J: Propagation model for In-Home PLT devices

J.1 Near field

The near/far field boundary is at a distance of:

$$d = \frac{\lambda}{2\pi}$$

Thus d varies across the PLT band from approximately 24m at 2MHz to 1.6m at 30MHz. A variation with distance of approximately 20dB/decade down to 3m has been observed in a number of measurements as described in section 7.1.2, so these measurements vary from near to far field across the band. Thus the near field model is in practice an extension of the far field model used at shorter ranges than it normally quoted validity

Continuing this extrapolation to shorter distances than 3m is still valid at higher frequencies but may break down at the lower frequencies involved. In practice with these very short ranges it is likely that the mains wiring can no longer be considered a homogenous item but that individual cable runs closest to the receiver will start to dominate.

There is a human factor involved here also. If a radio is placed in a location where it suffers interference, many users will attempt to move the radio a small distance to see if they can get better reception. If there is a rapid change in interference level, it is unlikely that the radio would be left in an area of high interference i.e. close to the relevant wiring.

We have therefore included the above extrapolation in the model, with the caveat that it may not apply at very short ranges.

J.2 Far field

Friis' equation describes mathematically the propagation of an electromagnetic wave in free space in terms of the power loss from the transmitter to the receiver. Excluding the antenna gains and expressing the remaining factors in logarithmic terms gives:

Path Loss = 32.5 + 20 log10(f) + 20 log10 (d)   dB

Where f is the frequency in MHz and d is the distance between antennas in km. This is already included in Seamcat as a standalone propagation model, and has been included in the custom model for the far field mode.

J.3 Ground wave

The ground wave propagation mode is modelled by the GRWAVE program [24]. It returns field strength values and transmission losses. The input values used for this study are:

- Atmospheric Constants: Refractivity =315; Scale height 7.35km (fixed values)
- Transmitter power = 1kW EIRP (fixed value)
- Ground Constants: Rel. permittivity = 33, Conductivity = 0.014mS/m. According to ITU-R R.832 [25] this is the upper end of the range of ground conductivity in the UK, which will give the strongest propagation conditions. It occurs over a large area of the Midlands extending to Lancashire, Somerset and Lincolnshire.
- Vertically polarised E-field
- Distances and frequency to suit individual simulation
- Transmitter and receiver height = 5m each. This represents the upper levels of mains wiring in a typical two-storey house and an external radio amateur's antenna at the level of the house eaves.

The effect of ground wave propagation with distance is illustrated in Figure 13.

The attenuation of 40dB per decade of distance is consistent but the overall level of attenuation varies with the above input factors. The transition between far field and ground wave is described in ERO Report 069 [**Error! Reference source not found.**] section 4. In order to assess the range at which this transition occurs, GRWAVE was run for a series of frequencies across the range 2-30MHz. This created the Easymptote values for the ground wave mode which could then be used to calculate the range at which it would intersect the free space propagation characteristic. The results are shown in Table 12 and Figure 36.

Frequency	2	3	6	8	10	15	20	25	30	MHz
E asymptote	107.9	106.3	100.8	97.7	95.1	90.9	88.3	86.7	85.6	dBuV/m

Table 12. Field strength asymptote values

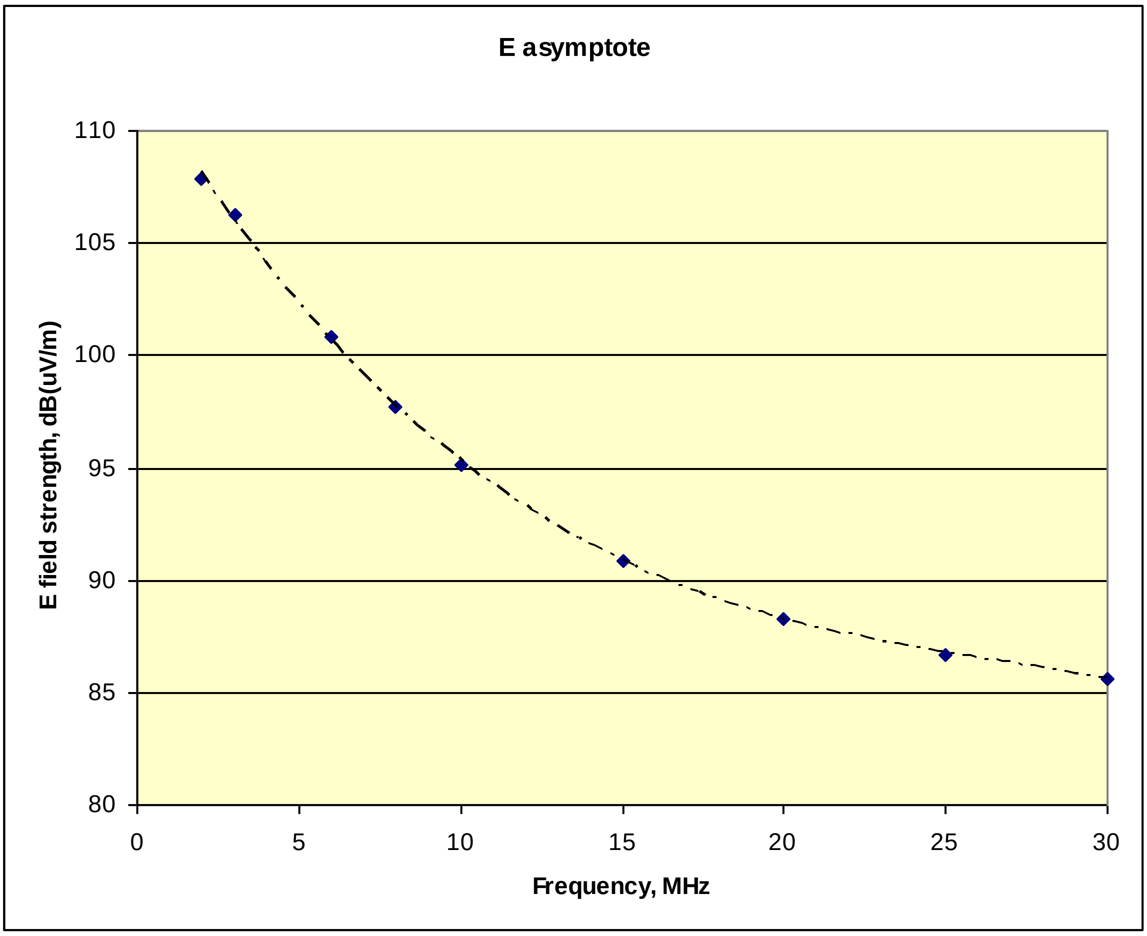


Figure 36. Field strength asymptote values

J.4 Sky wave propagation

Sky wave propagation is far more complex to model than the other propagation modes involved at HF due to the number of variables. A widely recognised software implementation of the relevant ITU recommendation 533 has been developed and released by the NTIA for predicting coverage of the Voice of America radio network. There are several variants, the ICEPAC Inverse model has been used here to illustrate the effects.

Figure 37 and Figure 38 show the difference between daytime and night-time propagation at 7.1MHz to a receiver in Lerwick, Shetland Isles. The location was chosen to best illustrate the propagation from the South. The minimum path loss is similar in both cases, 123dB and 125dB. However the geographical distribution is very different. During the day the minimum path loss is to be found in a belt across the UK, Ireland and Scandinavia. At night the reduction in solar radiation causes the ionosphere to become less active and the height of reflection of the sky wave rises, causing the lowest path loss to appear at a greater range. In this instance it moves down to Spain, Portugal and Southern Italy.

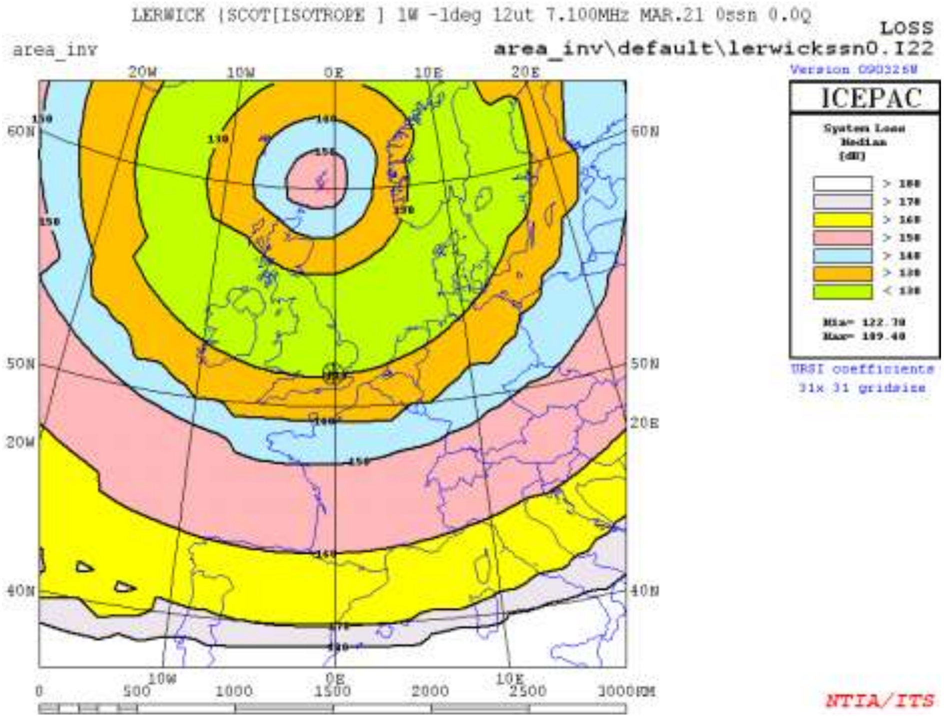


Figure 37 - Path Loss at Midday

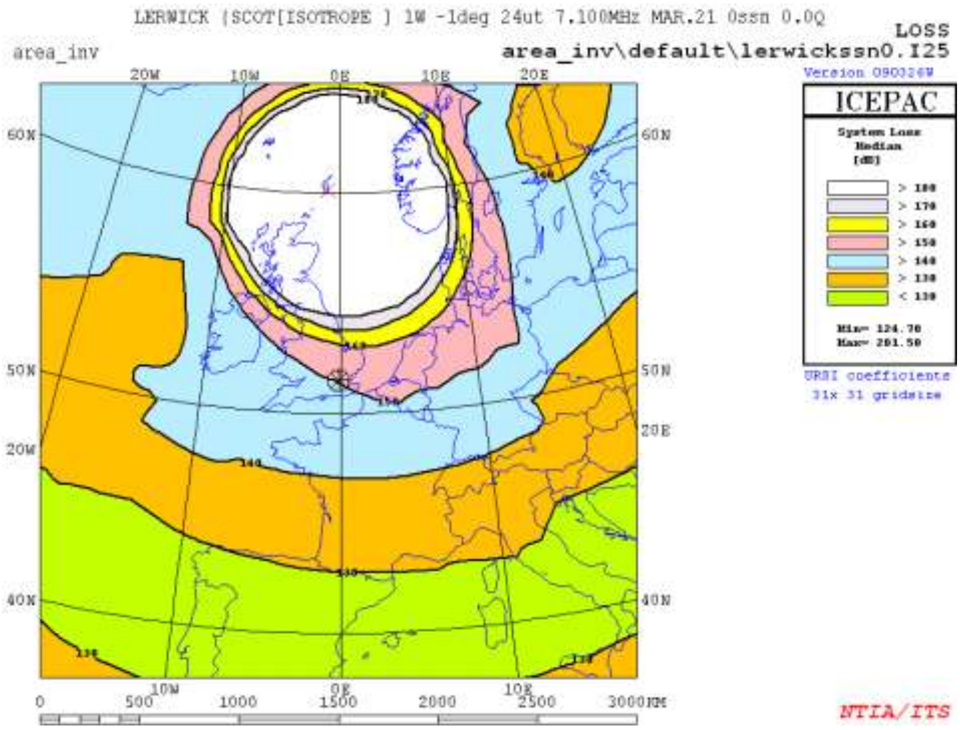


Figure 38. Path Loss at Midnight

The implication of this is that the received power via sky wave depends not only on the loss via the sky wave but the PLT density over a continent-sized area. Only a small part of that area will contribute significantly to the received power at any given time, frequency and receiver location.

Appendix K: Overview of Seamcat model

K.1 Introduction to Seamcat

Seamcat was developed by the European Radiocommunications Office (ERO) as a generic radio interference modelling tool. It takes as inputs some basic parameters about the transmitter and receiver such as power and sensitivity, and information about the spatial distribution of both. Many of these parameters can be given statistical distributions. Various propagation models can be chosen or custom models can be written. The threshold of what constitutes interference can be defined in several ways such as signal to noise ratio or increase in noise floor.

Having set the parameters the program executes a Monte-Carlo analysis on the parameters defined as distributions rather than fixed values. The power from the interfering source(s) and if relevant from the wanted source are calculated for each case and the percentage of cases where interference occurs is calculated. A post-processing function allows the input power to be varied and the impact on probability of interference is shown as a cumulative distribution function.

K.2 Seamcat model structure

For this study we have built up a Seamcat workspace to represent a low, medium and high frequency band in range of 2-30MHz for each of the three victim receiver types:

- Shortwave radio
- Amateur radio
- Aeronautical ground station representing professional users

For each simulation a victim receiver is placed at the centre of the simulation area and a number of PLT devices are then scattered around this victim receiver as per the density of PLT devices that has been forecast in our market analysis described in section 4.2. A link budget calculation is performed between each PLT device and the victim receiver and these are then summed to give the received interference signal, termed the iRSSunwanted, at the victim receiver. A typical screenshot of the setup we have used is shown in Figure 39 with the blue dot at the centre representing the victim receiver and the red dots representing PLT devices.

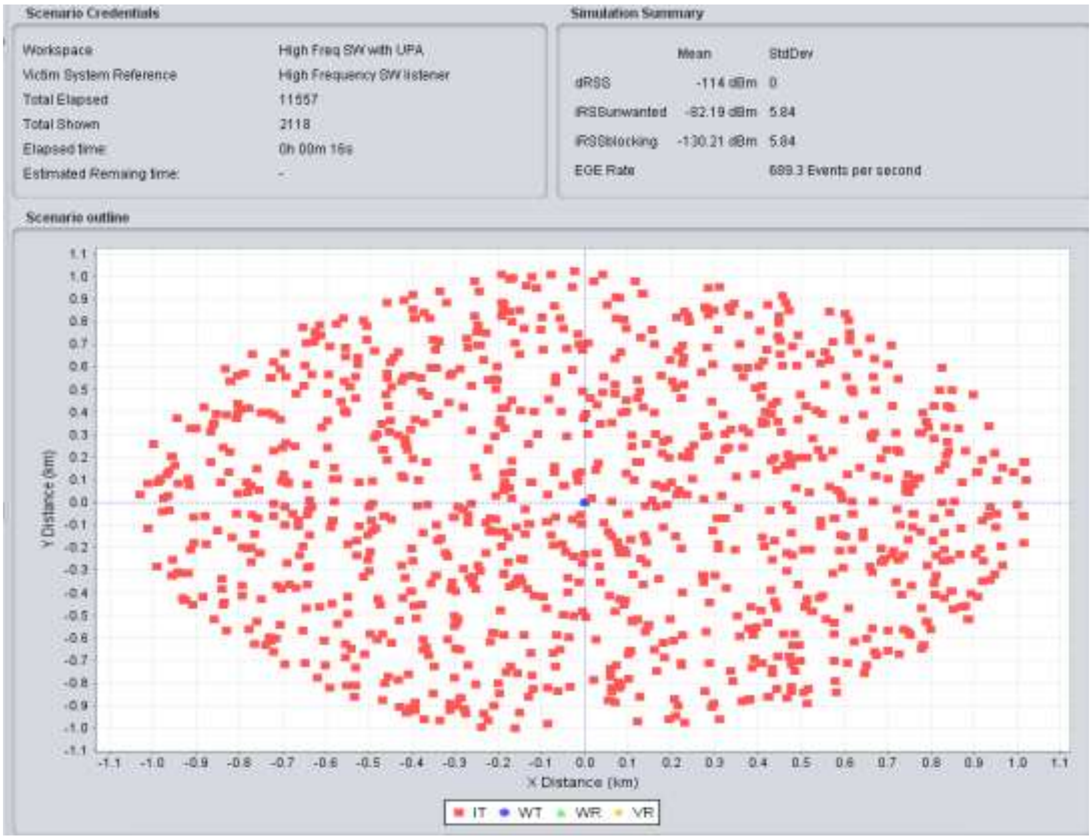


Figure 39– Typical screenshot from Seamcat

We have also used Seamcat to perform interference probability assessments based on the received interference signal at the victim receiver and the rise in background noise floor that this would create at the receiver.

K.3 The effect of increasing the number of active PLT devices in the model

In the simulation model, we can vary the distance between interfering transmitters and the victim receiver using two parameters:

- Number of active transmitters per simulation run
- Density of interfering transmitters given in devices per km²

The density of interfering transmitters or PLT devices is taken from our market analysis, detailed in section 4.2, for each of the environment types that the victim receivers will be operating in. The area that the simulation is run over is therefore set by the total number of active receivers. As illustrated in Figure 40 and Figure 41, Seamcat is forced to distribute the interfering transmitters over a larger area as the number of interfering transmitters increases but the density of PLT devices stays the same.

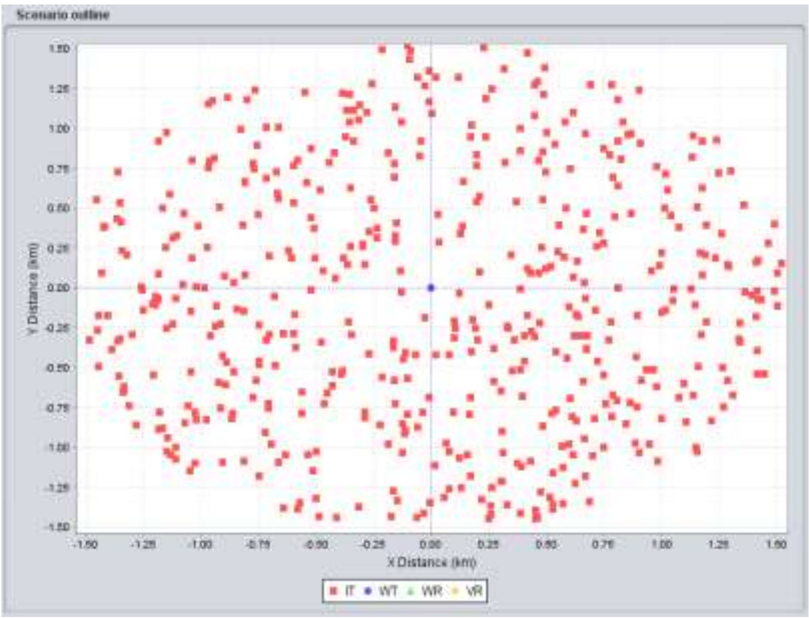


Figure 40 - Seamcat simulating interference to a victim receiver with 100m protection radius, and 500 active devices per simulation run.

In Figure 40 there are 500 PLT devices, indicated by the red squares, per simulation run. The radius of the area covered is approximately 1.5km with a protection radius (meaning no PLT devices within that radius) of 100m around the receiver represented by the blue dot.

In Figure 41 the parameters are the same except for the number of PLT devices being reduced to 100 per run. With the same density of PLT devices, the area covered has now been reduced to a radius of 750m.

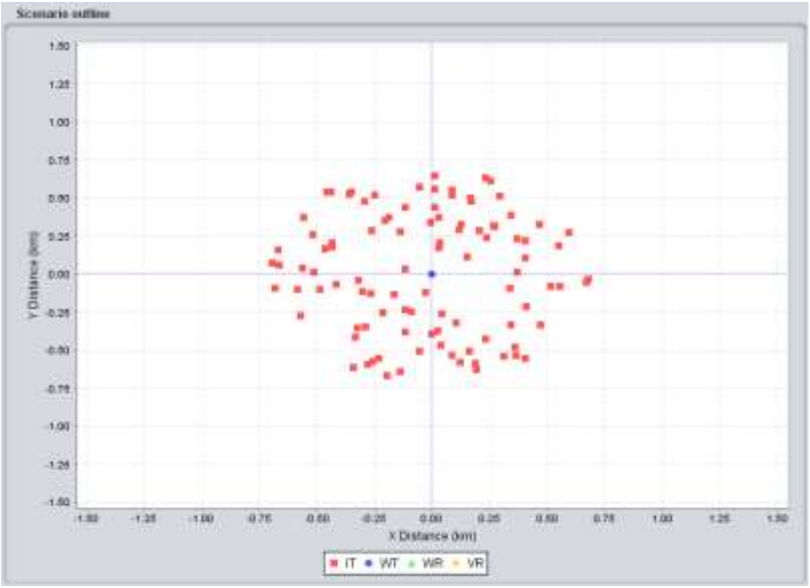


Figure 41- Seamcat simulating interference to a victim receiver with 100m protection radius and 100 active devices per simulation run

By monitoring the total received interference for different numbers of active users we can see if the interference is dominated by a few devices at close range or if the interference continues to increase as more interference sources are added and the simulation is run over a wider area i.e. is the cumulative effect is significant.

Appendix L: Assumptions on technical characteristics of PLT devices

L.1 The effect of wideband OFDM on a narrowband receiver

There is little literature around the interference impact of radiated emissions from PLT devices on narrowband receivers. However, Nasri and Lampe [23] have examined a similar effect between MB-OFDM, as used in UWB, and narrowband receivers. As well as being an OFDM based signal the "bursty" time domain nature of MB-OFDM creating by hopping the signal across multiple bands can be likened to the short bursts in idle mode from PLT devices. Nasri and Lampe have concluded that the interference effect will depend on:

- Ratio of the sub-carrier spacing to the victim receiver bandwidth.
- Offset of the dominant OFDM sub-carriers from the centre frequency of the victim receiver.

Their results show that in that in the worst case scenario the victim receiver performance can be likened to operating with interference from an impulsive noise source. However, in some cases the performance with the MB-OFDM interferer is better than performance with an AWGN interference source at the same level.

The bandwidth of the victim receivers being modelled are 2.2kHz, 3kHz and 4kHz and so compared to a UPA sub-carrier spacing of 19.5kHz will receive 0.11, 0.15 and 0.2 sub-carriers. Based on Nasri and Lampe's results, for the variation in performance for different ratios of sub-carrier spacing to victim receiver bandwidth, these scenarios should perform close to if not slightly better than AWGN interference at the same level.

Nasri and Lampe have also modelled the effect of the offset between the dominant OFDM sub-carriers from the centre frequency of the narrow band victim receiver. However, the performance curves produced indicate that performance varies equally either side of the AWGN performance as the offset varies from 0 to +/- 0.5 of a sub-carrier. This cycle of a slight increase and decrease in performance in steps of 0.5 of a sub-carrier spacing is an effect we have also seen in our lab tests (see appendix I.4). As the centre frequencies of the victim receivers are spread throughout the HF band, the victim receiver centre frequency will be a random offset from the sub-carriers in the OFDM signal from the PLT device. Therefore in some cases the performance will be worse, in others it will be better and on average will be approximately AWGN.

From Nasri and Lampe's results in a worst case scenario the performance of a victim receiver suffering interference from a MB-OFDM signal will converge on the performance of the same victim receiver in the presence of an impulsive noise source. Their results show an approximate difference in BER performance that would translate to a reduction in SNR of 2dB between the AWGN and impulsive noise case if performance in AWGN is taken as a reference level. Throughout this study we have assumed this worst case scenario that the effect of PLT radiated emissions is similar to an impulsive noise source of interference.

Our baseline interference criteria assume that interference will occur if the background noise floor is increased by 3dB. The PLT device can therefore produce interference equal to an AWGN signal at the same level as the noise floor. Given the effect of OFDM on a narrowband receiver, the PLT device will produce this equivalent AWGN interference level when it is 2dB below the background noise floor.

This gives our final interference criterion: $\frac{I}{N} = -2dB$.

L.2 Weighted duty cycle assumed in our simulation model

Our Seamcat model requires a duty cycle for the simulated PLT devices to model the effect that not all deployed PLT will be transmitting at the same instant. Our baseline model assumes usage of UPA PLT devices which, from our observations in the lab (see Appendix I:), transmit 30% of the time when in idle mode and close to 100% of the time when transmitting data.

To calculate a weighted average duty cycle for PLT devices we need to understand the average split between the number of devices in idle mode and transmitting data at any instant in time. This will depend on the time of day and application of the PLT device.

As the dominant deployment of PLT devices in the UK is for IPTV applications we have based this average split between the number of devices in idle mode and those transmitting data on TV viewing figures as follows:

- Viewing figures for 9pm on 7th October 2009 (from www.broadcastnow.co.uk) show a popular show capturing 2.3 million viewers representing 10% of the total audience at that time. This gives a total TV audience for this time of 23 million viewers.
- The UK population at mid 2008 was 61.4 million (from www.statistics.gov.uk).
- Therefore at 9pm on an evening approximately 40% of the population are watching TV.
- We therefore assume that at peak times 40% of PLT devices will be in transmit mode and 60% will be in idle mode.

This gives a weighted duty cycle of:

(0.3 x 0.6) + (1 x 0.4) = 0.58

Appendix M: Electricity distribution in the UK

This appendix supports the calculation of the probability that victim receivers share a mains circuit with a PLT user within a particular distance and are likely to suffer interference.

The area of interest is the low voltage (LV) distribution network[6]. Transformers act as an effective block to the high frequencies used by PLT and so consumers are considered as connected together for PLT purposes if they are on the same transformer and phase.

The term 'consumers' here refers to an electricity supply connection, not the number of persons who use that supply. It includes both business and residential users.

Country	Area	Total number of consumers	Consumer density per sq.km	LV overhead line km	LV underground cable km	Transformers per 1000 consumers
England	North	5600000	157	31780	87690	13.2
	Midlands	8100000	164	41275	110189	20
	South	6250000	170	32518	91775	18.7
	London	2100000	300	0	26458	6.6
Wales		2500000	99	10498	33439	48.8
Scotland	Hydro	600000	12	4833	17500	80.8
	Power	1600000	79	7854	21853	21.4
N.Ireland		700000	52	3433	9526	21.4
Totals		27450000		132191	398430	

Table 13 – UK Electricity distribution statistics from Mott MacDonald, "The Carbon Trust & DTI Renewables Network Impact Study Annex 3: Distribution Network Topography Analysis" [27]

Based on Table 13, the average length of LV cabling per household is 20m.

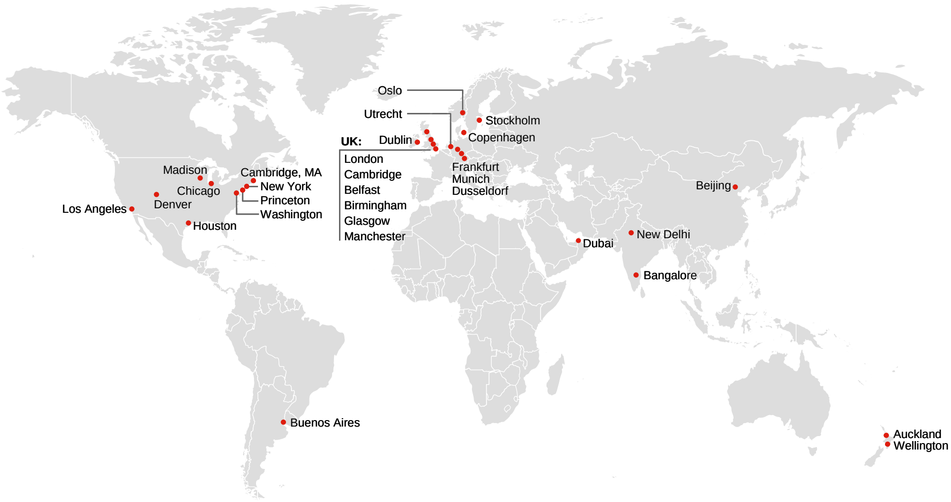
This is substantially smaller than the median value derived in Table 14 as a single cable from the transformer will supply multiple consumers.

[6] LV in mains electricity terms refers to the 230V single phase / 400V three phase network.

Country	Area	Consumers per transformer	Distance to farthest consumer, m	Median distance to consumer, m	% of line length overhead	% overhead line weighted by number of consumers
England	North	76	392	277	27%	0.0543
	Midlands	50	312	220	27%	0.0804
	South	53	316	224	26%	0.0596
	London	152	401	284	0%	0.0000
Wales		20	257	182	24%	0.0218
Scotland	Hydro	12	573	405	22%	0.0047
	Power	47	434	307	26%	0.0154
N.Ireland		47	535	378	26%	0.0068
	Averages:	57	402	285	22%	24%

Table 14 – PA analysis of statistics in Table 13

PA offices worldwide



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