The economic value of licence exempt spectrum

A final report to Ofcom from Indepen. Aegis and Ovum

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This report was commissioned by Ofcom to provide an independent view on issues relevant to its duties as regulator for the UK communications industry, for example on issues of future technology or efficient use of the radio spectrum in the United Kingdom. The assumptions, conclusions and recommendations expressed in this report are entirely those of the contractors and should not be attributed to Ofcom.

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Executive summary

I The study objectives

The main goal of the study is to develop methods to estimate the future economic value of licence exempt (LE) applications through to 2026, for both individual applications and aggregations of applications which share the same band. Ofcom can then use these methods to estimate the value of spectrum bands used by LE devices. (We refer to such spectrum as LE spectrum throughout the report). Such valuations are an important input to decisions about whether to license use of these bands or designate them as licence exempt.

II Making projections of the economic value of individual LE applications

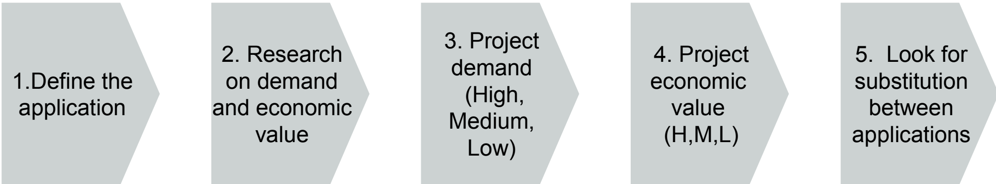
There are now a large number of applications for which LE spectrum is used. Moreover the number of such applications continues to grow. As the cost of transceiver chips falls and battery technologies improve still further, new, and as yet unidentified, LE applications become viable. Given the resources available to the study team, it is not practicable or feasible to make projections for all these applications. So instead we have selected 10 of them for detailed study and generalised from the experienced gained in researching and making demand and economic value projections for these 10 applications.

The 10 selected applications are:

- The use of LE spectrum in the 5.8GHz band for road usage charging
- The use of LE spectrum for anti-collision radar
- Medical in-body sensors using LE spectrum. We focus on in-body glucose sensors for the treatment of diabetes
- Inventory tracking in the retail sector using Radio Frequency Identification (RFID) tags
- Use of LE spectrum to provide public broadband communications services. In practice we focus on the use of WiFi
- Use of LE spectrum to provide home communications networks
- Use of LE spectrum for building automation (ventilation, lighting, heating control with possible access and security add-ons) in the commercial sector
- Use of high frequency (>70GHz) LE spectrum to provide high speed (>1 Gbit/s) line of sight communications links
- Telemetry in the utilities sector
- The use of LE spectrum to enable the provision of wireless home alarm systems in the consumer sector.

We have developed the five step approach shown in Figure S1 to make the value projections. The overall aim is to make projections using evidence-based and explicit assumptions.

Figure S1 Approach to projecting the economic value of LE applications



Source: Indepen

Under this approach the analyst:

- Defines the application as the use of a particular technology for a specific purpose by a specific group of users (Step 1). This provides a precise definition of an application that allows the analyst to make unambiguous projections of economic value
- Researches the application in term of its users, technical characteristics, expected demand and sources of economic value (Step 2)
- Makes high, medium and low 20 year projections of demand using an Excel spreadsheet model (Step 3). It is important here to reflect the uncertainty in demand projections so that decision-makers can take account of the likely range of possible outcomes as well as the most likely projection
- Estimates the economic value generated by the three demand projections (Step 4). This requires the analyst to define a baseline scenario from which to estimate the incremental cost and benefit streams and hence calculate the net present value (NPV)
- Looks for substitution between the applications (Step 5). It is likely that some LE applications will substitute for others over time. So the analyst needs to factor these substitution effects into the value projections to avoid over-estimating the economic value of LE spectrum.

III The impact of interference

It is likely that the value projections produced by this approach are unconstrained by interference effects. However this might not be the case and we need to consider the effects of spectrum scarcity. There are two main types of interference:

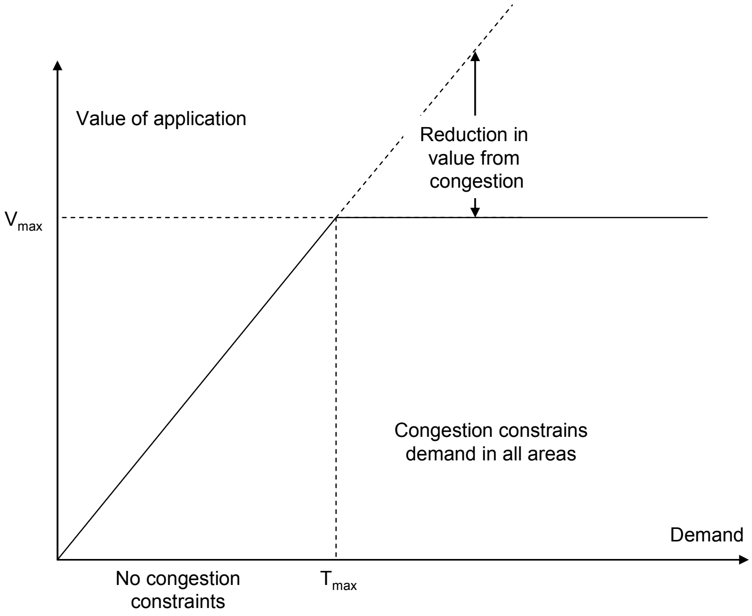
- Intra-application interference or ***congestion*** where the quality of service (QoS) experienced by the user starts to decline as the density of devices used for a given application increases past a certain point
- ***Inter-application*** interference where one set of devices for one application interferes with the use of another set of devices for another application. As the density of the two sets of devices increases so the QoS experienced by one or both sets of users becomes unacceptable

We have modelled the impact of ***congestion*** using the simple model of Figure S2. Demand is capped when density of use reaches a certain level in the busiest area of the UK. As demand increases beyond this point QoS declines and this stops demand growth. This, in turn, caps the economic value of the application at V_{max}.

We have estimated V_{max} for three of the 10 selected applications – public access WiFi, home data networking and wireless building automation. These three applications share spectrum at 2.4 GHz.

Our calculations suggest that congestion does not constrain demand or value projections for any of the three applications.

Figure S2 Degradation in value from congestion



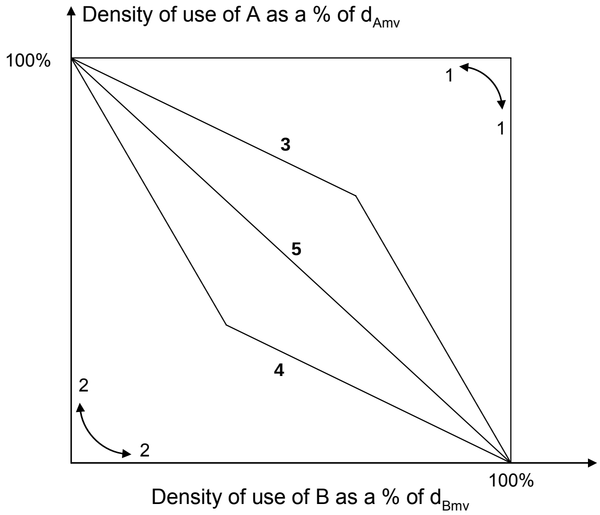
Source: Indepen and Aegis

We have modelled the ***interference*** between two applications, A and B, using the curves of Figure S3. These curves plot the density of use of the two applications as a proportion of the density of use at which congestion occurs in the busiest areas of the UK. At any point above and to the right of these curves there is interference. So demand (and value) must be scaled back until the realised density of use for the two applications lies on or below the curve. There are five ways to join the two points {d_{Amv} = 100%, d_{Bmv} = 0%} and {d_{Amv} = 0%, d_{Bmv} = 100%}:

- Curve 1 represents the case of no interference. A and B do not interfere at all
- Curve 2 represents the case of total mutual destructive interference. Even a little use of B in the presence of A produces damaging interference and vice versa
- Curve 3 represents the case of minor mutual interference
- Curve 4 represents the case of major mutual interference
- Curve 5 represents the transition between Curves 3 and 4. At any point on this straight line the maximum density of use d_A and d_B is constrained by the equation $d_A/d_{Amv} + d_B/d_{Bmv} = 1$.

For simplicity we consider Curves 1, 2 and 5 only, in modelling interference effects.

Figure S3 The different forms of mutual interference between applications A and B



Source: Indepen and Aegis

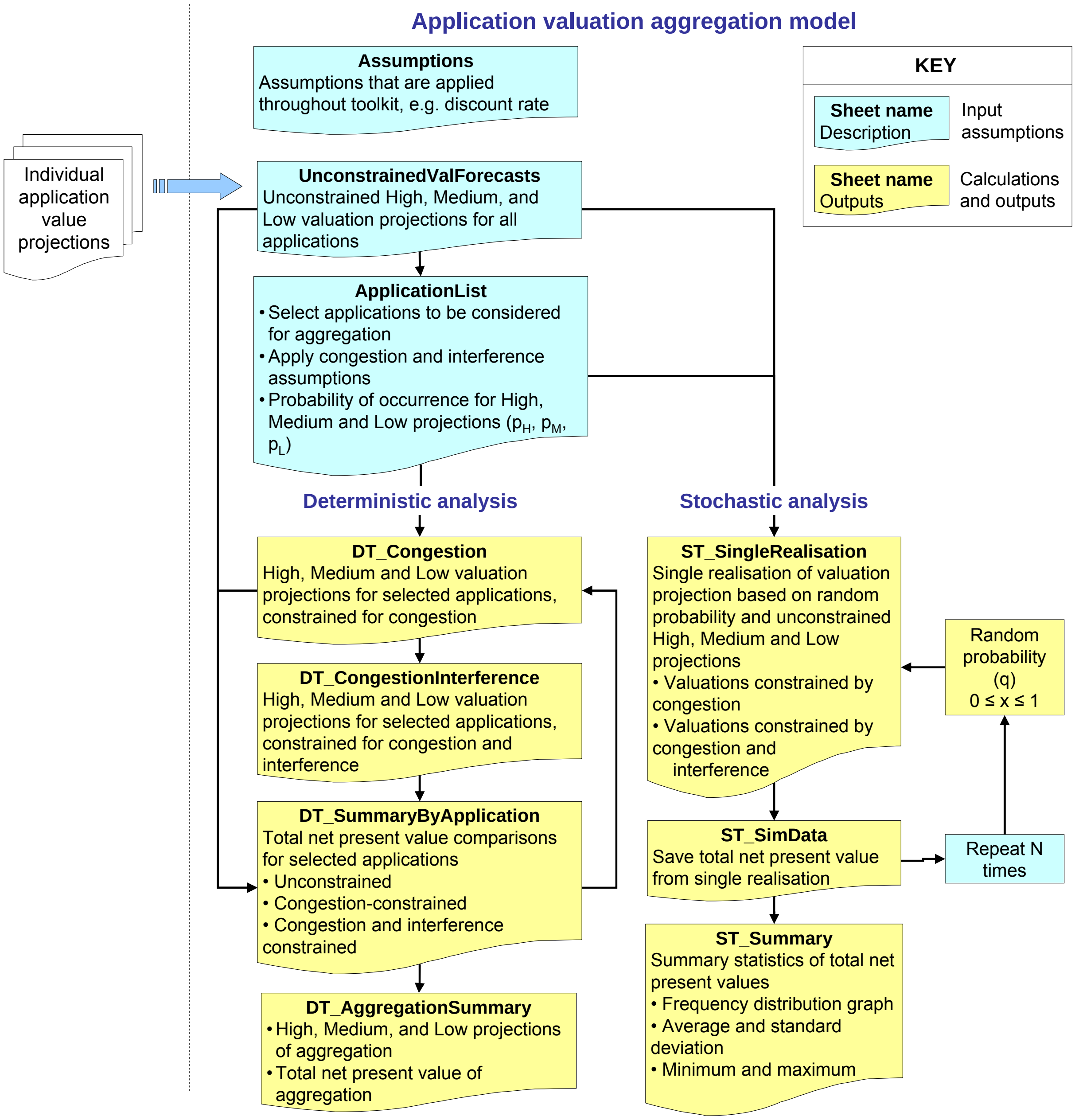
IV The aggregation toolkit

Having developed methods for making projections of the economic value of individual LE applications and for adjusting them for congestion and interference effects, the final step is to develop an Excel based toolkit which Ofcom can use to select applications for use within an LE band and then calculate the aggregated value of these applications. Figure S4 shows the architecture of the toolkit. This takes account of:

- The uncertainty in the value projections for individual applications
- Congestion effects within individual applications
- Interference effects between applications sharing the same band
- The fact that applications may use more than one spectrum band, or may rely on spectrum for more than one band to function.

The main body of the report provides a description of the toolkit together with a worked example showing how the toolkit is used in practice and the outputs it generates.

Figure S4 Architecture of the toolkit



V The costs and benefits of harmonising LE spectrum

Harmonising LE spectrum means agreeing between the UK and other countries a common designation of frequency bands and common requirements to avoid harmful interference. It generates both costs and benefits. These are tabulated in Figure S5.

Figure S5 The benefits and costs of harmonisation

Benefits	Costs
Avoidance of harmful interference and thereby promotion of efficient use of spectrum, thus increasing spectrum use and competition	Restrictions on use (or trade) of underused or unused spectrum for alternative uses.
Promotes international mobility (of terminals)	Restrictions on ability to re-farm spectrum for new services.
Reduction of equipment costs by reducing the number of bands equipment needs to operate in	Insufficient spectrum designated to some uses.
Creates large equipment markets	Delays caused by the time needed to agree harmonisation measures.
Promotes competition between equipment suppliers and choice for the consumer	Costs of clearing harmonised spectrum

Harmonisation is most important for:

- Equipment which is internationally mobile and where the equipment must interoperate with infrastructure in various countries (eg WiFi), or where the equipment must operate reliably without receiving (or generating) interference, as it moves from country to country (eg car door openers)
- Applications where there are significant scale economies in production of devices and where demand for the application is price sensitive.

Assessing the 10 selected applications against these criteria indicates that:

- Harmonisation is of little economic importance for *fixed wireless services* or *telemetry in the utilities*
- Harmonisation is of major economic importance for *collision avoidance short range radars*, for *RFIDs in retail* and for *WiFi public access services*
- Harmonisation is of little ***economic*** importance for active medical implants such as *blood glucose monitors* but, given the safety-of-life nature of these devices, is important from a ***social*** perspective.

The net benefits of harmonising use of LE spectrum for certain applications are considerable. We estimate that global spectrum harmonisation for collision avoidance short range radars, for RFIDs in retail and for WiFi public access services will generate an NPV for the UK of between £39 billion and £77 billion over the next 20 years.

Harmonisation does not always generate net benefits. Use of wireless telemetry devices in the UK's utilities is a good example where harmonisation would generate substantial net costs. This counter example suggests that Ofcom should carry out some kind of impact assessment to determine whether an application is a suitable candidate before proceeding with harmonisation

Harmonisation of use of LE spectrum at the EU level is often a slow process. This could put UK industry and end-users at a disadvantage globally. If Ofcom waits for EU harmonisation to be completed:

- UK industry may be put at a disadvantage relative to its global (non EU) rivals while benefits to UK users are delayed
- This delay can discourage innovation in LE applications in the UK

In addition, if Ofcom designates LE spectrum which is subsequently not harmonised, then again UK industry and end-users would lose out. In this case they would invest in devices which use un-harmonised spectrum and bear the cost of switching to devices which use harmonised spectrum in the long term.

What should Ofcom do here? We suggest that it should:

- Consider supporting activities by the Commission to replace the existing voluntary approach to LE harmonisation with mandatory EU-wide designations backed by an expanded Commission decision
- Be proactive in anticipating and responding to developments outside the EU as well as within it, in making decisions about use of LE spectrum.

There are problems in specifying spectrum user rights for licensed spectrum while, at the same time, allowing its use for LE applications. Harmonisation complicates this process. Our analysis suggests that Ofcom should only support harmonisation initiatives aimed at increasing sharing between licence exempt and licensed services if the associated technical conditions are such that it (and the affected licensees) are confident there will be no material risk of interference. It is important in doing this that it specifies any relevant underlay spectral masks.

VI The economic value of the 10 selected LE applications

Figure S6 tabulates our estimates of the NPV of the 10 selected applications, before adjustment for any congestion or interference effects.

Figure S6 The NPV of the 10 study applications

Application	*NPV (£bn) for demand scenario*			*Probability of scenario*			*Expected*	*Ratio of high*
	low	*medium*	*high*	*low*	*medium*	*high*	*NPV (£bn)*	*to medium NPV*
1. Road user charging	0.3	0.6	0.9	30%	40%	30%	0.6	1.5
2. Short range radars	2	26	88	30%	40%	30%	37.4	3.4
3. Blood glucose sensors	0	9	19	60%	20%	20%	5.6	2.1
4. RFIDs in retail	10	35	98	30%	40%	30%	46.4	2.8
5. Public access WiFi	9	68	239	30%	40%	30%	101.6	3.5
6. Home data networking	4	6	8	30%	40%	30%	6.0	1.3
7. Wireless building automation	0.3	1.2	4	30%	40%	30%	1.8	3.3
8. Fixed wireless links	0	0.6	1.7	30%	40%	30%	0.8	2.8
9. Telemetry in utilities	8	11	13	30%	40%	30%	10.7	1.2
10. Wireless home alarms	0.6	2.4	6.4	30%	40%	30%	3.1	2.7

Source: Indepen,Aegis and Ovum

It shows that:

- The expected NPV of the applications varies considerably – from less than £1 billion for road user charging and fixed wireless links to over £100 billion for public access WiFi
- There are three potential major LE applications amongst the 10 studied – automotive short range radar, RFIDs in retail and public access WiFi. These three applications are precisely the three applications where international harmonisation is most important
- There is considerable uncertainty in these projections. In most cases the NPV for the high demand scenario exceeds the NPV for the medium demand scenario by a factor of two or more

- As we might expect, uncertainty is greatest for embryonic applications like short range radars and least for well established applications like telemetry in the utilities.

Interference is unlikely to constrain the value projections for many of the 10 study applications, but more work is required to look at these effects. In particular it is important to consider the likely congestion affects of RFIDs, one of the three most valuable of the study applications.

After allowing for such constraints, certain LE applications, such as short range radars, RFIDs in retail and public access WiFi, could generate economic benefits for the UK which are substantially greater per MHz of use than the highest value licensed applications, ie mobile telecommunications and broadcasting. This finding is an important one for Ofcom to consider in determining possible future designations of licence exempt spectrum.

There is considerable uncertainty associated with the economic value projections. Ofcom can reduce this uncertainty by monitoring take-up of the most important applications and by studying in more detail the use which UK households make of wireless devices.

1 Introduction

1.1 Background to the study

In its Spectrum Framework Review Ofcom proposed that decisions about whether spectrum is licensed or designated as licence exempt should be based upon considerations of the relative economic value of the spectrum when used in these two different ways. It is relatively straightforward to assess the likely value of a licensed band, where use of the spectrum is well defined. But very little is known about the economic value of the different applications of licensed exempt (LE) spectrum. So Ofcom decided to commission a study from Indepen, Aegis and Ovum to carry out work to develop methods for estimating these values. This report presents the study team's findings.

1.2 The overall goal

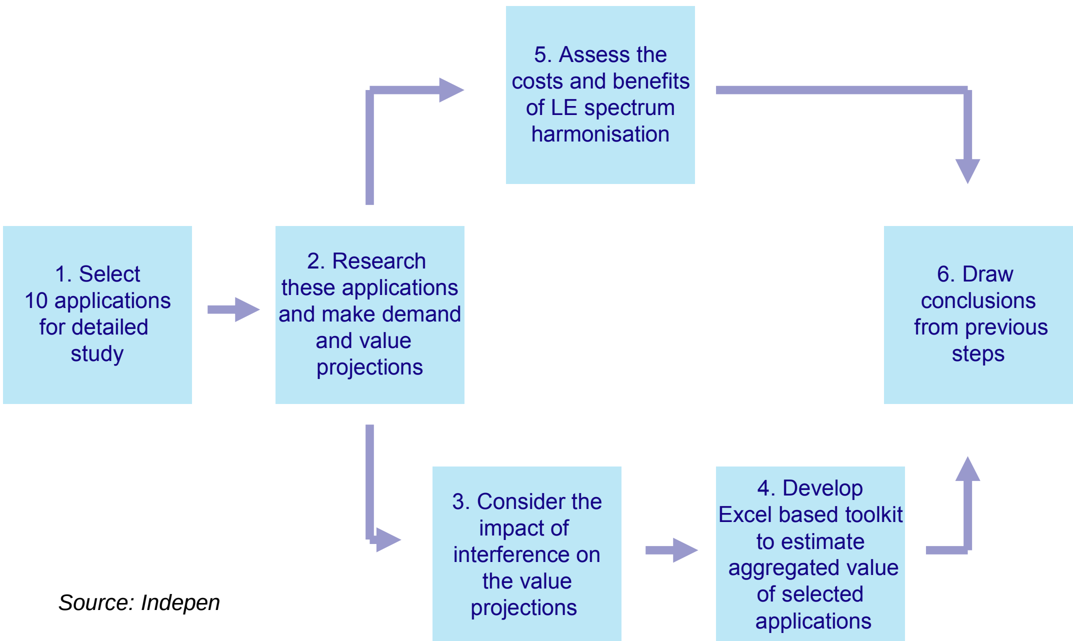
The main goal of the study is to develop methods to estimate the future economic value of LE applications through to 2026, for both individual applications and aggregations of applications which share the same band. Ofcom can then use these methods to estimate the value of LE spectrum bands. This is an important input to decisions about whether to license spectrum or designate it as licence exempt.

This report provides the findings of the study. The appendices referred to in the text are contained in a separate volume.

1.3 The tasks of the study

To meet this overall goal the study team divided the work into the tasks shown in Figure 1.1.

Figure 1.1 The study tasks



Source: Indepen

The team carried out the following tasks:

- Select 10 LE applications for study (Task 1), research these applications in detail, produce demand and economic value projections for each of them (Task 2) and, from these specific examples, develop a generalised approach to making value projections. Tasks 1 and 2 are discussed in Chapter 2 of the report
- Consider the impact of interference between LE devices on the unconstrained value projections of Task 2. This assessment is made in Chapter 3
- Develop an Excel based toolkit so as to enable Ofcom to estimate the aggregated value of a set of selected applications which use the same LE band (Task 4). As part of this task provide a worked example for the aggregated value of three applications using the 2.4 GHz band. See Chapter 4 for more details
- Assess the likely impact which global or EU wide harmonisation in the use of LE spectrum might have for the UK (Task 5). This assessment, which is both qualitative and quantitative, is set out in Chapter 5
- Draw tentative conclusions from the previous five tasks. The main goal of the study is to develop approaches which Ofcom can use to estimate the aggregated value of LE bands. But the work also provides findings on the relative value of licensed and LE applications and prompts recommendations on future information which Ofcom might gather to help it with future policy formulation. We set out these findings in Chapter 6.

The study was conducted in parallel with other studies on the use of LE spectrum commissioned by Ofcom, including studies on:

- LE applications in specific bands. Which applications benefit most from dedicated LE bands? What are the pros and cons of dedicated LE bands?
- Higher frequency bands (over 30GHz) for LE applications. Should all spectrum above a certain frequency be LE? If so what frequency?
- Measurement of LE usage for key LE bands
- Use of wireless for last mile access and the economic value of making spectrum available for this purpose.

So in addition to the tasks of Figure 1.1, the team attended co-ordination meetings with other study teams to discuss ideas and, in particular, to develop common definitions of applications and common approaches to economic valuation. Appendix E provides a mapping between the application definitions where they are used in different ways in the parallel studies

2 Making projections of the economic value of LE individual applications

2.1 Introduction

There is now a large number of applications for which LE spectrum is used. Moreover the number of such applications continues to grow. As the cost of transceiver chips falls and battery technologies improve still further, new, and as yet unidentified, LE applications become viable.

It is not practicable to make projections for all these applications. So instead we have selected 10 of them for detailed study and generalised from the experienced gained in researching and making demand and economic value projections for the 10 study applications.

Given this approach we selected the applications to span the range of problems which an analyst is likely to encounter in making projections. They are a mix of:

- Embryonic and established applications
- Mass and niche market applications
- Safety critical, government led, and commercial applications
- Applications where there are obvious substitutes and others where there are, as yet, no substitutes
- Applications with a variety of device ranges, suitable frequencies and bandwidth requirements

The 10 selected applications are listed in Figure 2.1.

We present the overall approach which we developed through this process below. In addition we provide the research profiles and the resulting projections for the 10 study applications in Appendix A.

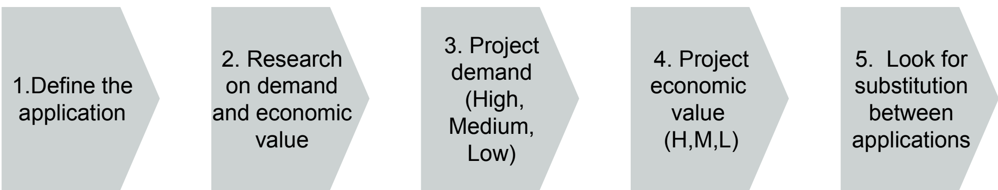
Figure 2.1 – The 10 study applications

Application reference	Description
1	The use of LE spectrum in the 5.8GHz band (dedicated short range communications, DSRC) for road usage charging. This covers city wide congestions schemes as well as road/bridge/tunnel tolling
2	The use of LE spectrum for anti-collision radar
3	Medical in-body sensors using LE spectrum. The focus here is on in-body glucose sensors for the treatment of diabetes.
4	Inventory tracking in the retail sector using RFIDs. This includes both in-store use and use upstream in the distribution chain
5	Use of LE spectrum to provide public broadband communications services. In practice we focus on the use of WiFi. WiMAX is out of scope. We assume that UK WiMAX services will use licensed spectrum
6	Use of LE spectrum to provide a home communications network – starting with home wireless routers and evolving into full scale home networks with entertainment, communications and automation functions
7	Use of LE spectrum for building automation (ventilation, lighting, heating control with possible access and security add-ons) in the commercial rather than residential sector
8	Use of high frequency (>70GHz) LE spectrum to provide high speed (>1 Gbit/s) line of sight communications links
9	Industrial telemetry. We focus on the use of LE spectrum in the utilities sector for the relay of monitoring and control information between remote equipment and control centres. Automatic meter reading in the consumer sector is excluded
10	The use of LE spectrum to enable the provision of wireless alarm systems in the consumer sector.

2.2 Overall approach

Figure 2.2 sets out in graphical form our five step approach to making the projections. We describe and discuss each of the steps in detail in the rest of this chapter.

Figure 2.2 Our approach to projecting the economic value of LE applications



Source: Indepen

It is clear that making projections of economic value over a 20 year period:

- Involves a high degree of uncertainty over projections. We believe it is important to reflect these uncertainties in our projections so that decision makers can take account of the likely range of possible outcomes as well as the most likely projection. We therefore make high, medium and low projections of value and associate probabilities (which sum to one) with each of the three projections.

- Requires a certain amount of subjective judgement on future outcomes. To minimise the impact of these subjective judgements we have researched the development of each application in some depth, made the assumptions underlying our projections explicit, and based them on firm evidence wherever possible. Appendix A provides this research, assumptions and evidence for the ten selected applications.

2.3 Step 1: define the application

We define an application as the use of a particular technology for a specific purpose by a specific group of users. The use of RFIDs for inventory management in the retail sector is a well defined application whereas the use of RFIDs is not an application because the purpose and user group are not defined. This approach provides a precise definition of an application that allows us to make unambiguous projections of economic value.

2.4 Step 2: research the application

There are a number of basic questions which the analyst needs to answer before attempting to build the application specific models required to make demand and economic value projections. Figure 2.3 provides a list of the questions to which we sought answers and Appendix A provides examples of answers to these questions for the study applications.

There are number of potential sources of answers to the questions. In our research on the study applications we gathered information from:

- Draft ECC PT43 report on short range devices
- Discussion with the UK's Low Powered Radio Association
- Cost benefit analyses conducted by Ofcom when considering spectrum allocations for automotive radar and RFIDs
- The Department of Trade and Industry's recent report on a mission to the USA to consider RFID developments and a series of documents and studies assembled by the European Commission on RFIDs and short range radars
- A wide range of application specific documents and statistics
- Telephone interviews with representatives in relevant industries.

Figure 2.3 The key research questions

Main question	Sub questions
1. What is the application?	What is the purpose? Who are the users? How does it work? What spectrum is used and how? What does the supply chain look like for the supply of the equipment which uses the LE spectrum?
2. What are the technical characteristics of the application?	What frequencies are used/planned? What bandwidth is required? What are the propagation requirements? (distance, in-building penetration) Are there any requirement for harmonisation (EU or global) and if so why? Are there any interference concerns? Is there a requirement for dedicated spectrum? If so why?
3. How will demand evolve?	What is the current level of use in the UK in terms of number of users and rate of growth? What is the current market value? What are the drivers of take-up? What are the barriers to take-up? What is the addressable market and how will it evolve over time? Are there substitutes and, in particular, what alternatives is the application replacing, what alternatives might replace the application in the long run, and with what other applications might this application be integrated in future? What is the likely take up as a percentage of addressable market in 5, 10 and 15 years time? What is the current level of use versus main alternatives – now and in 10 years time? What is the price of devices used for the application versus the price of the main alternatives? How will these prices change over time?
4. What are the sources of economic value?	What are the main sources of economic value? Is there a viable wired/physical alternative for which the LE application is substituting? If so what cost savings, if any, does the wireless application generate compared with the alternative and what additional benefits does the wireless application generate compared with the alternative? If not then what are the main benefits and costs of the application? Are there any studies which attempt to assess the economic value of the application? Are there any indicators of the scale of the applications economic value?

2.5 Step 3: Make projections of demand

The next step is for the analyst to make projections of future demand for the application. These projections reflect market demand and do not take any account of any congestion or cross application interference effects which might constrain demand due to spectrum scarcity. These effects are modelled separately and described in Chapter 3.

There are four tasks involved in this step.

Task 1: Define the basic measure of demand. What constitutes a sensible measure of demand varies considerably as illustrated in Figure 2.4? This shows the demand measures used for each of the ten applications. The number of relevant devices or device users is often specified as the measure of demand, although in the case of public WiFi access we use the volume of traffic carried by the service and the population served by congestion charging schemes for the road user charging application. The choice depends partly on what measure best reflects economic value and partly by what data are available to the analyst.

Figure 2.4 Demand measures for the study applications

Application	Demand measure
1. Road user charging	% of city centre population covered by a congestion charging scheme using DSRC
2. Short range radar in cars	Number of vehicles fitted with short range radar
3. In body blood glucose sensors	Number of patients fitted with such sensors
4. RFIDs in retail sector	% of retail sales sold through stores fitted with RFID based inventory management systems
5. Public access WiFi	Volume of traffic carried by such services
6. Home networking	Number of households with wireless networks
7. Wireless building automation	Square metres of office space fitted with wireless building automation systems
8. Fixed wireless links at >70GHz	Number of such links in use
9. Telemetry in the utilities sector	Number of wireless telemetry links
10. Wireless home alarms	Number of households fitted with such alarms

Task 2: Construct demand scenarios which reflect the range of likely outcomes and associate probabilities with each scenario. Figure 2.5 provides as an illustrative example the demand scenario for RFIDs in the retail sector. In using the parameters of Figure 2.5 we assume that demand follows the S shaped Gompertz curve.

Figure 2.5 Demand scenarios for RFIDs in the retail sector

	Low	Medium	High
% retailers that adopt RFID			
2006 - starting point	0%	0%	0%
2026 - ceiling	40%	60%	80%
Average growth rate at inflexion point	20%	20%	20%
Time of maximum growth	2011	2011	2011

In general we have associated a 30% probability of occurrence with the low and high demand scenarios and a 40% probability with the medium demand scenario. In some cases we use other probability distributions, for example the blood glucose sensors (Application 3 – active medical implants) we have allocated a probability of 60% to the low demand scenario (zero demand) to reflect the high levels of current uncertainty over the value of the technology and the likelihood that other technologies will substitute for in body blood glucose sensors before clinical trials are completed.

Task 3: Consider the drivers of demand and construct a basic demand model. In some cases we simply borrow projections from other studies. For example we use the forecast of short range radars (SRR) from the latest ETSI Technical Report as the basis for our demand projections for the automotive radar application. In other cases we use S-shaped Gompertz curves to project demand from current levels and growth rates, so that demand moves asymptotically over time towards a ceiling represented by the addressable market for the application. Sometimes this is the total addressable market. In other cases we have segmented the market and produced demand projections for each segment. Appendix B provides a brief description of the properties and calibration of these curves, which are used extensively to forecast market demand in many industries.

Task 4: Build the spreadsheet demand model to generate high, medium and low demand projections noting all the key assumptions made in so doing. These form the basis of the economic value projections in most cases where the economic benefits are directly attributed to the adoption by the addressable market. For the automotive radar application, however, this is not the case. The addressable market is measured by the take up of anti-collision devices in automobiles, whereas the benefits are quantified as the reduction in car accidents.

In practice we have found it simplest to build spreadsheet models which integrate the demand and value projections, given the large number of common assumptions which the two projections types share. We have then tabulated all the key assumptions as parameters in the first sheet of the workbook of each projection model.

2.6 Step 4: Project economic value

The next step is to use the demand projection to estimate the future costs and benefits generated by the application and so estimate its overall economic value. Again we make three projections which reflect the high, medium and low demand scenarios and hence the uncertainty over possible outcomes. There are five tasks in this step.

Task 1: Define the counterfactual (or baseline) from which to measure the incremental costs and benefits generated by the LE applications. For example for Application 2 (automotive radars in vehicles) the counterfactual is that these short range devices are not fitted to vehicles in the UK. Then the task is to estimate the incremental benefits and costs which arise from installing short range radars over time and so to calculate the net benefit stream and its net present value.

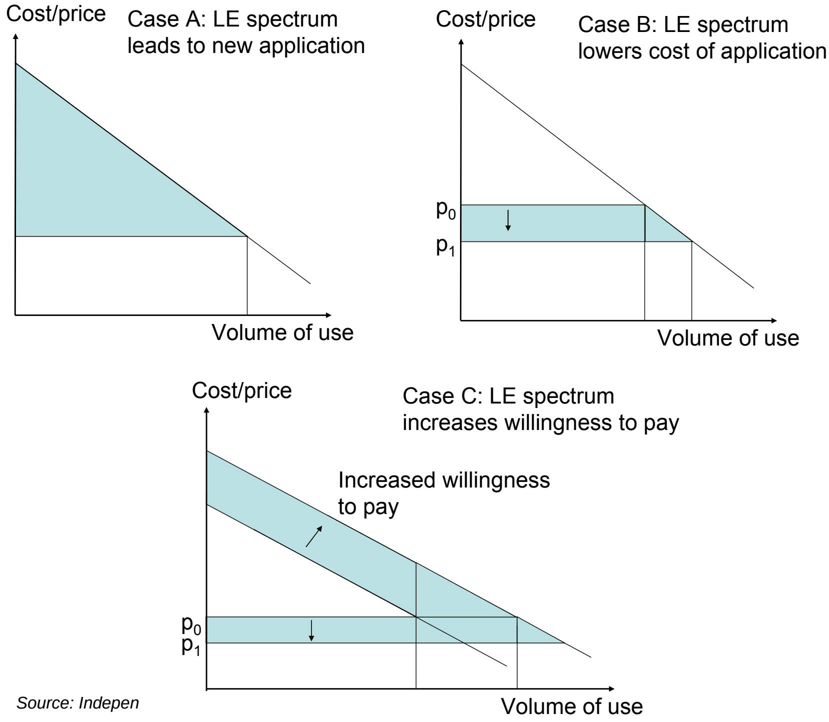
Task 2: Identify incremental costs and benefits which arise from the LE application relative to the counterfactual. At this point it is important to:

- Consider all possible costs and benefits
- Note that we are only interested in costs and benefits to the economy as a whole and not in transfer payments between different players. So while a reduction in price without a change in the cost of supply may be a benefit to consumers it also represents a corresponding loss to suppliers. In economic terms there is an increase in consumer surplus but a decrease in producer surplus. As a result total economic welfare, the sum of the two, is largely unchanged[1].

To simplify our analysis we assume that that all services are offered at economic cost of supply (i.e. costs in a competitive market) and that there is no producer surplus. This does not mean a zero financial profit – only that the financial profit is consistent with a reasonable return on capital employed. With this simplified assumption there are four theoretical cases to consider. The first three are illustrated in Figure 2.6 while the fourth is a combination of two of the cases illustrated.

[1] A price reduction does however stimulate demand and this produces a small increase in economic welfare.

Figure 2.6 The economic value of LE applications



Source: Indepen

The four cases are:

- **Case A:** There are no substitutes for the LE application and the whole of the consumer surplus, indicated by the shaded area in Figure 2.6 , is attributed as a net benefit to the application
- **Case B:** Use of the LE spectrum leads to lower costs of providing the application. For example use of RFIDs in the retail sector leads to lower stock control costs. Here the increment in consumer surplus is largely represented by the cost reduction as shown by the shaded area in Case B of Figure 2.6
- **Case C:** Use of LE spectrum leads to an increased willingness to pay for an application. In practice we did not come across this category in projecting economic values. Instead applications fell in Case D
- **Case D:** Cases B and C combine with both an increase willingness to pay and a lower cost of providing the application. Home wireless alarms (Application 10), home data networking (Application 6), and wireless building automation (Application 7) all fall into this category. In the case of home data networking for example we need to allow for both the avoided costs of a wired network and the stimulation of broadband demand which home wireless networks generate.

Task 3: Decide for which effects it is possible to produce credible projections and specify:

- Which costs and benefits are included in and excluded from the projections
- The likely impact of excluding those costs and benefits which it is not credible to quantify

In the home networking application example we have decided to make projections for home data networking, where developments are clear, but exclude home entertainment and automation where there are still a number of issues which need to be resolved before we can make credible projections. Figure 2.7 sets out the results of this step for the ten applications.

Figure 2.7 Costs and benefits excluded from the value projections

Application	Excluded costs and benefits	Significance of these exclusions
1. Road user charging	None	Not applicable
2. Short range radar in cars	Any increase in road capacity or reduction in congestion as a result of fewer accidents	Projections may underestimate net benefits slightly
3. In-body blood glucose sensors	Cost of the device and its implantation Time saved by patients not having to attend so many out patient clinics	Minor impact which could have positive or negative effect on projections
4. RFIDs in retail sector	Costs and benefits in other sectors Lower costs of tracing products	Projections substantially underestimate net benefits in all sectors Projections may slightly underestimate net benefits in the retail sector
5. Public access WiFi	Benefits which arise from WiFi substituting for fixed line services Costs of stress to workers who feel “always available” to their employer	Minor impact which could have positive or negative effect on projections
6. Home networking	Costs and benefits of home entertainment networking Costs and benefits of home automation networking	Projections substantially underestimate net benefits of home networking by concentrating only on data networking in the home
7. Wireless building automation	Costs and benefits of wireless building automation in industrial (as opposed to office) buildings Benefits of easier reconfiguration and better information on energy use	Projections substantially underestimate net benefits of wireless building automation by focussing on offices only Projections may underestimate net benefits slightly
8. Fixed wireless links at >70GHz	None	Not applicable
9. Telemetry in the utilities sector	Costs and benefits of automated meter reading (AMR) for consumers	Projections substantially underestimate net benefits of telemetry in utilities sector by excluding AMR
10. Wireless home alarms	Improved appearance of house without wires Ease of reconfiguration of alarm systems	Projections may underestimate net benefits slightly

Task 4: Build the logical model for projecting costs and benefits and implement within the Excel workbook using constant 2006 prices for all costs and benefits. We have found that costs and benefits sometimes depend upon the installed base of users. In other cases they depend upon the number of new installations of the LE device. For example the annual benefits of short range radars (Application 2) are proportionate to the installed base of devices but the annual costs are a function of the number of short range radars installed in that year. To estimate the number of devices installed in Year *t* we have used the equation:

$$I_t = [B_{t+1} - B_t] + \frac{B_t}{L}$$

where B_t = installed base of devices in year *t,* L = lifetime of the device, B_{t+1} = installed base of devices in year *t+1* and I_t = the number of devices installed in year *t.*

Task 5: Calculate the NPV of the net benefits. We discount the net benefit stream at a rate of 3.5% per annum. This is the rate recommended by the UK's HM Treasury in its Green Book[2]. We also need to calculate the termination value of the net benefit stream at the end of the study period in 2026. Here we assume that:

- The probability of the sum of the high, medium and low net benefit streams is 100% up to 2026
- From 2026 on the probability of the net benefit stream being realised reduces at 10% per year. This reflects the likely obsolescence of the application and the increasing probability that another technology will substitute for the LE application.

Appendix C provides more detail on this calculation of termination value.

2.7 Step 5: Look for substitution effects

So far we have made independent projections for LE applications. It is possible (and indeed likely) that some LE applications will substitute for others over time. So we need to factor these substitution effects into the value projections to avoid over estimating the economic value of LE spectrum. This type of modelling is application specific.

In practice we did not find any significant substitution effects between the 10 study applications. This is hardly surprising given that we considered only 10 out of more than 100 applications in total. It is likely that home automation, part of Application 6, will substitute for home alarm systems (Application 10). But given that we excluded home automation from our projections we did not consider this substitution effect further. Ofcom will however need to consider such substitution before using the toolkit of Chapter 4 to calculate the aggregate value of selected applications sharing the same band.

2.8 Findings

We tabulate and analyse the results of our 10 value projections in Chapter 6.

[2] HM Treasury, "The Green Book – Appraisal and evaluation in central government", 2003

3 The impact of interference on the value projections

3.1 Introduction

The value projections described in Chapter 2 are unconstrained by interference affects. They assume that there is enough spectrum available for each application to meet market demand without any deterioration in service quality. This might not be the case and we need to consider the effects of spectrum scarcity and interference effects.

There are two main types of interference:

- Intra-application interference or ***congestion***: The quality of service (QoS) experienced by the user starts to decline as the density of devices used for a given application increases past a certain point. At some point the QoS becomes unacceptable and there is congestion
- ***Inter-application*** interference: Here the use of one set of devices for one application interferes with the use of another set of devices for another application. As the density of the two sets of devices increases so the QoS experienced by one or both sets of users becomes unacceptable

Sections 3.2 and 3.3 provide a theoretical discussion of the issues. We then consider how to implement this theoretical framework in practice. Section 3.4 considers how to incorporate interference effects into the aggregation toolkit described in Chapter 4, whilst Section 3.5 provides a worked example in which we estimate interference capacity constraints for three applications sharing the 2.4 GHz band:

- public access WiFi
- home data networking and
- wireless building information.

3.2 The impact of congestion on the value of an application

To quantify the impact of congestion on the value of LE application we need to answer three questions:

- What happens to the QoS experienced by users as the density of use of LE devices increases in any specific area?
- How does degradation in QoS (as a result of interference) affect the value of the application for users in that area?
- How do these congestion effects impact on the total value generated by users of that application in all areas of the UK?

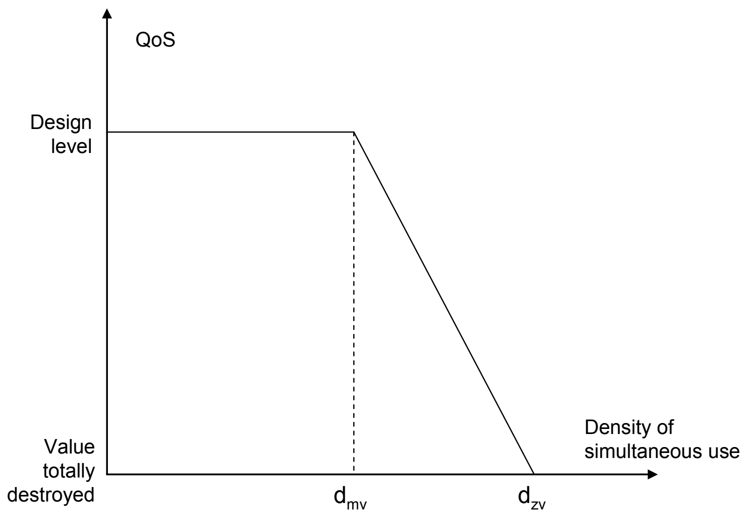
3.2.1 QoS versus density of use of LE Devices

The level of interference is largely determined by separation distance between victim and interferer, noting that there may be multiple interferers. In the LE situation where locations are uncontrolled it is only practically possible to consider an average separation distance which translates into density of use. It is then necessary to arrive at a relationship between density of use (which will come from demand forecasts) and QoS.

We can see the general form of the relationship between QoS and density if we consider how WiFi behaves. Starting from a very low density where the average distance between devices is great there is no interference and therefore no degradation. As the density increases the level of interference increases, but there is no degradation up until a point when the anti-collision protocols kick in. At this point the available channel capacity in an area is shared between the interfering devices within that area. As the density increases further there are more and more interfering devices within that area and the throughput for each device decreases until a point at which the quality is unacceptable to a user. The point at which this happens depends on the mix of applications being run over the WiFi network.

We illustrate these effects in Figure 3.1. For density of use below d_{mv} (mv = maximum value) there is no congestion and no reduction in the economic value of the application. Once density of use exceeds d_{mv} then the QoS experienced by the user declines and the value of the application reduces to zero at d_{zv} (zv = zero value). The difference between d_{mv} and d_{zv} will depend on a number of factors. In particular we might expect a steeper decline in QoS for applications which do not use polite protocols and for real time applications where packet loss, delay and jitter are especially serious.

Figure 3.1 QoS versus density of use



Source: Indepen and Aegis

Note that:

- We can calculate d_{mv} using modelling tools such those used in recent work by Aegis and Transfinite[3]
- This work gives us some real values for $d_{mv.}$ For example in the case of WiFi, d_{mv} is 15 co-channel access points per km^2. This value is estimated using RF interference criterion and no account is taken of the impact of sharing protocols
- At the macro level d_{mv} is the density of simultaneous use in the busy hour.

It is much more difficult to estimate d_{zv} and we do not propose that that Ofcom should do so when using the aggregation toolkit. Instead we propose that Ofcom should assume that d_{zv} = $d_{mv.}$ This keeps the modelling required to produce the inputs required by the aggregation toolkit of Chapter 4 to manageable proportions.

[3] *Evaluating spectrum percentage occupancy in licence-exempt allocations, 1606/LEM/R/4, 3rd August 2004*

3.2.2 The impact of degraded QoS on the value of the application

As discussed above, we propose to assume that QoS degrades to zero as soon as density of use exceeds d_{mv}. This in turn means that the value of using the application in a specific area stops growing, once the density of use in that area exceeds d_{mv}. In practice this might occur in one of two ways:

- The reduction in QoS could stop demand growth so that demand remains constant once the density of use exceeds d_{mv}
- Demand could increase as density of use exceeds d_{mv} but QoS degrades and the marginal value of using the application reduces so that total value remains constant.

We do not have any empirical evidence on this point. But the two arguments set out above both point to the same conclusion and suggest that our assumption is reasonable. Other outcomes are still possible. But our analysis suggests they are unlikely.

3.2.3 The impact of congestion on the UK wide value of the application

In estimating how an application's value is degraded with congestion we need to distinguish two cases:

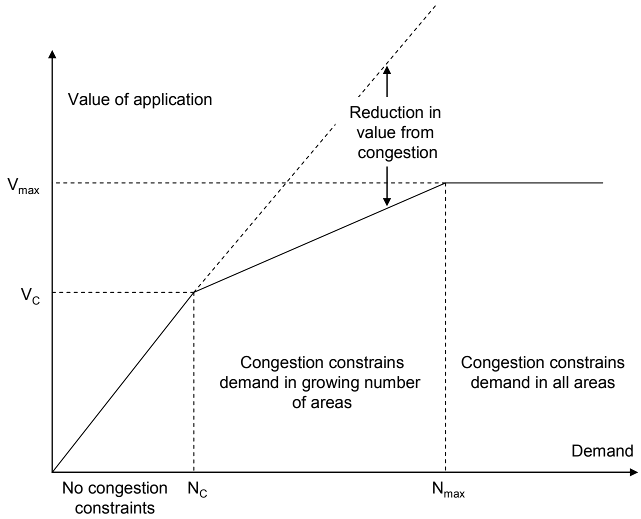
- ***Fixed applications***[4]. These are applications where the value is generated by using LE devices in a single fixed location or area eg wireless building automation, telemetry, home data networking or use of RFIDs. In the two latter cases the device is portable. But the value of the application depends on its use in a specific limited area (the home or warehouse) and it is the level of congestion experienced in that fixed area which determines its value. For fixed applications we can look at high and low density areas of the UK separately. Demand will continue to grow in areas where density of use is low even when demand in the high density areas is constrained by congestion
- ***Nomadic and mobile applications***. Here the value depends on the use of the LE device in a range of different areas e.g. use of WiFi enabled devices in public hotspots. It is the cumulative effect of congestion in a range of geographically separate locations which determines what value end-users generate from the application. This in turn determines the level of demand. In some areas LE devices may be lightly used and in others heavy use might lead to congestion. We assume that it is the average quality of service, experienced across all areas, which determines when demand is limited.

3.2.4 The fixed application model

Box 3.1 provides a formulation for the fixed application model. Under this model, as demand for an application increases, the degradation in the value of the application from congestion looks like that shown in Figure 3.2. There are two turning points on the curve at $\{V_C,N_C\}$ and at $\{V_{max},N_{max}\}$.

[4] Fixed applications include both in-building and out of building applications

Figure 3.2 The loss of economic value with the fixed application model



Source: Indepen and Aegis

Box 3.1 The fixed application model

Let us consider a typical fixed application in which the number of users is growing and estimate how the value of this application is constrained as a result of congestion. Let:

$N(t)$ = no of users of the application in UK at time t

P = population of potential users in UK (assume no time variation); $P>N(t)$

vu = economic value per user per year

Then value with no congestion = $V(t) = vu*N(t)$. But what is the value with congestion = $V_C(t)$?

Let the population of potential users of the application be distributed into areas of size A_i with density p_i. Then

$P = \Sigma p_i A_i$

Assume take up rate is uniform across all areas. So if density of users in area i is $d_i(t)$ then $d_i(t) = N(t)p_i/P$ and rises towards p_i as $N(t)$ tends to P.

Let probability of use in the busy hour = pu_{BH}

If $d_i pu_{BH} < d_{mv}$ then the value for the population in area i is not affected and:

$V_i(t) = A_i d_i(t) vu = p_i N(t) A_i vu/P$

If $d_i pu_{BH} > d_{mv}$ then congestion occurs and value is reduced. But demand will not fall to zero. Rather congestion will limit demand so that density of simultaneous use is kept below d_{mv}. The simplest assumption to make is that the density of use in the busy hour then remains at d_{mv} ie $pu_{BH} d_i = d_{mv}$. So in areas of this kind the value of the application is given by:

$V_i(t) = d_{mv} A_i vu/pu_{BH}$.

Then the total value for the application at time t is given by:

$V_c(t) = \Sigma_1 d_i A_i vu + \Sigma_2 d_{mv} A_i vu/pu_{BH} = \Sigma_1 p_i N(t) A_i vu/P + \Sigma_2 A_i d_{mv} vu/pu_{BH}$

where:

Σ_1 = sum over areas i where $d_i pu_{BH} < d_{mv}$ and Σ_2 = sum over other areas

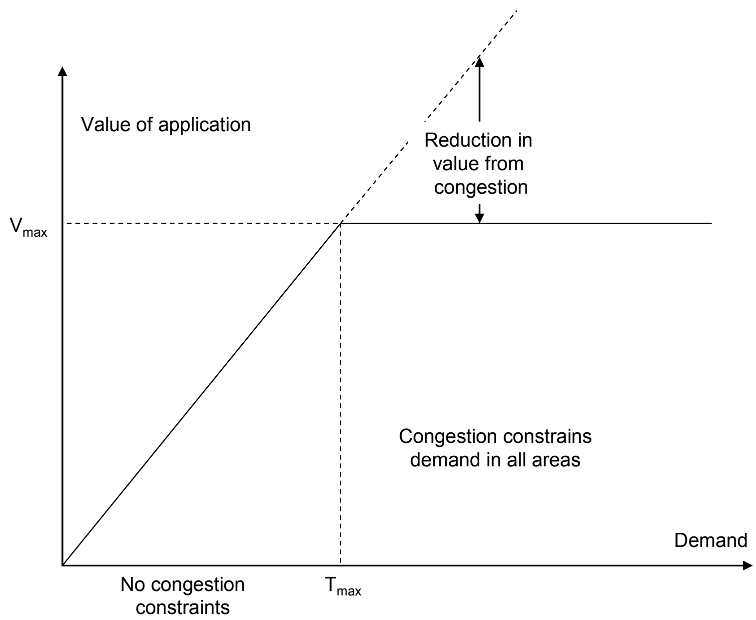
If we are to use the model of Box 3.1 to estimate V_{max}, V_c, N_c, and N_{max} of Figure 3.2 then we need to estimate:

- vu, N(t) and P. The basic projection models of Chapter 2 can provide these values
- The distribution of the population of potential users across the UK ie values for A_i and p_i. These may or may not be available from general demographics
- The probability of busy hour use by users (pu_{BH}) or something similar. Such statistics are readily available from service providers.

3.2.5 The nomadic application model

Here we focus on how heavily the base stations which serve nomadic LE devices are loaded, rather than on the density of use of LE devices in specific areas, as in the fixed application model. We assume that growth in the use of the application stops when the busiest group of base stations which serve the nomadic devices reaches capacity. Put another way we assume that once a certain number of base stations reach capacity demand growth stops everywhere because this condition limits nomadicity. So in this case the demand/value curve looks like Figure 3.3 with a single turning point[5].

Figure 3.3 Degradation in value from congestion for nomadic applications



Source: Indepen and Aegis

This is, in effect, a simplified version of the fixed application model described in the previous section, in which we divide the UK into two areas and assume that capacity is reached when the busier area reaches capacity. It is worth noting that we can use this simplified approach for fixed applications as well, if we are prepared to make some sacrifice of accuracy.

[5] For the nomadic applications it is more appropriate to measure demand using traffic generated rather than number of users

3.3 The impact of inter-application interference on value

3.3.1 Introduction

How does use of Application A affect the value projection for Application B and vice versa? Before attempting to model the impact of inter application interference on application values we need to consider whether such interference is likely to occur. There are a number of reasons why it might not be significant:

- In many cases there is sufficient "separation" between LE devices used for different applications that such interference is unlikely at any reasonable density of use. Separation may be through geographic distance between devices used for different applications or because walls separate devices of different kinds when they are used
- Low duty cycles and use of polite protocols might further reduce the probability of inter application interference
- For some combinations of A and B conditions of use in the same band may have already been set (for example following an Electronic Communications Committee study) so as to reduce the probability of interference to negligible levels.

In these circumstances we can assume that the impacts are minimal and leave application value projections unchanged. A parallel study on the need for application specific LE spectrum provides further guidance on when this approach is appropriate.

3.3.2 A mutual interference model

Assuming that there is a significant probability of interference between applications A and B then we need to model the nature of the interference. Previous work undertaken by Aegis and Transfinite[6] addresses this issue and, on the basis of extensive interference modelling, postulates a relationship between the densities of two applications that can be accommodated in the same piece of spectrum.

This previous work used a modelling approach called the N-systems method. This method initially determines the number of devices [$N_A(0)$] of Application A that can be deployed in an area without suffering interference as defined by a given criterion. Subsequently, the method determines the smaller number of devices [$N_A(N_B)$] of Application A that can be deployed in an area in the presence of a number of devices of Application B.

It was hypothesised that the number of Type A systems would be (at least initially) linearly dependent upon the number of Type B systems that were present, and hence there would be a relationship as follows:

$$N_A(N_B) = N_A(0) - \alpha_{AB} N_B$$

This hypothesis was tested using linear regression tools on the results of the interference modelling. It was found that there was an extremely strong correlation. So there is evidence that there is a linear relationship between the number of Type B systems added to an environment dominated by Type A systems and the number of Type A systems which can operate satisfactorily. In other words, for each N_B of Type B systems added the number of Type A systems is reduced by α_{AB} N_B.

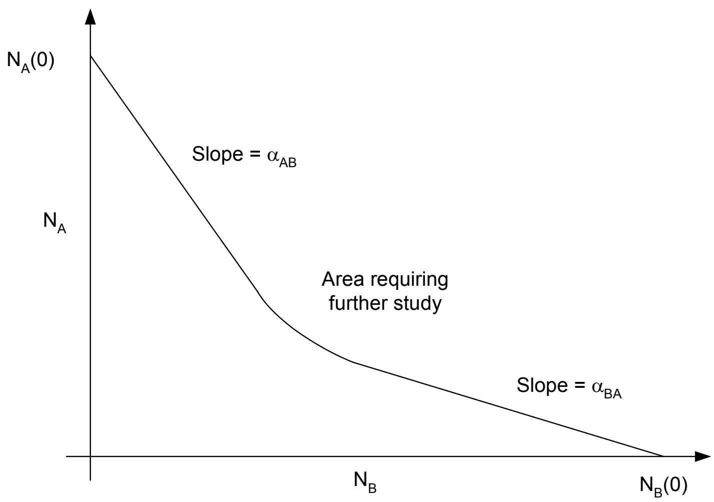
[6] *Evaluating spectrum percentage occupancy in licence-exempt allocations, 1606/LEM/R/4, 3rd August 2004*

The modelling did not cover the full range from “all Type A systems” to “all Type B systems”. This would have required impractical simulation times. To explore the other end of the range the process was reversed by seeing how many Type B systems can be introduced in an area where a small number of Type A systems have been deployed. Results suggested that the situation is indeed reversed when the environment is dominated by Type B systems. Note that the slope at either end of the curve may be asymmetric. In other words $\alpha_{BA} \neq \alpha_{AB}$[7]. The behaviour in the intermediate area where neither Type A or Type B systems dominate was not analysed and further work is required.

This work suggests that we can plot the N-Systems statistic for two systems as shown in the graph of Figure 3.4.

It is important to note that the previous work undertaken by Aegis and Transfinite was based on modelling of the physical level (i.e. RF power). This means that the criterion used to assess the interference relates most closely to the turning point (the point corresponding to d_{mv} in Section 3.2) in the earlier curves. No account was taken of polite protocols that would have led to greater densities of devices operating with a degraded, but potentially acceptable, performance.

Figure 3.4 The mutual interference between Systems of type A and B



3.3.3 A general model of mutual interference

Combining the Aegis/Transfinite work described above with the analysis of Section 3.2 on congestion, we can now produce a more general model of mutual interference. This is illustrated in Figure 3.5. Each curve in this figure represents the mix of density of use of applications A and B above which application value is destroyed.

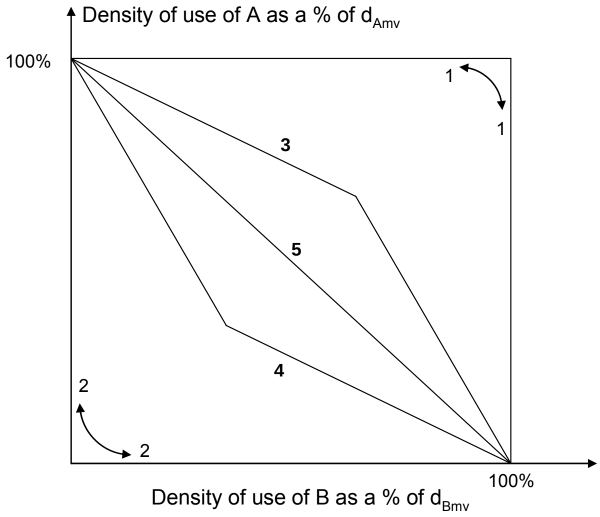
When $d_B = 0$ this occurs when $d_A = d_{Amv}$ for application A and when $d_A = 0$ it occurs when $d_B = d_{Bmv}$ for application B (where d_{Amv} and d_{Bmv} are derived from congestion modelling described in the last section). There are then five topologically different ways of joining these two points. These are shown by the numbered curves of Figure 3.5:

- Curve 1 represents the case of no interference. A and B do not interfere at all

7 For example where RFIDs operating at 2 watts share LE spectrum with other, lower powered, devices

- Curve 2 represents the case of total mutual destructive interference. Even a little use of B in the presence of A produces damaging interference and vice versa
- Curve 3 represents the case of minor mutual interference
- Curve 4 represents the case of major mutual interference
- Curve 5 represents the transition between Curves 3 and 4. At any point on this straight line the maximum density of use d_A and d_B is constrained by the equation $d_A/d_{Amv} + d_B/d_{Bmv} = 1$

Figure 3.5 The different forms of mutual interference between applications A and B



Source: Indepen and Aegis

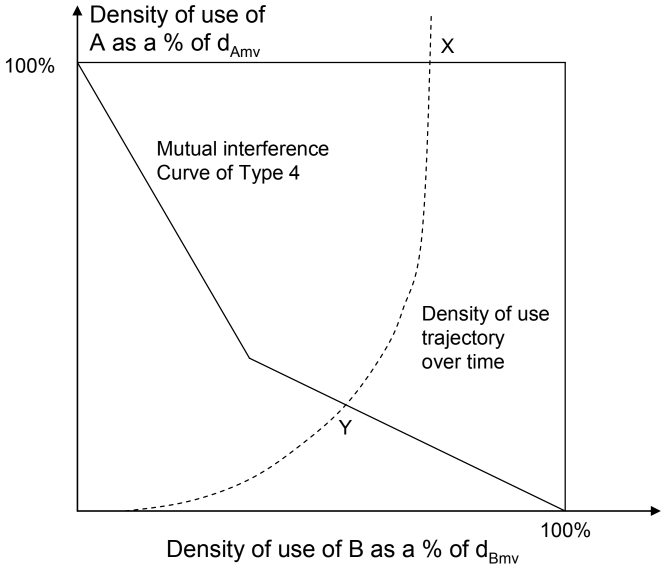
We have some limited information on the shape of the curve for Bluetooth and WiFi from previous Aegis/Transfinite work, but only for the slope of the curve at one end. In the range 0 to 2000 Bluetooth devices the number of WiFi access points in a 1 km x 1 km square was reduced from 25 to 10 to avoid unacceptable interference. The slope was calculated as 0.007 WLAN/Bluetooth. That is to say each 1000 Bluetooth devices added to the environment reduced the number of WiFi access points that could operate satisfactorily by 7.

3.3.4 The impact of mutual interference on the value projections

What do we do to discount the value of A (= V_A) and B (= V_B) in each of these cases?

- For Curve 1 V_A and V_B remain unchanged
- For Curve 2 one or other of V_A or V_B go to 0. Which happens is a matter of timing. If A is established first then this kills demand for B and vice versa
- For Curves 3, 4 and 5 the way mutual interference limits demand for A and B is determined by the trajectory of the density of use of A and B over time as illustrated in Figure 3.6. In this figure we assume that Application B is established first but that, with no interference effects, use of Application A grows more rapidly. In these circumstances the trajectory of the joint plot of the density of use of A and B (in high density areas) over time would be a curve like that of Figure 3.3 where congestion limits demand at point X but mutual interference is more constraining, limiting the density of use (and hence demand) to Point Y.

Figure 3.6 Density of use constraints from mutual interference



Source: Indepen and Aegis

We can quantify the adjustment as follows. For simplicity we use Curve 5. But it is relatively easy to generalise to Curves 3 and 4.

Let us assume that:

$d_A = \chi D_A$

$V_A = \alpha_A D_A$ if $d_A < d_{Amv}$ and $= \beta_A$ otherwise

with equivalent equations for B

where

V_A = value of A

D_A = demand for A and

d_A = density of simultaneous use in an area of high density use of the application

α and β are constants

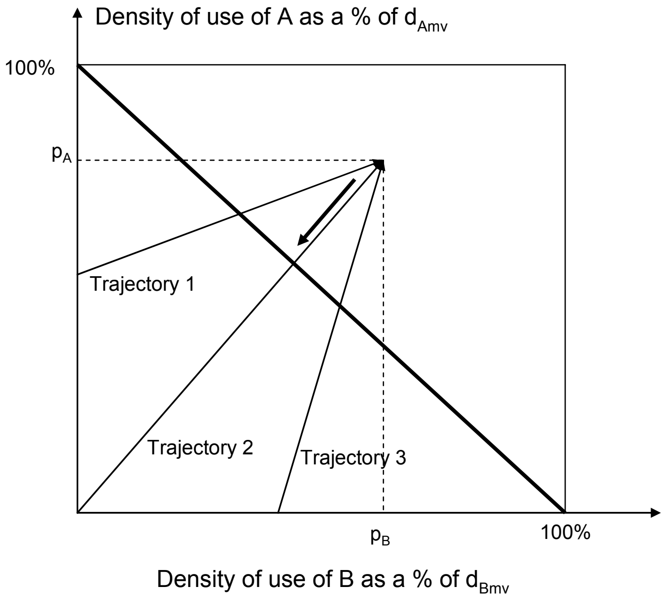
This is a simplified version of the fixed application congestion model, with a single discontinuity, rather than the two shown in Figure 3.2.

We assume that we have already adjusted V_A and V_B (by limiting demand for any congestion effects) so that d_A is less than d_{Amv} and d_B is less than d_{Bmv}. If interference between Applications A and B follows Curve 5 and:

$Z = d_A/d_{Amv} + d_B/d_{Bmv}$ is less than 1 then these applications retain their full value.

But if the demand puts the density mix of A and B at the point $\{p_A, p_B\}$ shown on Figure 3.7 then interference occurs. The trajectory of the joint density of use curve determines how demand is constrained. We have marked three possibilities on the diagram. For simplicity we assume Trajectory 2. This requires us to reduce d_A and d_B to d_A/Z and d_B/Z. This brings the density mix back to Curve 5 so that interference is reduced to minimal levels. This in turn means that we need to reduce V_A and V_B to V_A/Z and V_B/Z.

Figure 3.7 Reducing the value of A and B because of inter application interference



Source: Indepen and Aegis

3.4 Using the interference modelling in the toolkit

Ofcom will need to apply the framework of this paper within the toolkit used to calculate the aggregated value of selected applications which use the same LE band. To make this process manageable we propose to make the following simplifying assumptions:

- Demand for (and hence the value of) an application is capped at a single point by congestion effects ie we use the model of Figure 3.3 rather than the more accurate model[8] of Figure 3.2
- Density of use of an application in its hotspots is related in a linear way to overall demand for the application and projections of its value
- Interference between applications follow one of Curves 1, 2 or 5 of Figure 3.5
- In reducing the value of two applications which interfere according to Curve 5, the density reduction follows Trajectory 2 of Figure 3.7.

With these simplifications the process of modelling congestion and interference in the toolkit is then as specified in Box 3.2.

The process of Box 3.2 assumes that there is only pair-wise interference ie there is interference between Applications A and B but not between Application A and both of Applications B and C. In the latter case we can minimise the error by modelling interference between the two highest value applications.

[8] For fixed applications

Box 3.2 Interference modelling in the toolkit

<table><tr><td>
Estimate $VMAX_i$ (= maximum value of application i before congestion occurs) from the interference modelling as described in Section 3.2.
Cap each value projection $V_i(t)$ for congestion at $VMAX_i$. So if $V^*_i(t)$ is the value of application i constrained for congestions then:
$V^*_i(t) = V_i(t)$ if $V_i(t) < VMAX_i$ and $V^*_i(t) = VMAX_i$ otherwise
Deal with mutual interference between applications A and B by assuming that this mutual interference follows one of Curves 1, 2 and 5 of Figure 3.5. So if $V^{**}_A(t)$ is the value of application i constrained for both congestion and inter-application interference then:
a) If mutual interference is on Curve 1 then $V^{**}_A(t) = V^*_A(t)$ and $V^{**}_B(t) = V^*_B(t)$ ie no change
b) If mutual interference is on Curve 2 then:
$V^{**}_A(t) = V^*_A(t)$ if $V_A(t) > V_B(t)$ and = 0 otherwise ie only add the value of the higher value application
c) If mutual interference is on Curve 5 of Figure 3.5 then:
Calculate $V^*_A(t)/VMAX_A + V^*_B(t)/VMAX_B = x$
If $x>1$ then $V^{**}_A(t) = V^*_A(t)/x$ and $V^{**}_B(t) = V^*_B(t)/x$ ie scale back the values so that x = 1
If $x<1$ then $V^{**}_A(t) = V^*_A(t)$ and $V^{**}_B(t) = V^*_B(t)$ ie no change
</td></tr></table>

3.5 Calculation of V_{max} in practice

In this section we provide a worked example of how we might calculate the interference parameters required to use the toolkit for three applications which share use of the 2.4 GHz licence exempt band:

- public access WiFi
- home wireless data networks
- wireless building automation (offices only).

In particular we calculate V_{max} - the economic value of an application above which congestion limits demand and hence prevents further increases in economic value. We start by estimating d_{mv} – the maximum density of use in a hotspot above which quality of service starts to decline.

3.5.1 Estimating d_{mv} for the three applications

Let us consider the maximum density of use for ***public access WiFi*** and ***home data networking*** using 802.11 technologies.

In the ideal situation we would carry out detailed interference modelling to determine the density of devices at which interference becomes a problem. In the absence of dedicated modelling effort we rely on results obtained from previous Aegis/Transfinite work[9].

This work simulated a number of access points in an area and tested the interference environment at 50 test points within each access point cell area. This was undertaken for a variety of scenarios which included outdoor access points as one scenario (=WiFi public access) and indoor access points as another (= home networking).

In order to compare like with like we chose the same baseline for both the indoor and the outdoor scenarios, namely a simulation area of 1.5 km x 1.5 km and a cell radius of 30 metres. The difference

[9] *Evaluating spectrum percentage occupancy in licence-exempt allocations, 1606/LEM/R/4, 3rd August 2004*

between the two scenarios is the 10 dB assumed building penetration loss for the home data networking case. Other assumptions are:

- The access point activity ratio is 30%
- The 11 Mbps carrier is protected to ensure a BER of 10^{-5} (i.e. C/(N+I) = 7 dB)
- This protection is met for 90% of test points (50) in an access point service area (cell) and 90% of trials (1000) at each test point

The outdoor density of access points achievable with respect to the criterion above is 8.7 per sq km whereas the indoor density is 19.5 per sq km which reflects the additional 10 dB wall attenuation.

Noting that there are three non-overlapping RF channels at 2.4 GHz we can derive the busy hour data that can be supported in a square kilometre as follows:

> 3 channels x 11 Mbps x 30% access point activity x 60 minutes x 60 seconds x 19.5 access points per sq km (Indoor)/8 bits per byte = ≈ 87,000 Mbytes/km^2

The comparable figure for outdoor use is 39,000 Mbytes/km^2.

In practice, only half of the carrier data rate is usable for user data because of the transmission protocols. We have chosen not to make a correction for this as the 11 Mbps protected carrier rate is most relevant at the edge of an access point coverage and users nearer the access point are likely to be operating at a higher data rate (e.g. anything up to a 54 Mbps carrier / 27 Mbps user data rate). This higher data rate nearer the centre counterbalances the possible need for a correction factor as identified above.

The estimates made above assume that the access point transmits at 100 mWatt – the standard rate for 802.11 technologies. But we have found, through discussion with representatives of the Cloud, a leading UK WiFi public service provider, that capacity in an area can be increased by reducing the transmission power and installing more access points. It is uncertain how far this would increase capacity but it is reasonable to assume that such additional investment could increase capacity by a factor of ***two to four*** fold.

Congestion between ***wireless building automation*** devices and their coexistence with the other two applications depends on the extent of the building automation functionality and the technology used to implement it. If building automation is restricted to functions at the level of lighting, heating and air conditioning control for example, the amount of data generated is small and, if supported by 802.11 technology, has minimal impact on the radio environment. We might reasonably conclude that the maximum density of use before congestion occurs (d_{mv}) is many times higher than that of any reasonable market projection. If video links of any sort were involved and the system were supported by 802.11 technology then the capacity constraint would tend to that of either the indoor or the outdoor access points set out above (depending on whether the connecting radio links are entirely within a building or linked to devices on the exterior of a building).

3.5.2 Estimating V_{max} for public access WiFi

From the previous section we estimate that public access WiFi systems reach capacity when the density of use exceeds 39,000 Mbytes per square kilometre in the busy hour. To turn density of use into an overall annual demand constraint for the UK as a whole we make the following assumptions:

- the service reaches capacity when the top 1000 square kilometres in the densest urban areas, where 5 million people live, reach capacity[10]
- the remainder of the top 10 urban areas, where 13 million people live in 3,500 square kilometres, generate the same traffic volume as the top 1000 square kilometres
- the remainder of the UK, where 42 million people live in 240,000 square kilometres, generates the same traffic volume as the top 1000 square kilometres
- 15% of the traffic in the working day is carried in the busy hour and there are 250 working days in the year. So the ratio of busy hour to annual traffic is 0.15/250 = 0.0006

With these assumptions the capacity is given by:

39,000 Mbytes per sq km x 1,000 sq km x 3 (to allow for other areas) /0.0006

= 195 billion Mbytes per year

In our projections we estimate a value per Mbyte carried of £0.40 by 2026. So

V_{max} = 195 billion Mbytes per year x £0.40 per MByte = £78bn per year

For comparison the maximum value per annum projected under the high demand scenario is £20 billion per year by 2025[11]. This comparison indicates that congestion problems will not constrain the value projections for this application.

3.5.3 Estimating V_{max} for home data networking

From Section 3.5.1 we estimate that wireless home data networking systems reach capacity when the density of use reaches 78,000 Mbytes per square kilometre in the busy hour. This higher density of use, when compared with WiFi public access, reflects the ***indoor*** use of wireless home data networks compared with the ***outdoor*** use of public WiFi access services.

We then make the following assumptions:

- the service reaches capacity when the top 1000 square kilometres in the densest urban areas, where 5 million people live, reach capacity
- the remainder of the top 10 urban areas, where 13 million people live in 3,500 square kilometres, generate the same traffic volume as the top 1000 square kilometres
- the remainder of the UK, where 42 million people live in 240,000 square kilometres, generates the same traffic volume as the top 1000 square kilometres
- 15% of the traffic is carried in the busy hour of the day and there are 365 days in the year. So the ratio of busy hour to annual traffic is 0.15/365 = 0.0004.

With these assumptions the annual capacity is given by:

78,000 Mbytes per sq km x 1000 sq km x 3/0.0004 = 585 billion Mbytes per year

To calculate V_{max} we need to estimate:

- the value per wireless home data network. In our projections we estimate a value of £19 per annum by 2025

[10] See Office of National Statistics, People and Migration, Urban areas

[11] See Figure 6.1

- the traffic per wireless home data network. This traffic excludes home entertainment applications such as music downloads and video streaming[12]. With this proviso we assume that the average wireless home data network generates 250 Mbyte per week in traffic. This is consistent with the assumptions made by the Broadband Stakeholders Group in its recent report on home networking requirements[13].

Using these values we estimate V_{max} as:

585 billion Mbytes per year x £19 per MByte/[250 MBytes per user per week x 52 weeks]

= £856 million per year

For comparison the high demand valuation scenario for home data networking reaches a value projection of £344 million per annum by 2026[14]. So again these calculations indicate that V_{max} does not constrain our value projections.

3.5.4 Estimating V_{max} for wireless building automation

As explained in Section 3.5.2, there is no possibility of a cap on the projections unless video is used while our value projections for wireless building automation exclude such use. So we can set any arbitrary values for V_{max}, provided it is well above the 2026 annual net benefits for this application.

3.5.5 Interference between the three applications

In addition to V_{max} we need to make assumptions about how the three applications in the worked example interfere with each other before we can use the toolkit to calculate the aggregate value projections when the three applications share the same spectrum.

First we assume that there is no interference[15] between wireless building automation and the other two applications given that:

- the geographic separation. Wireless building automation systems are used in offices whilst wireless home data networks are used in the home and WiFi systems in public spaces[16]
- the relatively low traffic volumes generated by wireless building automation systems[17].

Secondly we assume that home data networks and WiFi systems do interfere as the density of use of the two applications increases, and that the interference effect follows Curve 5 as defined in the interference model. This is a conservative assumption. In practice there is geographic separation between the two applications and we might expect interference to follow a curve midway between Curves 1 and 5 of the model. So our assumption constrains the value projections more than is likely to occur in practice.

3.5.6 Conclusion

We use the estimates made above as inputs to a worked example of the use of the aggregation toolkit which is described in the next chapter.

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[12] This additional traffic which, if demand is realised, be very substantial, is likely to use the much more plentiful supply of LE spectrum allocated for 802.11 use at 5 GHz

[13] *Predicting UK future residential bandwidth requirements*, May 2006

[14] See Figure 2.8

[15] Curve 1 of the interference model

[16] Of course there is the possibility of interference between wireless office data networks and wireless building automation systems. But our work does not cover office wireless data networks.

[17] Excluding any video

4 A toolkit for aggregation of value projections

4.1 Introduction

The overall goal of the study is to provide Ofcom with the tools it needs to estimate the economic value of LE spectrum bands. With this in mind Chapter 2 provides guidance on how to make projections of economic value for individual applications of various types and Chapter 3 presents a framework for modifying these projections to take account of interference effects. A third requirement to meet this goal is to develop an Excel based toolkit which Ofcom can use to select applications for use within an LE band and then calculate the aggregated value of these applications. This aggregation process needs to take account of:

- the uncertainty in the value projections for individual applications
- congestion effects within individual applications
- interference effects between applications sharing the same band
- the fact that applications may use more than one spectrum band, or may rely on spectrum for more than one band to function. Figure 4.1 tabulates where this latter effect might be the case for the 10 study applications..

Figure 4.1 Where the 10 study applications make use of more than one spectrum band

Application	More than one frequency band required for the application?
1. Road user charging	No
2. Automotive short range radars	24 GHz and 77/79 GHz with cap on 24 GHz use
3. Active medical implants	MICS at 401 to 406 MHz and WTMS at 600 and 1400 MHz
4. RFIDs in retail	Different bands within 860 to 960 MHz range
5. Public access WiFi	Could spill over from 2.4 to 5 GHz band
6. Home networking	Could spill over from 2.4 to 5 GHz especially for home entertainment
7. Wireless building automation	Could spill over from 2.4 to 5 GHz especially if video surveillance takes off
8. Fixed wireless links	No – other frequencies treated as substitute applications
9. Telemetry in the utilities	Use of several bands
10. Wireless home alarms	Use of several bands for telemetry plus use of other bands for movement detection

In this chapter we provide a high level description of the toolkit. In addition Appendix D provides a more detailed user guide to the toolkit.

We illustrate how the toolkit functions through a worked example. We use the toolkit to calculate the aggregate economic value of the 2.4 to 2.5 GHz band when used for Application 5 (Public Access WiFi), Application 6 (Home Data Networking) and Application 7 (Wireless Building Automation).

4.2 A high level description of the toolkit

Figure 4.2 provides an overview in graphical form of the structure of the toolkit. The user:

- Specifies in ***Assumptions***[18] the common assumptions to be used in the model e.g. the discount rate for calculating net present values
- Builds his or her own models to make 20 year high, medium and low projections of the economic value of individual applications. These are the primary inputs to the toolkit and are stored in ***UnconstrainedValForecasts***
- Selects from this spreadsheet the applications to be considered for aggregation. The user specifies these applications together with congestion and interference assumptions and the probability of occurrence of each of the high, medium and low scenarios in ***ApplicationList***

The toolkit then carries out two parallel forms of aggregation - deterministic and a stochastic aggregation. Under the *deterministic* analysis the toolkit:

- Modifies the high, medium and low projections of the applications selected for aggregation to take account of congestion effects according to the rules of Box 3.2. The resulting projections are stored in ***DT_Congestion***
- Constrains the projections further to take account of interference effects, again using the procedures of Box 3.2, and storing the results in ***DT_CongestionInterference***
- Sums the NPVs of the selected applications, tabulating the unconstrained, congestion constrained, and congestion and interference constrained values in ***DT_SummaryByApplication***
- Estimates the aggregated value of the selection applications when constrained by both congestion and interference in ***DT_AggregationSummary***. This spreadsheet estimates the aggregated value if all the low value projections are realised, if all the medium value projections are realised and if all the high value projections are realised. It also calculates the probability of each of these combinations of projections occurring. Finally it allows the user to calculate the aggregated value of a manually selected combination of high, medium and low projections from the applications selected for aggregation.

Under the *stochastic* analysis the toolkit:

- Generates a random number between 0 and 1 for each selected application
- Uses this number to generate a single realisation of a valuation projection for each selected application. See the user guide for more details
- Applies the congestion and interference constraints to this projection using the procedures of Box 3.2 and stores the result in ***ST_SingleRealisation*** for each selected application
- Sums over the constrained projections to derive the aggregate value projection, calculates the NPV of this projection, and stores the result in ***ST_SimData***
- Repeats these four steps N times - where N is specified by the toolkit user
- Provide summary statistics on the NPV of the constrained aggregated projections. This includes the average, standard deviation, minimum and maximum together with a frequency distribution graph in ***ST_Summary***

[18] Spreadsheet names are indicated by bold italics

Figure 4.2 The structure of the aggregation toolkit

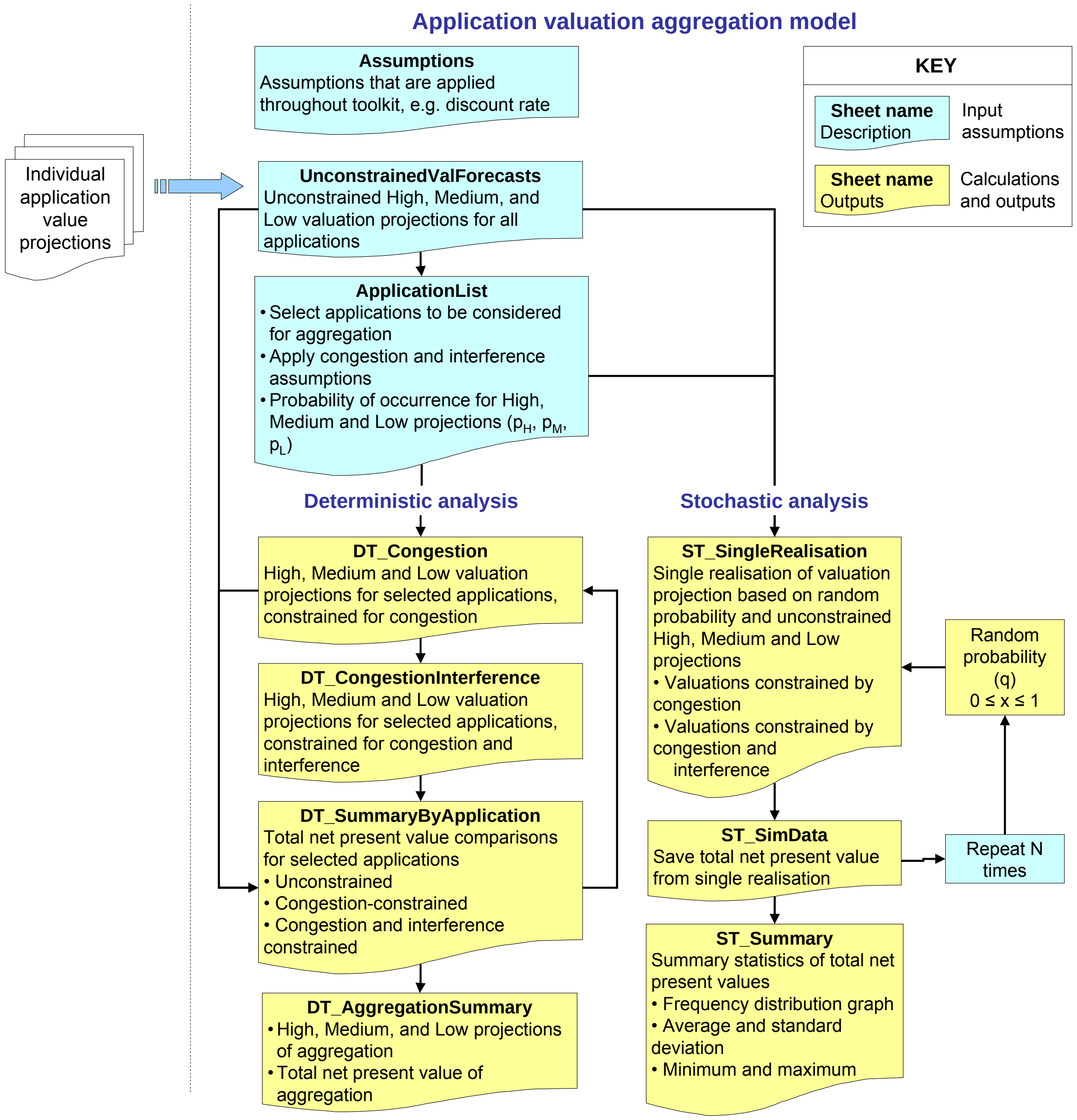
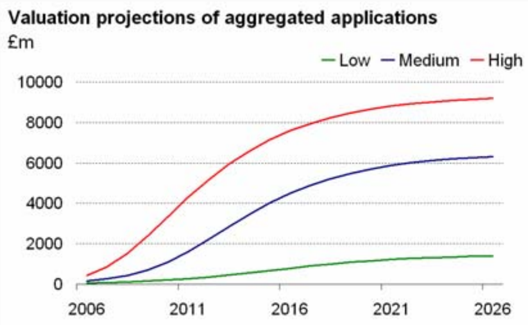
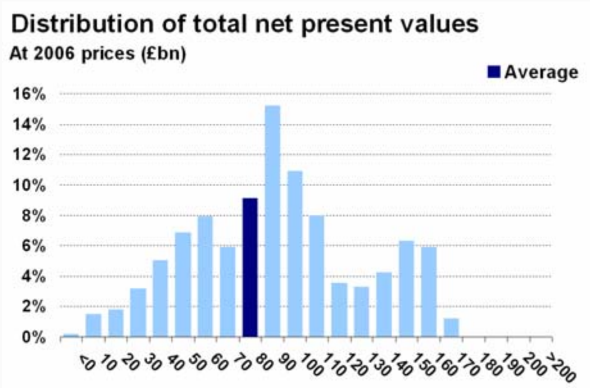


Figure 4.2 provides examples of the outputs from the deterministic and stochastic analysis of the toolkit.

Figure 4.2 Examples of toolkit outputs

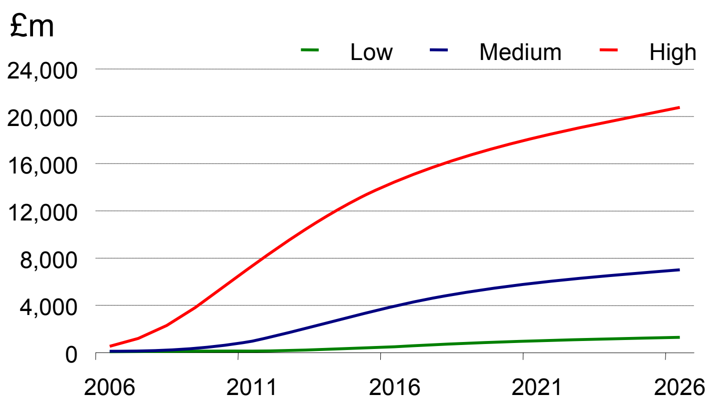
Deterministic analysis	Stochastic analysis
	

4.3 Applying the toolkit – a worked example

In this section we provide a worked example in which we use the toolkit to calculate the aggregated value of three applications – public access WiFi, home wireless data networking, and wireless building automation using spectrum in range 2400 to 2483 MHz.

The calculations of Sections 3.5 indicate that there are no congestion or interference constraints on the individual applications. So the aggregate value is the same as the sum of the values of each of the three applications. The resulting valuation projections are shown in Figure 4.3 - using the deterministic analysis. The low aggregation projection combines the low value projections for each of the three applications and has a probability of occurrence of just under 3% (30%x30%x30%). Similarly the higher aggregate projection combines the high value projections for each of three applications and has a similar probability of recurrence.

Figure 4.3 Worked example - the unconstrained aggregated economic value projections



To show the impact of the interference and congestion constraints we consider an alternative scenario in which the constraints are strengthened so that they bind the value projections. We assume that :

- Use of home data networking grows from 250 to 1000 Mbytes per week while the value per Mbyte remains unchanged at £19 by 2026. Then:

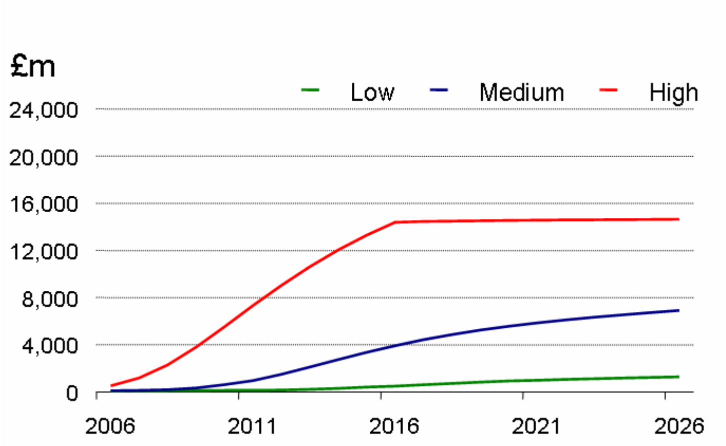
V_{max} = £856million x 250/1000 = £214 million per annum, compared with high demand scenario projection of £344 million

- WiFi reaches capacity when the top 100 square kilometres reaches capacity while the next 900 square kilometres generates twice this traffic. Then:

V_{max} = 39,000 x 100 square kilometres x 5/0.0006 = 35 billion Mbytes per annum at £0.40 per Mbyte = £14 billion per annum compared with £20 billion per annum for the high demand projection.

Under this scenario congestion constrains the aggregated projections of the combination of high value projections significantly as shown in Figure 4.4.

Figure 4.4 The effect of congestion under the alternative scenario

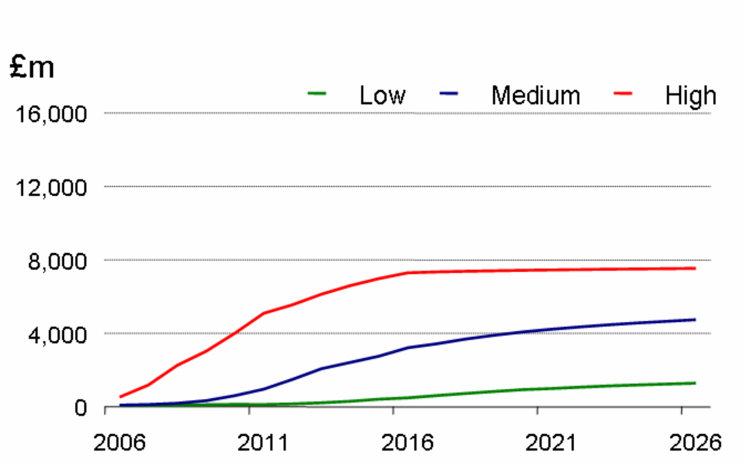


If we also assume that home data networking interferes with public access WiFi according to Curve 5 of Section 3.3.3, then the economic value of the two applications is constrained by the equation:

$$V_{HDN}/VMAX_{HDN} + V_{WiFi}/VMAX_{WiFi} = 1$$

As Figure 4.5 illustrates, the effect of interference is to further reduce the aggregated value by about 50% for both the high and medium demand scenarios while leaving the low demand scenario unaffected.

Figure 4.5 The effect of inter-application interference under the alternative scenario



5 The costs and benefits of harmonising LE spectrum

5.1 Introduction

What are the costs and benefits of harmonising licence exempt spectrum for the UK? We use the term harmonised to mean:

- The common designation of frequency bands for LE use by a number of countries ***and***
- The designation of common minimum requirements to avoid harmful interference (e.g. limits on transmission power).

Note that this definition does not include harmonisation on common standards or technologies.

Harmonisation of frequency bands does not necessarily require the same frequencies to be used in each country or region. Multiple or overlapping bands can often be supported economically using current technology. 20 years ago radio technologies had little frequency agility because of crystal control issues. Today frequency agility is much easier to implement. There is, of course, a limit to the degree of customization to local conditions that is possible, because additional development and chip set costs are incurred. To be affordable, these additional costs need to be spread over a relatively large market; European or global rather than national markets may be required. For example, while global harmonisation is particularly attractive for high volume, cost-critical applications like RFID, finding suitable frequencies that are available globally is not a trivial task and may involve having to re-farm spectrum from other applications. This has been overcome at 900 MHz by ensuring that RFID tags have sufficiently wide bandwidth to accommodate all the global frequency variants.

5.2 The costs and benefits of harmonisation

5.2.1 Benefits

There are five main benefits which arise when frequencies (and technical conditions) are harmonised. Such harmonisation:

- Reduces the likelihood of harmful interference between services operating in different countries, particularly in border areas, and thereby increases the available spectrum for each country
- Creates a European-wide market for equipment and services thereby reducing manufacturers' risks and allowing them to take advantage of scale economies
- Reduces equipment costs by limiting the number of frequency bands for which equipment must be made
- Creates the possibility for international roaming[19]. This is more important for some applications than others. It is very inconvenient if car door openers on car keys do not work all over Europe. There is much less benefit in having garage door openers or cordless phones work in every country
- Provides greater certainty (protection) to users of spectrum that the spectrum will not be reallocated to other potential uses.

[19] This will also require standardisation for interoperability between consumer equipment and different networks.

5.2.2 Costs

But there are also costs associated with harmonisation. If harmonisation is introduced retrospectively, when there is already a significantly installed base of devices using national unharmonised frequencies, then there is the transition cost for the user base in moving to the new harmonised band. There may also be significant costs in clearing the harmonised spectrum of existing applications before it can be used for its harmonised purpose[20]. But even if harmonisation is done on a forward looking basis so as to use virgin spectrum there are still costs. Demand for a service, and the associated demand for spectrum, varies between countries for many reasons – such as differences in income, geography, demographics and the provision of competitive wired services such as cable TV. Frequency harmonisation could, for any given service, mean that harmonised spectrum remains idle in some countries (where demand for the harmonised application(s) is low) while there is insufficient harmonised spectrum in others (where demand is particularly high). So frequency harmonisation could:

- Constrain the UK's ability to match supply and demand for spectrum to meet national conditions. This is clearly inefficient
- Constrain the UK's ability to allow refarming or trading of spectrum so that higher value uses replace lower value uses.

Harmonisation is also often a slow process which limits the speed at which suppliers who want to use the harmonised spectrum can develop commercial devices. So harmonisation can:

- Constrain the ability of UK firms to innovate rapidly in radio technology by selling innovative, interference-free devices in the home market soon after development and then exporting them into receptive markets elsewhere.
- Discourage UK entrepreneurship in LE radio technology since harmonisation is a time consuming process that puts the entrepreneur at a real disadvantage.

Figure 5.1 summarises the costs and benefits of frequency harmonisation.

Figure 5.1 The benefits and costs of harmonisation

Benefits	Costs
Avoidance of harmful interference and thereby promotion of efficient use of spectrum, thus increasing spectrum use and competition.	Restrictions on use (or trade) of underused or unused spectrum for alternative uses.
Promotes international mobility (of terminals).	Restrictions on ability to re-farm spectrum for new services.
Reduction of equipment costs by reducing the number of bands equipment needs to operate in.	Insufficient spectrum designated to some uses.
Creates large equipment markets.	Delays caused by the time needed to agree harmonisation measures.
Promotes competition between equipment suppliers and choice for the consumer.	Costs of clearing harmonised spectrum

[20] This assumes dedicated LE bands. In practice many LE applications coexist with other primary devices. So for example 802.11 devices share spectrum with radars and microwave ovens

5.2.3 Licensed versus LE spectrum

This evaluation of the costs and benefits of harmonisation applies to both licensed and LE spectrum. But the first two costs listed in the text above apply more to licensed spectrum, where harmonisation often applies to individual applications, than to licence exempt spectrum, where a band is shared across a number of applications. In the latter case national variations in relative demand for this set of LE applications may not introduce additional inefficiencies in spectrum use because the band is shared between the applications[21].

At the same time one of the benefits of harmonisation, minimising cross border interference, is much weaker for LE applications than for licensed applications. LE devices almost always operate over much shorter distances than devices using licensed spectrum. So cross border interference issues are less significant – especially for the UK which shares a land border only with Ireland and where bilateral agreements offer the most efficient solution.

5.3 Where is harmonisation most important?

Harmonisation of frequency bands, and associated technical conditions, is most important:

- For equipment which is internationally mobile and where:
    - the equipment must interoperate with infrastructure in various countries (eg WiFi), or
    - the equipment must operate reliably without receiving (or generating) interference, as it moves from country to country (eg car door openers)
- Where there significant scale economies in production
- Where demand for the application is price sensitive.

In Figure 5.2 we make a qualitative assessment of the extent which each of the ten selected LE applications meets these criteria.

This analysis suggests that:

- Harmonisation is of little economic importance for Application 8 (fixed wireless services) or Application 9 (telemetry in the utilities)
- Harmonisation is of major economic importance for Application 2 (short range radars for collision avoidance in cars), Application 4 (RFIDs in retail) and Application 5 (WiFi public access services)
- Harmonisation is of little ***economic*** importance for active medical implants such as blood glucose monitors but, given the safety-of-life nature of these devices, is important from a ***socio-political*** perspective.

[21] Assuming the allocation is not made on an application specific basis

Figure 5.2 An assessment of the importance of harmonisation for the 10 selected applications

Application	Economies of scale in production	Price sensitive demand?	International portability	Importance of harmonisation
1. Road user charging	High	Yes	Limited for UK (1)	Low
2. Automotive radar	High	Yes	High	***High (2)***
3. Active medical implants	Low	Limited	Limited	***High (3)***
4. RFIDS in retail	High	Yes	High	***High***
5. WiFi public access	High	Yes	High	***High***
6. Wireless home networking	High	Yes	Limited	Medium
7. Wireless building automation	Medium	Yes	Not applicable	Low
8. Fixed wireless links	Low	Limited	Not applicable	Low
9. Telemetry in the utilities	Low	Limited	Not applicable	Low
10. Home alarms	Medium	Yes	Not applicable	Low or negative (4)

(1) But not for rest of EU where cross border vehicle flows are substantial; (2) Important for socio political ***and*** economic reasons; (3) Important for socio political ***rather than*** economic reasons; (4) Harmonisation might make alarm systems less secure

5.4 The scale of the costs and benefits of harmonisation

5.4.1 The benefits of harmonisation

How big are the benefits of harmonisation for the key applications identified in Figure 5.2? The net benefits estimated in Chapter 2 of these applications assume full global harmonisation. So we need to consider what happens to these value projections if there is no harmonisation or if harmonisation occurs only slowly. There are two likely outcomes:

- ***Scenario 1:*** *the projected benefits are delayed*. We assume a 5 year delay in modelling such a possibility
- ***Scenario 2:*** *long term demand is substantially reduced*. All three of the applications involve price sensitive, mass markets of highly portable devices. Without harmonisation economies of scale in production are limited, device prices are significantly higher, and so the viability of the application is limited as illustrated in Figure 5.3. We assume that demand is reduced by 70% without harmonisation under Scenario 2 for RFIDs and WiFi and is the same as Scenario 1 for SRRs.

Figure 5.3 The possible impact of voluntary harmonisation

Application	Possible impact of voluntary harmonisation
Short range radars (SRRs)	Device prices remain high (currently €50 each) Demand for SRRs is limited to luxury cars in the short term Impact on injuries, deaths and damage to cars is correspondingly reduced SRR benefits are delayed but not reduced in the long term
RFIDs in the retail sector	Price of RFID tags remains at several € cents RFID tagging of individual items is not justified in most cases RFIDs are limited to "back of store" applications This reduces benefits by up to 85% (1)
Public access WiFi services (2)	Requirement for frequency agile chips raises prices significantly Installation of WiFi chips in basic laptops and mobile terminals substantially delayed Take up of WiFi public access services correspondingly delayed

(1) Wal-Mart estimates that 85% of cost savings from use of RFIDs comes from "in-store" applications

(2) This scenario has not occurred. But it may well have done if WiFi spectrum had not been harmonised on a global basis

Figure 5.4 shows the impact of these two scenarios on the net present value of the three applications. It indicates that the NPV to the UK of the benefits of harmonisation of spectrum use for these three applications is between £39 billion and £77 billion.

Figure 5.4 The impact of global harmonisation – NPV of net benefits for the UK (in £bn)

Application	*NPV of net benefits (£bn)*			*Incremental benefits of harmonisation (£bn)*	
	Full harmonisation	*Scenario 1*	*Scenario 2*	*Scenario 1*	*Scenario 2*
RFIDs	30	21	9	9	21
SRRs	25	15	15	10	10
WiFi	65	45	20	21	46
Total				39	77
Average				13	26

5.4.2 The costs of harmonisation

Harmonisation generates costs as well as benefits in terms of:

- The cost of clearing existing UK users from the spectrum designated for harmonisation
- The cost of less efficient use of spectrum because of variations in demand across countries. This could lead the UK to allocate too much harmonised spectrum to applications where demand is low by global standards and to allocate too little to applications where demand is abnormally high.

To assess the scale of these costs we consider the position of the three selected applications against these two measures below.

In addition to these two costs there is also a cost associated with the UK specifying frequencies for harmonisation which are out of line with market developments elsewhere. It is clearly important for the UK to minimise this cost by considering such developments before reaching any harmonisation decision. We discuss this issue further in Section 5.6.

Short range radars

Short range radars use harmonised spectrum at 24 and 77 GHz with strict limits on the density of use of the 24 GHz allocation[22]. There are no clearance costs at 77 GHz and the costs of less efficient use of this spectrum because of harmonisation are insignificant given that:

- Short range radar used very high frequencies for which other uses are limited.
- The short range and directional use of this spectrum by short range radars means that there are opportunities for its use to be shared with other, as yet unidentified, applications.

At the same time there is a cap on SRR usage at 24 GHz which is designed to protect existing radar and fixed link deployments.

RFIDs

RFIDs are designed to respond to interrogators in the frequency range 860 to 960 MHz. So there is a wide range of options for harmonised bands to use with the tags[23]. The EU has proposed harmonised use of RFIDs in the 865 to 868 MHz band. But so far member state implementation of this recommendation is poor[24].

Clearance costs for the recommended harmonisation are low. There may be military applications in some countries and there are a few CT2 devices still using the band. More spectrum is required if interrogators are to work at the densities implied by our net benefit projections. Possible expansion bands include 915 to 917 MHz and 870 to 872 MHz. Again clearance costs should be low – these bands are currently free in the UK for example.

RFIDs can be used across a wide range of frequencies. So the UK has considerable freedom to adjust its national allocations to meet national demand patterns. This should minimise the inflexibility costs introduced by harmonisation.

WiFi

Spectrum for WiFi is already harmonised. WiFi uses 83.5 MHz of spectrum at 2.4 GHz where it co-exists with other unlicensed users such as wireless audio links and outside broadcasts. It also uses 455 MHz of spectrum at 5 GHz where it co-exists with use by devices such as radars. In both cases the ability of WiFi[25] to co-exist with established applications means that the need to clear existing applications from the harmonised spectrum is limited.

It is more difficult to assess the inflexibility costs of the WiFi spectrum allocation. But again we believe that they are likely to be modest given that:

- There is a wide range of applications which are likely to use WiFi (public access telecommunications, home data networks, home entertainment, wireless building automation and home automation)
- The universal appeal of these applications should mean that national variations in demand for this spectrum are limited.

[22] Which is also designated in the USA for the same purpose

[23] It is also desirable to harmonise the frequency used by the interrogators to much narrower bands. But it is mass production of the tags which will ultimately drive RFID prices down and determine what applications are viable

[24] See for example the latest version of ERC Recommendation 70-03

[25] With its listen before talk functionality and use of spread spectrum techniques to minimise the impacts of interference

Conclusions

Based on the analysis of the three individual applications set out above we conclude that:

- The costs of clearing spectrum for harmonisation are likely to be modest given that these LE applications can often co-exist with other applications and use frequency agility techniques to find otherwise unused spectrum
- The inflexibility in spectrum use introduced by harmonisation is modest in practice
- Overall the costs of harmonisation are likely to be small compared with the benefits. We therefore do not attempt to quantify them.

5.4.3 Grossing up for other applications

Based on the analysis so far we estimate (in Figure 5.4) that the net benefits of harmonisation are worth between £39 billion and £77 billion at net present value, depending on whether we consider Scenario 1 or Scenario 2. These estimates reflect the impact of the three selected applications alone.

In practice it is highly likely that other LE applications, where harmonisation is equally important for maximising economic benefits, will emerge. To gross up from the three selected applications to LE applications as a whole we assume that:

- Applications where harmonisation is important emerge every ***five*** years for the next 30 years. This period reflects the fact that WiFi, short range radar, and RFID applications are projected to generate net benefits which exceed 0.1% of UK GDP within a six year period (ie three years between important applications). So assuming a five year, rather than a three year, gap is conservative. In addition steady improvements in battery technology combined with the falling costs of transceiver chips means that other, as yet unidentified, major LE applications are likely to become viable over the next two decades. This could further shorten the interval between major applications emerging
- The incremental value of harmonisation for each such application has a net present value of £13 billion (Scenario 1) or £26 billion (Scenario 2). The NPV used is the average of the individual applications of Figure 5.4
- The NPV of each application is then discounted back to 2006 using a real discount rate of 3.5%[26].

With these assumptions we estimate that the NPV to the UK of harmonising LE spectrum lies between £58 billion and £113 billion. Such benefits are substantial. For example the higher NPV of £113 billion is equivalent to a perpetual annual net benefit of £4.5 billion, or 0.35% of the UK's current GDP, if discounted at 3.5% per year.

5.4.4 The need for an impact assessment before proceeding with harmonisation

Harmonisation for LE spectrum is not always beneficial. In some cases the costs outweigh the benefits. Use of wireless telemetry devices in the UK's utilities is a good example. In a previous report for Ofcom[27] Indepen considered the case for harmonising the UK's use of spectrum for telemetry in the 433 and 868 MHz bands. This would have required the utilities to stop using radio technologies at 458 MHz and to use fixed wireless links instead. This in turn would have generated a net present cost over a 10 year period of £4.1 billion. This cost far outweighs other costs and benefits.

[26] The rate recommended by H M Treasury in its Green Book

[27] Costs and benefits of relaxing international frequency harmonisation and radio standards, Indepen and Aegis, March 2004

This counter example suggests that Ofcom should carry out some kind of impact assessment to determine whether an application is a suitable candidate before proceeding with harmonisation. The analytic framework of Figure 5.2 is a useful starting point for such assessments.

5.5 Harmonisation status of key applications

Our analysis indicates that harmonisation is of greatest economic importance for Applications 2, 4 and 5 and has socio-political importance for Application 3. Figure 5.5 summarises our understanding on how far harmonisation has got for each of these four applications. It shows that harmonisation of the most important of the LE applications studied is already well under way, although progress towards harmonisation on a voluntary basis in the EU is often slow (eg for RFIDs).

It is important to note that our analysis only considers 10 selected applications out of a population of well over 100. There are, almost certainly, other applications which would create significant economic benefits through harmonisation, and where harmonisation is far from complete.

Figure 5.5 Harmonisation status of key applications

Application	Status of harmonisation
Application 2 – Short Range Radars	The EU allows limited harmonised use in the 24 GHz band and unlimited use at 79 GHz The US uses 24GHz for SRRs Use of this frequency in the EU is limited by the installed base of fixed links eg for mobile network backhaul
Application 4 – RFIDs	Tags are designed to respond to interrogation across 860 to 960 MHz Different countries use different bands e.g. US at 902 to 928 MHz, the EU at 865 to 868 MHz The EU will need more harmonised spectrum if current long term demand projections are to be met
Application 5 Public Access WIFI Services	There is already global harmonisation at frequencies in the 2.4 and 5 GHz bands
Application 3 – Active Medical implants	US and EU have designated dedicated spectrum in the 402 to 405 MHz band for medical implant communication services (MICS) US has designated lightly licensed spectrum for wireless medical telemetry services to complemented the MICS CEPT is in the process of making similar allocations

5.6 Key harmonisation issues for Ofcom

The analysis of the previous section indicates that the UK can enjoy substantial net benefits from harmonisation of use of spectrum from some, but not all, LE applications. There are two key issues which Ofcom will face when it considers how to proceed with such harmonisation:

- Issue 1: Should Ofcom focus its efforts on EU wide or global harmonisation?
- Issue 2: As spectrum liberalisation proceeds how does Ofcom frame the spectrum user rights for licensed users in a way which is compatible with harmonisation of LE spectrum?

5.6.1 Issue 1: Global versus EU wide harmonisation

Recent work by Mott Macdonald et al[28] concludes that harmonisation of use of LE spectrum at the EU level is often a slow process and this means it could put UK industry and end-users at a disadvantage globally. For example:

- If Ofcom waits for EU harmonisation to be completed then UK industry may be put at a disadvantage relative to its global (non EU) rivals while benefits to UK users are delayed
- If Ofcom waits for EU harmonisation then this can discourage innovation in LE applications in the UK
- If Ofcom designates LE spectrum which is subsequently not harmonised then again UK industry and end-users lose out. In this case they invest in devices which use un-harmonised spectrum and bear the cost of switching to devices which use harmonised spectrum in the long term.

What should Ofcom do here? There is provision under the Radio Spectrum Decision for the European Commission to adopt binding measures to achieve necessary harmonisation. Furthermore, the Commission has recently stated its intention to apply decision mechanisms that yield binding results to be commonly applied by all Member States in respect of unlicensed bands, where the use of spectrum should be made subject to general authorizations, and where conditions applicable to the use of spectrum in those bands would be co-coordinated[29]. ***To speed up the harmonisation process Ofcom might wish to support such activities by the Commission*** so as to replace the existing voluntary approach to LE harmonisation with mandatory EU-wide designations backed by an expanded Commission Decision. This might involve:

- A review of existing ERC Recommendations 70-03
- The development of a simple categorisation of LE use of spectrum with different rules for each category. The objective here is to provide something which is much easier to understand than the current rules and which offers LE users the maximum flexibility which is compatible with interference constraints
- Their incorporation into a revised and expanded European Commission Decision covering all harmonised LE applications.

Ofcom will also need to consider the process of global harmonisation in reaching decisions about use of LE spectrum. In particular it will need to consider whether it should sanction use of spectrum for LE underlays or overlays[30] that may have been adopted in the US and/or East Asia but which are not yet approved at the EU level.

As new LE applications are enabled in portable devices, global harmonisation becomes increasingly important. In some cases Ofcom may have little choice but to implement decisions taken elsewhere in the world as harmonisation is impacted by market developments. If the rules fail to keep place with market developments, LE devices are often used illegally, either intentionally or inadvertently, as illustrated by the example of the i-Trip device in Box 5.1

[28] Study on Legal, Economic and Technical aspects of collective use of spectrum in the European Community, Final report, September 2006

[29] "Review of the EU Regulatory Framework for electronic communications networks and services", Commission Staff Working Document, COM(2006) 334 final, 28 June 2006.

[30] Underlay technologies operate in spectrum that is used for other licensed or licence-exempt use but at very low power levels. An overlay approach permits higher powers that could cause interference to existing users, but overcomes this risk by only permitting transmissions at times or locations where the spectrum is not currently in use.

Box 5.1 The i-Trip and global harmonisation

In 2003 a consumer device that transmits on licensed FM broadcast frequencies came onto the market. The device offered the consumer the ability to listen to their music tracks from a portable mp3 player through a radio (typically a car radio) without the use of wires and an adapter kit. The user selects an otherwise vacant radio channel, and the iTrip then transmits the music to the car radio (at low power – short range). Throughout Europe, the audio broadcast spectrum is licensed; therefore, the iTrip is illegally transmitting in licensed spectrum. Some European regulators stated that the devices were illegal. Nonetheless, the devices were being purchased over the web, and a grey market and use developed. The Swiss regulator was the first to change its law to allow the use of the iTrip. Other European regulators have followed suit, taking into account that the devices would cause very little interference to other users, and that it would be very difficult in any case to stop the grey market. Ofcom made this decision in October 2006.

Similar issues could very well arise in the context of ultra wide band (UWB) if European harmonisation measures are not agreed in a timely manner, as devices equipped with UWB are expected to enter the US market in 2006. Those devices are likely to find their way to Europe; moreover, if consumers find them useful, they will tend to be used, whether they are authorised or not. *De facto* global harmonisation will occur, forcing the need for *de jure* harmonisation.

These developments suggest that Ofcom should be proactive in anticipating and responding to developments outside the EU as well as within it, in making decisions about use of LE spectrum.

5.6.2 Issue 2 – spectrum user rights and harmonisation

Ofcom's policy of spectrum liberalisation involves progressively removing restrictions on spectrum use and replacing existing licences with spectrum usage rights (SURs)[31]. Licences in SUR form would restrict the permissible emissions into frequency bands and geographic locations of neighbouring users. There would (as far as possible) be no restrictions on the technology and service deployed. This approach is intended to give licensees greater flexibility in spectrum use while providing adequate protection against harmful interference. In November 2006 Ofcom published a statement announcing its intention to proceed with work to develop specific SURs[32].

At the same time, there is a growing number of LE applications seeking to share spectrum licensed bands either as an underlay or an overlay to the incumbent licensed use – for example UWB in 3-10 GHz, WiFi in 5GHz radar bands, licence exempt broadband at UHF and low power FM radio transmitters in the FM radio band. Many of these applications will be harmonised on a European basis and there is intended to be no increase in the risk of interference to the licensed user as a result of the sharing. However, in practice certain proposals for underlays and overlays have involved an increased risk of interference that is sometimes justified with reference to the benefits from the licence exempt application. Analysis of the likelihood of interference is typically undertaken with reference to an existing or imminent licensed use of the affected bands. Generally there is no regard to the possibility that the use of the band might change in future. This means that there is a risk that the

[31] "Spectrum Usage Rights", A Consultation, Ofcom, 12 April 2006.

[32] http://www.ofcom.org.uk/consult/condocs/sur/next_steps2/

permitted underlay/overlay could block future changes of use. In particular changes involving a move from fixed to mobile use are likely to be problematic. For example:

- Proposals for licence exempt wireless broadband services in TV bands could block redeployment of fixed broadcast channels to mobile TV use
- In the US the FCC has announced its intention to allow the "white space" spectrum in TV broadcasts to be used for LE applications[33]. If this proposal were implemented and TV broadcasting then moved to a cellular architecture then major interference issues would arise
- WiFi is now permitted as an overlay in 5GHz bands used by radar. WiFi is designed to coexist with such radar devices. But if other primary use devices were to acquire flexible rights in this band there is a risk that they will interfere with/suffer interference from WiFi use.

While the LE applications might be allowed into the band on the proviso that they accept any future interference from the licensed system, in practice we doubt that that such interference would be permitted to occur by the regulator if it caused disruption to many consumers and/or affected applications that affect safety of life services such as alarms, automotive radars, or sensors. At this point politics would probably intervene[34]. Underlays and overlays could also reduce the value of licensed bands and thereby inhibit trading activity.

In summary there is potential conflict between moves to SURs and permitting increased access to licensed bands by LE underlays and overlays. If underlay technologies are to be permitted then any newly assigned frequency bands should have the underlay spectral mask (e.g. akin to the FCC's Part 15 mask) defined at the outset, so that those acquiring spectrum rights are clear about what they are buying. Overlays may be feasible in bands where licence exempt use can be shown to share without causing interference to mobile application but given that many new interference mitigation technologies are still at a rudimentary stage (i.e. they may not work as promised) this suggests that it will be necessary to proceed cautiously in this regard.

This analysis suggests that ***Ofcom should only support harmonisation initiatives aimed at increasing sharing between licence exempt and licensed services, if the associated technical conditions are such that it (and the affected licensees) are confident there will be no material risk of interference.*** It is important in doing this that it specifies any relevant underlay spectral masks.

[33] http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-267867A1.pdf

[34] We note that in a similar vein the US PCS operators did not lease spectrum to rural broadband suppliers for fear they would never get it back even once the leases had expired. This is discussed in "Implications of International Regulation and technical considerations on market mechanisms for spectrum management" Aegis and Indepen for the Independent Spectrum Management Review, November 2001, http://www.indepen.co.uk/panda.html

6 Main Study Findings

6.1 Introduction

The main study deliverables are the three main methodologies:

- The models for making economic value projections for individual LE applications described in Chapter 2
- The interference framework of Chapter 3 and
- The aggregation toolkit discussed in Chapter 4

In addition the process of developing these methodologies has led us to certain more specific conclusions which we set out in this final chapter.

6.2 The economic values for the 10 study applications

Figure 6.1 tabulates the net present value of the 10 study applications.

Figure 6.1 The NPV of the 10 study applications

Application	*NPV (£bn) for demand scenario*			*Probability of scenario*			*Expected*	*Ratio of high*
	low	*medium*	*high*	*low*	*medium*	*high*	*NPV (£bn)*	*to medium NPV*
1. Road user charging	0.3	0.6	0.9	30%	40%	30%	0.6	1.5
2. Short range radars	2	26	88	30%	40%	30%	37.4	3.4
3. Blood glucose sensors	0	9	19	60%	20%	20%	5.6	2.1
4. RFIDs in retail	10	35	98	30%	40%	30%	46.4	2.8
5. Public access WiFi	9	68	239	30%	40%	30%	101.6	3.5
6. Home data networking	4	6	8	30%	40%	30%	6.0	1.3
7. Wireless building automation	0.3	1.2	4	30%	40%	30%	1.8	3.3
8. Fixed wireless links	0	0.6	1.7	30%	40%	30%	0.8	2.8
9. Telemetry in utilities	8	11	13	30%	40%	30%	10.7	1.2
10. Wireless home alarms	0.6	2.4	6.4	30%	40%	30%	3.1	2.7

Source: Indepen,Aegis and Ovum

It shows that:

- The expected NPV of the applications varies considerably – from less than £1 billion for road user charging (Application 1) and fixed wireless links (Application 8) to over £100 billion for public access WiFi
- There are three potential major LE applications amongst the 10 studied – Application 2 (automotive short range radar), Application 4 (RFIDs in retail) and Application 5 (public access WiFi). These three applications are precisely the three applications where international harmonisation is most important
- There is considerable uncertainty in these projections. For example in most cases the NPV for the high demand scenario exceeds the NPV for the medium demand scenario by a factor of two or more

- As we might expect, uncertainty is greatest for embryonic applications like short range radars (Application 2) and least for well established applications like telemetry in the utilities (Application 9).

The values tabulated in Figures 6.1 assume global harmonisation and no interference constraints. But our analysis indicates that imposing these constraints would not change valuations significantly:

- Chapter 5 suggests that lack of harmonisation is unlikely to be a problem for the major applications (Applications 2, 4 and 5) where it is important
- Chapter 3 indicates that the interference effects are unlikely to constrain the value of Application 5 (public access WiFi)
- The plentiful supply of spectrum at higher frequencies suggests that spectrum scarcity is unlikely to constrain Application 2 (short range radars).
- There are however strong indications that the interference effects could constrain the value projections of RFIDs in retail (Application 4). See for example the research profile on RFIDs in Appendix A.

6.3 The value of licensed and LE spectrum compared

Figure 6.2 compares the average value per MHz for the 10 LE applications with the corresponding measure for certain licensed applications. The economic value of licensed spectrum is taken from the Ofcom study on the economic impact of spectrum published in December 2006. The table compares the annual benefits generated by licensed applications ***now*** with the medium demand scenario value projections for LE applications in ***2020***[35], again at 2006 prices. In making this comparison it is important to remember that the values for licensed spectrum are estimates of benefits which have actually been realised, while the values for LE spectrum are projections of future economic benefits which are uncertain and where the impact of interference effects has not been fully evaluated.

The table indicates that:

- the major LE applications will probably generate net economic benefits per MHz which substantially exceed those generated by the most valuable licensed applications, mobile telephony and broadcast, do now
- use of RFIDs in the retail sector is the highest value application per MHz of bandwidth used. But this estimate needs to be interpreted with care. Projections of economic values for other LE applications in the table are unlikely to be constrained by interference. But the 4 MHz currently allocated to RFIDs is likely to be insufficient. However even if the RFID spectrum allocation were increased by a factor of 10 to deal with spectrum scarcity, it is likely that the value per MHz generated by use of RFIDs in the retail sector will still exceed that of mobile telephony and broadcasting
- Application 3, blood glucose sensors as an example of active medical implants, does not show any economic benefits by 2020. This reflects the fact that patients do not, on average, benefit from the sensor until 20 or more years after implantation. When we look at Figure 6.1 we find that the expected NPV of this application, when measured over a much longer time scale, is greater than two of the other nine study applications

[35] We have chosen this date as one where most of the study applications are reasonably mature, but where there is still some growth potential.

- Excluding this application, it is the higher frequency applications, Applications 2 and 8 which generate the lowest economic value per MHz used. We expect that these applications, both of which operate well above 50 GHz, will generate less than £1 million per MHz per year by 2020. However it is important to remember that the opportunity cost of using this spectrum is very low and may even be zero for certain applications.

Figure 6.2 Spectrum value per MHz – licensed versus licence exempt

Licenced spectrum

Application	*% of 0.3 to 3 GHz used*	*Value £m pa at 2006 prices and output levels*	*Value per MHz (£m)*
Mobile telephony	16%	21786	50
Broadcast	17%	12269	27
Fixed links	5%	3883	29
Maritime	5%	1.2	0.009

Source: Ofcom economic impact study, December 2006; Maritime estimates based on earlier Cave study of 2001

Unclicensed spectrum

Application	*Value (£m pa) in 2020 (1)*	*Bandwidth used (MHz)*	*Frequency used (GHz)*	*Value (£m) per MHz*
1. Road user charging	53	20	5.8	2.65
2. Automotive short range radars	1776	5000	79	0.36
3. Active medical implants (2)	0	5	0.4	0
4. RFIDs in retail	2478	4	0.8	620
5. WiFi public access	5270	83	2.4	
6. Home data networking	395	83	2.4	69
7. Wireless building automation	96	83	2.4	
8. FWS	50	9500	70 + 80	0.005
9. Telemetry	600	2	0.4	300
10. Home alarms	143	5	0.9 + 0.4	29

(1) In 2020 for medium demand scenario
(2) Benefits do not accrue until 20 or 40 years after implementation
Source: Indepen, Aegis and Ovum

6.4 Reducing uncertainty in the value projections

As Figure 6.1 illustrates, there is considerable uncertainty in the value projections which we have made. This makes it difficult for Ofcom to make the best possible spectrum allocations decisions so as to maximise future economic benefits for the UK. This leads us ask what Ofcom might do to reduce this uncertainty.

Figure 6.3 tabulates the main sources of uncertainty in our value projections. A number of important points arise when we examine it:

- There is need to monitor take up rates for almost all of the study applications to see if they follow our demand projections. This is particularly important for Applications 2, 4 and 5 which are projected to generate the greatest economic value

- In the case of RFIDs there is a need to monitor the application for possible congestion effects constraining demand and value
- For a substantial number of applications there is a requirement to get a better understanding of how UK consumers use wireless devices in their homes and to measure trends in this usage. For example it would be useful to have a better understanding of:
  - what determines when households use home networking
  - the extent to which wireless home networks stimulate demand for broadband
  - applications for which households use these networks (data versus entertainment versus information)
  - the rate at which automated meter reading might be rolled out to UK households
  - the factors which determine use of wireless home alarms.

  Given this requirement, Ofcom might wish ***to initiate periodic market research studies to better understand the use of wireless devices in UK homes.***
- in a number of cases there is a need for application specific studies to determine more accurately key parameters in the value projection models such as:
  - the impact of short range radars on road accidents (Application 2) and
  - the impact of home wireless alarms on burglary rates (Application 10).

Figure 6.3 The main sources of uncertainty in the value projections

Application	Main source of uncertainty
1. RUC	Speed of take up of DSRC based RUC schemes Rate of displacement by national satellite based scheme
2. SRRs	Impact of SRRs on road accidents Rate of take up of SRRs
3. AMI – blood glucose sensor	Probability of mainstream clinical use Extent to which sensor extends life expectancy
4. RFIDs in retail	Reduction in operating costs from RFIDs Speed of take up of RFIDs for front of store applications Impact of congestion on density of interrogators which is possible
5. Public access WiFi	Rate at which service substitutes for 3G Extent to which service stimulates demand for broadband
6. Home data networking	Extent to which wireless home networking stimulates demand for broadband Value of flexibility of wireless solution Future take up of home entertainment and home automation applications through wireless networking
7. Wireless building automation	Speed of take up Savings on heating, ventilation and air conditioning energy bills from control of individual offices
8. FWS links	Take up of FWS links Cost saving possible through use of FWS links vs substitutes
9. Telemetry in utilities	No major uncertainties as defined but Take up of consumer automated meter reading a major factor in future
10. Home wireless alarms	Take up rate Impact of home wireless alarms on burglary rates

6.5 Main study conclusions

Certain LE applications, such as short range radars, RFIDs in retail and public access WiFi could generate economic benefits for the UK which are substantially greater per MHz of use than the highest value licensed applications. This finding is an important one for Ofcom to consider in determining possible future designations of LE spectrum.

Interference is unlikely to constrain the value projections for many of the 10 study applications. But more work is required to look at these effects. In particular it is important to consider the likely congestion affects of RFIDs, one of the three most valuable of the study applications.

There is considerable uncertainty associated with the economic value projections. Ofcom can reduce this uncertainty by monitoring take up of the most important applications and by studying in more detail the use which UK households make of wireless devices.

Appropriate harmonisation of LE spectrum is important and could be worth up to £4.5 billion per annum to the UK. The three most valuable LE applications studied already use spectrum which is largely harmonised on a global basis. But potentially there are many other LE applications which are internationally portable and where there are critical mass problems in growing the market. For this subset of applications harmonisation could generate substantial economic gains.

Not all LE applications require harmonisation. Indeed harmonisation could generate substantial economic costs (e.g. telemetry in the utilities) so it make sense for Ofcom to carry out an impact assessment before deciding to press for harmonisation for spectrum use for any given LE application.

In deciding what position to take on harmonisation, Ofcom:

- Should be proactive in anticipating and responding to development outside the EU as well as within it, before deciding on harmonisation of LE spectrum
- Should only support harmonisation initiatives which increase sharing between licence exempt and licensed services if it is confident there will be no material risk of interference.