**Report for Ofcom**

# Use of wired vs. wireless study – Part 2

## Spectrum planning for the London 2012 Olympic Games and Paralympic Games

*01 June 2009*

*YGXA001B*

analysys mason

# Contents

Analysys Mason Limited
Bush House, North West Wing
Aldwych
London WC2B 4PJ
UK
Tel: +44 (0)20 7395 9000
Fax: +44 (0)20 7395 9001
enquiries@analysysmason.com
www.analysysmason.com

## ACKNOWLEDGEMENTS

*This report was made possible through support from Broadcast RF, Gigawave, Link Research, SFP (Société Française de Production) and SNG Broadcast Services. Analysys Mason gratefully acknowledges their contributions to this study.*

# 0 Glossary

| *Term* | *Gloss* |
|---|---|
| **ASI** | Asynchronous interface |
| **BVT** | Broadcast Venue Team |
| **COFDM** | Coded orthogonal frequency-division multiplexing |
| **ENG** | Electronic news gathering |
| **HB** | Host broadcaster |
| **HD** | High definition |
| **IBC** | International Broadcast Centre – the facility where the host broadcaster receives the video/audio signals from the venues and distributes them to the RHBs |
| **IF** | Intermediate frequency |
| **IOC** | International Olympic Committee |
| **IP** | Internet Protocol |
| **LOCOG** | The London Organising Committee of the Olympic Games and Paralympic Games |
| **MRC** | Maximum ratio combining |
| **OB** | Outside broadcast – refers to any television or radio programme that is broadcast from a location away from the normal studio setting |
| **OBS** | Olympic Broadcasting Services |
| **ODA** | Olympic Delivery Authority |
| **PMSE** | Programme making and special events |
| **RF** | Radio frequency |
| **RHB** | Rights-holding broadcaster |
| **SNR** | Signal-to-noise ratio |
| **UHF** | Ultra-high frequency |

# 1 Executive summary

## 1.1 Introduction

In our earlier report to Ofcom, the *Use of wired vs. wireless study*, Analysys Mason identified three deployment options for wired or hybrid wired-wireless technologies to support wireless camera systems, which could help reduce the requirement for radio spectrum for the London 2012 Olympic Games and Paralympic Games. We assessed the options in terms of technical feasibility, advantages and disadvantages of deployment to the various parties, the costs, and the legacy benefits.

Ofcom has subsequently commissioned Analysys Mason to conduct an extension to this study (the *Use of wired vs. wireless study – Part 2*) to examine in more depth the merits of two of the options presented in relation to wireless camera use:

- In-venue hybrid wired-wireless technical solutions for wireless camera signals between 2GHz and 7GHz.
- A city-wide receive network for wireless camera signals suitable for covering the proposed wide-area sports disciplines in London.

This new study provides Ofcom with example high-level technical solutions and associated high-level costs, to allow an assessment of the trade-off between effective spectrum planning and the estimated cost and risks of implementing the different options.

## 1.2 Key findings

***The outside broadcasting (OB) equipment manufacturers and suppliers are confident that a city-wide receive network suitable for Olympics broadcasting is deliverable, and that wireless camera frequencies up to 2.5GHz are suitable for this application.***

The proposition for a city-wide network does not present any new technical concepts, and from this perspective, we believe its implementation is certainly achievable. The proposed routes for the wide-area events, and the nature of the disciplines to be covered, present a challenging urban environment in which the system must operate. For this reason, the lower frequencies for wireless cameras – those up to 2.5GHz – would be most likely to deliver the robust solution needed for Games coverage.

***The number of receive sites needed to deliver the city-wide receive network is dependent on the transmission power levels, and the frequency band(s) used.***

This study has identified seventeen sites that could be suitable candidate locations for receive points, based on the positioning in relation to the proposed wide area routes and the type of site. We believe twelve of these would be needed to form a core network, and the number of additional infill sites required would depend on the permitted transmit power levels, and the frequencies of operation. Operation at low power (e.g. 100mW) for all wireless cameras used at the wide area events is extremely unlikely; it is standard practice for coverage of wide area events to use 1W or 2W booster amplifiers (or sometimes even higher) on the chase vehicles and/or motorbikes.

***For Ofcom, the benefit this wide-area network would deliver is a reduction in the overall concurrent channel requirement for coverage of the wide-area sports disciplines.***

By reducing, or eliminating, the reliance on aerial relay of wireless camera signals, we estimate the potential overall concurrent channel saving could be up to fifteen channels.

***The indicative cost for implementation of a city-wide receive network at 2GHz to support the wireless camera requirements for wide-area sports coverage, for operation during the Games and associated test events, is between GBP2.13 million and GBP3.20 million.***

The base case cost of GBP2.13 million is based on current technology, but detailed testing is essential to determine the precise number of receive sites needed, the fibre availability, and hence the cost. The base case retains one aerial helicopter receive point and downlink, and makes use of wireless point-to-point backhaul for one third of the receive sites. An all-fibre solution with no aerial relay would cost in the region of GBP3.20 million.

***We do not believe that such a network is deliverable at higher frequencies; this has not been attempted before, and if the technical barriers could be overcome, the economic barriers would likely prevent this being a feasible option.***

There is significant uncertainty as to whether a wide-area receive network for wireless cameras working on frequencies above 2.5GHz could be achieved. If a technical solution could be developed within the challenging timescales, it would be more complex, with significantly higher levels of receive sites and radio equipment, and with associated increase in costs. The other important consideration is the increased level of risk. Unlike some of the sports disciplines, where wireless cameras are used to enhance the coverage, the host broadcaster is completely reliant on the wireless camera links to deliver uninterrupted coverage for the wide-area events.

***We do not recommend a shared receive network between sports and ENG during the Games.***

We do not recommend sharing a receive network between sports coverage and news gathering applications because of the different characteristics and requirements of the two applications. However, there could be scope for sharing tower infrastructure, particularly at the Olympic Park, where news broadcasters do not currently have infrastructure. We believe that the radio equipment and networks should remain separate.

***There are three different ways a city-wide receive network could be delivered: private funding, public/private funding, or public funding.***

Models for delivery of new infrastructure and its operation are particularly important where a variation is likely between the cost of implementing a solution for broadcast coverage driven by the broadcasters' priorities, and the cost of a solution driven by efficient and effective overall use of spectrum. The viability of any level of private funding is likely to require that the spectrum made available for the network for the purposes of the Games will continue to be available after the Games. The options for funding will include consideration of whether the entire network remains in place after the Games, or whether some, or all, of the infrastructure/equipment is decommissioned after the Games.

***The city-wide receive network could have direct legacy benefits in the central London portion of the proposed coverage area; the likelihood of sustained requirement for this infrastructure in east London will be dependent on the profile of the future use of the Olympic Park venues.***

The post-Games use for the Olympic Park venues, and most notably the Olympic Stadium, is not yet certain, so it is difficult to assess the potential demand for wireless camera receive infrastructure after the Games in this portion of the network. Part of the proposed coverage area coincides with the annual London Marathon route, which could be one use for it. A commercially sustainable proposition is most likely to come from ENG demand for receive points over and above the existing provision in London, most of which is currently concentrated around the South Bank, and covers the regular news gathering locations, such as Westminster.

The key legacy benefit from this network could be the associated fibre infrastructure, as was the case at the Beijing Games, where the radio equipment was decommissioned after the Games, and only the fibre infrastructure element of the receive network remained in place.

***In-venue hybrid wireless-fibre systems are currently used to good effect by broadcasters, and are likely be the solution of choice for the host broadcaster (OBS), and its suppliers, for the venues that require wireless camera reception.***

In-venue hybrid fibre-wireless systems are widely used, and could be the OBS solution of choice for certain venues. A typical solution would use diversity reception at two or more sites within the stadium, and feed these into a central receiver that provides an output base for each wireless camera summed from all received signals. Receive equipment would typically be located in the OB compound at the venue, connected to the antenna arrays via fibre extender links. We believe there is little scope to improve the spectrum efficiency of the current systems.

The cost for a two-site fibre-wireless solution, for both the Olympic Stadium and the Eton Dorney rowing/kayaking park, would be in the region of GBP215 000 per venue. This would be suitable if using up to 2.5GHz transmission. At 7GHz the site requirements increase, and the cost for the Olympic Stadium would rise to approximately GBP450 000. The Eton Dorney solution would rise to approximately GBP340 000.

***For Ofcom, the real benefits can instead come from using higher frequencies for stadium and other contained events.***

The most attractive option for spectrum planning is to migrate from the lower, congested bands around 2.5GHz to higher frequencies for stadium applications. Operation at 7GHz is proven in certain sports venue environments, and is being used increasingly by broadcasters. Any given frequency up to 7GHz can theoretically be used for these types of receive systems, although to operate at frequencies that are not typically used at present would require investment in new radio equipment; equipment is designed for use for a specific range of frequencies – the usual tuneable range is up to 500MHz.

# 2 Introduction

## 2.1 Context

Ofcom is responsible for organising a full spectrum plan for the London 2012 Olympic Games and Paralympic Games ('the Games'). It faces a considerable challenge to meet the guarantees made by the Government to the International Olympic Committee (IOC) that the frequencies required for the organisation of the Game will be allocated and that fees payable by the 'Olympic Family' will be waived. The group of users to which the guarantees apply include the Olympics host broadcaster (HB) and the rights-holding broadcasters (RHBs).

In 2008, Analysys Mason delivered its report to Ofcom detailing our study on the use of wired versus wireless technologies for the Games (the *Use of wired vs. wireless study*).[1] The report identified three deployment options and three sub-options to support wireless cameras that could help reduce the requirement for radio spectrum for the Games and associated test events.

Ofcom has commissioned Analysys Mason to conduct an extension to that study (the *Use of wired vs. wireless study – Part 2*) to examine in more depth the merits of two of the options presented in relation to wireless camera use. These are a city-wide receive network and in-venue solutions. This new study provides Ofcom with example high-level technical solutions and associated high-level costs, to allow an assessment of the trade-off between effective spectrum planning and the estimated cost and risks of implementing the different options.

This section introduces the key issues facing Ofcom regarding spectrum planning and broadcasting for the Games, outlines the findings of the original study, and sets out the scope of this further study.

## 2.2 Spectrum planning for London 2012: key issues

- Ofcom is responsible for organising a full spectrum plan for the Games. It has published a consultation on a draft plan in April 2009, and intends to issue its statement later this year.
- Spectrum is an increasingly scarce resource, and Ofcom faces an extremely challenging task in balancing demands from the different end-user groups within the 'Olympic Family' as well as between Games and business-as-usual use.
- Ofcom wishes to explore the potential to use wired technologies to reduce the demand for wireless applications, and therefore reduce the requirement for spectrum.
- The *Use of wired vs. wireless study* was the first step to achieving this understanding; this additional study provides further information to inform Ofcom's spectrum planning work.

---

1 Published, with this study, alongside Ofcom's consultation on a draft spectrum plan for the Games.

## 2.3 Broadcasting the Olympics and wireless camera requirements: key issues

- The HB's use of wireless cameras almost doubled between the Athens Games (2004) and the Beijing Games (2008). We expect this increase to continue with the London Games, for the coverage of some sports disciplines, but the increase is likely to be of a lower order.
- The number of *concurrent* wireless camera channels needed in the London 2012 spectrum plan is dependent on the distance over which the channels can be reused (which varies depending on which frequency band is used), as well as the time-dependent factors, such as the competition timetable.
- Sports coverage has arguably driven the outside broadcast (OB) industry. This, along with the immense revenues generated by rights fees, means that sports OBs have become the most pressured of production environments.
- Wireless cameras are a key part of the broadcasters' production plans. These plans cover both the venue production plans – an Olympic Broadcasting Services (OBS) responsibility – and other wireless camera use, such as electronic news gathering (ENG) and RHBs (200+ broadcasters).
- Sports OB solutions are currently driven by picture quality, and not spectrum efficiency, and decisions on the solutions are taken by the HB and the broadcast venue team (BVT) contracted by the host broadcaster to deliver the production for each discipline.
- In the past decade, the most notable changes in sports broadcasting have come from increasing consumption, which increases the pressure on the HB to produce compelling and innovative sports content. Wireless cameras have an increasing role to play in this, as technology improvements have ensured a high link reliability and performance can be achieved. The following two examples illustrate the developments in consumption and demand for Olympics content:

  – the BBC televised 250 of the 4000 hours of sport for Sydney in 2000 (6%); in Beijing 2008 this had increased to 1250 hours (31%), and the aim for London is to televise 100% of the sports action
  – there were 2.4 million Web streams from the Athens Games in 2004, which increased to 38 million streams from Beijing in 2008.[2]

## 2.4 Findings of the original *Use of wired vs. wireless study*

In the *Use of wired vs. wireless study*, we identified wired or hybrid wired-wireless technologies and developed deployment scenarios for the technologies that could replace some of the wireless requirements. We assessed the scenarios in terms of technical feasibility, advantages and disadvantages of deployment, costs, and legacy benefits. Our key findings were:

[2] Source: *Broadcast*, 13 February 2009.

- we do not believe that a reduction of the key wireless broadcasting applications from usage levels seen in Beijing is a viable option
- certain wired technology options can reduce the number of channels needed to support the broadcasters' requirements, or enable a move to less-congested channels
- maximum spectrum savings will be realised by focusing on wireless camera use at the wide-area sports events and the Olympic Park
- implementation of proven alternative technology options could result in a channel saving of up to 35% on the wireless camera base case.[3]

The calculation for the 35% channel saving was based on the combination of three 'wired' options:

- where possible, replacing wireless cameras with wired (up to 3% channel saving)[4]
- the use of in-venue hybrid wired-wireless systems for roving wireless cameras, using frequencies in the 2GHz to 7GHz range (up to 5%)
- use of an appropriate city-wide receive system for covering the wide-area sports disciplines, eliminating the use of aerial relays (up to 27%).

## 2.5 Scope of the *Use of wired vs. wireless study – Part 2*

The brief from Ofcom for this new study was to examine in more depth the merits of two of the options presented in the *Use of wired vs. wireless study*. This study provides Ofcom with typical high-level designs and associated high-level costs, to allow Ofcom to assess the relative benefit of implementing the alternative deployment options against the base case option, which is a solution typically implemented by the broadcasters at present.

The aims of this *Use of wired vs. wireless study – Part 2* are outlined below. The two options that require further investigation in this study outlined in Sections 2.5.1 and 2.5.2.

- To define and cost in-venue hybrid wired-wireless technical solutions for wireless camera signals between 2GHz and 7GHz, and additionally up to 10GHz if feasible, that had been identified as having potential to reduce the channel requirements for this application:
  - to achieve this, we have chosen to develop typical solutions for the Olympic Stadium, and for Eton Dorney (the rowing and flat-water canoeing venue).
- To define and cost a city-wide receive network for wireless camera signals suitable for covering the proposed wide-area event routes in London. Wide-area events include the marathons, road walks, road cycling and road cycling time trials, and the triathlon cycling.

---

3 The 'base case' is one that is not driven by spectrum efficiency; it is the solution that a broadcaster would typically choose at present, based on comparable sports events.

4 See the *Use of wired vs. wireless study* for a full breakdown of each wireless camera used in Beijing for the sports coverage, and the assumptions on which our analysis was based. There are obvious difficulties in estimating the number of wireless cameras that could be wired 36+ months ahead of the London Games, not least without knowing the precise location and immediate environment of each camera at the proposed London 2012 venues. However, we were able to conclude that the potential to save wireless camera channels in this way will be extremely limited, if the quality of the broadcast production is not to be overly compromised.

- To develop views on the possible models for implementation, ownership and operation of the above solutions.
- To develop views on potential legacy use for the above solutions.

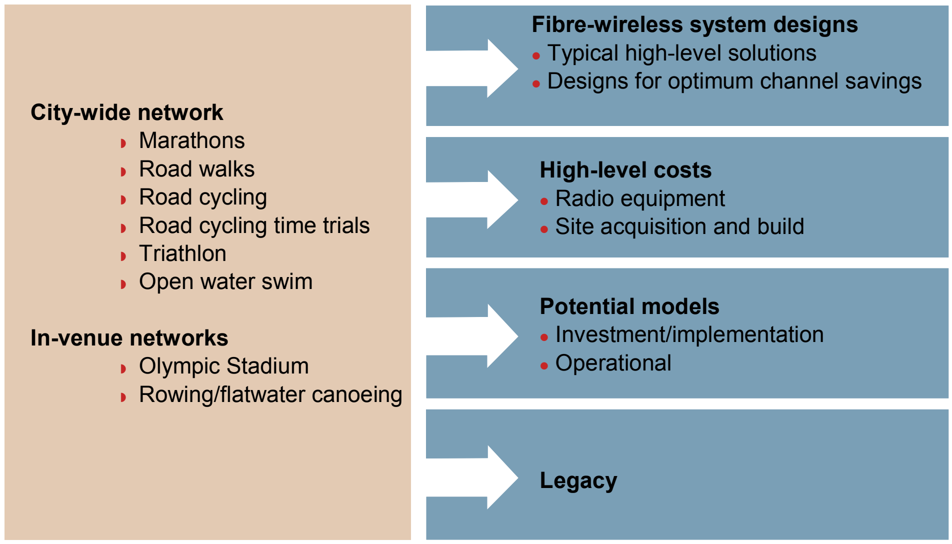


*Figure 2.1: Scope of the Use of wired vs. wireless study – Part 2 [Source: Analysys Mason]*

### 2.5.1 In-venue hybrid wired-wireless solutions

This study has explored in detail the potential of hybrid wired-wireless solutions deployed within venues to reduce the overall number of concurrent channels needed to meet the wireless camera requirements we defined in the *Use of wired vs. wireless study*.

The hybrid systems we describe in this report are not *alternative* deployment options in the sense that they are new; the solutions we describe in this report may closely resemble the solution of choice for OBS or its suppliers for these types of venue. However, the solution choice has traditionally been driven by the required picture quality, and not the effective use of spectrum across all the venues considered together. Therefore, we have assumed, for the purposes of our analysis, that overall spectrum efficiency is the primary driving factor, and that this would result in an alternative solution to one driven by other factors.

The design and subsequent cost of in-venue solutions are particular to individual venues. We have chosen to focus on the Olympic Stadium and Eton Dorney, as these are outdoor/open venues[5] that host events with a high level of wireless camera use.

5 The significance of this factor is the difficulty of containing the signals within the venue, as opposed to a closed arena that would be more effective in this regard.

### 2.5.2 City-wide receive network

A city-wide receive network would address, as a minimum, the use of wireless cameras at the wide-area sports events, where the end user of the system would be the HB, OBS.

We have also addressed the option of sharing infrastructure for sport and ENG at various levels. ENG requirements would include those in central London and also at the Olympic Park. For example, we identified in our previous report that it was common for the major broadcasters to set up an area near the main Olympic concourse to be used as an interview area. This would be one potential ENG use of a shared receiver infrastructure.

For the wide-area events, the benefit of having fixed receive points that connect directly into a high-speed fibre network is the potential to eliminate the aerial relays traditionally used to transmit the wireless camera signals to the broadcast centre – in this case the International Broadcast Centre (IBC), located at the Olympic Park[6]. Aerial reception and downlink via helicopter is often the only feasible option for parts of the routes, and this increases the radio channel requirements.

## 2.6 Related documents

This study forms part of Ofcom's programme of work for spectrum planning for the London 2012 Olympic Games and Paralympic Games, and builds on the consultation and studies set out in the following five documents:

| *Title* | *Document type* | *Publication date* |
|---|---|---|
| Spectrum planning for the London 2012 Olympic Games and Paralympic Games | Discussion document (Ofcom) | 31 November 2007 |
| Examining the potential to use SHF and EHF spectrum to support Wireless Camera PMSE applications | Study (Sagentia) | 25 January 2008 |
| Spectrum planning for London 2012: summary of discussion document responses | Statement (Ofcom) | 07 May 2008 |
| Spectrum planning for the London 2012 Olympic Games and Paralympic Games | Consultation (Ofcom) | 27 May 2009 |
| The use of wired versus wireless technologies (the *Use of wired vs. wireless study*) | Study (Analysys Mason) | 27 May 2009 |

*Figure 2.2: Relevant Ofcom London 2012 spectrum planning documents*

6 Often the signal is relayed to an intermediate helicopter receive point for onward transmission by point-to-point microwave or fibre.

## 2.7 Document structure

The remainder of this document is laid out as follows:

- Section 3 reviews the level of wireless camera use, and the types of use that would typically be used to cover the relevant sports disciplines
- Section 4 provides our discussion and analysis of wide-area receive solutions
- Section 5 addresses the typical in-venue hybrid solutions
- Section 6 provides our view on the potential models for implementation and operation of the solutions described in the previous sections
- Section 7 sets out our conclusions of the study.

# 3 Overview of wireless camera use at the Games, and the scope of this study

In the *Use of wired vs. wireless study*, we researched the level of wireless camera use for sports coverage at the Beijing Games. We have used this as our base case for wireless camera use at the London 2012 Games. In this section we outline the findings from the previous study, and highlight the overall design considerations that apply to wireless camera use at the Games.

## 3.1 Competition venues with a wireless camera requirement

The illustrative map in Figure 3.1 indicates the sports venues that will use wireless cameras in the base case. The number of cameras indicate the HB use only; later we outline our assumptions on RHB use within venues. Please note that the number of cameras does not necessarily equate to the wireless camera channel requirement – this is often higher.

This study focuses on the London area, which includes all sports venues as they currently stand, with the exception of the five football stadia being used for the preliminary rounds of the football tournaments, and the sailing events at Portland and Weymouth. [7]

The five large football stadia outside London present relatively few problems in terms of spectrum planning, given their distance from London, and the minimal use of wireless cameras. There were no wireless cameras used at the football tournament in Beijing prior to the finals (hence their absence from Figure 3.1), and this could be the case again for London 2012.

Portland and Weymouth is the most important venue outside London, and will host the sailing events. The considerable ramp-up of infrastructure needed at this venue will present many challenges, however, in the context of this report, it is sufficiently isolated from the hub of the Games activity in London for it not to warrant special consideration in this study.

We note that there is a distinct possibility that the wireless camera requirements in London 2012 will include sports events for which they were not used in Beijing 2008. Equally, the requirements for some sports may show an increase. However, it is not possible at this stage to predict with any certainty where these new developments may arise, and to what extent. We therefore believe that flexibility and scalability are important characteristics of any chosen wireless camera solution.

7 We include Broxbourne, Eton Dorney and Hadleigh Farm as being within the London area, even though these sports venues fall outside the M25.

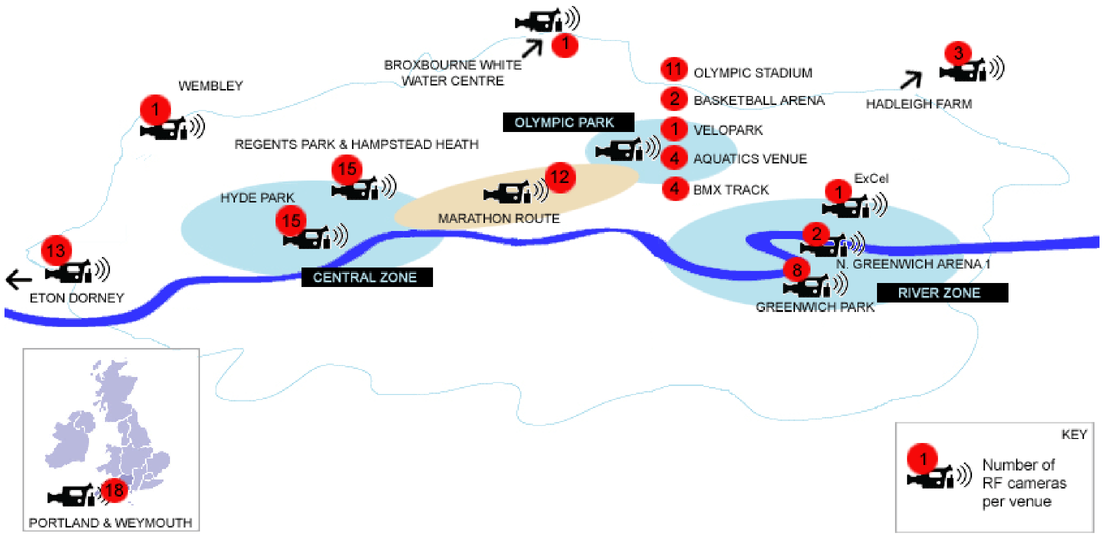


*Figure 3.1: Venues with wireless camera requirements in the base case – illustrative map [Source: Analysys Mason, Use of wired vs. wireless study, 2008]*

## 3.2 Wide-area events

Wide-area events have the largest wireless camera requirements, and will be concentrated in the Central to East London areas. The map in Figure 3.2 gives an overview of the proposed routes.


*Figure 3.2: The proposed wide-area event routes [Source: Analysys Mason]*

## 3.3 Concurrent wireless camera requirements

We have used the proposed venues and the proposed competition schedule to generate our estimate for concurrent wireless camera requirements, although we note that both these are not yet finalised.

By grouping the venues by geographical zones, a picture emerges of the key venues that might drive the overall wireless camera channel requirement. By overlaying the competition timetable, the most beneficial areas on which to focus when looking at alternative scenarios becomes clear, as shown in Figure 3.3.

We have chosen to address solutions for three different applications for the purposes of developing cost estimates, and identifying the benefits and risks for these types of hybrid fibre-wireless solution:

- in-venue fibre-wireless receive system at the Olympic Stadium
- in-venue fibre-wireless receive system at Eton Dorney
- a city-wide wireless receive network to cover the routes illustrated in Figure 3.2 and the Olympic Park.

The above solutions could be extended to other competition and non-competition venues.

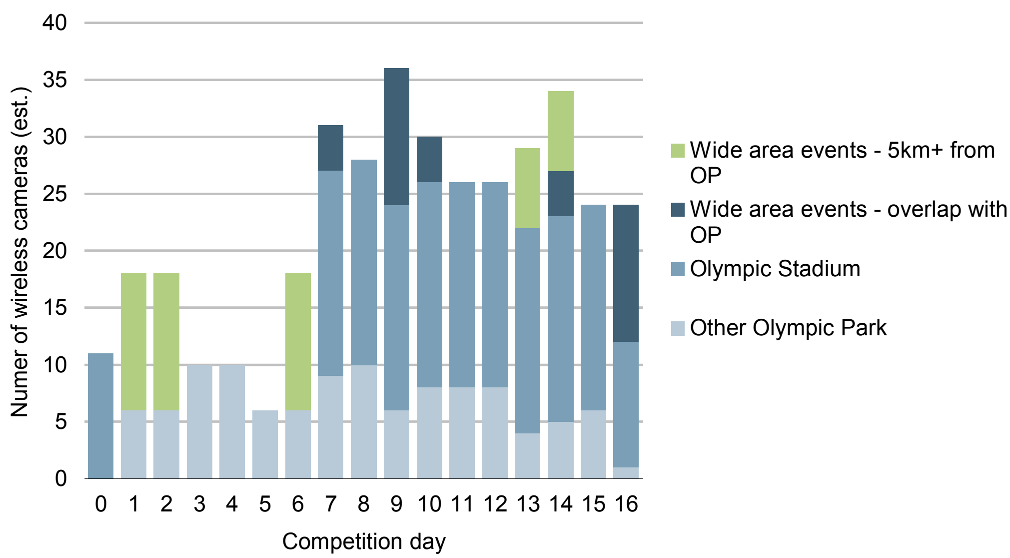


*Figure 3.3:* *Breakdown of wireless camera use in and around the Olympic Park on the days of peak usage – day 11 and day 12 of competition. [Source: Analysys Mason]*

Figure 3.3 illustrates that days seven to ten are the critical competition days, because the wide-area events with finish lines in the Olympic Stadium (marathons and road walks) are taking place during the track and field schedule, which also take place in the Olympic Stadium.

### 3.3.1 Wireless camera use

The level of OBS (host broadcaster) wireless cameras at the venues covered in this study is provided in Figure 3.4.

| *Event* | *Handheld/ Steadicam* | *Airborne* | *Vehicle-mounted* | *On-board* | *Mini* | *Flown wire* |
|---|---|---|---|---|---|---|
| Opening & closing ceremonies | 3 | | | | | 2 |
| Track & Field | 9 | | | | | 2 |
| Marathons | 2 | 3 | 7 | | | |
| Road walks | | | 4 | | | |
| Road cycling | | 1 | 9 | | | 1 |
| Cycling time trial | 2 | 3 | 7 | | | |
| Open water swim | | | | 7 | | |
| Triathlon | 4 | 2 | 7 | | 2 | 4 |
| Rowing | | 1 | | 7 | | |
| Flat-water canoeing | 1 | 1 | 4 | 3 | 1 | 1 |

*Figure 3.4: Wireless camera use at certain sports venues [Source: Analysys Mason,* Use of wired vs. wireless study*, 2008]*

We identified in our previous study that the Olympic Stadium will be a significant source of demand for wireless camera frequencies for the opening and closing ceremonies, and for the track and field events. Wireless camera requirements for sports coverage in other Olympic Park (OP) venues are relatively low, and predominantly from indoor venues, such as the aquatics centre. Depending on its construction, and the frequencies used for wireless camera systems, an indoor venue is typically able to contain the signals effectively. A predominantly glass structure would not perform as well as a concrete structure in this regard.

We have assumed that the River Zone venues (Greenwich area) are a sufficient distance from the OP to reuse the frequencies between these two zones for the ground-based wireless cameras.

A detailed breakdown of the wireless camera use for the wide-area events is provided in our discussion of the wide-area receive network in Section 4.

Eton Dorney has a large wireless camera requirement, but is isolated from the rest of the London venues.

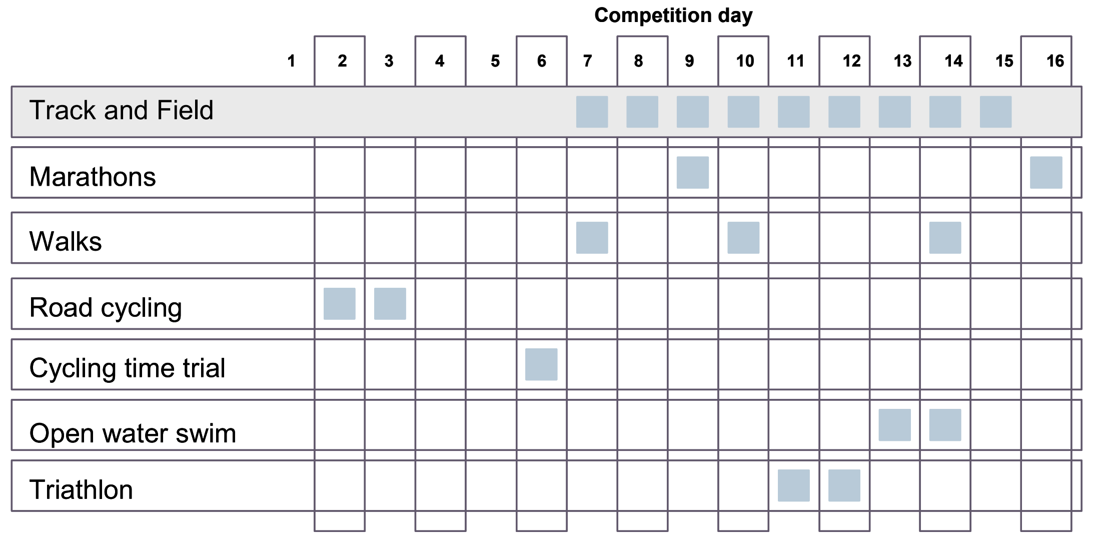


*Figure 3.5: The proposed competition timetable for the wide-area events and the track and field events [Source: LOCOG]*

As shown in Figure 3.5, there is no major overlap in the competition schedule for the wide area events. This is will help in keeping the capacity requirements to a minimum for the wide-area receive network.

## 3.4 ENG

Preparing and transmitting news reports is one of the most challenging tasks for broadcast organisations. ENG requirements, by nature, will be much harder to predict than the sports requirements, as ENG systems are generally used in rapid deployment situations where the signal path will be dictated by the origin of the event, and clear line of sight may not be available.

The ENG requirements during the Games will be additional to existing ENG needs that will continue to take place in London during the Games.

We assume that key tourist attractions in Central London, and the public areas around the Olympic Park, are likely to be important locations for news organisations during this time.

## 3.5 Technical design considerations

Robust radio link performance is critical for achieving a high-quality high-definition (HD) transmission from a moving source. Two factors dominate the received signal quality:

- signal strength
- distortions due to multiple received signals (multi-path).

Because a typical transmission wavelength at 2GHz is only 15cm[8], even minor relative movement between the transmitter and receiver will transcribe multiple full-cycle phase changes seen by the receiver. When the multiple signals are in phase, the receiver will see a signal significantly in excess of that expected. Conversely, a 180-degree phase conflict could cause total signal cancellation if the microwave power is reflected highly efficiently.

### 3.5.1 Wireless camera frequencies

The allocated spectrum for video links are at 2GHz, 2.5GHz, 3GHz, 5GHz, 7GHz, and 8GHz to 12GHz.[9] Current wireless cameras typically operate in the spectrum from 2GHz to 3GHz, although manufacturers do have standard equipment available for operation at up to 7.5GHz, and are able to make equipment for higher frequencies to order. Large scale migration to channels outside the 2GHz to 3GHz range will require the broadcasters and OB hire companies to carry out significant replacement of their radio link equipment.

Ofcom is interested in the differences above and below 4GHz when looking at relative costs and feasibility. Previously, we have referred to 3GHz as the cut-off because this is where the large majority of current purchased equipment is designed to operate.

### 3.5.2 Diversity

Diversity is a key concept in microwave transmission systems, and the typical systems described in this report make use of diversity reception. Signals from camera back transmitters and vehicle-mounted systems are often transmitting in environments that greatly attenuate the signal, such as crowded urban areas. The signal is often reflected off walls and other solid objects, and the signal transmitted from the camera will arrive at the receiver many times, having taken many different reflected paths.

The signals could add constructively or destructively, due to the instantaneous phase relationship. In a mobile phone, for example, the mobile transmitter is not perfectly fixed in space, so the summation at the antenna is continually changing. This is referred to as fast fading, and can cause lost reception. The communication link is built with a minimum signal-to-noise ratio (SNR) required to demodulate the signal. Diversity allows for a higher probability that a signal will arrive at the receive site above the minimum SNR.

Using diversity antennas – which means the use of an array of two or more physically separated antennas at the receive site – increases the chances that a signal with sufficient receive strength will be found. While one antenna may be experiencing destructive interference, the other may not.

---

8 Wavelength (λ) = c/f where c = speed of light ($3 \times 10^8$ m/s) and f = frequency.

9 Full details of the current band plans for programme making and special events (PMSE) spectrum are available on the JFMG website (www.jfmg.co.uk).

The diversity receiver equipment improves the quality of the output signal by instantly switching to the input that has the best signal at that point in time. This is currently achieved using Maximum Ratio Combining (MRC), a COFDM diversity technique.

It is not possible to determine which order of diversity antenna (e.g. two-way, four-way, etc.) is needed until the system is tested in its specific environment. For the purposes of building a cost model, we have assumed that four-way diversity will be sufficient.

### 3.5.3 Transmit power

We have applied the following rules of thumb:

- 100mW camera transmit results in a 1km range (non-line of sight); standard wireless transmitters from Link Research and Gigawave produce 100mW of RF.
- 1W camera transmit results in a 3km range (non-line of sight); 1W represents the maximum that could reasonably be produced by a unit sitting directly in the triax socket, in other words, the maximum for portable equipment.
- The approximate range with a 5W amplifier would be 6km. In Beijing, 4W to 10W transmitters mounted on the back of motorbikes were used. This gave each receive point a footprint of approximately 20km, but the upper range of these transmit powers is very unlikely to be permitted in London, and would restrict the ability to reuse frequencies in the other London venues.

An important point to note here is that the footprint for a receive site cannot necessarily be increased by simply increasing the transmit power of the wireless cameras, and this would not represent best practice. Having several cameras all transmitting at high power can cause problems, most notably the 'near-far effect'. This is where a high power transmitter close to a receive site drowns out the lower power signals further away from the receive site, effectively making it very difficult to detect or filter out a weaker signal amongst stronger signals. The power levels would need to be carefully managed, with cameras close to receive sites turned down to 100mW.

### 3.5.4 Scalability

The wireless camera requirements will not be static until the last weeks, or even days, before the competition starts – it is usual for the venue broadcast plans to undergo a certain amount of refining at this late stage, and it is important for a solution to be able to accommodate a certain level of last-minute adjustment.

One advantage of a wide-area solution that uses helicopter relays over an all-terrestrial solution is the responsiveness of helicopters to make adjustments in positioning to suit the needs at any particular instant in the race. A fixed receive network is a rigid design, and this is a potential risk, as the design needs to be formulated well in advance of the Games.

# 4 Analysis: City-wide receive network

## 4.1 Introduction

A city-wide receive network is achieved by combining the signals from several receive sites located across the city that have been received from one or more wireless cameras, and producing resultant output signals (one for each camera) that represents the strongest possible for each camera.

This is made possible by using the COFDM modulation scheme, diversity technology and sectorised antennas. The outcome is a multi-site network that can seamlessly track a wireless camera transmitting on a single channel from the coverage area of one receive point to the coverage area of another, allowing the camera operator to roam freely throughout the combined coverage area without loss of signal.

A typical diversity receiver network is illustrated in Figure 4.1, which shows how a single wireless camera could be tracked across the combined coverage area of three receive sites.

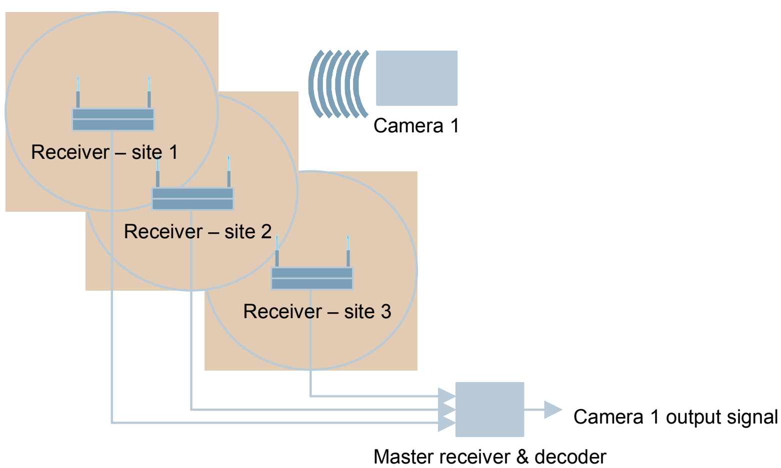


*Figure 4.1: A typical diversity receiver network [Source: Analysys Mason]*

In the diagram above, each of the three receive sites has been illustrated with two-way diversity – this means each has two physically separated antennas, and the receiver compares the signal from each, and switches instantly to the one with the best signal. The resulting three signals are fed to a master receiver, which performs diversity on the three input streams, to select the best output signal for Camera 1. This builds a complete video and audio output regardless of the antenna from which the input originated – even building a valid signal out of several inputs from different antennas within the same network.

## 4.2 Benefits for spectrum planning

The most efficient spectrum plan will support the required number of wireless cameras over the required coverage area using the least number of channels possible, while limiting the extent of transmission beyond the required area. The city-wide network would help achieve this by providing a ground-based means to receive signals transmitted at low power (ideally up to 100mW), so that the reuse of frequencies used for wireless cameras can be achieved over the shortest distance possible, and the risk of harmful interference with other transmissions in neighbouring areas is minimised.

One approach to achieving this is to restrict the use of aerial relays of wireless camera signals via helicopter, in which the wireless camera signals from the ground are multiplexed, and the combined signal is transmitted to a terrestrial receive point, usually an intermediate location. Typically, this downlink transmission would be on a higher frequency. This approach effectively doubles the overall number of channels required for wireless cameras, and also increases the area over which some of these frequencies are used and therefore limits re-use – the precise distance is dependent on the transmit power of the uplinks and downlinks.

## 4.3 Examples of current use

The UK's major news broadcasters have each implemented single ENG central receive sites in London. In addition, an independent receive network aimed at ENG users was launched by SNG Broadcast Services in late 2008. These systems use diversity reception to cover the main news locations, which include Westminster, the Bank of England, and parts of the Square Mile in the City, typically using a 1W camera back transmitter operating at 2GHz.

SFP, a major broadcast company in France, and one of the European leaders in digital RF ground-to-air and relay transmissions, manages the Tour de France host broadcast production, and was also contracted to produce wide-area events at the Games in Athens and Beijing.

For both the Beijing road cycling and the Tour de France, SFP designed and implemented a receive network over a very wide area (much wider than the proposed London 2012 routes) that relied on transmitters operating at high power, and used several helicopters and aeroplanes as mobile relay points. In Beijing, a total of 12 receive points, mainly situated upon hotel buildings, were erected to cover wide-area events. Backhaul from the receive sites was via a fibre network provided by the host broadcaster, and handed over to local telecoms operators at the conclusion of the Games. The receive points covered an area of over 120km, and were all temporary installations, using their own generators for power at each site.

In Beijing, 4W to 10W transmitters mounted on the back of motorbikes were used. This gave each receive point a footprint of approximately 20km, however this was still not complete contiguous coverage of the wide-area events. In areas where even the high transmission power was not enough to reach the receive points, helicopter and aeroplane relays were used to cover these black spots.

For the Tour de France, a very similar set-up is often used, with temporary receive points, high transmission power, and heavy reliance on helicopter relay. In this case, rather than using a fibre network for backhaul, point-to-point terrestrial microwave links are used.

## 4.4 Illustrative solutions for London 2012

For the purposes of this study, we have defined a city-wide receive network as an interconnected network of two or more fixed receive sites to a central studio or control room, in order to receive signals from roaming wireless cameras in an urban environment.

The generic schematic diagram for this type of system is outlined in Figure 4.3, which illustrates a system able to support up to two wireless cameras. This type of system is modular, which means it is completely scalable to support the required number of wireless cameras. The diagram shows the system using two antennas per site (two-way diversity); four antennas (four-way diversity) and higher can be used to provide (at increased cost) a more robust solution if needed.

### 4.4.1 Scope

There are many variables involved in designing this type of system. In the absence of precise specifications at this stage (36+ months ahead of the Games), we have had to make a number of assumptions, and, where necessary, indicated the effect on the estimated cost of flexing some of these variables.

We have categorised the assumptions as follows:

- users of the city-wide network
- the use of aerial relays
- backhaul solution from the receive sites.

*Users*

We have identified three possible models of use as outlined below.

- OBS use only, for the live coverage of wide-area sports events. The receive sites would be backhauled on a fibre network provided by the London 2012 communications partner (BT) to the IBC production facility, where the signals from each camera chain are distributed to the RHBs.
- Some degree of sharing of the receive network between OBS and RHBs, some of whom would typically have their own directable cameras at certain venues. The RHB video output may not necessarily go via the IBC.
- A system that could cater for ENG use in addition to sports use. ENG audio/video output would need to be transmitted to the relevant broadcaster's production facility.

We believe the most likely achievable model for the wide-area network is to design for OBS use only. The reasons for not using the network for both ENG and sports include the practicalities around the control of data streams, relinquishing control of the links, particularly when rigging (e.g. the need to tune the antennas) and when it fails, and maintaining the system.

It could be beneficial to have a level of infrastructure sharing, whereby ENG users could have access to sites that have been acquired for the wide-area receive network, but would use their own radio equipment and backhaul links. Similarly, a shared receive point on the Olympic Park concourse would provide the site infrastructure in an area that no broadcasters currently cover with wireless receive points, and allow Ofcom a certain level of control of the placement of receive locations.

*Use of aerial relays*

In this report we look at the option for all-terrestrial solutions versus a mixture of terrestrial and aerial. The attraction in having at least one helicopter relay is the flexibility to be positioned where it is needed on demand. A fixed network is not responsive, and needs careful planning with a degree of contingency built in for unexpected increases in capacity. It is likely that some trade-off would be needed between spectrum efficiency and practicality, so it may be difficult to remove the helicopter relay altogether.

The terrestrial receive points around the course could be designed as helicopter receive points, to limit the distance of the downlink path, and hence the transmit power, as far as possible.

*Backhaul – all fibre versus some terrestrial point to point*

IP networks have been used successfully in many contribution networks for sporting events. For example, for the 2006 Asian Games in Qatar, the host broadcaster used fibre-optic IP networks to transmit the video signals from all the major venues to the IBC. A number of the RHBs also relied on IP networks for the distribution of their finished programming to their home countries.

The all-terrestrial solution would relay all wireless camera signals from fixed receive points via fibre to a master diversity receiver, then onward to the IBC on the Olympic Park. Alternatively, point-to-point terrestrial links could be used for backhaul from some receive sites, in certain frequency bands, where a fibre link is not feasible, or undesirable.

### 4.4.2 Geographical coverage requirements

The coverage area for the city-wide network comprises the routes for the road events, which includes the routes for the marathons, road walks, road cycling, road cycling time trials, and the triathlon route. The proposed routes for these events are described in Section 3.2.

### 4.4.3 Capacity requirements

The number of cameras that need to be supported around the wide-area routes is susceptible to change, particularly from the current point in time, over 36 months away from the start of the Games. We have estimated the cost of various implementations of a wide-area network based on our 'base case', which is outlined in Section 2 of this report, and expanded in Figure 4.2.

| *Discipline* | *Start only* | *Finish only* | *Entire course* | *Aerial* |
|---|---|---|---|---|
| **Marathons** | 1 x handheld RF unit at start area | 2 x handheld RF unit at finish area (reception via the Stadium solution, not the wide-area network) | 4 x RF units on motorbikes; 3 x RF units on chase vehicles | 2 x RF units on helicopters |
| **Road walks** | N/a | N/a | 4 x RF units on motorbikes or vehicles | N/a |
| **Road cycling** | N/a | N/a | 9 x RF units on motorbikes | 2 x RF units on helicopters<br>1 x flown-wire RF unit |
| **Road cycling time trial** | 1 x handheld RF unit at start area | 2 x handheld RF units at finish area | 4 x RF units on motorbikes<br>3 x RF units on parked vehicles on the course[10] | 2 x RF units on helicopters |
| **Triathlon** | 3 x handheld RF unit start/finish | N/a | 7 x vehicle mounted RF units for cycling & running stages<br>1 x RF unit on chase boat for swim<br>2 x RF at the transition area near the water for polecams | 2 x RF units on helicopters |
| **Open water swim** | N/a | N/a | 7 x onboard units around the 2.5km circuit | N/a |

*Figure 4.2: Base case assumptions on wireless camera use for the wide-area disciplines [Source: Analysys Mason]*

10 Reception is not needed across the entire course, but without knowing the position of the parked vehicles we assume a worst-case scenario where all receive sites could need to support these RF units.

The capacity requirements for the wide-area network are dependent on the number of cameras used for each event, but also how those cameras are used within each event. Small intermediate receive sites might serve a subset of the wireless cameras for the event. For example, in our base case, the marathon would have a total requirement for 12 RF cameras, but we would assume that only the vehicle-mounted units are needed throughout the entire course.

### 4.4.4 Solution description

The generic modular solution is illustrated in Figure 4.3. Detailed radio planning and thorough testing would be required to formulate a working solution. This detailed level of design is out of scope, but we have been able to identify a typical solution based on information from vendors and from the OB organisations' operational experience of such systems. We believe this is sufficient for obtaining the order of costing accuracy needed at this stage of the spectrum planning.

We note that there will almost certainly be developments in the technologies, and therefore the costs, between writing this report and the venue solutions being put in place.

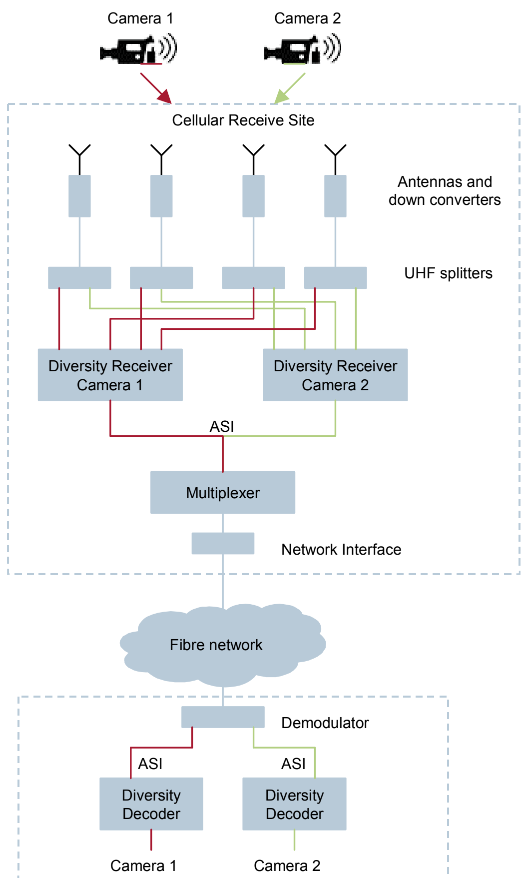


*Figure 4.3:* *Generic city-wide receive network design, shown for a system that supports up to two wireless cameras [Source: Analysys Mason]*

Figure 4.3 illustrates a receive site that has four-way diversity and supports two wireless cameras. Signals from the antennas are first fed through two-way splitters, and then into each of the diversity receiver units. The resulting signals from each diversity receiver unit are then multiplexed, typically at the asynchronous interface (ASI) level, before being transmitted via a fibre network to the master diversity receive site. The final destination will be the IBC for the host broadcaster video/audio feeds.

The above concept is modular. It is scaled up to support as many wireless cameras as necessary at each receive point. One diversity receiver is needed at each receive point for each camera, and the number of down converters and splitters will also scale up accordingly. The number of cameras that the network needs to support is a critical cost element. A 10-site network that supports two cameras will require 20 diversity receivers to operate – each additional wireless camera adds a further ten diversity receivers to the total radio equipment requirement.

### 4.4.5 Receive sites – indicative

An initial survey, undertaken for this study by a wireless camera system supplier, has identified around 17 candidate receive sites across London, based on suitable building structures and their location in relation to the proposed routes. Not all of these would be needed, as some are likely to have a large degree of overlap in coverage area. This assumes a wireless camera system using 2GHz transmission. The actual number of sites needed will depend on a number of factors, including:

- the transmit power levels that the broadcasters are permitted to use
- the transmission frequency
- any local environmental factors
- the ability to acquire the desired radio sites.

The potential receive sites have been judged purely on their proximity to the wide-area event routes, their relative positioning, and line of sight to the proposed routes, and the provision of coverage overlap. An in-depth survey would need to be carried out to ensure the suitability of these candidate sites, in terms of RF design, the facilities available at the site, and co-operation of the landlord.

In looking at the candidate receive sites, the following assumptions have been made:

- environmental effects (such as foliage and other obstacles) have a minimal impact on coverage
- the antennas are set up to give a regular 360-degree receive footprint
- transmission power is consistent
- power will be available at all receive sites
- operation at no greater than 2.5GHz is likely to be required, as this range will give the reliable penetration required, while keeping receive site numbers to a practical level.

*100mW transmission*

The standard camera back transmission pack is designed to transmit at 100mW, which generally gives a transmission distance of up to 1 km, but often lower. The power is limited to 100mW, because this is usually the licensing limit, and also in line with health and safety guidelines for portable cameras. Figure 4.4 below shows how the typical coverage might look when operating at 100mW to the candidate receive sites identified by the black dots on the diagram.

It is clear from this illustration that suitable coverage using 100mW transmission will be very difficult to achieve, even if appropriate locations for infill sites can be found. While some sites in North and East London give good overlapping coverage, there is a shortfall in central London, and a number of coverage black spots would result. In theory, the number of sites can be increased to create the desired footprint; a detailed survey will be required to determine whether or not suitable sites exist to provide the required coverage at 100 mW.

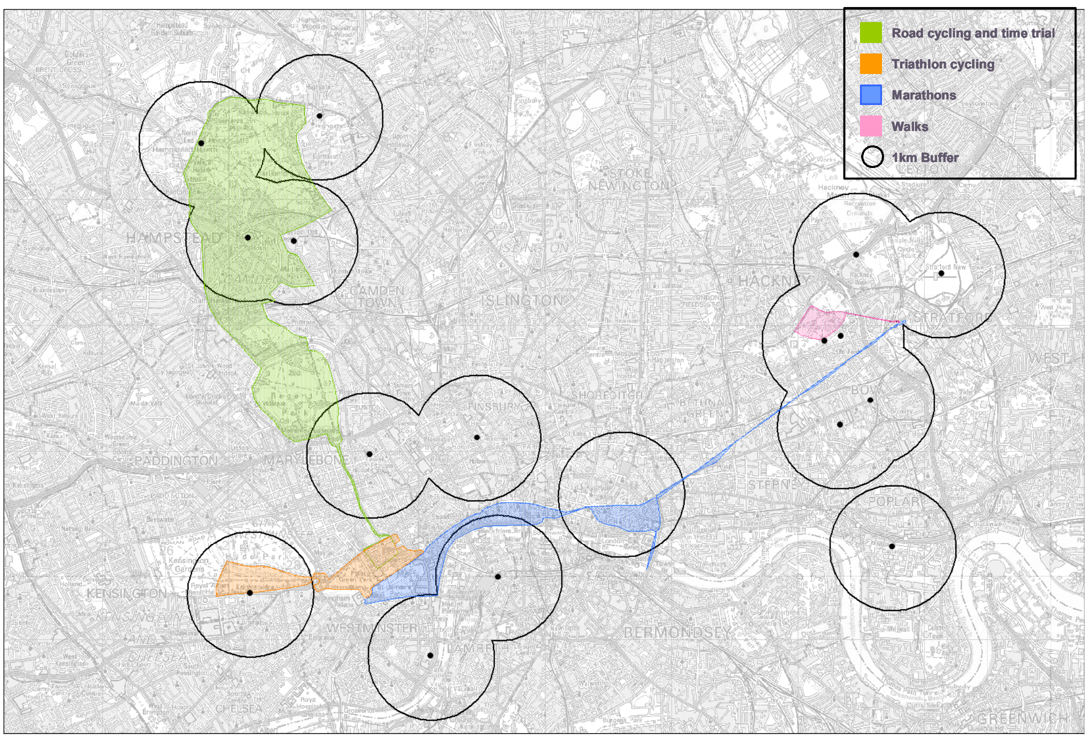


*Figure 4.4:* *Signal coverage area using a 100mW transmitter for all candidate receive sites. [Source: Analysys Mason]*

*1W transmission*

Camera back transmitters can be designed to enable a 1W booster to be added to the pack. This booster is very small (roughly the size of two match boxes) and typically enables a transmission distance of up to 3km.

Figure 4.5 suggests that 1W transmission will give a city-wide network complete coverage for the wide-area events. The areas of overlap are such that the signal *should* be received throughout the network with few possibilities of loss of transmission. However, in practice, particularly in built-up urban areas, there could be local factors, such as narrow streets and tall buildings that would require almost vertical reception from the transmitter. In these cases, helicopter reception is usually the only feasible option.


*Figure 4.5: Signal coverage area using a 1W transmitter for all candidate receive sites, with our estimate of number of receivers required at each of the core sites [Source: Analysys Mason]*

We believe that 12 of the 17 sites identified as suitable candidate locations for receive points will be needed for the core network, and we have indicated the estimated levels of receivers required at each of these core sites in Figure 4.5.

Based on the frequencies of operation and the power levels used, a number of infill sites would be needed to complete the coverage. We have not plotted these in Figure 4.4 or Figure 4.5 because our estimates for infill site requirements in our cost model are not based on known potential site locations, but on theory. We believe this approach is sufficient at this stage for estimating the likely order of variation in the overall cost in different scenarios.

Caution is needed when discussing the ability to increase power levels to increase coverage area. As discussed in section 3.5.3, it is not best-practice to simply increase the transmit power of all the wireless cameras. The 'near-far effect' in particular means that management of camera powers is very important in order to avoid a high power camera close to the receive point swamping lower power signals that are located further away.

### 4.4.6 Suitability of different frequency bands for a wide-area network

The indicative receive sites have been selected based on up to 2.5GHz transmission. The potential to use higher frequencies for the wide-area events is limited by propagation characteristics at the higher frequencies, which reduce the probability of achieving a robust design. These physical characteristics at higher frequencies include those outlined below.

- The free space path loss increases by 6dB, with a doubling of frequency. This means that the link budget at 8GHz will already include 12dB additional losses from that of a 2GHz link before other effects are taken into account (see next bullet).
- The effects of masking, shadowing and blocking are more pronounced at higher frequencies, and more likely to create unmanageable path fade – these effects could typically add up to 5dB to the link budget between 2GHz and 7GHz.
- To make up for the above link budget deficit, a 7GHz link would have to be transmitted at considerably higher power levels, which would be undesirable, and potentially prohibited on health and safety grounds, particularly with the handheld cameras that are operated within close proximity to the camera operator's head.
- One alternative to increasing power levels is to improve the antenna gain – this is most feasible in the head-end (transmit) antenna by using a narrow beam. It is very difficult in practice to design an effective narrow beam receive antenna because any link budget gains are at the expense of the desired coverage area. In addition, this method has proved ineffective in non-line of sight situations in the past. This example highlights the difficulty in predicting the performance of COFDM systems, as they often do not follow the usual mathematical models in practical situations.
- The other alternative to offset the link budget deficit at higher frequencies is to have many more shorter paths, i.e. many more receive points. We cannot judge with certainty how many more receive points would be needed, and whether it presents a robust solution, as this has not been tested or trialled for this type of application before. In theory, halving the length of the path results in a 6dB increase in link budget. On this basis, if a typical signal path is 1km at 2GHz transmission, then a reduction of the path length to around 300m would make up for the free space path loss introduced by transmitting at 7GHz instead of 2GHz.

Although we are not ruling out any frequency above 2.5GHz for on-the-ground wireless camera coverage of wide-area events, we would say that operational experience certainly discourages this approach at present.

Taking the marathon events as an example – these are high profile, with a complete reliance on wireless cameras for uninterrupted coverage; other sports events use wireless cameras to enhance the interest factor, but *could* switch to the fixed cameras if necessary to ensure continuous coverage if the wireless link failed.

The wireless aspect of the marathon coverage has to be incredibly robust because there will be many areas of the course where a fixed camera would not be in range of the action. It is possible that around 50% of the marathon transmission originates from one of the lead cameras mounted on motorcycles or chase vehicles. Overall, our view is that the engineering solution to ensure uninterrupted coverage of this high profile event is already complex; to add further complications to the RF solution by using higher frequencies would be impractical, but not impossible.

## 4.5 Costing

We have developed a high level cost model that includes the cost categories and items listed in Figure 4.6. The main inputs to the model are:

- number of receive sites usually required for 2GHz operation, and their type (for example roof top tower or radio tower). We have identified and mapped 12 'core' sites. We have assumed that a number of infill sites will be needed in addition to the core sites, and that the number of sites varies with the different scenarios presented. We have assumed that the transmit powers on vehicle-mounted cameras can be increased to sufficient levels in order to make reception within the required coverage area possible
- receive capacity of each site (i.e. number of cameras it can support)
- proportion of the sites that already have fibre to the building
- proportion of sites that will use microwave backhaul (0% in the case of an all-terrestrial solution).

| *Cost category* | *Items – typical* |
|---|---|
| Site acquisition | Negotiation, planning application, rent, lease, third-party fees (surveyor, legal, architect) |
| Site design | Technical review and drawings |
| Site rental | Rental cost |
| Civil works, Installation and Commissioning | Prelims, enabling works, tower base, interface steelwork, meter cabin base, cabin base connection, fixing & sealing of cabin and cabinet, hoisting & craneage, electrical services, cable management, lightning protection, handover pack, contingency, installation and commissioning |
| Decommissioning | Civils for decommissioning and reinstatement |
| RF equipment | Antenna array, down converters, splitters, diversity receivers (1 per camera per receive site), decoders, demodulators, power equipment (solar cells, diesel generators, chargers and batteries) |
| Backhaul link | Network interface, connection charge, rental |

*Figure 4.6: Cost categories for radio sites [Source: Analysys Mason]*

| *Solution* | *Receive sites required (est.)* | *Average no. receivers per site (est.)* | *Cost estimate (GBP millions)* | *Channel saving on the base case (est.)* | *Sensitivity to key inputs* |
|---|---|---|---|---|---|
| Up to 2GHz operation, 1 helicopter relay, 30% wireless backhaul ***[base case]*** | 12 | 9 | 2.13 | Up to 7[11] | +20% Sites -> +16% cost<br>Rental period 6 months instead of 18 -> -10% cost |
| Up to 2GHz operation, no aerial relays, 30% wireless backhaul | 18 | 8 | 3.00 | 15 | +20% Sites -> +22% cost<br>Rental period 6 months instead of 18 -> -10% cost |
| Up to 2GHz operation, no aerial relay, all-fibre backhaul | 18 | 8 | 3.20 | 15 | +20% Sites -> +22% cost<br>Rental period 6 months instead of 18 -> -9% cost |
| 4GHz+ operation, 1 helicopter relay, 30% wireless backhaul | 24 | 8 | 3.92 | Up to 7[11] | +20% Sites -> +16% cost<br>Rental period 6 months instead of 18 -> -10% cost |
| 4GHz+ operation, no aerial relays, 30% wireless backhaul | 36 | 7 | 5.62 | 15 | +20% Sites -> +22% cost<br>Rental period 6 months instead of 18 -> -10% cost |
| 4GHz+ operation, no aerial relay, all-fibre backhaul | 36 | 7 | 6.11 | 15 | +20% Sites -> +22% cost<br>Rental period 6 months instead of 18 -> -9% cost |

*Figure 4.7: High-level costs – summary table [Source: Analysys Mason]*

We estimate the overall channel saving for an all-terrestrial solution to be 15 wireless camera channels. Retaining one aerial relay would save up to seven channels, the exact level of saving being dependent on how many wireless cameras the aerial relay would need to support.

11 Assumes that two aerial relays would be used for each wide area event in the base case. The actual number of channels saved depends on how many of the wireless cameras would be supported by each aerial relay. We also assume that the use of wireless backhaul from receive sites has no impact on the wireless camera channel requirement, as these point-to-point links can be accomplished at most frequencies.

The 2GHz and 4GHz solutions are compared in Figure 4.8. The largest proportion of the costs are in the radio equipment, although the site rental and fibre network costs represent significant proportions of the overall cost.

The site rental is based on a requirement for an 18-month lease. A six-month period would result in a 10% reduction in the overall cost of the solution.

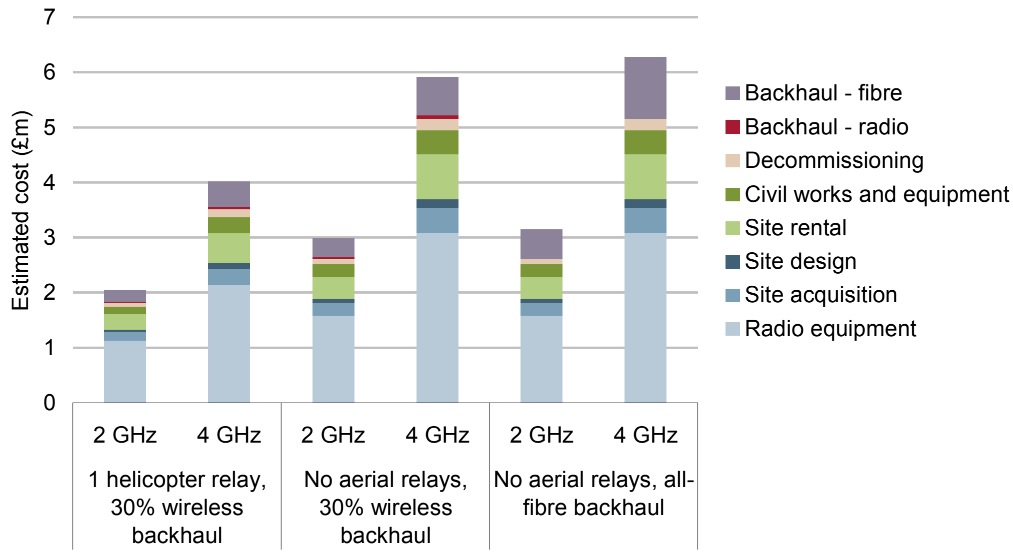


*Figure 4.8: Indicative wide-area network costs – 2GHz system versus 4GHz system [Source: Analysys Mason]*

### 4.5.1 Operation at 4GHz

To calculate the approximate order of cost increase to implement a system using 4GHz wireless camera transmission instead of the widely-used 2GHz or 2.5GHz frequencies, we have used the relative number of receive sites needed based on theoretical free space path loss as a proxy, in the absence of existing case studies for this type of system operating in this environment at 4GHz.

According to RF theory, if the transmission frequency is doubled, then the distance of the signal path is halved if all other parameters are to remain the same. We have therefore provided a cost for using twice the number of receive sites to double the number of cells in the network. In practice it may be also be necessary to increase the transmit power, for example on the vehicle-mounted units, and use some additional directional receive antennas at the receive sites.

It may not be possible to achieve the coverage to the required level of reliability at these frequencies. Only on-site testing can provide the answer to this.

The additional cost (not included in Figure 4.7) to replace the wireless camera transmitters to accommodate a move to a new frequency band is at least GBP400 000, which is the cost of replacing the 40 units used on the wide area events.

### 4.5.2 All-terrestrial solution for diversity reception versus some aerial relay

The all-terrestrial solution for diversity reception has no aerial relay of signals; it has ground-based receive sites only. This may well be an appealing solution for the overall spectrum plan, but for the broadcast venue team tasked with implementing this solution it would present considerable challenges in some areas of the course, particularly where tall buildings or narrow streets present difficulties for reliable ground-based reception. A further disadvantage is the relatively rigid design with little scope for adjustments prior to the event, and during the event itself. Helicopters would still be used for capturing aerial shots, and the reception for these could be incorporated into the diversity reception solution relatively easily.

We have assumed that the base requirement for receive sites would be increased by 50% to enable continuous reception without the use of aerial reception.

### 4.5.3 All-fibre backhaul versus some wireless backhaul

Our calculation for the fibre network cost includes assumptions on the proximity of the sites to street cabinets in Central London, and for the sites that already have fibre to the building. Of the sites that do not already have fibre, we have assumed that 30% of them would use wireless backhaul links in the base case.

We have assumed that all receive sites are connected back via fibre to a central diversity receiver, from which point the feed for each camera is transmitted via fibre to the IBC, located at the Olympic Park.

Not only are wireless backhaul links lower cost than fibre backhaul, there is also the advantage of more flexibility for late adjustments to the dimensioning of the link. Lead times for changes and re-grades of the CP fibre product run into tens of days, so the fibre service has to be designed with a certain level of spare contingency bandwidth that might not be used.

Even so, fibre would be the preferred method for broadcasters, for its optimum reliability and capacity.

## 4.6 Risks associated with site acquisition and build

The table in Figure 4.9 outlines the typical risks associated with radio site acquisition and build. One particular area for concern could be the risk of landlords increasing their rental prices for a Games-related project. The acquisition process is affected by a number of risks that can result in delay and escalating cost. One such risk to the budget is the high abortive costs if the site is not used after the acquisition process has already started. One counteractive step we would recommend is to start land banking as early as possible, in which the sites are acquired early in the project, but rents are not triggered until the site is needed.

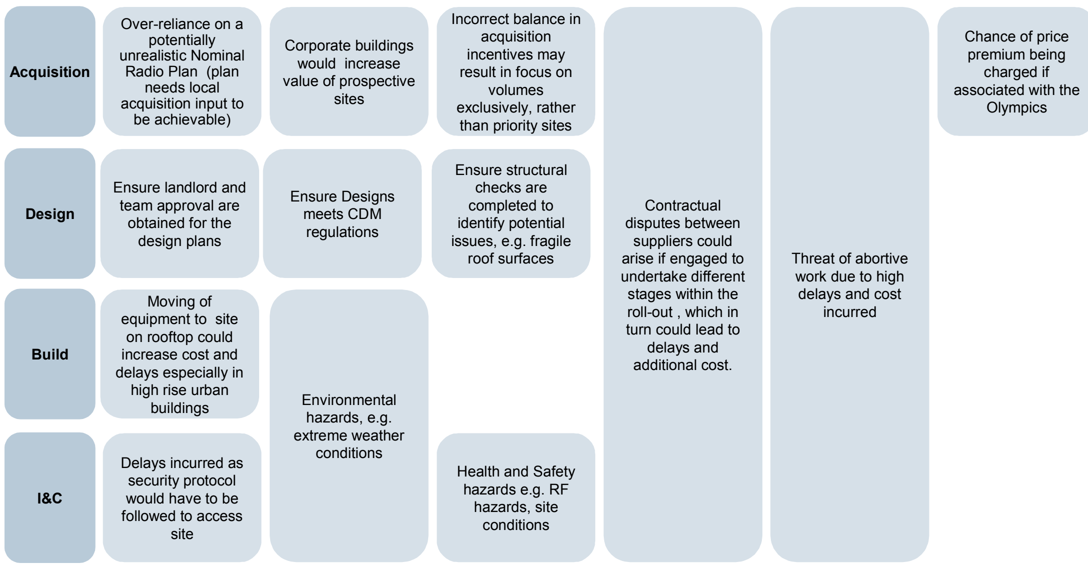


*Figure 4.9:* *Typical risks involved at each stage of the site acquisition and build [Source: Analysys Mason*

# 5 Analysis: In-venue hybrid solutions

## 5.1 Introduction

The in-venue hybrid solutions are based on similar diversity reception concepts to the city-wide network described in the previous section. In these venue situations they are implemented on a smaller scale and in a more controlled environment. This is not to say the environment is completely predictable, but there are fewer unknown variations in the local environment and signal path conditions to deal with.

## 5.2 Benefits for spectrum planning

There are two areas of interest to Ofcom when looking at in-venue hybrid wired-wireless solutions and how they can assist with an efficient spectrum plan for the Games:

- enabling the migration to higher frequencies, for example in the 7GHz band
- assisting with frequency reuse by enabling robust operation on lower transmit powers.

The latest diversity reception techniques assist with the former requirement. Over the last twelve months a number of live tests in challenging sports OB environments have proven the ability of wireless cameras to operate in the 7GHz band in a stadium environment. The wireless camera manufacturers indicated that the problems associated with designing systems at 7GHz could be overcome in these particular applications.

The fibre element of the hybrid system allows the large volume of receive equipment to be housed in a hospitable environment away from the main arena, usually inside an OB truck, in addition to providing reliable high bandwidth transmission over a long distance.

In general, limiting transmit powers helps reduce unwanted interference and improves reuse distance. In the case of the Olympic Stadium, we believe that increasing the number of receive sites to allow a lower transmit power will bring little benefit in terms of channel savings. In theory, a small improvement can be made in terms of retaining the transmitted signals within the stadium. However, the OB compound is located outside the stadium, and there will be nothing to prevent a technician from testing or troubleshooting the wireless cameras in this OB area outside the competition times.

## 5.3 General schematic for this solution

A typical solution would use diversity reception at two or more sites within the stadium, and feed these into a central diversity receiver that provides an output base for each wireless camera chain summed from all received signals. Receive equipment would typically be located in the OB compound, connected to the antenna arrays via fibre extender links. A generic schematic diagram of the in-venue solution is shown in Figure 5.1 – in this example, the system would support two wireless cameras.

The signals picked up at the antenna sites are block down-converted to an intermediate frequency (IF), usually in the UHF band, to perform filtering and improve frequency selectivity.

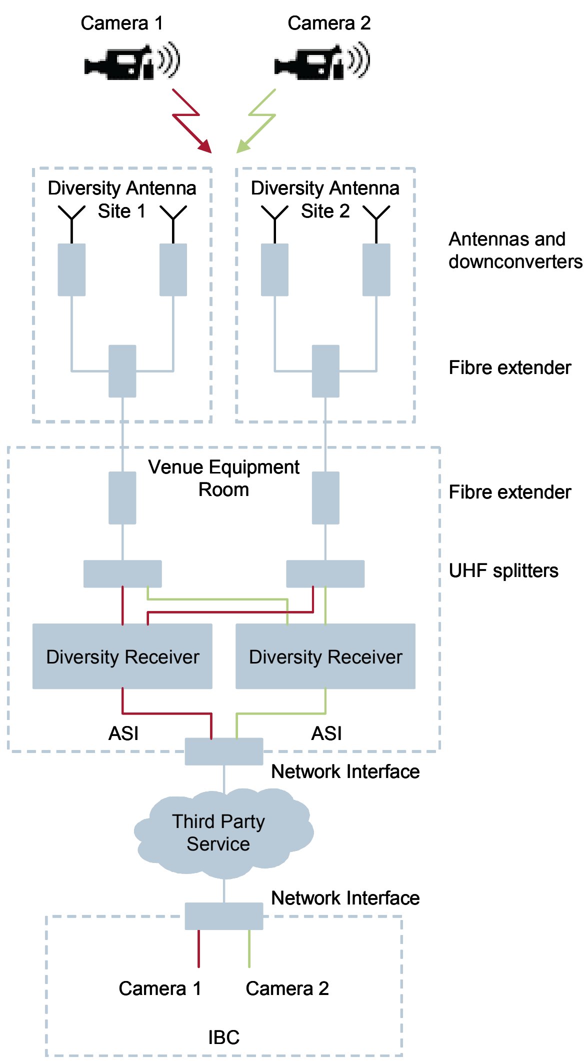


*Figure 5.1: In-venue network design [Source: Analysys Mason]*

## 5.4 Illustrative solutions for London 2012

### 5.4.1 Solution 1: Olympic Stadium

The Olympic Stadium is located within the Olympic Park in Stratford. It will be the venue for the Athletics track and field events, as well as the opening and closing ceremonies. It is designed to have a capacity of 80 000 for The Games, and will be converted to a 25 000-seat capacity venue afterwards.

The system configuration for operation at 2.5GHz (a typical current solution), is illustrated in Figure 5.2. It has two receive locations in the stadium and four-way diversity. The configuration at 7GHz (a solution that would be optimum for spectrum planning) would simply be scaled up to provide four receive sites, also with four-way diversity.

*Solution specification*

As there are up to eleven wireless cameras in use within the stadium in the base case, eleven diversity receivers are needed at each receive site.

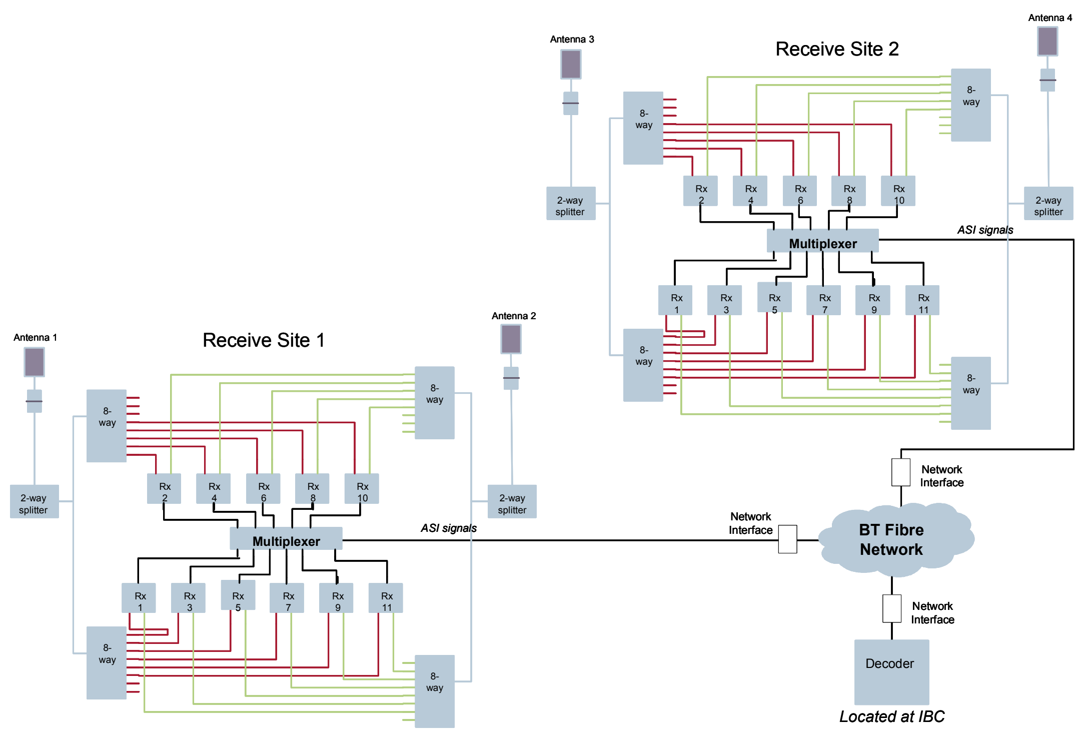


*Figure 5.2: Schematic diagram for the Olympic Stadium solution at 2.5GHz [Source: Analysys Mason]*

*Legacy considerations*

The Olympic Stadium will be converted to a 25 000-seat capacity venue after the 2012 Olympic and Paralympic Games. The Olympic Delivery Authority (ODA) will be responsible for the use of the venue and infrastructure post-Games.

The future use of the stadium has not been decided at the time of this study. There have been many suggestions for use of the Olympic Stadium after the Games, including propositions of a number of London football and rugby clubs moving to the stadium, and even as the base of a new secondary school, or a base for the English Institute of Sports and National Skills Academy for sports and leisure industries.

## 5.5 Solution 2: Eton Dorney

Eton Dorney, near Windsor, about 25 miles west of London, will be the setting for the rowing and flat-water canoe/kayak events. Dorney Lake is set in a 400-acre park Nature Conservation area. It has a 2200m eight-lane course, with a separate return lane to allow competitors to warm-up and return to the start of the course.

It is an existing venue, with enhancements being made before the Games for the warm-up lane, access points for the canoe/kayak racing and a new finishing tower. The site will provide for 20 000 seated spectators, and a further 10 000 viewers along the bank.

*Solution specification*

The illustrative solution for Eton Dorney is shown in Figure 5.3, in which two receiver sites are located at each end of the eight-lane course.

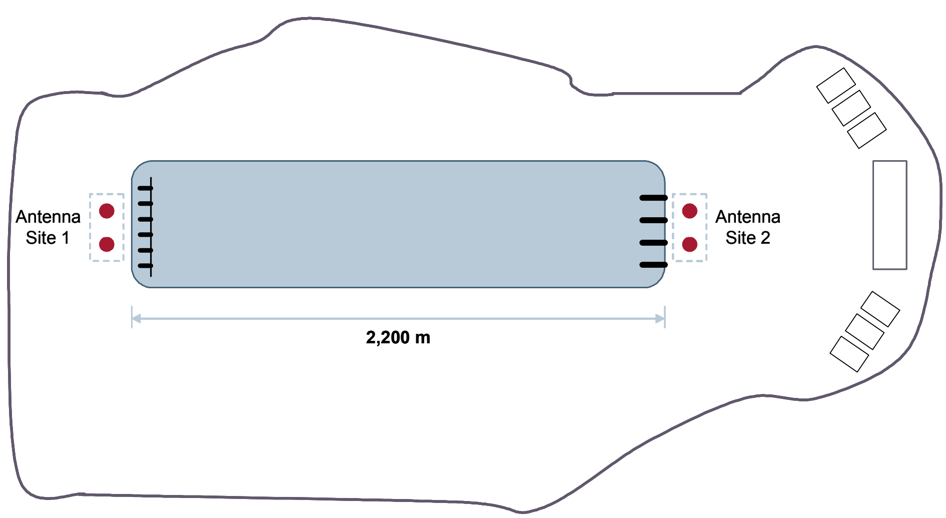


*Figure 5.3: Eton Dorney Solution [Source: Analysys Mason]*

We believe that two-way diversity at the two receive sites will be sufficient for this venue. The two antennas at each site should be placed high enough to ensure clear space to receive the radiation paths from the wireless cameras.

The schematic diagram in the previous section for the Olympic Stadium also applies to this venue, and shows the detailed typical solution for the purposes of costing.

For a 7GHz solution, we have assumed an additional receive site mid-way along the course using four-way diversity – two antennas directed towards the finish line, and two directed towards the start line.

As with the stadium solution, we believe that this venue offers the opportunity to migrate to the higher frequencies for wireless cameras. As with the wide-area receive network, the receive antennas can be configured to act simultaneously as a helicopter receive site, and for ground level wireless camera signals.

A similar solution has previously been used for the annual Oxford Cambridge University Boat Race. This solution uses permanent fibre links, with five receive sites placed along the 8km course of the River Thames. The event was covered using a total of 30 cameras, including eleven wireless camera systems. The flexibility of the system allowed wireless cameras to roam freely within the coverage area without having direct line of sight.

*Legacy*

Eton Dorney is an existing venue, and will continue to be used as a training and competition facility after the Games. Whether the venue continues to require a diversity receive network after the Games will depend on the likelihood of the venue attracting televised events. Dorney Lake hosted the Rowing World Championships in 2006, but it is not clear how soon the venue could be selected again to host this event, which does not currently attract large television audiences.

## 5.6 Costing

We have developed a high level cost model that includes radio equipment, fibre distribution, civil works and equipment, and decommissioning (the base assumption is for a temporary network).

The main inputs to the model are:

- number of receive sites usually required for 2GHz and 7GHz operation
- receive capacity of each site (i.e. number of cameras it can support)
- fibre costs.

| | *Olympic Stadium* | *Eton Dorney* |
|---|---|---|
| Up to 4GHz operation | GBP215 000 | GBP215 000 |
| 4GHz + operation | GBP450 000 | GBP340 000 |

*Figure 5.4: Approximate costs summary for in-venue solutions [Source: Analysys Mason]*

# 6 Potential models and legacy considerations

Models for delivery of new infrastructure and its operation are particularly important where a significant variation is likely between the cost to the broadcasters (whether the HB, RHBs or others), and their suppliers, for implementing the optimum solution for spectrum efficiency, and the cost of implementing the optimum solution driven by their own priorities.

## 6.1 Funding options for delivery of new infrastructure

For each of the infrastructure options for the London Games discussed in this report, we believe that there are three funding options that could be suited to delivery of services for the Games: private sector funding of the infrastructure required for the Games, part private, part public funding, and public sector funding covering the cover the full costs of the infrastructure. These three options are briefly described below.

### 6.1.1 Commercially-funded infrastructure

This option would involve the assets being installed, owned and managed by a third party, using their own funding. Given that significant new infrastructure is required, this model would most likely require that the commercial third party expects to be able to gain profit from the investment made for the infrastructure for the Games, after the Games have been completed. This has a number of implications:

The infrastructure deployed for the Games would be designed for longer-term use after the Games, requiring continued access to suitable spectrum, sites, core network connection and other requirements to operate a telecommunications infrastructure. It is likely that for this option to be viable, the infrastructure would need to be designed on an 'open access' basis, meaning that the assets are managed by a third party, but any operator or broadcaster may use them – similar to the infrastructure owner offering a wholesale service. Any revenues gained whether before, during, or after, the Games would accrue to the infrastructure owner. Another implication of this model would be that since the infrastructure is 'owned' by the commercial provider, this provider also controls its use. This may not be desirable for the Games if, for instance, LOCOG or government departments wish to retain some control over the network's use.

Allowing multiple operators to use the infrastructure could allow a return on investment for the infrastructure owner, but this would depend on the owner being able to negotiate the necessary ongoing agreements for the infrastructure's use after the Games. This option would not be practical if, for instance, the spectrum used to provide the infrastructure is only available for the duration of the Games, since this would require the infrastructure owner to re-engineer the infrastructure after the Games to a new 'permanent' spectrum band, incurring additional cost.

### 6.1.2 Part private, part public funding

An alternative option could involve assets being managed by a third party, on an open-access basis, so that any operator/broadcaster can use them, but using a combination of its own plus public sector funding. In this model, it is possible that public sector funding is used to provide the infrastructure, with a third party managing the assets.

An example of this business model is illustrated below.

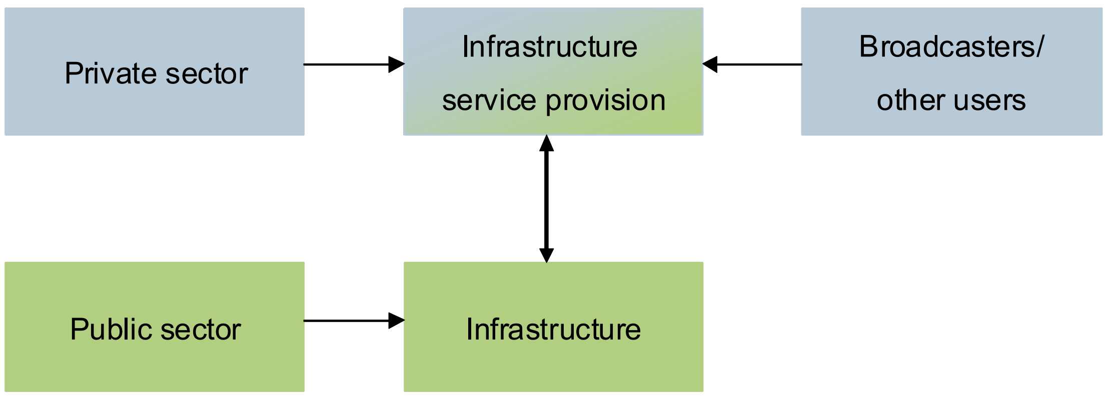


*Figure 6.1: Example of public-private funded model [Source: Analysys Mason]*

There are a number of alternative approaches to public sector intervention initiatives, which are fully described in other reports.[12] The advantage of a model such as that described above is potentially that it leaves the assets under public ownership, and also allows for a return on investment for the public sector after the Games have completed. However, the returns to the public sector may not be in excess of the capital invested, if the project is not commercially viable beyond the duration of its use for the Games.

### 6.1.3 Full funding from public sector

A final option that could be utilised would be for the public sector to build and operate the infrastructure for the Games, and/or for the lifetime of the infrastructure. However, we believe it more likely that if the infrastructure is being fully funded by the public sector, it will exist only for the duration of the Games (an example of this is the Beijing Games, where all infrastructure was temporary, with the exemption of fibre links, which, by nature, need to be 'permanently' dug). This fully funded, fully operated model would require the public sector to manage the infrastructure's use during the Games, and it is possible that this may not be a role that LOCOG or other Government departments wish to take on. Additionally, there may be EC implications to this model, due to State Aid, which would need to be investigated.

12 For example, BSG models for effective and efficient public sector interventions in next generation broadband access networks, Analysys Mason, June 2008.

An alternative to this fully funded option, overcoming State Aid concerns, might be for the public sector to procure a service for the duration of the Games. Under this option, public sector funding is used by the service procured and offered to third parties, to propose a solution using appropriate technology(s) to meet the specified requirements. Any infrastructure assets are therefore owned by the private sector/third party who is successful in gaining the contract, however the public sector would most likely need to provide an upfront payment in order to provide funding for the necessary infrastructure development.

Once the Games contract has expired, it is possible that the third party is then able to continue operation of the infrastructure on a fully commercial basis, or, alternatively, the infrastructure could be decommissioned and cease to operate.

A possible benefit of this is that the risk to the public sector in 'owning' infrastructure after the Games have ended is reduced.

# 7 Conclusions

The fibre-wireless hybrid solutions we have presented in this report are based on existing wireless camera receive solutions that are used today. We have indicated the order of the trade-off between channel saving and cost when the proportion of terrestrial-only transmission used in a typical solution is increased from current levels to the theoretically most spectrum efficient all-terrestrial solutions.

In doing this, we have noted that an all-terrestrial solution may not necessarily be a feasible option, even if the design would suggest otherwise; it is often the case that the reliability of a link is worse, but sometimes better, than expected when tested in practice, because it is impossible to model all the variables that can affect the link path.

When assessing the trade-off between cost of implementation and the spectrum channel saving, it is important to consider the allocation of the channels, as well as the absolute number of channels required. The cost-benefit of a particular solution should be assessed in terms of its ability to reduce reliance on the congested channels.

For example, the impact on the overall spectrum plan of using an aerial relay for wireless camera signals can be reduced by using alternative bands for the downlink. Helicopter downlinks often use a higher frequency to transmit the downlink, and this application of the higher frequencies works well (albeit with a higher link budget than terrestrial links, to account for the movement of the helicopter) because line-of-sight can usually be guaranteed.

## 7.1 The city-wide receive network

We have established that the city-wide receive network, which relies on seamless switching between antennas at a receive site, and automatic handover between a number of antennas mounted on separate receive sites across the routes, is a feasible concept that is deployed today for ENG and sports OB applications. In general, the manufacturers welcome this idea, and would not be uncomfortable about developing this type of solution for the wide-area sports events.

For optimum spectrum efficiency, the ideal implementation would be all-terrestrial, with no use of aerial relays and no use of point-to-point links to backhaul the receive sites. This is the most costly option. We have estimated the cost at GBP3.15 million, based on a requirement for 18 receive sites, at 2GHz transmission. The actual cost is dependent on the current provision of fibre at the sites that are eventually used, which is not possible to assess at this stage in the design, and the actual number of receive sites needed. The equivalent 4GHz solution would cost in the region of GBP6.27 million.

The base case site requirement has been based on 2GHz operation because the manufacturers strongly believe that this is the only likely option for coverage of wide-area events. They have indicated that attempting to use frequencies higher than 2.5GHz becomes very difficult in practice, particularly in a cluttered urban environment. For completeness, we have calculated an indicative cost for a system that would use 4GHz frequencies. In doing this, we are not suggesting that the solution would provide the robust operation required for Olympic standard wide-area event coverage; we have put forward a theoretical cost based on an increase in the number of cells and receive sites required, and the corresponding increase in RF equipment, peripherals and fibre backhaul links. A move to an unusual band of operation would also require the complete replacement of camera back transmitters.

We have also provided the indicative cost for a solution that retains some use of wireless relay transmission. We have factored in the use of one aerial relay for the marathon, for the road cycling, and the road cycling time trials. We have also factored in a proportion of wireless backhaul from receive sites to the central hub to indicate the impact this has on cost in comparison to the all-fibre solution. The costs for 2GHz and 4GHz would be approximately GBP2.13 million and GBP3.92 million respectively.

We understand from manufacturers that the nature of the proposed marathon and road cycling routes in particular would present some areas of difficulty in finding an appropriate receive site, and that, in their view, a helicopter receive point will be a necessity. One of the advantages of the diversity solution for the wide-area network, is that receive sites can easily be engineered to be used as helicopter receive points. It would be possible to limit the impact of using aerial downlinks by ensuring the path length of the downlink is as short as possible, to limit the interference potential with nearby venues.

In terms of the models of use for a city-wide network, we believe that a combined Sports-ENG receive system would present too many complications to be considered a feasible option. The two applications have very different characteristics and requirements, and there would be particular concerns from broadcasters around relinquishing control of the signal path.

There could be some scope to provide a level of infrastructure sharing, so that some access for ENG to sites acquired for the city-wide sports receive network could be permitted. The radio equipment itself would not be shared, and the ENG users would arrange for their own transmission circuits from the receive site. This would allow the news broadcasters to retain control of their links, and, if a fibre link is being installed to the site, access to fibre transmission for sending their video/audio feeds to the studio.

For those news broadcasters without a wireless receive site in London, or those requiring additional coverage or capacity to their current facilities, the independent model, such as the private network operated by SNG, could provide the ability to ramp up quickly for a relatively short period, in the areas covered by the independent operator's network.

## 7.2 The in-venue solutions

The equipment manufacturers and solutions providers are confident that the in-venue requirements described in this study could be met with a 7GHz solution. We have provided costs for a typical 2GHz implementation and a 7GHz option. The difference between the two solutions is simply the number of receive sites required, and because the solutions are modular, the costs increase linearly with the number of sites. We believe there is little scope to reduce the overall wireless camera channel requirement through adjustments to the current in-venue hybrid wireless-fibre solutions.