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The Institution of Engineering and Technology

# Delivering London 2012: ICT enabling the Games

**INSIDE THIS SPECIAL INTEREST PUBLICATION** Selected papers highlighting the rich diversity of ICT coming together in the UK to deliver the Olympic and Paralympic Games


Published by the Institution of **Engineering and Technology**


***LONDON***
*Flickr Geotag Map*

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We would like to thank the following groups for their involvement in review of papers in this publication:
ICT KTN committee
IET Information and Communications Sector committee
IET Multimedia Communications Network committee
IET Vision and Imaging Network committee
LOCOG
UKTI ICT group committee



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Government and industry worked together to set up Knowledge Transfer Networks which offer businesses and academia invaluable opportunities to connect and catalyse to enable new technologies to be realised.

The ICT Knowledge Transfer Network (ICT KTN) was established by an industry-led group of key players in the sector. It is funded by the Technology Strategy Board, which is an executive non departmental public body (NDPB), established by the UK Government in 2007 and sponsored by the Department for Business, Innovation and Skills (BIS).

The ICT KTN facilitates knowledge exchange within the ICT segment and adjacent sectors, acting as a catalyst to accelerating innovation and focuses on fixed and mobile communications, IT networks and broadcasting:

- Spanning the entire value chain of vital components including, equipment manufacturers, solution providers, system integrators, network operators, service providers, component manufacturers, application developers, broadcasters and universities.
- Operating as a Network-of-Networks, working through other networks, support organisations and communities of interest.
- Working closely with other sectors such as transport, education, health, energy and the environment – for which ICT are transformational technologies.

Visit www.ictktn.org.uk or email info@ictktn.org.uk for more information. Membership is Free.

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The IET has recognised that the demands on the modern engineering community have changed. By prioritising five Sectors; Built Environment, Design and Production, Energy, Information and Communications and Transport, the IET has provided an access point to the vast array of knowledge, experience and content available to members and the global science, engineering and technology community.

The Information and Communication Sector's vision is to become a focal point for all those working or interested in information and communications. It also recognises the importance of promoting professional qualifications and certifications in this field. Its aims are:

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- to bring together relevant IET products and services related to the Sector
- to identify key hot topics and activities to ensure the IET deploys its expertise where it will have the greatest impact
- to publicise and represent the information and communication engineering profession to a wider audience

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# Delivering London 2012: ICT Enabling the Games

## Introduction and forewords

Delivering the London 2012 games is set to become one of the largest single ICT achievement stories of the 21st Century. The UK eco-system of suppliers and partners have been diligently working, since being awarded the games in July 2005, to ensure the experience of the most digitally enabled games ever, to be positive and demonstrate the strength of the UK ICT profession and community worldwide.

The IET special interest publication, Delivering London 2012: ICT Enabling the Games, identifies and demonstrates the innovation, legacy, best practice and lessons learned from the ICT delivery of the Games and provide recommendations for future projects and programmes. The content of the publication provides an excellent overview starting with the ODA and LOCOG papers setting the scene for the London 2012 Games overall programme, followed by technical papers detailing the fixed, wireless, mobile and web platforms implemented, to deliver the ICT infrastructure and services required, finishing with technology to maximise GB athletes performance at the games with a legacy for technology reuse into the eHealth market.

The Olympic Delivery Authority (ODA), London Organising Committee of the Olympic Games (LOCOG), The Institution of Engineering and Technology (IET), ICT Knowledge Transfer Network (ICT KTN) and UK Trade & Investment (UKTI) worked together to facilitate this IET special interest publication and each organisation is pleased to provide a foreword for such an important publication.

## Gerry Pennell, Chief Information Officer, London Organising Committee of the Olympic Games and Paralympic Games

LOCOG are pleased to support this publication, highlighting the rich diversity of technologies being brought together in the UK to deliver the Olympic and Paralympic Games. Our part in this as LOCOG (the London Organising Committee of the Olympic and Paralympic Games) is to prepare and stage the 2012 Games, requiring that we deliver a set of critical services to support the varying needs of athletes and technical officials, the public and spectators, press, broadcasters and members of the Olympic Family, including National Olympic Committees and International Sports Federations – plus of course the LOCOG team of staff, sponsors, contractors and volunteers.

Within this publication we are providing an overview of the Technology Landscape for the London 2012 Olympics, outlining the key technical principles applied by LOCOG Technology to assemble the broad set of solutions and technologies required to support an operation as complex and as high profile as the London Olympic and Paralympic Games. This overview is supported by more detailed papers covering specific areas of Technology that we are responsible for delivering.

Space has not permitted us to address some of the broader – but equally critical – aspects of our delivery approach. So, to provide some context to the technical discussion, I briefly summarise them here:

– a milestone-driven approach to programme and project management, coupled with an emphasis on scope management and change control

– our philosophy regarding the commercial and operational management of the many sponsors, partners and suppliers with services being provided both within the UK and from overseas

– the priority given to testing, both functional, non-functional and operational, particularly in the months leading up to the Games themselves.

To manage a programme of this scale (and it represents very nearly a quarter of the LOCOG's budget) requires a team with significant technical, commercial and managerial competence and no little scale, peaking at around 380 staff employed by LOCOG at Games-time working to manage the broader technology operation. This will have over 5000 staff at the Games – once staff from our sponsors, suppliers and volunteers are included.

In the end, it is the skills and commitment of this team that will make the programme a successful contribution to the greater success of the London 2012 Olympics. I hope you find the papers both interesting and relevant.

## Gordon Shipley, Head of Systems and Technology, Olympic Delivery Authority

The Olympic Delivery Authority (ODA) was responsible for building the Olympic Park and ODA's Systems and Technology (S&T) team was responsible for ICT provisions. Many of the ICT systems associated with the Olympic Park are complex and involve numerous interfaces and multiple stakeholders. ODA realised, from the outset, the importance of defining ICT requirements clearly and unambiguously and of managing them through to delivery. In doing this, ODA needed quickly to establish close and effective working relationships with key stakeholders, particularly including LOCOG.

ODA had adopted a procurement strategy that allocated responsibility for the design and construction of the venues and major infrastructure on the Olympic Park to different contractors through separate contracts. This achieved the intended benefits of cost-effectiveness and prompt delivery but did mean that no prime contractor was accountable for the functioning of the Park as a whole or for an overall ICT strategy and architecture. As a result, the ODA S&T team took on those responsibilities. The task was made more challenging by the continuous evolution of requirements for ICT services as Park design and build work progressed. The ODA ICT team had to ensure that systems and services were flexible and adaptable whilst conforming to fundamental principles, notably a high degree of information security.

The existence of many stakeholders from different organisations put a premium on the role of ICT governance. The ODA team introduced rigorous mechanisms to ensure that all ICT projects had a clearly defined business purpose, an identified 'business sponsor' and were closely monitored from feasibility assessment to final delivery of benefits. Lessons learned were transferred to subsequent projects to further refine the process. The overall process was controlled by an ODA 'capability manager' – effectively a client-side project manager – to represent the business sponsor in ODA's interactions with the technology supplier. This approach ensured that the evolution of the diverse ICT infrastructure needed for Park development remained cost effective and delivered the outcomes needed by the wider organisation.

In addition to the usual back-office and desktop applications needed to operate any large business, the ICT demands of a major construction programme give rise to specific service requirements. ODA introduced advanced geospatial data services (CAD, on-Park GIS and National-level GIS for Transport planning); project tracking and cost control services; contracts management (ODA let around 1000 contracts directly and very many more were let by ODA's Tier 1 contractors) applications; and broader information management and exchange facilities. As Games drew closer, ODA's entire ICT systems were tightly secured and formally accredited to demonstrate their suitability to hold protectively marked information.

ICT services interlocked closely with the Park's technical security services, including CCTV and access control systems. The ODA S&T team provided the governance and architectural direction needed to ensure that the security-related ICT worked as a coherent whole, with effective interfaces to external stakeholders including the London Metropolitan Police and the emergency services.

In addition to the design of the ICT systems delivered by ODA itself, ODA was also required to ensure that the Olympic Park was ready to receive the temporary systems and services needed for Games. These included systems for timing, scoring and media operations, police, fire and ambulance services and Park security. The temporary systems were to be installed by LOCOG, its sponsors and others including the emergency and security services. ODA S&T had to ensure that the Park, including its physical and logical infrastructure, was prepared to receive the temporary systems and then to facilitate their removal when the Park was prepared, post-Games, for legacy transformation. This work made extensive use of recognised standards and best practice, provided to all participants by ODA in the form of a 'Systems Designer's Guide', but a great deal of stakeholder engagement and broad systems architectural thinking was also essential. Finally, ODA supported the Olympic Park Legacy Company (OPLC), the Park's post-Games owner, in developing its ICT strategy, in planning the conversion of Park ICT to address future needs, and in ensuring that the information and IT services needed by OPLC were available.

## Dr Mike Short, IET President Institution of Engineering and Technology

The UK is enthusiastically preparing to host its biggest sporting event in decades, the Olympic and Paralympic Games, with a new purpose-built park in London. Behind the preparations is an incredible array of engineering and technology, creating a world class environment of construction, communications and transport infrastructure, hospitality, tourism and more. In all these areas, it is engineers and technicians who have enabled a successful delivery.

The Institution of Engineering and Technology (IET), Europe's largest professional group for engineers and technicians, is keen to demonstrate the central role that engineering and technology has, and will, play in the Games. An effective way of doing this is through working in partnership with organisations such as the ICT Knowledge Transfer Network (KTN) and UK Trade and Investment.

In a world where disciplines merge, today's engineers and technicians need a broad understanding of engineering and technology issues. As a multidisciplinary organisation, the IET brings these issues together within five focused sectors; one of which is Information and Communications.

The sector provides professionals with a 'lens' to focus on knowledge services, events, professional support, news, views and communities of like-minded people in the Information and Communications field. Those familiar with the IET will know that it is Europe's premier organisation for the engineering community. In fact, this year marks the 140th anniversary of the IET. Today, the IET has over 150 000 members in 127 countries around the world, and provides a professional home for life for its members, supporting them throughout their careers.

For more information, visit www.theiet.org/info-comms

## Phillip Hargrave ICT KTN CEO ICT Knowledge Transfer Network

The ICT Knowledge Transfer Network (ICT KTN) is delighted to have been associated with the formulation of this special interest publication. Its objective is the dissemination of the knowledge learned as a result of the major ICT programme that is underpinning the London 2012 Games, which will be the most digitally connected Olympic Games ever held.

The ICT KTN focuses on Knowledge Transfer as a stimulus to economic growth. With funding from the Technology Strategy Board, our aim is to bring a competitive advantage to the UK by facilitating the development and take up of information and communications technologies and their adoption as key enablers in other industries. Operating as a network of networks, partnering with and working through other networks, industry associations, support organisations and communities of interest, we seek to be the focal point in the UK for innovation in digitally enabled ICT systems. Our objective is to maximise the economic and social benefits realised by the UK through such systems. The London 2012 Olympic Games presents us and the UK ICT community with a unique opportunity to showcase UK technology, skills and strengths, and to position the UK as the ICT partner of choice to key decision makers worldwide.

This publication, as well as being a valuable source of knowledge in its own right, has also been designed to underpin a series of events that will provide a platform for showcasing the UK ICT that is enabling the Games. It should provide a solid foundation on which a lasting business and innovation legacy can be built.

For more information, visit www.ictktn.org.uk

## Sir Alan Collins, KCVO CMG, Managing Director, Olympic Legacy, UK Trade & Investment (UKTI)

The clock is counting down to the 'Greatest Show on Earth'. London 2012 will be a defining moment for the UK, when the eyes of the world will be firmly on us.

A key part of the legacy of the Games will be economic and UK Trade & Investment is utilising the Olympic spotlight to enhance the UK's reputation as a can-do, can-deliver partner to increase exports and drive inward investment. UKTI has the remit to deliver the international business legacy from London 2012. The IET special interest publication is a key document that supports this business legacy and covers some of the ICT challenges for the Games, how these have been addressed and how the UK experience could be applied to future large scale projects and major sporting events.

In addition to the publication, stakeholders will be running a series of events to share lessons learned, transfer knowledge and encourage collaboration with businesses globally. The publication will help to inform the ICT learning legacy lessons from London 2012 to help raise the bar of sector excellence globally and so position the UK as the global technology partner of choice.

UKTI will be utilising Lancaster House in London to host our Games time business programme. The ICT sector day will be held on 3 August 2012. In addition, the online British Business Club is a one stop shop where members will find up-to-date details of networking events, business opportunities, news and potential partners related to international sports events. www.britishbusinessclub.org

UKTI is the government organisation that helps UK-based companies succeed in the global economy and assists overseas companies to bring their high quality investment to the UK.

For more information, visit www.ukti.gov.uk/home.html

## London 2012 statistics and numbers

- Equivalent to **46 World Championships** at the same time:
  - **300 medal events** for **26 Olympic Sports** in **34 venues** over **19 days** of competition
  - **471 medal events** for **20 Paralympic sports** in **20 venues** over **11 days** of competition
  - Altogether, there will be **36 competition venues** and **41 training venues**
  - If all London 2012 sports competitions were held on consecutive days, **the Games would finish in October 2013.**
- **10,500 Olympic Athletes** from **205 NOCs** and **4,200 Paralympic Athletes** from c**170 NPCs**
- **10.8 million tickets** (8.8m Olympic, 2m Paralympic)
- **21,000 media and broadcasters** for the Olympic games and **6,500 media and broadcasters** for the Paralympic games
- **Transport for 800,000 spectators & 55,000 athletes/ officials/ media/ sponsors** on busiest Olympic competition day - more than the entire population of Leeds (160,000 and 16,500 respectively for Paralympics)
- Up to **70,000 London 2012 Games Makers** from **240,000 applications**
- **10,989 workers on the Olympic Park and Athletes Village:**
  - 98% live in the UK; 62% in London; 25% in Five Boroughs; 11% previously unemployed
  - 82% of Olympic Park workforce paid London Living Wage or above - £7.85/hr; [61% of Village workforce]
- **4,380 Londoners** have completed 90 hours of training and 30 hours of volunteering through 'Personal Best'. 42% go on to further training, 33% to further volunteering, 15% into work.
- **1,000 young ambassadors** have been recruited together with the Youth Sports Trust to promote 2012 and sport in schools
- **108 Pre-Games Training Camp Agreements** already in place
- **19,582 schools and colleges** have signed up to Get Set, representing **over 2 million students.** 6,221 have applied to the Get Set Network.
- **1,229 London 2012 Open Weekend events were held in communities this year - 22-24 July 2011**. 989 were held in 2010; 800 in 2009; and 655 in 2008. <u>3,673 in total over four Open Weekends.</u>
- **1,715 Inspire Mark projects** have been awarded – including over 400 from the cultural sector, and over 700 from sport.
- **6 million young people involved in International Inspiration and being connected to sport – soon in 15 countries**


# Systems Integration: a Programme-Wide Approach to Delivery of Information and Communications Technology, Security and Mechanical and Electrical Systems

*V. Buscher   J. Luke   G. Shipley   P. Hyde*
*ODA*

**Abstract:** Early planning, a programme-wide approach, consideration of centralised procurement and analysis of all stakeholder requirements were key to delivering Information and Communications Technology (ICT), Security and Mechanical and Electrical (M&E) systems across multiple capital projects on a single campus. This enabled Olympic Delivery Authority (ODA) delivered systems to be operationally effective and efficient; whilst providing flexibility for systems to integrate at a local and campus-wide level and accommodating additional 'overlay' systems provided by others during the London 2012 Olympic and Paralympic Games.

## 1 Introduction

This case study provides an overview of adopting a programme-wide approach to the delivery of ICT, Security and M&E systems across multiple capital projects on a single campus, including:

– Delivering systems to be operationally effective and efficient

– Providing flexibility for systems to integrate at a local and campus-wide level

– Accommodating additional 'overlay' systems provided by others during the London 2012 Olympic and Paralympic Games.

Fig. 1 shows the dependencies of the major themes which will be the focus of this study. They all contribute to de-risking a construction programme, ensuring successful systems delivery and informing the procurement strategy. These themes will be explored in more detail in the subsequent sections of this document.

i. Leadership and Organisation – The organisation acknowledged the role and importance of technology and systems early in the programme, leading to the implementation of a programme-wide governance and strategy for the delivery of ICT, security and building systems.

ii. Strategy – A top down, rather than bottom up approach to systems delivery was adopted, starting with a strategic view regarding the ICT, security and building systems in Games and Legacy. This was essential to change the bottom up


**Figure 1** *Key themes in a successful approach to programme-wide systems delivery*


*Delivering London 2012: ICT enabling the Games*, pp. 8–13

approach that can often be found in other construction projects.

iii. Operational Requirements – The ODA developed an understanding of operational and broadcast requirements to de-risk the construction programme and enable the Park and venues to deliver a world class experience to spectators. This included the consideration of the safety and security of all users (employees, athletes and spectators).

iv. Master Systems List – The creation of a Master Systems List enabled the ODA tea, to provide guidance on the procurement of ICT, Security and M&E systems within each project. This guidance identified when systems should ideally be delivered, exploiting potential Game-time Overlay that may defer the need for systems until after the Games and to determine who should be responsible for their delivery. Thus, taking advantage of systems space savings and cost efficiencies. This approach informed the following:

(a) Model Venue – a common approach to the delivery of ICT, Security and building systems in venues to ensure an appropriate and consistent delivery across all London 2012 ODA projects and identifying boundaries that exist between each party and their interfaces.

(b) Site wide infrastructure – future proofed venue site-wide infrastructure in terms of systems space planning against evolving or emerging user requirements. The approach sought to ensure the most appropriate use of space between temporary, permanent, in-venue and Back of House (BoH).

(c) Procurement Strategy – Procurement of systems that were replicated in all venues, exploiting economies of scale and a common interface which might otherwise be replicated in all venues, space savings, cost efficiencies and greater operational efficiencies and effectiveness.

# 2 Industry Context

Typically, ICT, Security and building systems are not implemented until building work on a construction project is nearly complete.

The definition of systems in this context includes electronic systems within venues that generate and deliver information, assist in the transport of information (voice, data or video) to support operation of a building (alarm monitoring) and those which enable an event to continue in the event of a power failure (event continuation).

Often, planning for systems delivery is not developed in parallel with the construction programme. This can often lead to multiple suppliers on site requiring access to install, test and commission systems, re-work to existing infrastructure to accommodate previously undefined requirements and unforeseen integration if systems are required to integrate on a local and site-wide level. These factors can often incur programme delays and increase the costs for systems delivery.

Therefore, planning for systems delivery early in a project lifecycle can minimise implementation conflicts and compatibility and increase the success of systems integration.

# 3 Olympic Park Context

The ODA was tasked with delivering multiple projects on the Olympic Park which would be required to be integrated during Games, accommodate Games-time ‘overlay’ by LOCOG during the Games (removed post-Games) and remain in Legacy.

# 4 Leadership and Organisation

London 2012 was benchmarked and compared against other major ICT, Security and Building systems programmes and as a result ODA acknowledged the material impact systems requirements could have on the objectives of the project. It therefore focussed on dealing with the risks and opportunities appropriately. This led to changes in the organisational and leadership structure in the ODA with the creation of ODA Systems Integration to focus on these programme wide technology issues.

ODA recognised the benefits of adopting a programme-wide approach to the delivery of ICT, Security and Building systems across the London 2012 ODA project which ensured London 2012 Olympic Park projects, from a systems perspective, were fit for purpose, capable of supporting the Games-time Overlay, and minimised redundancy in Legacy.

ODA Systems Integration set about providing systems assurance management of London 2012 ODA projects and had the engineering capacity and capabilities to develop authoritative design solutions across all relevant programme activities.

To achieve this, ODA Systems Integration, in conjunction with Programme Managers and Designers (engineering consultants), developed a guidance literature which provided details on the following:

– The appropriate allocation of equipment space within temporary and permanent facilities, and the affinities these have with other spaces within the built environment.

– The location of cable-pathways, equipment spaces and the opportunity for sharing cabling and networks.

– The application of appropriate systems standards and protocols.

– Test and commissioning requirements.

To ensure a consistent approach to all projects a governance process was established for engagement with designers. The engagement process focused on ensuring venues were operationally effective, efficient and offered the appropriate degree of flexibility for systems to integrate at a venue and Park-wide level, and to accommodate Games-time 'overlay'.

ODA, Programme Managers and Designers were available at all stages of the design review process to support and inform design teams, advise on best practice, assist with identifying the degrees of integration required (once requirements have been defined) and help define appropriate standards, especially where there was an express or implied need for future integration.

It was understood that each venue design team had a specific scope and responsibility to deliver stand-alone venues. To enable these venues to be capable of accommodating the Games requirements there were certain basic conditions which had to be met for ICT, Security and Building systems. This also applied to permanent venues being handed over to the Olympic Park Legacy Company (OPLC) and Lea Valley Regional Park Authority (LVRPA) in Legacy.

## 5 Master Systems List, 'fitted for but not with'

It was identified that by providing guidance on the procurement of ICT, Security and Building systems it could ensure when systems should ideally be delivered, exploiting the Game-time Overlay that may defer the need for systems until after the Games, and determined who should be responsible for their delivery. This was referred to as the Master Systems List.

It was important to understand the Games-time Overlay systems to be delivered by others to enable the planning of appropriate enabling infrastructure to accommodate them, for example LOCOG (London Organising Committee for the Olympic Games) and their key partners; Telecoms, Timing & Scoring, Broadcasting requirements. All these systems were to be installed in venues and the venues needed to be able to accommodate these requirements i.e. "fitted for but not with".

Initially there was limited information with regards to systems integration requirements. As such, ODA Systems Integration produced a guidance document, entitled Systems Designers' Guide (SDG). This imposed certain system requirements upon the London 2012 ODA projects which enabled the 'fitted, but not with' approach, for example, the SDG required projects to:

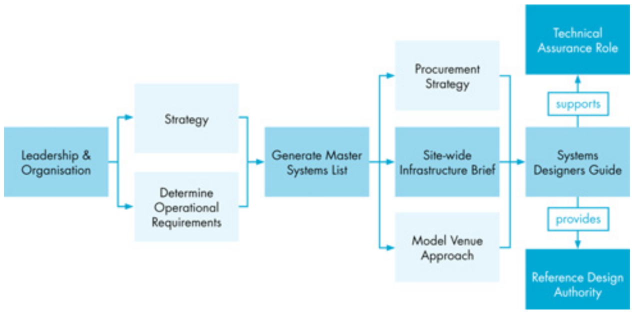
i. Provide a venue Fire System with the ability to have a secondary repeater panel in a venue Back of House area for Games-time expansion – the capability was safeguarded but not delivered.

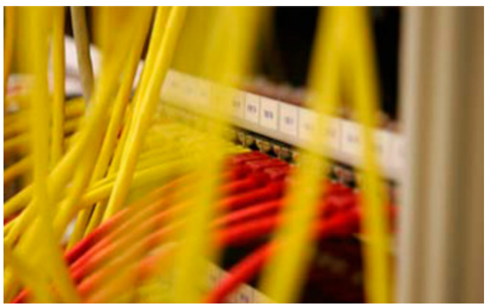
ii. Safeguard for the provision of Games-time temporary broadcast infrastructure.

iii. Provide a standards based common card solution for access control systems, to enable future integration at a campus wide level if required.

iv. Provide clarity to projects on the nature and type of overlay systems to be delivered by others, with the enabling infrastructure required to support this (eg Timing & Scoring systems delivered by Omega, Worldwide Olympic Partner of the IOC).

The Master System List had an impact on the built environment, both on a local 'venue' and at a site-wide level. The Systems Designers Guide introduced the concept to understand what systems a venue was responsible for delivering or not and included the Master Systems List.




The local list informed the Model Venue Approach, the park-wide items informed the Site-wide Infrastructure Strategy and the whole list was used to undertake an analysis of those systems which would benefit from Centralised Procurement. All these were combined to inform the systems procurement strategy, including design and delivery. These three areas will be further explored in the following sub-sections.

BENEFITS: By understanding the systems requirements, stakeholders and delivery phases which led to the development of the Master Systems List it enabled ODA to:

(a) establish clear responsibilities for the delivery of ICT, Security and Building systems.

(b) translate system requirements into systems architecture and components, with an associated assurance role to ensure this happened.

(c) ensure an appropriate and consistent delivery across all London 2012 ODA projects and enabled an effective solution to be developed which best met the needs of the Games and Legacy.

## 6 Model Venue Approach

Once the Master Systems List had been developed a common approach, the 'Model Venue', was adopted for the delivery of ICT, Security and Building systems in venues to ensure an appropriate and consistent delivery across all London 2012 ODA projects, identifying boundaries that existed between parties and the relevant interfaces.

The top down approach enabled the requirements of all the stakeholders to be collated which focussed on the potential need for systems integration and the impact on the venue designs and delivery responsibilities. It was acknowledged that whilst LOCOG had the responsibility to deliver a number of Games-time systems, their requirements would have an impact on the venue designs. As such, ODA, Programme Managers and Designers engaged with the various stakeholders, including LOCOG, to understand their requirements to enable an effective solution to be developed which best met the needs of the Games and Legacy.

In some instances there was a lack of detailed requirements available. Therefore, operational assumptions, constraints and potential future requirements were identified to safeguard potential integration requirements. This impacted on both permanent and temporary venues, and modified approaches were adopted for each. This ensured systems being delivered by venue design teams would support LOCOG and park-wide operations and the ability to conduct one or more of the following at a park-wide level:

- Monitor systems
- Control systems
- Collate data

The intention was not for a venue to deliver integrated park-wide integration, as this would be defined separately. This approach intended to ensure systems within venues were designed and delivered with the capability to integrate in the future and in a cost effective manner at a later date by others, without significantly or adversely impacting on the design, procurement and cost of systems within venues. This was achieved by the production of a guidance document, Systems Designers Guide (SDG), which supported the Model Venue approach.

Some guiding principles in relation to systems space planning applied across all venues. In addition, specific principles applied to venues that have a Legacy requirement i.e. Permanent venues. These are detailed as follows.

For Permanent Venues:

- Equipment rooms and other technology spaces should be sized for the Legacy requirement and placed within the permanent area of the venue.

- Equipment rooms should be fitted-out to support the systems being installed by ODA, i.e. this would mean only installing enough racks for the head-end equipment needed to obtain building certification.

- Mechanical, Electrical and Public Health (MEP) services should be designed and installed to meet the Legacy requirement. Where the Games requirement is either greater in terms of capacity or resiliency than the Legacy requirement, consideration will be given on how to meet this in Games with a temporary solution.

- Other non Legacy technology spaces required by LOCOG, stated in the LOCOG venue requirements (LVR), should be planned wherever possible in temporary parts of the venue, e.g. under temporary stands or in BoH areas. This should take into account any required affinity between technology and operational areas, e.g. On-venue Results Room (OVR) requiring a view of the Field of Play

(FOP), score boards and depending on the sport, a view of the finish line.

– Containment routes and risers for ODA and LOCOG Overlay systems should be common-use wherever possible, whilst adhering to any specific LOCOG and British Standards (BS).

For Temporary Venues:

– Temporary venues are defined as those with no Legacy requirement. As such, Temporary venues will typically be expected to meet Games-time requirements during Games only and then removed or relocated post Games.

– The following principles apply for the design and creation of equipment rooms and other technology spaces within temporary venues:

– LVRs define requirements regarding space planning.

– Consideration should be given on the most cost effective methods of providing MEP services to technology spaces.

An ongoing Technical Assurance and management role during the design, construction and delivery phases was required to ensure the implementation by the capital project delivery teams of the Model Venue strategy met the required technical standards.

BENEFITS: Adopting a Model Venue approach enabled ODA to:

(a) plan for and enable park-wide integrated operations in a cost effective manner;

(b) de-risk systems delivery, realise costs savings and provide a systems environment aligned with operational requirements;

(c) delay procurement of selected systems and re-allocation of Legacy equipment space during Games, thus creating a space saving and minimising redundant space in Legacy;

(d) ensure Legacy systems were not redundant (due to the short lifecycle of many ICT systems, typically 5–10 years) by the time they became operational in Legacy;

(e) create a potential cost saving by exploiting the Games-time systems for Legacy use.

## 7 Site Wide Infrastructure Strategy

A key issue faced by ODA was how to plan for, and future proof the site-wide infrastructure in terms of systems space planning against evolving or emerging user requirements, for both Games and Legacy.

Ducting to support communications systems, broadcast systems and electrical distribution networks needed to be designed at the earliest stage of the project, often before venue designs were at a concept design stage.

The Master Systems List, coupled with an understanding of operational requirements and the use of these systems, enabled the ODA to make an informed decision on below ground civils infrastructure that would ultimately be required to support the campus for years to come.

Key to this approach was an understanding of the resilience required for each of the communications and broadcast systems across the Park, as this was used to inform the design and number of interfaces to each venue across the Park.

Once these designs were finalised at a campus wide level, guidance was provided to the venue design teams to support the design development and planning through the various construction phases to ensure an ‘appropriate’ level of safeguarding for future users was identified and provided.

Legacy telecoms requirements, cable pathways, containment and space for broadcasting and other specific Games ‘overlay’ cabling was all taken into account.

BENEFITS: By future proofing infrastructure to support technology overlay this enabled ODA to:

(a) ensure the appropriate level of safeguarding for future users was identified and delivered;

(b) maximise the efficiency and usage of the infrastructure during Games;

(c) minimise ‘overlay’ works required.

## 8 Centralised Systems Procurement vs De-centralised and Common Interfaces

A review was undertaken to consider those systems which could benefit from a centralised procurement approach. These opportunities arose where systems were replicated in all venues, where a common user interface and experience would be required in Games, or where systems across multiple venues would require extensive technical integration to meet Games time operational requirements. Consideration was also given to the potential economies of scale and resultant cost saving opportunities that arise from centralised procurement.

The benefits of a centralised approach for ICT and Security systems were considered against the following five categories:

i. Cost savings – cost reduction in the benefit of reduced hardware or purchasing power of a number of systems through one vendor.

ii. Programme Risk – The potential programme impact from having to integrate a number of systems across venues to enable Games.

iii. Integration Risk – The complexity and risk associated with the integration of a number of systems across venues, from a technical perspective.

iv. Space in venues – Ability to save space in venues due to a reduction and/or centralisation of hardware.

v. Operational – the ability for a single vendor supplied system to offer operational efficiencies, this includes training savings for central operatives, single interface into systems.

Following a review, several systems were identified which could benefit from a centralised procurement approach. However, it was recommended that the security systems would benefit the most from being delivered across all geographies and construction projects on the Olympic Park. The benefits of technical integration would allow central monitor and control, provide the ODA with significant system integration cost savings and enable a common user interface allowing operational savings.

BENEFITS: Identifying systems which could benefit from centralised procurement enabled ODA to:

(a) centrally monitor and control park-wide security systems, thus providing operational advantages;

(b) realise significant system integration cost savings;

(c) enable a common user interface and operational efficiencies.

## 9 Conclusions

A programme-wide approach to the delivery of Information Communications and Technology (ICT), Security and M&E systems enabled ODA to advise and plan the infrastructure early in the design stages and assist with the venue design teams with the delivery of the installation, whilst realising programme and cost savings across multiple capital projects on a single campus.

Through guidance and technical assurance the systems were enabled to be operationally effective and efficient and offer the appropriate degree of flexibility for systems to integrate at a local and park-wide level whilst accommodating additional 'overlay' systems provided by others during the London 2012 Olympic and Paralympic Games.

# Overview of the Technology Landscape for the London 2012 Olympics

*David Finch*

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**Abstract:** To host the Olympic and Paralympic Games demands the design, delivery and operation of an extremely diverse range of technology solutions, from specialist timing and scoring systems precisely capturing the performance of athletes through to corporate IT systems, mobile telephones, specialist results systems for the media and what will undoubtedly be one of the most visited websites worldwide showing the latest results information.

## 1 Key Principles

To design and integrate these various technologies and deliver what is needed for the Games, it is essential to understand the key principles that characterise the Games environment. Whilst individually some or all of these principles may be applied to any given IT project, the Games' uniqueness lies in the combination of factors. The following sections summarises the key principles and provides some insight into the types of challenge that the Games present and how they are being tackled for London 2012.

### *1.1 Availability*

There is only one opportunity to get it right and so technology solutions must be robust, using proven technologies that are extensively field-tested. There is no room for unproven technologies that may or may not cope with the unexpected during Games-time. An important element of the design process for the Olympic Games is to impose freezes at specific points in the project to help ensure stability, for example, all key hardware components (PCs, Laptops, Servers, network equipment, printers and more) were selected during 2010 with subsequent freeze milestones for software, detailed architecture and configuration.

Availability also extends to the capabilities required to rapidly recover from various levels of failure and the need for operational simplicity within the solutions to facilitate troubleshooting and problem resolution. This was a particular focus area for end-user network services, for example with internet access provided to the media an important design consideration was the ability to quickly diagnose a problem as the network or their laptop configuration.

Finally, availability is not just a technical consideration and therefore LOCOG have also built a comprehensive support structure with a clearly defined organisation and processes that are being embedded into the Technology team by training and through constant use during test events and finally in specific technical rehearsals to be carried out during 2012.

### *1.2 Performance & Capacity*

The huge interest in the Games drives demand, but predicting exactly what this demand will be is complex and fraught with difficulty. Whilst useful as a reference, information from previous Games often has limited benefit because of external factors such as the growth of the internet, changes in user behaviour, developments in technology and because an Olympic or Paralympic Games is not simply a replica of the last one. An excellent example is in the rapid development of digital photography in recent years, enabling professional photographers to take images in excess of 20 megapixels and using raw format, which they must then transmit as quickly as possible – either during or immediately after an event – for publication.

During the years leading up to the Games, models of the expected Games-time demand for the different services are continually developed, refined and questioned. Test events and other real-world scenarios are used to inform and validate this modelling, however capacity management really does have a unique meaning when applied to the Games and it is essential to focus on what the peak demand is going to be throughout the lifetime of the project and to design a system capable of handling that peak. Again referring to internet use from venues by the media, the anticipated behaviour – and what has been observed from previous Games and test events – is that for any given venue the peak demand is immediately after the event when stories and photographs need to be uploaded and it is this peak that must be designed for, not just at a venue level but at the aggregation points where traffic from multiple venues converges and will peak based on the coincidence of events completing at different venues. For this reason, the competition schedule has also been considered as part of the modelling, although of course that schedule may flex during the Games for various reasons, e.g. due to weather.

### *1.3 Standardisation*

Standardisation of technology solutions is fundamental to delivering the Olympic and Paralympic Games and it enables the technology team to design, test, deploy and operate systems using a common understanding of the solution with a consistent terminology. This significantly avoids the need to understand the particular nuances of a venue and makes it much easier to train new recruits into the team and for them to become operationally effective.

During the early design phases for London 2012, a set of infrastructure requirements were defined that led to the selection of hardware components. The design was then progressed using those components as a building block but developed into standard 'mission-specific' configurations based on the service to be delivered. Each of these hardware/software configurations has a unique product code allocated. There are numerous ways in which this approach underpins the Games Technology, for example at a venue planning level only the standard product codes can be selected for deployment and custom hardware/software configurations are banned; quality assurance checklists are established for each different product and must be completed at installation time, ensuring consistency of installation.

The approach of using such a standardised solution is often questioned during the course of the Games, for example where an existing venue is used which already has substantial infrastructure there is the obvious question of why the Games solution has to be an overlay and why it isn't possible to simply use what is there or to integrate it. Given the sheer scale of the Games to re-use this infrastructure would in most cases prove impractical and add risk, requiring extensive review of the adopted infrastructure and revisions to designs, test plans, implementation and operational processes, staff training and alignment of support contracts as well as resolution of management of contractual and marketing rights for sponsors who are committed to delivering for the Games.

Finally, a substantial commercial benefit is also available with a heavily standardised solution, making it possible to negotiate more advantageous contracts based on volume.

The above principles are by no means exhaustive and there is equally detailed consideration for many other aspects of the architecture including security, sustainability and legacy, however they do serve to highlight particularly unique aspects of the Olympic and Paralympic Games and the level of detailed analysis necessary in order to achieve success in 2012.

## 2 Scope

For many years an Organising Committee must operate in the same way as any typical corporate organisation with services such as telephony, Email, specific line of business applications, a 'web presence' and so on. Unlike few other organisations however, the Organising Committee must scale from supporting a handful of people when the IOC first awards the bid to supporting many thousands of people in just a few years as the workforce rapidly increases with the approach of the Games.

To establish this corporate infrastructure was an early test of capability for the LOCOG Technology team, requiring a migration from an existing set of systems that had developed 'organically' from the bid days to a much more scalable platform able to support the increasing number of users and ultimately migrate seamlessly into Games-time: key within this exercise was to model the anticipated demand and as far as possible avoid any major 'forklift' upgrades in the future, for example because of exceeding constraints on platforms such as Storage Area Networks (SAN). At the same time, the opportunity was taken to significantly enhance security controls, with the refresh project requiring a parallel user communications workstream to put in place training and achieve changes to user behaviour and working practices. This refresh was also instrumental in bringing forward decisions on the different standard hardware and software platforms to be used for the remainder of the project.

In parallel with the rapid expansion of the corporate ICT services, the Organising Committee must also manage the design, testing, implementation and operation of the wide range of mission-critical services required during the Olympic and Paralympic Games to serve the differing requirements of the general public, spectators, athletes, broadcasters, press and other Olympic Family stakeholders.

## 3 Approach

All technology services are delivered predominantly by integrating products and services from sponsors, who have either already established an agreement with the IOC to cover multiple Games or have a domestic sponsorship arrangement solely with LOCOG.

Given this complex environment of stakeholders, services and providers, an early initiative for the LOCOG architecture team was to establish a reference framework encompassing the scope of technology and clearly identifying:

- All key services
- Users of those services
- Solution and logical positioning within the architecture
- Organisation(s) with delivery responsibility
- Interdependencies

A greatly simplified version of this framework is shown in Fig. 1 below, with the colour coding being used to identify the delivery responsibilities associated with the different services.

This framework has proven an invaluable tool, putting the different elements of the architecture into context and enabling newcomers to the project to understand the scope of technology and how the different pieces fit together. It has also served as the basis for many other aspects of the project: to enable prioritisation of testing activities for example, a corresponding risk 'heat-map' has been created to align with the framework, encompassing business impact analysis, identification of risks associated with each system and complexity of the transition of that service from Olympics to Paralympics.

Whilst not an exhaustive description, the main areas within the LOCOG Technology framework are summarised below and details are available (where noted) in the accompanying papers.

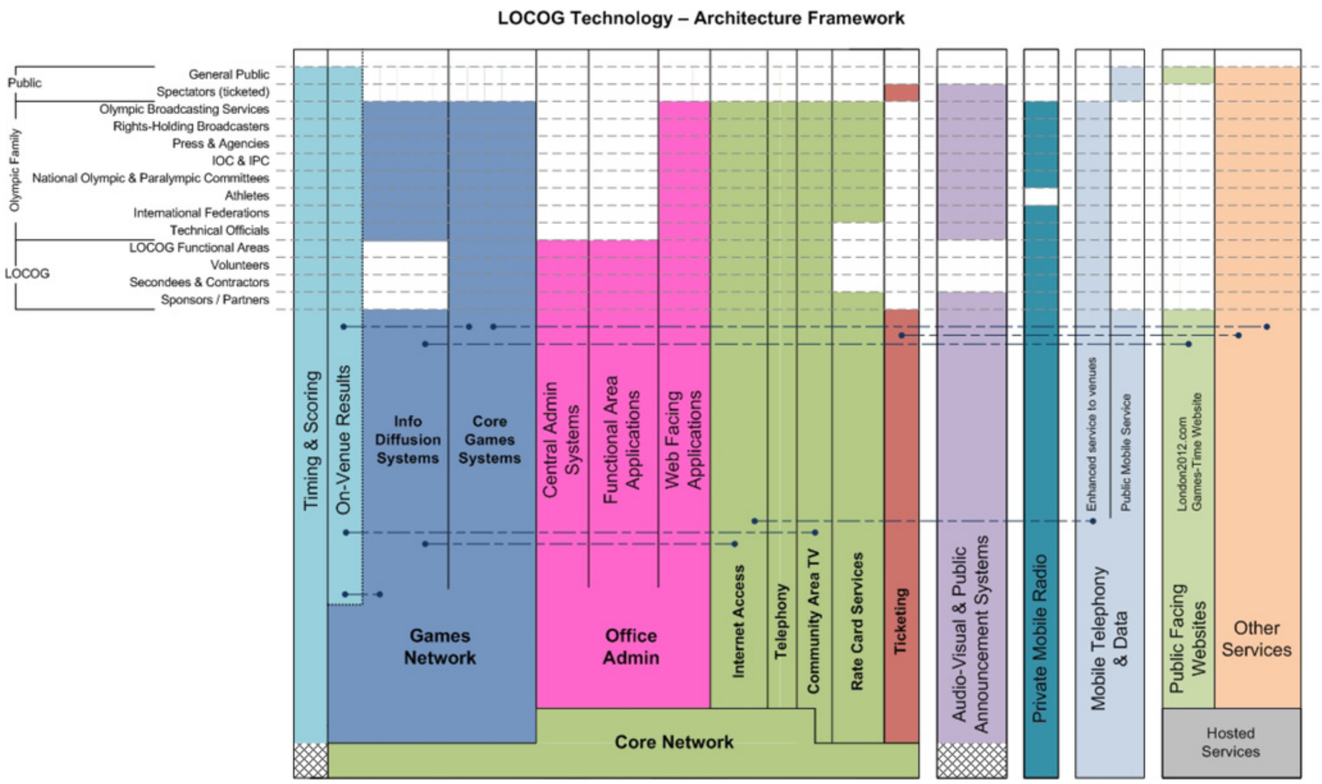


**Figure 1**

**Table**

| | |
|---|---|
| Timing and Scoring | Systems deployed on or adjacent to the field of play to capture as accurately as possible the timing and/or scoring information appropriate to the sport. These systems often employ purpose-built hardware, such as the starting blocks and touch pads used for swimming events. |
| On-Venue Results (OVR) | A small network of PCs, Laptops, Servers and Printers in each venue that receive and process information from Timing and Scoring, generating outputs for the scoreboard, TV Graphics and data feeds for onward distribution. Whilst in this case standard hardware platforms are used, software is again specific to the individual sport. |
| Games Network comprising of:<br>• Info Diffusion Systems<br>• Core Games Systems | These systems receive the data from On Venue Results, carrying out local venue distribution to provide real-time information to Commentators as well as forwarding data to central systems for additional processing. Those central systems publish results for use by the media on an intranet and extranet, provide printed reports for distribution to the media and distribute the Olympic Data Feed for use by the Games-time website, press agencies, broadcasters, International Federations and others to carry out their own processing of the comprehensive set of results and related information.<br>A range of critical Games-time operational applications, for example Accreditation which manages the production of Accreditation passes for Olympic Family, Athletes, Workforce and media to enable access control for specific areas of the venue. |
| Office Admin | The LOCOG corporate network which supports the organisation during the years leading up to the Games and also provides many important Games time applications developed by the Organising Committee, often specific to the particular functional area (department). |
| Core Network<br>• Internet Access<br>• Telephony<br>• Community Area Television<br>• Rate Card Services | The underlying data network supporting the Competition and Non-Competition venues. For further details of the network and the services it provides refer to:<br>– Delivering London 2012: BT Communications Services enabling the Games<br>– Openreach super-fast fibre and the London 2012 Olympic and Paralympic Games<br>Provides wired and wireless internet access, primarily for members of the media.<br>Fixed line telephones distributed across the competition and non-competition venues, along with a range of associated services.<br>Video feeds distributed within competition and selected non-competition venues using either locally generated content and/or channels made available from the International Broadcast Centre (IBC).<br>A range of network services available for purchase by press, broadcast and other organisations. |
| Ticketing | Systems at competition venues for ticket checking, queries and box office. |
| Audio-Visual & Public Announcement Systems | The wide range of different audio-visual and public announcement systems used at venues. |
| Private Mobile Radio | Private mobile radio service used to primarily support handheld radios used by workforce and other key groups. |
| Mobile Telephony & Data | Enhanced mobile telephony and data services required for Olympic Family. For further details refer to Delivering London 2012: meeting the mobile data demand challenge |
| Hosted Services | Hosting of London2012.com and the many associated websites. For further details refer to Developing the London 2012 Games-Time Website. |


# Delivering London 2012: BT Communications Services enabling the Games

*Tim Boden*

*C.Eng, MIET, MBCS Technical Director, London 2012 BT Global Services*

**Abstract:** The appointment of BT as official communications services partner to the London 2012 Olympic Games and Paralympic Games entrusted the company with the heart and pride of the United Kingdom. In the words of the LOCOG Chair, Sebastian Coe: 'Delivering the London 2012 Olympic and Paralympic Games without BT would simply have been inconceivable.'

With an expected global audience of over four billion people, BT carries enormous responsibility. And, with advances in technology, London promises to be the most connected Games ever. Along with its technology partners, BT will carry every image, every commentary, every sports report, and every visit to the Games web site – along with countless millions of calls, emails, and text messages.

In designing and implementing the infrastructure, BT has drawn on its enormous experience, as well as lessons from previous Games. Above all, strongly enforced risk management pays big dividends. Putting simplicity and reliability ahead of heroics is the surest strategy, while detracting nothing from the achievement of the highest technical standards.

This paper chronicles the technical journey, while providing valuable pointers for those already considering their strategies towards future Games.

## 1 Telecoms – and towels – for London 2012

In 1948, London played host to the Olympic Games – the first after the end of the Second World War. It wasn't just food that was in short supply; athletes were even asked to bring their own towels. But despite this, it was a huge success, with 4689 competitors from 59 nations, competing in 136 events. It was also the first time the Games were shown on British television – although few people in Great Britain owned sets and most people tuned in to the radio commentary, enabled by more than 1000 circuits.

Sixty four years on, the Games are back with London 2012 – and the contrast could not be starker. There will be more than 14 500 athletes from over 200 countries participating in nearly 700 events at venues throughout the country – watched live worldwide by around four billion people.

Telecoms technology has moved on in leaps and bounds, with history repeating itself in one sense, as one of BT's exchange buildings in London was one of the broadcast service locations in 1948 – and again is one of the locations for London 2012's network.

But there the similarities end. In 1948, the network hub was the post office inside the stadium grounds, with circuits radiating to all parts. The public address system announced progress and results for the track events. For field events, a telephone network was installed, passing information to an operator for display on the scoreboards, with extension telephones at various points in the arena.

Records in BT archives show that telephones were the American army type field telephones fitted with breastplate transmitters, headgear receivers and waterproof plugs and sockets. When it rained, adhesive tape over the cords overcame any water problems.

In 1948, there were 2000 press representatives. Fast forward to 2012 – and the picture is very different. The communication services infrastructure will be carrying every image, sports report and visit to the London 2012 website – along with millions of calls, e-mails and texts.

At the London 2012 Games, there will be a staggering 22 000 media people, using 80 000 connections – almost enough to have one for every seat in Wembley stadium.The International Broadcast Centre (IBC) and Main Press Centre (MPC) will be a 24-hour hub for the media – and it's vital they can transmit reports and photos reliably and quickly. Fig. 1 gives an idea of the scope in terms of venue connectivity, service deployment, and the resources that BT is committing. There will be 14 000 cable TV outlets – and giant interactive screens in UK city centres, allowing people to send messages to friends worldwide.

The infrastructure will be transmitting correct number of 60 Gb/sec – the equivalent of 60 000 novels or the entire content of Wikipedia every 0.5 seconds.

Mobile technology away from the competition venues will help photographers capture images outside the main venue and send them to the press centre. And internet cafés and wireless access will link athletes to whatever's happening outside the Games.

It's communications on a massive scale – encompassing mobile, wide, local and metropolitan area network, internet protocol telephony, TV and broadcast, fibre-to-the-premises, applications, service and support.

## 2 Technology overview

Solutions for the Olympics are not designed to be leading edge. Rather, they're tried and tested; proven in service for at least two years. This drives the key principles used to develop the solution:

- Reliability: Services use proven, well-understood and mature components, connected to a central carrier class infrastructure.

- Flexibility: A range of circuit connectivity options will be offered to meet different venue requirements and allow the late ordering of additional services where physical capacity permits.

- Scalability: End-user service infrastructure is centralised wherever possible to allow services to scale easily in response to orders.

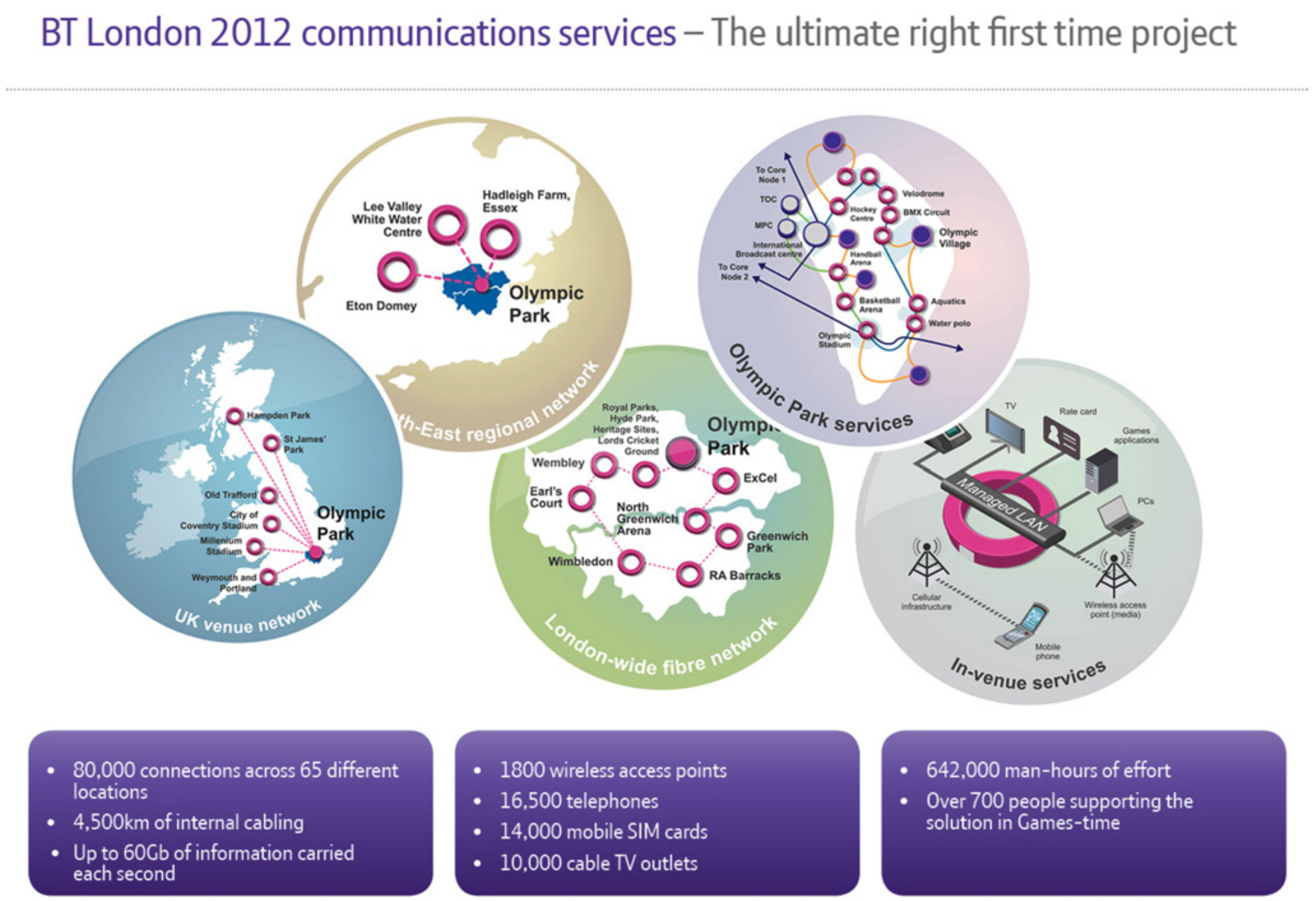


**Figure 1** *Beyond the Olympic Park in London, services provided by BT extend to football venues like Hampden Park in Scotland and the sailing venues at Weymouth and Portland in the West Country*

• Security: Services are designed following best practice, and ensure the integrity of the network and so protect it from attack.

• Manageability: All elements of the system will be proactively monitored and managed such that any faults can be quickly investigated and resolved.

• Cost-effectiveness: The Games needs to be seen to be cost-effective, with any incremental costs spread among multiple customers.

• Sustainability: The communications infrastructure is designed for maximum reusability, to leave a lasting legacy for the local community.

The resultant communications network for London 2012 is built on a set of standard BT services to form a customised solution (see Fig. 2). It provides users with access to:

• The Games Network which supports around 10 000 PC ports and servers. The ports provide access to Games Information Systems; including results and athlete information. The servers operate Games Management Applications which administer the competitions themselves.

• LOCOG administration systems that provide LOCOG's workforce with access to internal email, office automation, and finance systems.

• Up to 16 000 IP telephony handsets, together with wireless offload for 14 000 mobile handsets used by the Olympic family.

• The Internet with over 5000 media users expected to purchase flexible access to the Internet for the Games-Time period from a range of ports within venues and the media centres.

• Rate Card services, supplying up to 10 000 communications services to accredited organisations through a Games-specific catalogue, e.g. data services both within the estate and dedicated connectivity to the internet.

• Games Community Area TV, distributing up to 40 channels of Olympic TV programming from the International Broadcast Centre.

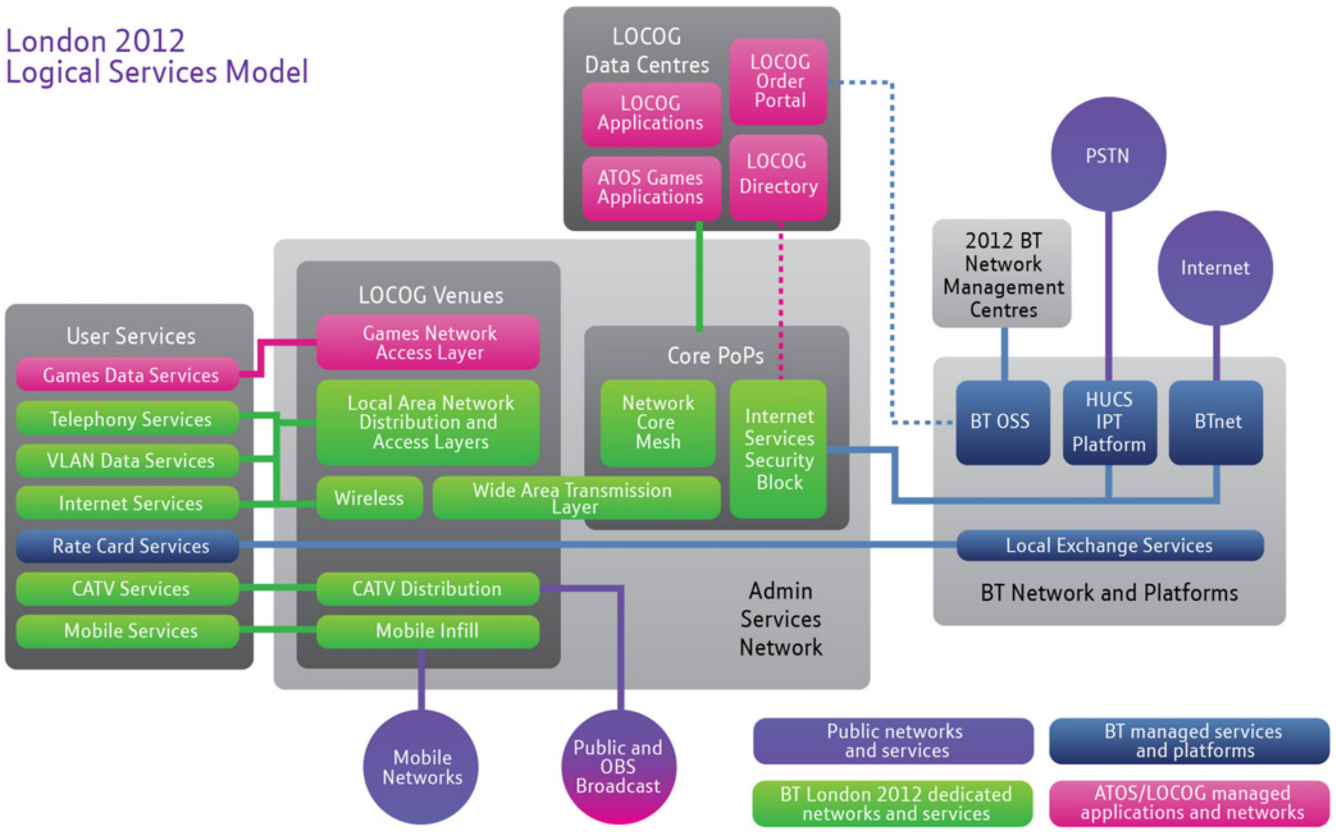


**Figure 2** *The core of the London 2012 logical services model delivers a scalable and flexible foundation on which resilient and secure end-user services are built*

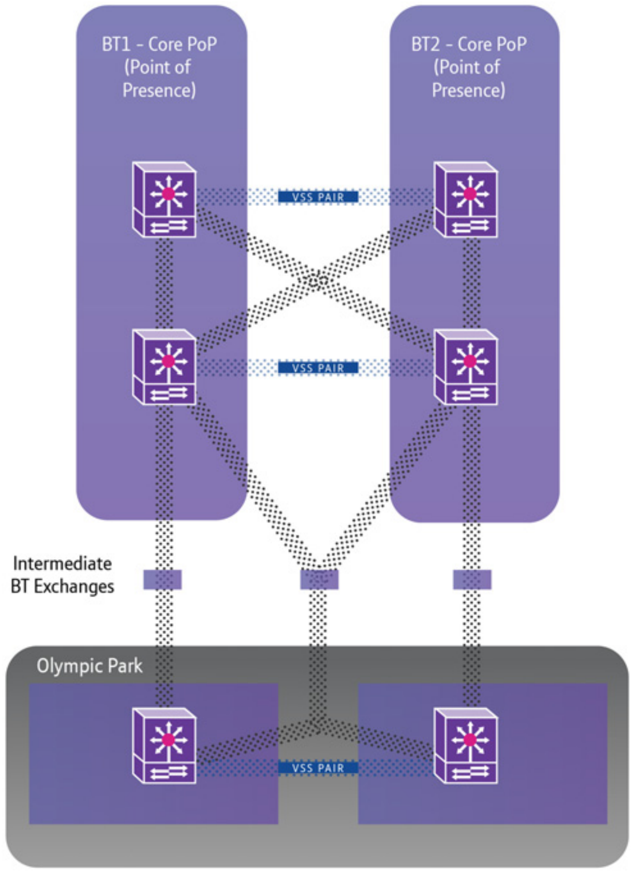


**Figure 3** *The wide area network uses end-to-end Ethernet for low cost and high capacity*

The main architectural and technical building blocks of BT's Communications Services deployment are further described in the following paragraphs.

## 2.1 Network core mesh

The network core provides the connectivity between the Olympic Park and other venues to the central Points of Presence (PoPs) which control connectivity between venues and from the Olympic estate to the outside world. It consists of a mesh of pairs of switches using Cisco's virtual switching system (VSS) technology. It adopts virtualisation to provide uninterrupted service in the event of failure of any of the separately-routed communications systems provided between every venue and the core. Each VSS pair appears as a single logical switch capable of surviving hardware or circuit failure in its constituent systems.

The VSS pairs are interconnected using Dense Wavelength Division Multiplexing (DWDM) systems that carry multiple optical wavelengths on a single fibre, with each wavelength presented as a distinct 10 Gbps Ethernet interface. There are two wavelengths (providing 20 Gbps of capacity) between each of the Olympic Park aggregation nodes and the PoPs and twelve (providing 120 Gbps of capacity) between the PoPs themselves. Several physically separate routes run between the Olympic Park and the rest of the network, and also between the PoPs.

## 2.2 Wide area transmission

Wide area transmission is based on Ethernet as illustrated in Fig. 3. In the Olympic Park, each venue is provided with separate dark fibre routes back to the on-park PoPs. Around 14 venues produce up to 20 Gbps of traffic.

There are a variety of options for connectivity for off-Olympic Park venues supporting the connection of around 50 locations with a potential peak aggregate traffic of a further 40 Gbps. Each competition venue has separate Ethernet access bearers to each PoP, providing either 1 Gbps Ethernet Access Direct (EAD) or 10 Gbps Optical Spectrum Access (OSA) capacity designed to a five-nines (99.999 per cent) availability target. Smaller non-competition venues have a choice of dual or single EAD access bearers supporting 100 Mbps or 1 Gbps capacity but with lower availability targets.

For venues outside the range of BT's standard Ethernet access products such as the Weymouth sailing venue, a hybrid solution comprises local access from the venue at 1 Gbps, connecting to the nearest BT metro nodes. From there to the core PoPs, carriage is via a 1 Gbps long-haul WDM wavelength across BT's carrier infrastructure.

## 2.3 Local area network access and distribution

The Local Area Network distributes most end services at venues, with the exception of the Community Area TV services which use co-axial cabling in-venue and specific high audio quality communications services which are delivered directly from the local public exchange.

Where services are deemed to be critical, these will also be protected by a UPS. These switches also supply Power over Ethernet to compatible devices such as IP phones. Horizontal access cabling is typically Cat 5e structured cabling.

## 2.4 Wireless LAN

BT's wireless services provide access to the internet for accredited users including Rate Card customers and LOCOG workforce as well as supporting the offload of data traffic from the Olympic Mobile network. Typically wireless access is not expected to be the primary means of connectivity to the Internet as service levels are easier to guarantee using wired access, hence wireless is typically only deployed in informal work locations where it is impractical to provide cabling such as conference rooms.

Wireless access points operate in both the 2.4 GHz and 5 GHz bands, with traffic tunnelled to the core services block in the PoPs, where user access is authenticated.

## 2.5 Internet Services Security Block

The Internet Services Security Block is replicated across the PoPs, providing resilience in the event of a site failure. It implements best practice security, including inner/outer firewalls and intrusion detection services provided by BT Counterpane which review firewall, server, and proxy logs.

Outbound Internet access services are primarily for media use and are procured via the Rate Card in one of two forms. Large organisations can purchase their own dedicated connectivity, typically delivered to a LAN port in a private office. This is available at 2 Mbps, 10 Mbps, 50 Mbps, or 100 Mbps designed to a low contention ratio of 1:6.

Alternatively, individual users can be provided with a broadband-like service via a username and password. This allows them access to any of nearly 20 000 Internet Access ports distributed around the venues or 1000 wireless access points placed in conference rooms and similar areas. Traffic-shaping is then implemented to provide a maximum throughput per user of either 1 Mbps or 8 Mbps dependent on the purchased profile with a business-oriented contention ratio of 1:20.

With an expected peak traffic of between 3 Gbps and 4 Gbps, two 10 Gbps bearers provide resilient connectivity to the internet from each POP. Inbound traffic mainly supports remote access by LOCOG staff, and Rate Card access to dedicated IP addresses.

## 2.6 Hosted unified communications services IP telephony

London 2012 will benefit from cloud-based BT Hosted IP Telephony running on a secure and resilient platform to support voice services.

This supports standard IP phones, conference phones, and analogue adaptors which allow analogue telephones to communicate with an IP telephony service. Fax services however will typically be provided over a normal PSTN line. Telephones are provided with IP addresses by the BT Diamond IP service. Connectivity to the hosted platform is over MPLS from the PoPs. The service also provides switchboard functionality and voicemail services.

A reserved number range has been allocated by Ofcom for the Games providing users with external 030-2012-xxxx numbers.

## 2.7 Mobile infill and associated mobile networks

The complete mobile solution for the Olympics is brought together from a number of parties. For the public, the mobile operators are collaborating to provide services inside the Olympic Park and competition venues. Typically this involves providing temporary base stations and associated in-building infrastructure to augment capacity in these areas.

This is being extended by BT to address the specific needs of the Olympic family – who comprise LOCOG and their workforce, the international sporting federations and their officials, the athletes and their team management, and those press and broadcasters accredited to work within the venues. It augments the public services of the BT mobile partner with additional capacity in specific areas of the venues, typically back-of-house, where network coverage is limited or non-existent.

Both 2G and 3G services will be provided, with distributed antenna systems or temporary base stations enabling the additional capacity. These will be either linked directly to switching capacity on site or, as in the case of the Olympic Park, via a radio-over-fibre link to an on-site mobile 'hotel'. This allows all the public mobile operators to share infrastructure within the venues whilst breaking out to their separate backhaul circuits from a single aggregation point or 'hotel'.

Given that radio spectrum is at a premium inside the Venues, and hence actual capacity is limited, the use of the 3G spectrum needs to be prioritised for voice use. As a result, all Olympic family mobile handsets will have access to a private wireless LAN in busy parts of the venues, ensuring that data traffic does not use up that limited capacity.

## 2.8 Broadcast solution

The broadcast solution is designed to provide cost effective transport of HD video feeds from the venues outside the Olympic Park to the International Broadcast Centre (IBC) where the broadcast rights holders are provided with the video feeds that they have purchased and can edit them for transmission back to their home countries. Within London, BT's Broadcast Access product provides the ability to transmit uncompressed HD content on a point-to-point fibre link. Orders for around 220 circuits are anticipated.

For football and sailing, compressed HD is used to make transmission bandwidth more cost-effective. BT is exploiting existing connectivity provided to football stadia by BT Media and Broadcast over its dedicated broadcast-tuned MPLS network. BT Media and Broadcast is also providing dedicated connectivity to the IBC and the Weymouth sailing venue.

## 2.9 Community area TV distribution

Forty Olympic channels are produced from the feeds described above in the IBC and provided to the broadcasters who have purchased the rights to screen the Olympics in their home countries. That same programming provides the basis of the CATV services, distributed in-venue over co-axial distribution systems. The use of RF distribution is critical for locations such as press tribunes where there is visibility of the field of play, and where the delays introduced by encoding and decoding are very visible. The same distribution system also supports real-time data services which include results and timing feeds.

Most competition venues have access only to their local competition feeds plus a Freeview package distributed to TVs locally around the venue. The exceptions are the central venues for Football and Modern Pentathlon which require feeds from the other venues hosting their sports to be transmitted to them for central coordination. Selected non-competition venues such as the Main Press Centre and LOCOG operational centres have the full Olympic channel package distributed over the network to them.

In these cases where channels are required to be distributed over the network, they are encoded to MPEG and multicast over the core from head ends at the IBC. In venue, they are decoded by a Quadrature Amplitude Modulation device for distribution over the local co-axial network.

## 2.10 Web hosting services

BT is hosting the London 2012 website, which changes significantly during its lifetime, initially providing a rich user experience before moving to a much more intense data presentation service during the Games. To assist with these extremes, BT has engaged a Content Delivery Infrastructure partner to provide a Content Delivery Network (CDN) and associated enhanced security controls.

Services are provided from two data centres in an active/active configuration, each providing multi-layered firewalling, load balancing, and intrusion detection. A blade server environment is used to support content applications with virtualisation for maximum flexibility and optimised resource usage.

The solution is designed to accommodate over 30 000 000 concurrent sessions at peak during Games-Time, with web traffic demand during the Games estimated at more than 1 PB per day, resulting in a potential peak traffic into the hosted infrastructure of around 2 to 3 Gbps. The bulk of web demand, potentially up to 60 Gbps, will be handled by the CDN using data caching.

## 2.11 Verification and testing

As a key element of the Programme. BT has established a sophisticated test environment, known as the Design Definition Environment (DDE). It mirrors the live Games network environment, enabling individual devices and configurations to be thoroughly tested in the lab. All infrastructure components are pre-configured and put through verification tests at a staging centre, ensuring that they work out-of-the-box when shipped to site.

Sporting test events provide a live opportunity for technology appraisal with forty-four planned in the run up to the Games, although as most are actual competitions, they are run at Games-Time service levels and are not an opportunity for experimentation. Finally, two full technical rehearsals will examine the performance of people, process and systems in different situations selected from a playbook of over 1000 different technology scenarios built up over previous Games.

# 3 Service management

In this section two themes deemed central to the customer experience are outlined, Service Management and Order Management. The traditional command and control service model for communications management needs modification for a 17-day, highly visible event where equipment failure will at best remove resilience and at worst affect the operations of the Games. Furthermore, levels of last minute change are expected to be high as press and broadcasters move in to their Games-time accommodation. As a result, non-standard approaches are required for both service restoration and order management, as described below.

## 3.1 Network management

The need for rapid response means that a highly customised service model is required for the Games. Within the LOCOG Technology Operations Centre, BT Games-specific services are supported by the BT team using customised versions of the BT standard proactive management and repair toolsets that report on all active equipment.

Augmenting this, there are over 400 venue-based BT engineers providing an on-site presence to ensure that any faults are fixed quickly. Only a minimal number of faults are expected to occur during Games-time – most of which will have no actual impact on service, although some may impact resilience. In either case, restoration targets are set at less than one hour, hence on-site resources are underpinned by a carefully designed sparing policy and the strategic placement of spare part stocks.

## 3.2 Order management

The LOCOG Rate Card defines a catalogue of services available to organisations which need to operate temporarily inside venues for the duration of the Games. In many cases these offer shorter than normal lead times for Games-Time orders enabled by automated ordering and supported where appropriate with pre-provisioning of infrastructure.

Most of these services are delivered over the core network and hence exploit its high availability and service levels, whilst a few others are delivered separately from the local exchange. Overall there could be around 14 000 orders across broadcasters, press, international federations, Olympic committees, athletes and sponsors.

The order management and venue build systems have been constructed from standard BT tools, but heavily configured to meet the needs of the Games. The system deals with the reception of orders from the LOCOG order portal, providing flow-through provisioning for high volume items (e.g. telephony) and bespoke workflows for lower volume items where automation is not appropriate or where complex configuration is required (e.g. VLANs).

# 4 Key challenges, best practice, and innovation

Whilst it is impractical to distil three years of learning into a short paper, the following paragraphs draw attention to four key areas from the BT experience so far.

## *4.1 Design and service assurance*

Critical Games-time services are designed for carrier-class 99.999 per cent availability. Yet long-term availability is not an appropriate measure of Games-Time performance as a chance catastrophic failure could have a dramatic impact. As a result, each service has been subjected to a rigorous programme of critical design and service design reviews.

Held in conjunction with independent reviewers, they focus on assessing the services against six architectural views, namely requirements, lifecycle conformance, security, manageability, performance and reliability and data integrity. The aim is to identify particular classes of failure, their potential impacts, and how long they would take to resolve. That predictive intelligence is built into service contingency plans to assure appropriate responses before the event rather than after.

## *4.2 Process and resource optimisation*

The concentrated nature of the Olympic Games and Paralympic Games presents a truly unique operational environment. No matter how carefully end customer requirements are captured and specified, there will always be unexpected last minute requests. The BT infrastructure was dimensioned and built with flexibility, agility and scalability front of mind with the worst case the inevitable starting design assumption.

BT chose to adapt existing processes around a service model supporting all Games-accredited customers, with end user requirements channelled into a smaller number of generic propositions. That classic 80:20-style thinking allowed room to focus appropriate resource on the inevitable beyond the norm customer need, and on managing the demands of a busy period. As well as dealing with business-as-usual, BT will need to support both the Queen's Diamond Jubilee celebrations just four weeks before the Games and other sporting events prior to the opening ceremony.

The BT people management framework was designed to identify and recruit, well in advance, the highly skilled people necessary to support the Games. Careful resource scheduling brings those people into play at exactly the right time: over 200 are already full time on the programme; others are in training ready to join the team nearer Games-time. To safeguard BT business-as-usual activities a backfill programme using contractors and ex-BT staff protects core operations and normal BT customer service.

## *4.3 Venue access and venue design capacity*

One of the key challenges for BT lies outside the Olympic Park. Designing and deploying the communications infrastructure for venues across the UK proved more of a challenge than originally expected. On the one hand BT needed to negotiate access for network diversity at busy existing venues such as football stadia; on the other the company has to rise to the challenge of providing resilient network services to remote temporary venues not in the original plans. Careful analysis and scheduling around such unexpected barriers was necessary to avoid the deployment programme becoming compressed causing unsustainable resource peaks near Games-time.

Traffic forecasting is also critical as there is limited if any opportunity to monitor and adjust capacity over time. The network needs to be designed to deliver its greatest responsiveness at the time when it is most stressed, for example during the peaks that occur just after major events when the media upload most of their photographs. As a result, smoothing traffic is not a good approach and worst case modelling has to be adopted.

Complicating this position is the fact that the ordering deadline for many services occurs late in the timeline when compared to the dates by which the network circuits are needed, and hence volumes can vary from estimate to actuals. To address this, the capacity needs of those services subject to limited change are assessed, together with a baseline load from more variable services. If this value exceeds 70% capacity on a 1 Gb link, then a 10 Gb circuit is provided. If not then 1 Gb has been provided, and orders are monitored to ensure that further capacity is provided should the limits be exceeded.

### 4.4 Sustainable thinking

Working with the World Resources Institute and the World Business Council for Sustainable Development, BT has adapted best practice carbon footprint assessment to meet the needs of the Games. Responsible sourcing and a converged architecture have substantially reduced the total footprint, while a legacy strategy will save up to 30 per cent more. For example, the fibre network installed at the London and Weymouth Athletes' Villages will remain in place for longer-term residential use.

## 5 Recommendations

In summary, BT would recommend the following top-level agenda for anyone facing similar challenges and seeking to learn from BT.

### 5.1 Adopt a right first time mindset with proven technology

Supporting a major worldwide event like the Olympic and Paralympic Games is a golden opportunity to boost the communications service provider's brand, motivate its staff, and showcase its capabilities on a global scale. But any failure would be visible and brand affecting. A right first time mindset recognises that what can go wrong will go wrong and therefore getting the network architecture right is crucial. Using tried and tested technology is the key.

### 5.2 Identify people early and mitigate broader service impacts

The people management framework is close to the top of the list of critical success factors. Those with the necessary skills and attitude must be identified early then trained, motivated, and equipped to deliver a faultless customer experience. A backfill programme is essential to avoid impacting business-as-usual customer service and operations. Finally, developing beyond-the-Games career roadmaps for the people involved maximises their future benefit to the company and its customers as well as benefiting the individuals.

### 5.3 Mandate service simplification and automate where possible

Supporting the Games requires extremely high service levels for a very short period of time, and standard delivery models will not suffice. It's very important to define the service catalogue at an early stage. Custom end-user requirements should be, wherever possible, channelled into a small number of generic propositions to simplify provision and reduce deployment risk. Maximising order processing automation minimises touch points, lowers costs, and reduces the opportunity for human error.

### 5.4 Anticipate venue challenges and use cloud-based services

The distributed nature of the venue programme provides a major challenge to negotiate early access, reserve space for equipment deployment, and via the deployment of cloud-based services, build sufficient flexibility into venue network design to cope with unexpected last minute customer demands. For the first time at a summer Olympics BT has adopted a converged network architecture and is using centralised cloud-based services such as hosted unified communications for voice. This approach enables rapid deployment and provides cost effective flexibility and scalability, while minimising hardware and software requirements at the venues.

### 5.5 Design a test & verification programme

A BT test and verification environment mirrors the live Games network. Equipment is pre-staged, configured, and tested before being shipped to site. Rigorous design reviews are applied at critical stages, covering both technology and process. These are coupled with formal operational readiness reviews to verify implementation.

## 6 Conclusion

Over the years, the Games have become increasingly dependent on communications services and technology. This technology is not decorative, world records require accuracy and reliability, otherwise their credibility could be undermined. The Games have also become an important global showcase for new technology, and are considered by many to be the most complex information technology challenge in the world. From supercomputers for predicting weather and pollution, to laser timing devices for precision results, technology is having a profound impact on the Olympics.

# Openreach super-fast fibre and the London 2012 Olympic and Paralympic Games

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**Abstract:** As the official telecommunications infrastructure partner to the London 2012 Olympic Games and Paralympic Games, Openreach is supporting BT in its role as the official communications services partner to the Games.

Super-fast fibre connections are being provided to each of the apartments in the Olympic Village on behalf of BT Global Services, the BT business supplying telecommunications services on behalf of BT to the London Organising Committee of the Olympic and Paralympic Games (LOCOG).

The communications services from the Olympic Park in Stratford and other venues across the UK – 94 locations in all, when non-competition sites are included – are also being provided by BT, allowing millions of people in the UK and billions more around the world to see all the action as it happens. The same services will help to keep the 14 700 competitors living in the Athletes' Village in touch with friends and family in 205 countries.

This paper focuses on the challenges faced during the installation of super-fast fibre at the Athletes' Village at Stratford, where it is set to provide a legacy communications infrastructure that should encourage further regeneration in an area with high deprivation. It was also felt that this would be an appropriate opportunity to showcase the best of innovative UK technology.

FTTP infrastructure will initially be capable of delivering speeds of up to 100 Mbit/s. However, laboratory trials have already indicated that FTTP could easily run communications services of 1 Gbit/s and more going forward.

## 1 About

Openreach is a BT Group business with its own headquarters, systems and financial reporting processes, employing around 33 000 people (including 25 000 engineers and a 2700 strong customer service organisation).

Their communications infrastructure supports 28 million phone lines in the UK. It consists of hundreds of thousands of kilometres of copper and fibre cables, ducting, electronics and data centres required to connect 5000 local telephone exchanges to homes and business premises around the country.

Customers include the nation's largest communication and entertainment brands, plus many smaller broadband and voice service providers. It is they who sell the data, broadband and voice services used by consumers, businesses and all levels of government.

Regardless of their size and influence in the marketplace, every customer is treated in an impartial manner and no customer, including other BT Group businesses, is given preferential treatment.

This equal and open access the business provides has led to the creation of a vibrant communications industry in the UK, where healthy competition is helping to keep down retail prices and end users are free to choose the right deal for them, from the widest possible choice of suppliers.

## 2 Super-fast fibre across the UK

The learning from the super-fast fibre deployment at the Athletes' Village at Stratford is already proving invaluable in the nationwide rollout of super-fast fibre, particularly with regard to its deployment at new multi-dwelling residential developments similar to those at Stratford.

£2.5 billion committed by the BT Group is being spent to make super-fast fibre available to 10 million homes in the UK by December 2012, increasing to 16 million homes – the equivalent of two-thirds of the population – by March 2015.

Openreach is working with central government and local authorities to bring super-fast fibre (subject to the BDUK Broadband Delivery Project bidding process) to the remaining third of the population, where the financial case for deployment and therefore further private investment from the BT Group cannot be justified.

## 3 Technology choices

The majority of fibre delivery across the UK will be FTTC, with FTTP mostly serving new developments like the Athletes' Village at Stratford. FTTP is also being deployed across the UK, where it proves to be a viable investment.

*FTTC: Fibre to the Cabinet*: FTTC is a practical and cost effective solution in built-up areas, as it involves far less digging and disruption. Solutions to deploy FTTP by overhead cable are being developed. This should help to overcome some of these issues in the longer term.

With FTTC now capable of speeds up to 80 Mbit/s (and potentially even more in the future), it would easily have met the needs of the majority of people in their homes, which is what the flats in Athletes' Village at Stratford will become after the competitors have moved out.

For the second Athletes' Village, serving the sailing competitors at Portland and Weymouth, the decision to deploy FTTC means that local residents should be able to benefit from the same speeds.

80 Mbit/s over copper is achieved by adopting new signalling frequency ranges within the Very fast Digital Subscriber Line (VDSL2) technology that underpins FTTC. This enables higher bandwidth rates to be achieved over copper cable currently providing speeds of up to 40 Mbit/s.

This improvement in VDSL2 speed is dependent on the length of the copper cable between the cabinet and the apartment. Copper lines with the shortest distance between the cabinet and the apartment should be able to achieve 80 Mbit/s, while those that are further away will achieve lower speeds. The vast majority of FTTC lines across the UK are expected to run at 60 Mbit/s or higher.

*FTTP: Fibre to the Premises*: FTTP is being laid alongside copper for the entire Stratford site, including the Olympic Park. A total of 5000 fibre and 20 000 copper connections are being provided.

The scale of the Stratford site meant that FTTP was an economic investment. When the Games are over, the Stratford infrastructure will enable Openreach customers, the communications providers, to provide everything from stand-alone voice services over copper, to fibre-based voice and data services and cloud-based applications. The beneficiaries will be the hundreds of new businesses and thousands of new residents who will be attracted to the area because of its impressive facilities, including the communications infrastructure.

## 4 Installation challenges

With several different construction companies working on the Athletes' Village at any one time, each with their own deadlines, security arrangements and health & safety procedures, the logistics were always going to be challenging.

The first engineers arrived on site in June 2010. They wrote individual method statements for each of the plots, including risk assessments. This was critical. If they did not follow each contractor's rules, the engineers would not be permitted to work on the plots and the FTTP deployment would be severely disrupted.

Working in such a crowded environment often meant re-arranging the day at very short notice. A flexible, can-do approach, coupled with mutual respect, overcame the tensions that can all too easily arise when everyone is under pressure to meet tight deadlines.

Certain design challenges also had to be overcome before the first fibre connections could be completed. The FTTP equipment for the apartments at the Athletes' Village is not the standard white wall box typically installed in a domestic environment. Four boxes are required – one to connect the fibre to, one for the electronics, one for the power supply and one for battery back-up.

Clearly, locating these boxes in a living room or bedroom would not have been aesthetically acceptable. While it does not reflect standard practice in domestic FTTP environments, it was decided that the ideal place to locate the four boxes would be on a hidden shelf unit in the kitchenette of each apartment.

The shelf units were manufactured to a design agreed with the developers and the FTTP boxes were attached to them before they arrived on-site. This saved a great deal of time, as the engineers were able to simply slot in the shelves and connect up the appropriate fibre to the appropriate box. This procedure also guaranteed consistency of installation throughout the Athletes' Village.

It is BT's intention to make communications services available to the apartments in the Village via (V.3) of their wireless Home Hub. This poses a technical challenge from potential RF interference and conflicts, as so many units (2818 of them) are going to be installed within a relatively small area. Surveys are underway now, to assess potential issues and resolve them well before the Games start.

## 5 Architecture

FTTP uses many more components than FTTC. This required careful consideration in the design of routing throughout the 67 blocks of flats and across the site itself.

Planning and agreement with the building owners and on-site contractors was sought on where to place aggregation nodes, optical splitters, distribution points (with manifolds) and customer splice points. Logical designs for arranging these components required adjustment to fit layout constraints.

For example, decisions had to be made on how many distribution points would be required in each block of flats. Would one distribution point be capable of serving all the floors, or would one be needed on each floor? Where on the floor would the distribution point be located, and how would the fibre be routed through to it?

It soon became apparent that there could never be a one-fits-all architecture for FTTP deployment. This generated the design of several different arrangements for new and existing developments.

Away from the site, within the Next Generation Access (NGA) telephone exchange serving the Athletes' Village, an investment was made in new switch/head-end equipment. This provides sufficient capacity for the 2818 connections to the apartments. It will also meet future super-fast broadband demand from other commercial areas within the wider complex and surrounding residential areas. This infrastructure is capable of delivering a total of 2.4 Gbit/s downstream bandwidth and 1.2 Gbit/s upstream, utilising Gigabit Passive Optical Networking (GPON) technology.

Each connection is being divided between up to 32 apartments. Dimensioning the network to this level will enable each apartment to receive a super-fast broadband service capable of 100 Mbit/s peak rate downstream, while offering 15 Mbit/s upstream bandwidth.

Actual broadband service is affected by backhaul capacity from the local exchange/handover location back to the core network. Sufficient capacity is being provided to meet the immediate needs of the athletes during the Games. Backhaul capacity can be grown to meet market requirements as they grow in the future.

## 6 Fibre installation

The 5 km cable bringing the fibre into the Athletes' Village from the local telephone exchange contains 276 fibres. Around 100 of these hair-like glass strands are providing connectivity to the apartments. The remainder will serve up to 16000 new homes and many new businesses on an adjacent site.

Running fibres from the telephone exchange was relatively straightforward. Compressed air was used to blow them through a 25 mm diameter tube to the perimeter of the site, at which point the fibres reserved for the Athletes' Village were separated into bundles of four and blown along a 14 mm diameter tube to the telecoms intake room in each of the 67 apartment blocks.

The easiest and fastest way to complete the connections was to install the FTTP equipment shelf in each apartment, fusion splice a fibre to it and blow the other end down a riser to a distribution point, known as a splitter.

Splitters work like prisms. They split the light from a single main traffic-bearing fibre 32 ways and direct the output to individual fibres serving the same number of apartments (NB: 64-way splitters are being developed for deployment at other large-scale residential installations around the UK).

Engineers are currently testing some of the fibre runs between the telephone exchange and the apartments. Intense testing is scheduled to start in September 2011. At the time of writing (July 2011), around 2400 of the 2818 apartments have end-to-end fibre connections. The remaining 418 apartments should be connected within weeks, by which time engineers' will have completed over 7000 fusion splices in the Athletes' Village alone.

Notes:

- *Blown fibre:* The fibres are attached to a blow head that acts like a piston. The blow head is inserted into a hollow tube and the compressed air is switched on. This sends the blow head (and the fibre it is carrying) to its destination. This procedure is utilised to blow fibres in main cables for several kilometres. It can blow individual fibres or fibre bundles for up to a kilometre.

- *Fusion splicing:* This is the electrical fusion of two hair-like fibres ends. Even though engineers use machines to do this job, a steady hand is essential. If the fibre ends are not perfectly matched, there will be no signal. The cable carrying the fibre contains a number of elements, each of which protects 12 fibres. An engineer strips off the cable's outer protective coating and slices open the protective coating on the elements to reveal the fibres.

## 7 Learnings

Working in a unique environment like the Athletes' Village, alongside many different contractors, was an especially challenging experience. Engineers had to quickly adapt to the working rules and conditions of other organisations.

They also had to be quick-thinking. The idea for the hidden slot-in FTTP equipment shelf in the kitchenettes of each apartment is a typical example of that kind of thinking. It saved valuable time by eliminating the need for several engineer visits to each apartment and will provide an aesthetically-pleasing solution for future residents after the Games.

Several FTTP design arrangements have been developed to meet the requirements of multi-dwelling units (MDUs) across the UK, on both new developments like the Athletes' Village and existing sites.

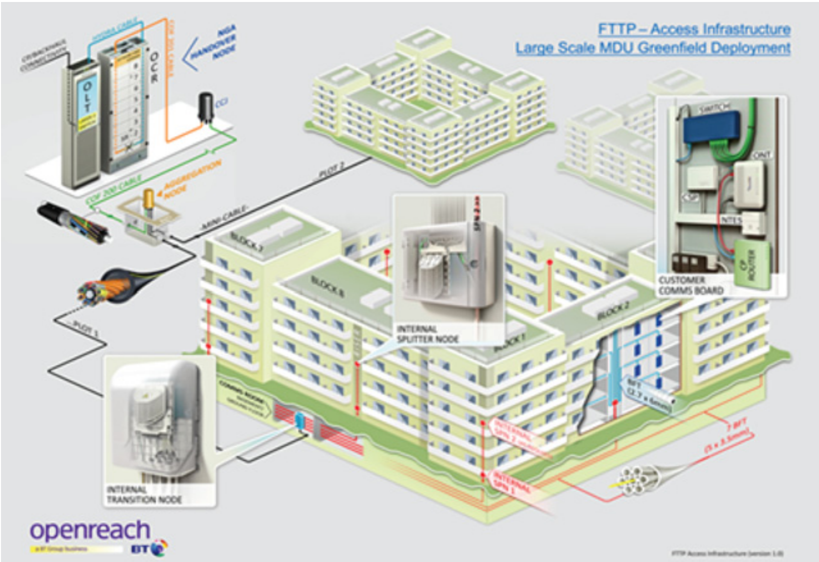
In future, fibre cabling will be used for new large-scale installations, as opposed to blowing fibre through pre-installed tubing, as it's technically less complex to install. Fibre cabling will enable traditional wiring techniques to be used versus using compressed air techniques for forcing fibre through tubes.

A combination of copper, FTTC and FTTP will provide the network infrastructure of the future. In the face of a continually rising demand for bandwidth, only a comprehensive infrastructure of this nature will be capable of satisfying the requirements of consumers and businesses alike.

# 8 Diagrams and photographic reference

## *8.1 FTTP deployment arrangement at the Athletes' Village*

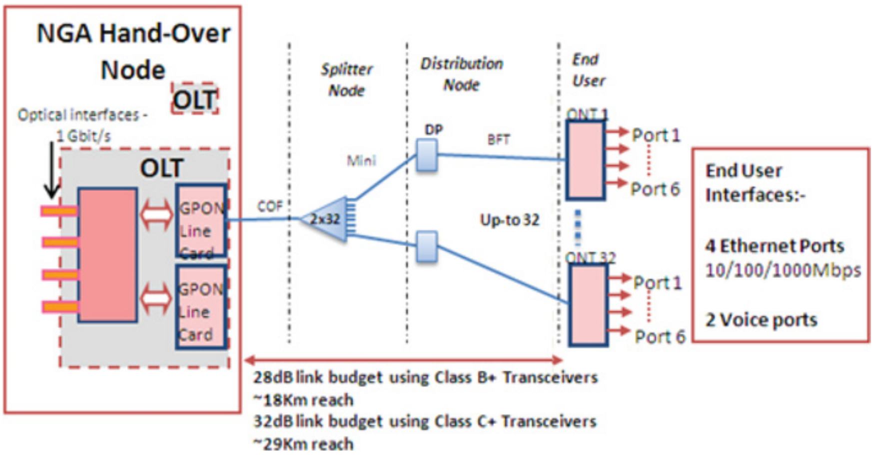
The following schematic illustrates the FTTP infrastructure for large-scale MDU deployments at new developments:




## *8.2 FTTP architecture at large-scale installations at new developments*

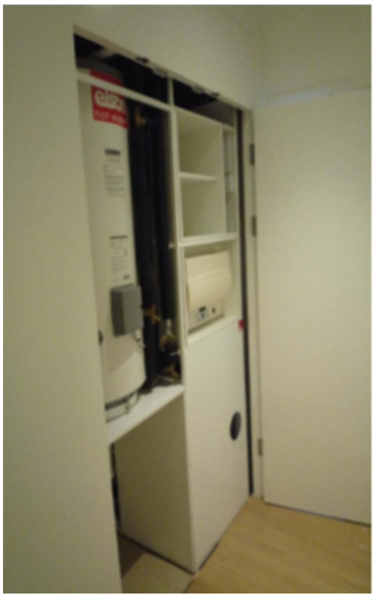
The target infrastructure is FTTP, based on standard GPON technology, upgradeable to XGPON to meet future bandwidth demands, utilising a 32-way or 64-way passive splitters that reduce the need for the number of fibre runs within buildings.

At each apartment at the Athletes' Village, the infrastructure terminates on an Optical Network Termination (ONT) that presents 4 Ethernet ports and an analogue telephone adapter point, enabling the provision of data and voice or bundled communications services.



## 8.3 FTTP installation in an apartment

The following pictures show slot-in shelves with FTTP boxes fitted to each of the apartments in the Athletes' Village.

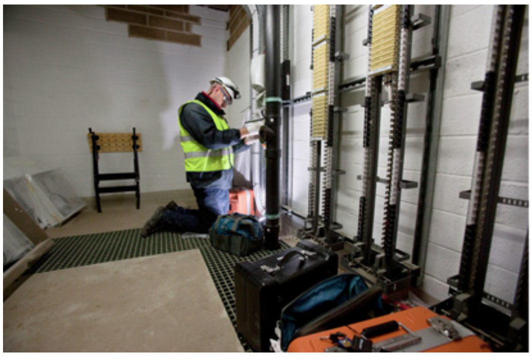


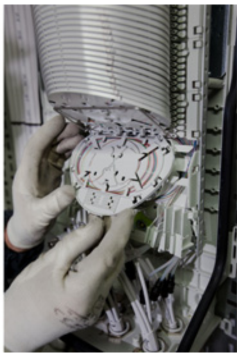
## 8.4 FTTP and copper installation in a town house

These pictures show engineers working on FTTP and copper installations in a town house at the Athletes' Village.

### 8.5 FTTP installation in a communications intake room

These pictures show engineers working on an FTTP installation in the communications intake room of one of the apartment blocks at the Athletes' Village.





### 8.6 FTTP installation in a riser cupboard in an apartment block

This picture shows an engineer working on a riser cupboard in an apartment block at the Athletes' Village.

## 9 Plant

• *Telecoms intake room on each plot:* Fibre termination cabinet, 2 copper terminations and frames, plus external fibre and copper cabling connections from the Village-wide duct network.

• *Risers in each apartment block:* Fibre splitter cabinet for up to 32 apartments and a copper distribution cabinet for up to 50 apartments.

• *Within each apartment and town house:* Fibre termination box, ONT, ONT power supply, ONT battery back-up and Network Terminating Equipment 5 (NTE5). NTEs are the point within each apartment at which the Openreach infrastructure ends and the customer's equipment is connected; in this case using BT Home Hubs.

• *Between telecoms intake rooms and apartments and town houses:* Blown fibre tubing and fibres from the termination cabinets in the telecoms intake rooms to fibre splitter cabinet riser positions, blown fibre tubing and fibres from splitter cabinet riser positions to ONTs in apartments, copper cabling pairs from the telecoms intake rooms, copper termination frames to copper distribution cabinet riser positions and copper cabling pairs from copper distribution cabinet riser positions to NET5s in the apartments.

## 10 Super-fast fibre and regulation the post-Games environment

In the post-Games environment, as the apartments at the Athletes' Village pass into a mix of public and private ownership, wholesale access will be provided on an equivalent basis, to whichever Communications Provider (CP)/Internet Service Provider (ISP), future residents choose to supply their communications services.

## 11 Reference sites and documents

More information about the investment in super-fast fibre and its deployment can be found at: www.openreach.co.uk/orpg/home/products/super-fastfibreaccess/superfastfibre.do

Additional information about Generic Ethernet Access over FTTP (GEA-FTTP) and Generic Ethernet Access over FTTC (GEA-FTTC) infrastructure and product design differences can be found at: www.openreach.co.uk/orpg/home/products/super-fastfibreaccess/fibretothepremises/fttp.do; www.openreach.co.uk/orpg/home/products/super-fastfibreaccess/fibretothecabinet/fttc.do

## 12 Abbreviations

CP: Communications Provider

FTTC: Fibre to the Cabinet

FTTP: Fibre to the Premises

Gbit/s: Gigabits per second

GEA-FTTC: Generic Ethernet Access-Fibre to the Cabinet

GEA-FTTP: Generic Ethernet Access-Fibre to the Premises

GPON: Gigabit Passive Optical Networking

ISP: Internet Service Provider

LOCOG: London Organising Committee of the Olympic and Paralympic Games

Mbit/s: Megabits per second

MDUs: Multiple Dwelling Units

NGA: Next Generation Access

NTE5: Network Terminating Equipment 5

ONT: Optical Network Termination

VDSL2: Very fast Digital Subscriber Line 2


# Delivering London 2012: meeting the mobile data demand challenge

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**Abstract:** This paper outlines the technical challenges faced by the UK's mobile network operating companies (MNOs) in delivering world class mobile services to their customers and international visitors during the London 2012 Olympic Games. This paper focuses on the design of the radio (i.e. physical) layer necessary to provide high quality, high capacity voice and data services to venues within the Olympic Park at Stratford, East London.

Other Olympic venues, legacy concerns and the impact on normal MNO business activities are beyond the scope of this discussion, however, the principles discussed are currently being adopted at similar venues across the UK.

The paper begins with an overview of the mobile voice and data capacity challenges expected during the 2012 Games. The paper goes on to describe the trial activities at Twickenham Stadium during 2010 to develop the approach of sector densification that is now a fundamental building block in delivering a high capacity mobile network service for London 2012.

A case study is provided to show how the trial approach has been applied at a primary Olympic venue – the Aquatics Centre. Finally the paper provides some key learnings and conclusions. Particular importance is placed on stakeholder engagement, antenna selection, having a joined up approach with the surrounding macro cellular infrastructure and the importance of utilising a proving ground several years prior to the London 2012 games. The experience gained positions the UK at the forefront of mass event 3G design.

## 1 Context: forecasting traffic demand

In 2009 the UK mobile industry met under the auspices of a BBC workshop to determine likely demand during the London 2012 Games period. The objective of this workshop with the mobile network operators was to investigate potential media consumption and phone usage during the games. This included a number of parameters such as mobile web usage, visitor numbers, data traffic, new devices types (e.g. smartphones and tablets) and the need to support those running the games. Whilst each mobile operator has their own proprietary interpretation as to how this demand should be managed the BBC workshops provided a common foundation for traffic demand assumptions. Forecasted traffic levels represented a tenfold increase on some MNOs experience at similar venues in early 2010.

Customer expectations have been raised by the increased functionality of the latest smartphones and the increase in domestic broadband adoption. The ability to personalise portable devices, for example by downloading Apps to the device and their low cost means that they have become the first choice for many people to access data services and understandably consumers want to be able to replicate the experience they get with their home computers on their portable devices when they are out and about.

The philosophy of some UK MNOs is that it is not sufficient for operators to merely catch up with demand, but to provide the infrastructure to stay ahead of the demand curve. Customer behaviour is changing and some spectators at each event will monitor progress of other events by video streaming or web browsing, particularly during pauses in the event they are watching. This results in bursts of demand across the network but the effect is particularly pronounced at the venues themselves. For example, at the Football World Cup in 2010 large peaks of voice and data traffic were observed at half-time and full-time as well as during significant incidents e.g. penalties, sending-offs etc.

Timed ticketing at the Games will also exacerbate this issue as similar numbers of people will be waiting outside a venue to access the next session to those inside the venue watching the current session and many of those waiting are likely to want to view the current session's action on their mobiles.

## 2 Strategy: spectrum and capacity approach

The UK MNOs plan to deploy 2G (GSM) in the 900 & 1800 MHz spectrum bands and 3G (UMTS) in the 900 & 2100 MHz spectrum bands to support its services at all Olympic venues. 4G (LTE) deployment has been considered but the 800 MHz and 2.6 GHz LTE spectrum bands have been allocated by Ofcom for broadcasting purposes during the Games and therefore will not be available for use by mobile operators during this period.

3G will carry the majority of mobile data traffic during the games, the limited 3G spectrum available to some UK MNOs has driven the need for innovative thinking to provide the required high capacity services. One approach has been to 're-farm' some of the GSM 900 MHz spectrum for UMTS use, however whilst increasing the number of 3G carriers, this alone will not resolve the high demand for capacity in and around Competition venues.

The key to providing an order of magnitude increase in capacity over current systems is to drastically increase the number of 'cells' or 'sectors' at traffic hotspots (games venues, queuing areas etc.) within the Olympic park. A cell/sector can be thought of as being the physical area over which the antenna of a mobile base station provides coverage on a particular channel. In 3G, all channels may be re-used in every sector provided there is sufficient isolation between each sector to prevent interference.

## 3 The testing ground: Twickenham sector densification trial

A series of trials was undertaken by a UK MNO at Twickenham stadium during 2010, culminating in the deployment of a high capacity system in time for the 2011 Rugby Six Nations Tournament.

As per the forecast of the BBC workshop, the challenge set was to deliver a tenfold increase in the existing capacity of Twickenham Stadium seating bowl. The bowl was covered by 4 individual sectors (or cells), one in each quadrant. The aim therefore was to increase this to 40 sectors in order to provide for the expected increase in demand.

From a radio design point of view large stadiums and arenas present a unique set of challenges that are not normally encountered in standard in-building cellular systems and these need to be overcome. The key issues are as follows:

*Density of users:* Twickenham at full capacity houses 82 000 spectators in the seating bowl resulting in a target capacity of approximately 2000 spectators per sector. Applying this model to e.g. the Aquatics Centre on the Olympic Park with a capacity of 17 500 spectators, the coverage solution will need at least 9 sectors in order to meet the anticipated demand during the 2012 games.

*Lack of subscriber mobility:* Spectators tend to sit in one place for an extended period of time hence a good quality connection needs to be available over a large percentage of the coverage area.

*Absence of clutter:* In conventional macro networks and in-building systems, engineers rely on local clutter (obstacles) to provide isolation between neighbouring cells and minimise the effects of co-channel interference on the achievable data rates. In stadia and arenas there is little clutter in the seating bowl that can be used to provide isolation between adjacent cells on the same level. However, in some cases the different seating tiers can be used to demarcate between sectors vertically.

*External network penetration:* In the case of stadia, interference can arise from macro layer cells serving the surrounding area and beyond.

Each of these challenges was overcome using the following five step methodology:

### *3.1 Creating Signal Dominance*

In 3G the data throughput available to each individual user is governed by the Signal to Interference-plus-Noise Ratio (SINR). All available spectrum is reused in each cell using industry standard WCDMA modulation techniques in order to maximise spectral efficiency. As a result, interference from neighbouring cells is far in excess of the noise floor and this is therefore the limiting factor.

One of the key aims for the 2012 Olympic Games is to provide a greater proportion of coverage areas where the wanted signal was significantly higher than any interference thus creating dominant areas of signal over the majority of the serving cell.

Higher data throughput is possible when the dominance is high and users experiencing high data rates tend to complete their sessions faster which ultimately reduces congestion in the network.

This approach provides better performance over a larger proportion of the venue. Clearly, higher dominance can be delivered by providing greater isolation from neighbouring cells resulting in a more efficient network.

For the trial our aim was to explore the degree of dominance that can be achieved in an open seating bowl and subsequently the data throughput that can be realised. The lessons learned would then be applied across all 2012 venues.

## 3.2 Capacity – Increasing the Sectors

Increasing the signal dominance across the cell improves the efficiency and maximises the throughput. However, there are still only have a limited number of resources (connections) per cell as determined by the capacity of the nodeB (3G base station).

In order to raise the overall capacity in a particular venue, the number of sectors has to increase, each driven by its own nodeB and hence each with its own pool of capacity. Therefore, the logical approach to increasing capacity at the stadium was to reduce the footprint of each cell (or sector) in order to fit more capacity in the same physical space.

## 3.3 Specialised antenna solution

To deliver dramatic improvements in both signal quality (dominance) and capacity, antenna technology is at the heart of the high capacity solution.

The traditional approach to providing coverage in stadia is to use macro style antennas at an elevated position on the venue to try and illuminate as many people as possible, which is fine until the capacity is insufficient to meet the demand.

To reduce the size of the cell the antenna must be brought closer to the subscribers making the footprint smaller. Consequently, the path loss is reduced and so the transmitted signal power can be decreased which in turn helps to reduce the interference to neighbouring cells.

To preserve the dominance there should ideally be a line of sight between the antenna and the mobile device. This introduces less variability in the signal from interactions with the stadium structure e.g. reflections. Illuminating spectators from the front is impractical in stadia (since spectator sight lines cannot be compromised) and illuminating them from the rear of the seating tiers can result in issues with excessive body loss through the multiple rows of spectators. The answer in this case was to illuminate the seating areas from above with antennas mounted in the roof structure of the stadium.

Even then, initial trials using standard antennas quickly indicated that although an increase in sectorisation

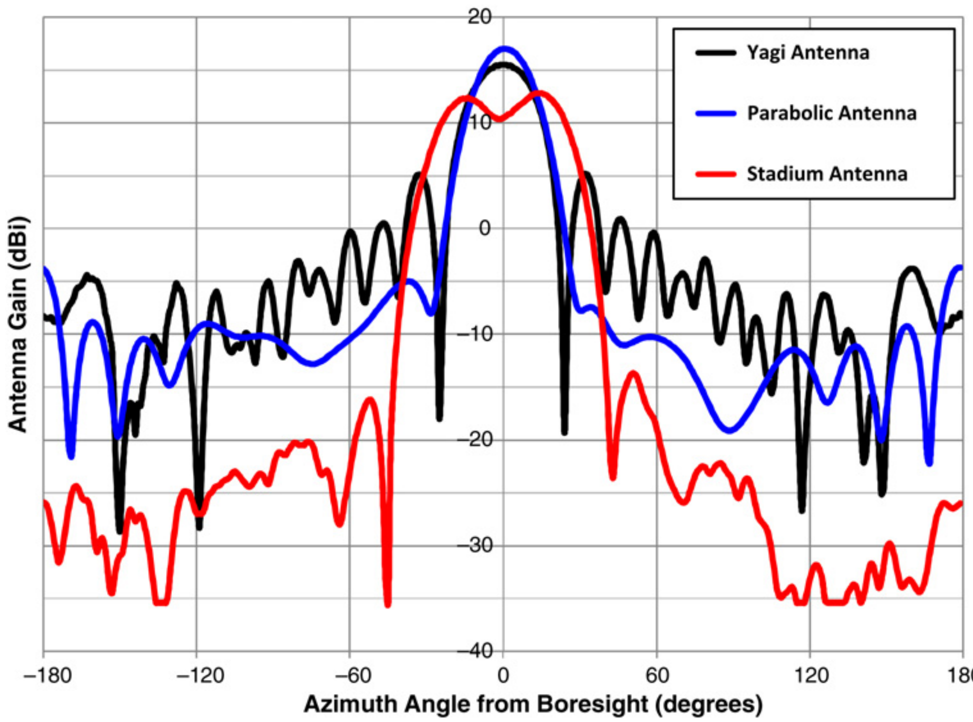


**Figure 3.1** *Antenna pattern comparison*


**Figure 3.2**

was possible, the signal dominance across the cell was low and the sectors were poorly defined. This is due to the fact that the gain roll-off from standard antennas is not sharp enough to reduce leakage between cells to an acceptable level. The sidelobes (unwanted extraneous radiation) of the antenna pattern can also cause appreciable interference if they are not sufficiently below the boresight gain.

An innovative antenna specially designed for use in stadia, but not previously deployed on a major scale, was proposed. The antenna, a large flat panel array with exceedingly high roll-off in the gain profile and an appreciable 50° × 50° beamwidth, would allow reasonable sized sectors. The antenna radiation characteristics are represented in Fig. 3.1 alongside those of more conventional antennas which were also tested.

The antenna was mounted in various test positions in the stadium at distances from the seating tiers of 25 m to 40 m. The resulting footprint was expected to range from 30 × 30 m to 45 × 45 m. The antenna was tested initially using radio frequency (RF) Carrier Wave signals to check the footprint definition and gauge the expected levels of dominance and isolation that might be achieved. Measurements were made not only in the sections adjacent to the target coverage area but all around the stadium to ensure that reflected signals wouldn't cause problems to more distant sectors. Testing of the antenna units is shown in Fig. 3.2.

Once it was confirmed that the stadium antenna had the potential to deliver the desired performance a live-trial was conducted in one quarter of the stadium which was previously covered by one of the 4 original sectors. The trial consisted of 4 stadium antennas rigged above the Glass Reinforced Plastic (GRP) roof (relatively transparent to RF) and data was collected during live matches at the stadium during autumn 2010. Installation above the GRP roof is shown in Fig. 3.3.

**Figure 3.3**


**Figure 3.4**

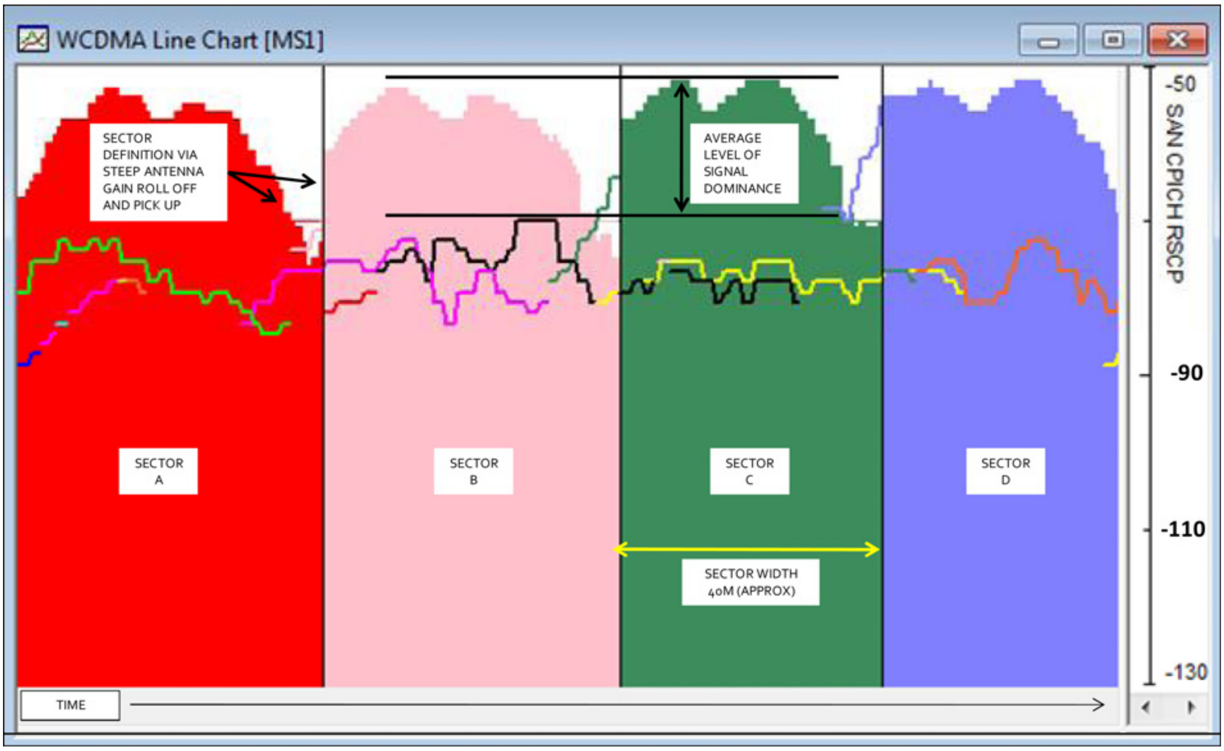


**Figure 3.5**

The initial results were promising but indicated that the maximum potential was being curtailed by the remaining 3 sectors of the original system in the remaining quadrants. A full scale deployment in the remainder of the stadium was then progressed, with an option to maintain the original system as a fall-back. The original system would be turned off for live events and only brought on-line in case the high density system failed to live up to expectations. The full scale deployment is depicted in Figure 3.4.

## 3.4 External network optimisation

In parallel, an exercise was initiated to optimise the coverage in the vicinity of the stadium to minimise interference from macro cells. It is often the case that nearby macro cells are directly aligned towards the venue in an attempt to alleviate the congestion that is typically evident on event days. A key step therefore is to ensure that any existing coverage or neighbouring coverage can be reduced to a level that it is possible to overcome with the proposed high capacity solution. Re-orientating antennas and in some cases switching off sectors on event days gave as 'clean' an RF environment as possible in which the high density stadium solution could operate.

## 3.5 Final configuration and performance

The fixed radiation pattern of the stadium antennas means that the coverage footprint is governed by the stadium geometry and in particular the distance between suitable antenna mounting positions and the spectators. The farther away the antenna is positioned, the larger the footprint and the less well defined the sector becomes. This is an important concept for stadia that are not uniform in their cross-section. Modern stadia often have arched roofs and curved structures which makes it challenging to provide nicely tessellated coverage areas whilst some of the older stadia (football grounds in particular) may have different stand structures on each side of the pitch which presents further implementation challenges.

Typical sector coverage definition plots are shown in Fig. 3.5.

The available mounting positions at the trial site effectively fixed the spacing between the antennas resulting in a system of 30 sectors in the stadium bowl, 14 illuminating the lower tier and 16 illuminating the middle and upper tiers together. Whilst below the original 40 sector target this still represents almost an 8-fold increase in the original capacity. The full Twickenham sector deployment is depicted in Fig. 3.6.

The 30 sector system was initially operated under full load conditions in early 2011 and delivered exceptional performance, verified by the engineers that were monitoring the system on the day.

- Bowl coverage cells were significantly loaded for 3 hours surrounding the event, with peak traffic occurring at half time

- Exceptional data session accessibility and retainability was achieved during peak times

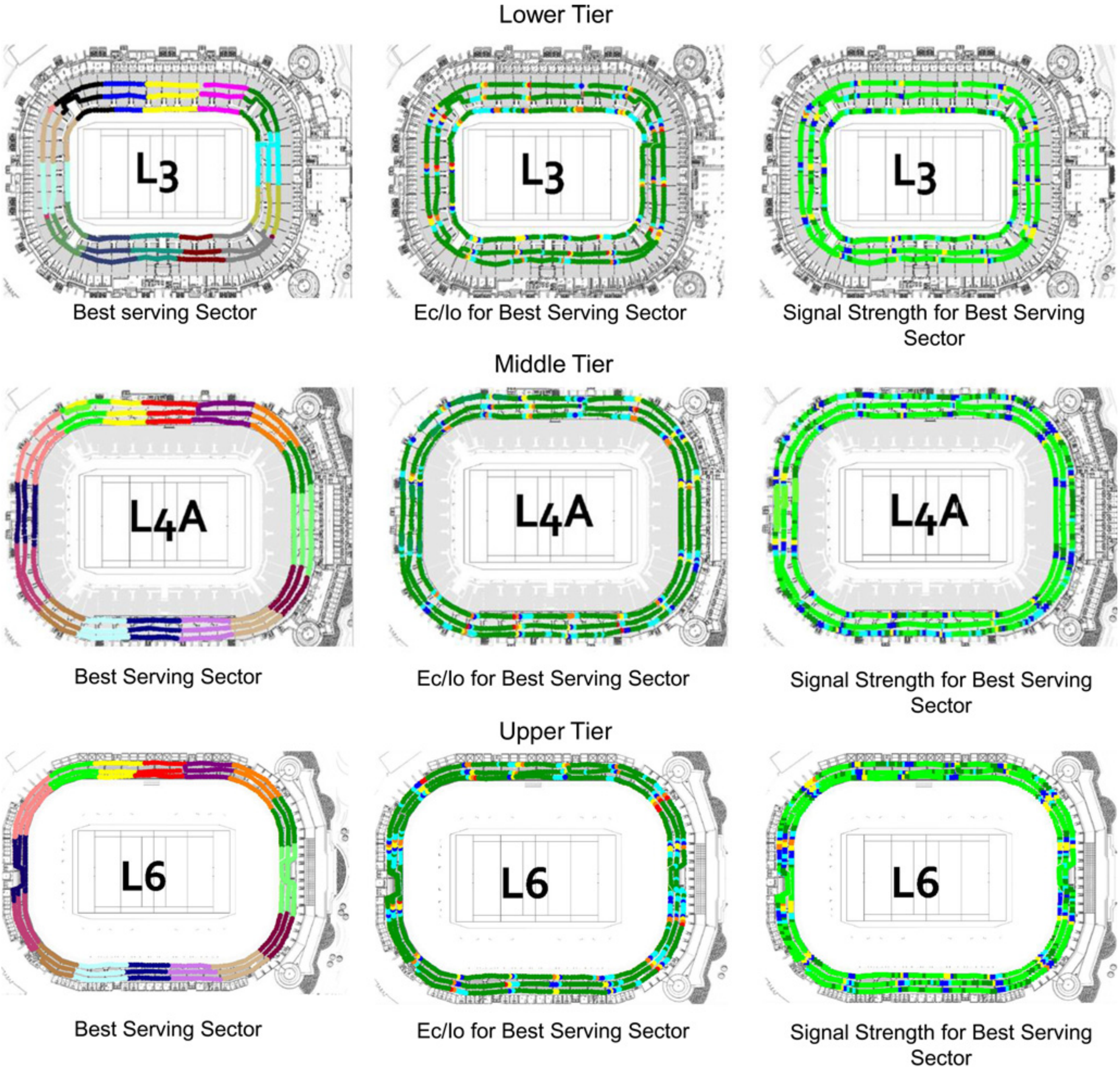


**Figure 3.6**

- Statistical information proved that the sector overlap (indicated in Fig. 3.6) was very well defined and minimal, significantly improving performance overall

Whilst the stadium antennas in the bowl were demonstrated to deliver excellent performance within the main seating area it was clear that additional measures had to be taken to provide coverage to subscribers without a clear line of sight to the bowl antennas such as those shadowed by overhanging tiers, people in concourses, executive boxes, bars, restaurants etc.

It was clear that it is not sufficient to provide a good customer experience solely for the duration of the event. Call demand (traffic) needs to be managed carefully in the run up to an event and afterwards to cater for the flow of spectators as they arrive and depart.

The result is that numerous low power conventional in-building antennas are planned to be deployed at the stadium to provide in-fill coverage in the bowl area and to provide continuity throughout the venue as customers circulate around before and after the event. Supplemental conventional ('bell box') antenna installation is shown in Fig. 3.7.

Increased numbers of low-height micro cells are also planned for the immediate vicinity of the stadium to manage the 'buffer zone' between the in-building system and the conventional macro network, particularly where the external macro coverage has been reduced in order

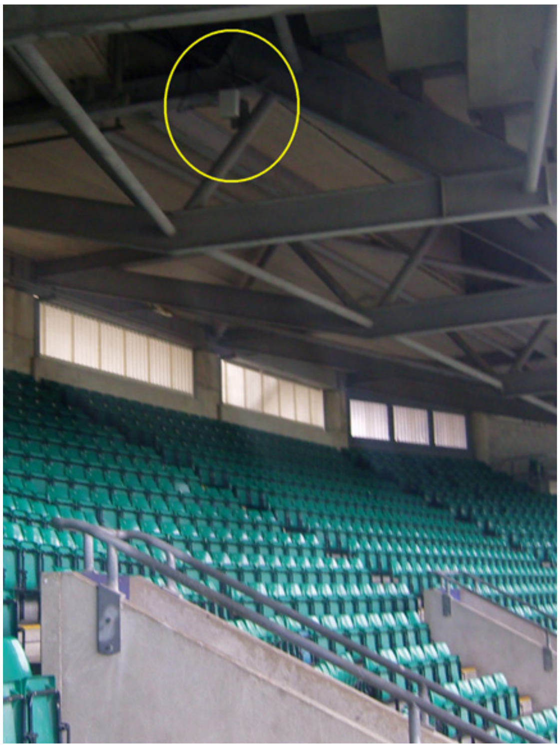

**Figure 3.7**

to protect the capacity of the in-building system. This is a particularly important concept for venues on the Olympic Park since the density of in-building systems will be high.

The stadium trial has been considered very successful. The design concept and implementation methodology have now been widely adopted in the development of solutions for the 2012 Olympic Games venues.

## 4 Olympic venue case study – the Aquatics Centre

Whilst common design guidelines and best practises are applied to each venue, it is not possible to have a 'one design fits all' policy: every venue has to be independently reviewed. The following section explores the detail design of the Aquatics Centre in-venue cellular coverage system. An artist impression of the external view of the completed venue is depicted in Fig. 4.1.

Located on the Olympic Park the Aquatics Centre is approximately 175 metres long × 90 metres wide. It consists of a ground floor area containing the main pool and conventional rooms of concrete and stud partition construction. The main roof is steel framed structure covered in aluminium. The underside of the central roof structure has a suspended timber cladding housing lighting pods. The external building walls are a combination of concrete and glass on the ground floor with an all glass construction above this level. Two temporary tiered seating 'wings' have been constructed for the Olympic Games these will have a plastic fabric roof and wall covering, housing the majority of spectators during the games. The Aquatics is one of seven sporting venues on the park, all being fed from a BTS Hotel, reference to Fig. 4.2.

**Figure 4.1**

*A basestation (BTS) hotel is the key component of a specific cellular architecture whereby a number of basestations belonging to multiple operators and offering multiple technologies (2G, 3G, TETRA etc) are located at a central facility for ease of installation, integration, commissioning and maintenance. The basestations are connected to a network of RF repeater units over a greater geographical area such as a large building, campus or metropolitan area.*

*The wideband repeaters can support all operators and require a much smaller footprint than individual operator base stations. They are connected over an optical fibre network and provide the RF drive power to numerous distributed antennas within each location.*

*The use of BTS hotels provides the opportunity to considerably reduce CAPEX and OPEX through economies of scale with savings on space, power and cooling.*

*From the point of view of the Olympic Park the basestation hotel concept has been essential due to high security and therefore limited operational access during the 2012 games.*

*Remote Radio Unit's (RRU) which convert the fibre analog feeds into RF Modulated signals are connected to a distributed antenna system (DAS) in venue to deliver RF coverage and capacity to the target areas.* Fig. 4.2 shows the concept

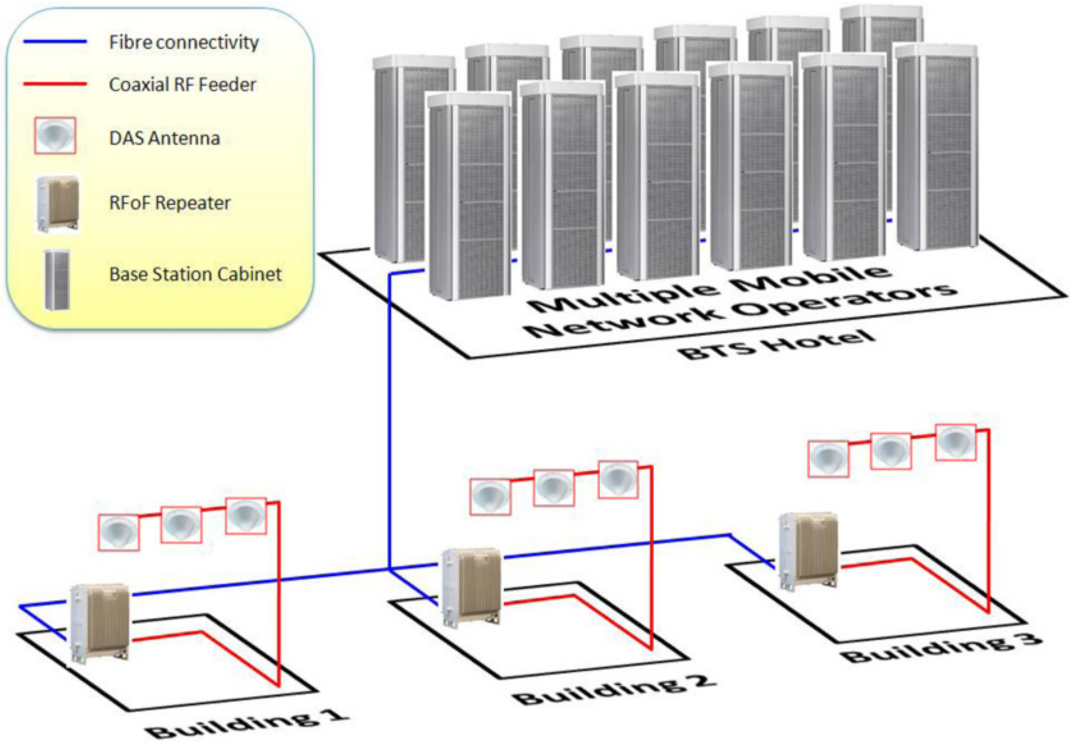


**Figure 4.2**

The main design considerations are volume of total customer demand, Public and Olympic Family users, existing and planned network coverage, construction and layout of venues. Another consideration for the majority of venues is the temporary nature of the requirements and hence a high proportion of the systems will not be required after the games. The Aquatics Centre is a good example where the majority of spectator seating is temporary and hence will be removed post games – along with the cellular infrastructure.

A pragmatic three phase approach to design has been taken for all venues:

1. *Feasibility study* – taking demand requirements, assessing what is possible based on venue survey and construction drawings. Typically existing coverage is reviewed at this stage.

2. *Mid-level design* – applying what is physically possible based on the output of the feasibility study, light touch modelling of the proposed solution to gain approval, in principle, that the solution is fit for purpose.

3. *Detailed design* – building on the mid-level design, providing a complete documentation pack detailing all of the physical requirements and completed 3D modelling for all 2G/3G sectors.

Initial venue spectator figures were provided by the London Organising Committee of the Olympic and Paralympic Games (LOCOG) and applied to the 2012 traffic demand model outputting forecast sector requirements based on the high level assumptions. These fed into the initial design requirements, detailed in Table 4.1:

**Table 4.1** Forecast Aquatic Centre Sector Requirements

| Technology | Forecast Sectors |
|---|---|
| 2G: GSM900 & GSM1800 & 3G: UMTS900 | 14 |
| 3G: UMTS2100 | 14 |

**Table 4.2** Designed Aquatic Centre Sector Requirements

| Location | 3G U2100 | 3G U900, 2G G900 & G1800 |
|---|---|---|
| Bowl Seating Tiers | 12 | 6 |
| Concourse & Mezzanine | 2 | 2 |
| Ground Floor | 6 | 3 |
| External Microcell | 3 | 2 |
| Total Counts | 23 | 13 |

Following the venue surveys and RF modelling assessments sector counts were changed to align with what was physically possible, implementation of external Micro cell sectors and whilst remaining sympathetic to the aesthetics of the building. This is shown in Table 4.2.

The Twickenham trial demonstrated that poor sector definition will have an adverse affect on the capacity and quality. The added complication of the swimming pool area exacerbates the potential for cross sector interference. Frequency planning of 2G 900 MHz and 1800 MHz services is also compromised if there is significant existing coverage and/or inter-sector leakage from in building systems. This is especially problematic on the Olympic Park where there is a high concentration of cellular infrastructure being installed in close proximity.

The design phase of the Aquatics Centre was complicated by construction work preventing on-site RF Carrier Wave (CW) testing (these tests use a simple un-modulated RF carrier to perform simple coverage validation). To overcome this problem the venue was modelled using a 3D planning tool which had been calibrated using empirical measurement results from the Twickenham trial.

*RF prediction tools are the primary means for planning macro mobile networks and there are numerous solutions in the market place. As the need for in building coverage systems has grown, so has the need to be able to accurately plan these, without the need for time consuming CW measurements, post processing of results, creation of CAD drawings and inventory management. In-building radio coverage prediction tools have been developed and calibrated by users to suit specific applications and simplify designs. A venue CAD drawing provides the means to design a system with confidence for a structure that does not yet exist, key for the 2012 project work. Added benefits of the tool chosen for the 2012 project is the ability to produce a complex 3D design, system schematic, inventory lists and the resulting radio coverage all in one place overlaid on to architects CAD drawings.*

Significant use of 3D wire diagram modelling was employed, with all internal and external walls/partitions represented and having RF attenuation figures applied on a per material basis. A 3D wire diagram is shown in Fig. 4.3.

The proposed design was then overlaid on to this model with each individual sector being assessed across all

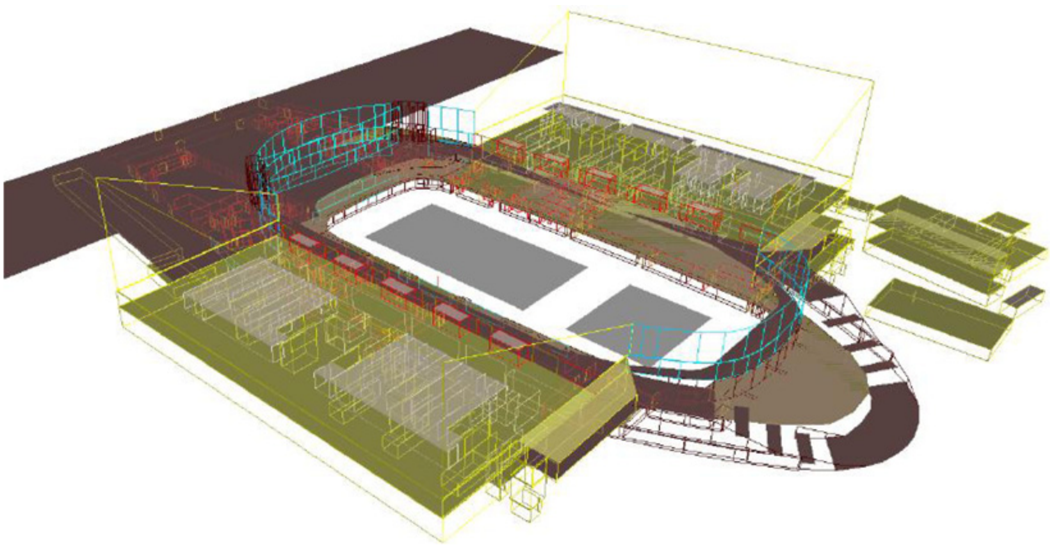

**Figure 4.3** *Aquatic Centre 3D wire diagram*

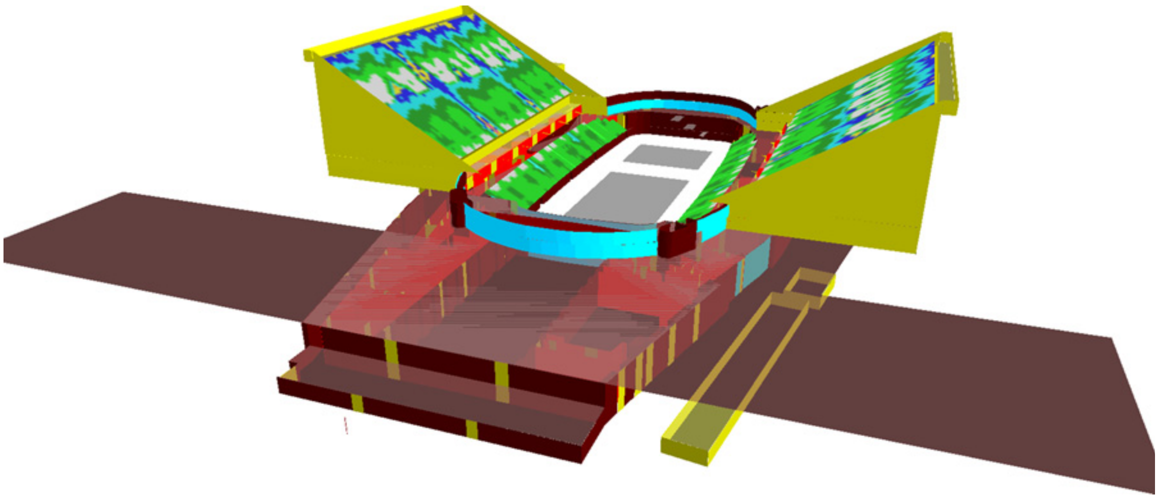

**Figure 4.4** *Example Aquatics Centre prediction, 3G RSSI*

frequency bands to produce per sector and composite RF predictions. The assessment was also extended to 3G soft hand over (SHO) regions, assuming 10 dB dominance margin requirement.

In the Aquatics Centre, interference is one of the main concerns and compounded by the transparency and height of the seating tiers which offer little isolation from external interference and if poorly engineered the in-building system will leak causing issues to the surrounding areas.

To minimise this issue the stadium antenna solution was proposed for the seating tiers and modelled to confirm they would deliver the desired coverage and sector definition. To achieve the required sector definition and homogenous coverage on the tiered seating areas multiple stadium antennas per sector will be utilised. A typical prediction diagram is shown in Fig. 4.4.

Other sectors within the Aquatics Centre use conventional Omni antennas for the in building concourse and back of house areas. As with the main bowl area, all sectors were modelled to assess the coverage levels. As with the proof of concept trial, externally facing low level directional micro cell antennas sectors are proposed acting as a buffer zone to capture users in the immediate area to a venue.

## 5 Key learnings and conclusions

A number of key learning points have been identified:

• The importance of starting with a clear Mobile Service Demand Analysis – involving mobile operators, interested parties and examinations of previous events and dovetailing with independent Olympic people movement studies and demographic groups.

• The footprint for a given antenna is dependent on the coupling distance from the subscribers which is generally set by the geometry of the stadium/arena itself. For that reason there is a limit to the capacity that can be installed and that capacity varies from venue to venue.

• Venues with a regular geometry are easier to design than those that aren't. For example some football stadia which have grown organically over the years and vary from stand to stand, present the most challenging locations.

• High signal dominance quality is essential to deliver the high data rates necessary to deliver the best customer experience.

• Effective service in venues depends on operators optimising their macro coverage in the vicinity of these high density solutions. Essentially a 'joined up' approach is required managing the 'in venue' coverage with the surrounding macro infrastructure.

• Key to success is buy-in and stakeholder engagement from all parties – the mobile operators, equipment providers, design teams and stadium landlords.

• The importance of a trial system, such as Twickenham, to validate design and optimisation philosophies well ahead of the games has been a critical success factor.

• Lifting the capacity is also a key enabler for potential value added services that can be offered by operators in order to open up additional revenue streams and engage directly with their customers.

• London 2012 has provided the Mobile Network Operators with a unique opportunity to plan for a mass GSM and 3G event, dominated by smartphone and new device classes. It positions the UK as a leading global centre of excellence for event and stadia design.

## 6 Glossary

| | |
|---|---|
| Accessibility | The ability to establish a voice call or data session |
| Boresight | The angle at which a directional antenna produces it's maximum gain |
| BTS/Node B | Base Transceiver Station. 2G radio equipment providing mobile service via nearby antennas. Node B performs the same function for 3G |
| CAD | Computer Aided Design |
| Carrier Wave (CW) | Use of a single un-modulated frequency radio signal for coverage testing |
| Cell/Sector | The area covered by one or more antenna(s) of a mobile base station with limited capacity to support voice and data calls |
| Clutter | Effect of buildings and other object to attenuate radio signals and cause interference |
| DAS | Distributed Antenna System – General name for systems, usually inside buildings, where the antennas are remote from the BTS/Node B |
| dB | Decibels – a multiple of power used in radio and other transmission systems |
| Dominance | Ensuring a strong wanted signal to avoid interference from lesser unwanted signals |
| GSM/2G | Global System for Mobile or Groupe Special Mobile. 2nd generation mobile network |
| GSM900/ GSM1800 | Frequencies used for GSM: 900 MHz and 1800 MHz |
| Interference | Degrading effect of unwanted radio signals being received at similar levels to the wanted signal. Can cause distorted voice, low data rates and dropped calls |
| LTE | Long Term Evolution. 4th generation mobile network |
| Macro cell | Usually covers an area between 100 m – 30 Km |
| Micro cell/In building cell | Usually covers an area of less than 100 m |

*Continued*

**Glossary** *Continued*

| | |
|---|---|
| Path loss | Signal loss between the radio transmitter and receiver |
| Retainability | The ability to sustain a voice call or data session once established |
| RF | Radio Frequency |
| RF over Fibre (RFoF) | A system for transmitting radio signals over fibre optic cables when the BTS/Node B is some distance from the antenna |
| RRU | Remote Radio Unit – An element of the RFoF system at the antenna end of the fibre optic cable |
| Sidelobes | Unwanted antenna radiation which can cause interfere with adjacent cells |
| SINR | Signal to Interference and Noise Ratio. Defines the impact of interference on a wanted signal by unwanted interference and noise |
| UMTS/3G | Universal Mobile Telecommunications System. 3rd generation mobile network |
| UMTS900/ UMTS2100 | Frequencies used for UMTS: 900 MHz and 2100 MHz |
| WCDMA | Wideband Code Division Multiple Access. Method of converting voice and data signals for transmission over radio systems |

# Developing the London 2012 Games-Time Website

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**Abstract:** In July 2010 the programme was initiated by LOCOG to design, build and manage the official games–time website, and mobile website for the London 2012 Olympic and Paralympic Games. This paper will show how the Games-Time website project is demonstrating innovation in a number of key areas. These are fundamental to the success of high traffic sports websites which involve live results, and which must also be engineered for the multi-platform age. A core innovation we will explain is the Olympic Results Platform (ORP). This is a bespoke platform which takes the Olympic Data Feed (ODF), processes this large and complex data set, and renders it for multiplatform use. In this case the official london2012.com website and mobile platforms. The second innovation is the ability to create a broad Digital Media Offering for LOCOG which puts the user at the heart of the design process, and ensures a holistic experience recognising that users consume content on a variety of devices. In addition, the paper will demonstrate best practice in the high level project planning to help ensure personnel and budget efficiencies. There are already a number of lessons to be learned and recommendations for future projects.

## 1 Project overview

LOCOG initiated the official Games-Time website (GTW) project in July 2010. The key objectives of the project are for the website to be:

(1) Best-in-class – the Games-Time website should be regarded as the best-in-class results and information service at the time of the Games.

(2) Engaging – the site should give the public a seamless, rich Games-Time experience and an opportunity to participate whether they are able to attend in person or not.

(3) Efficient delivery of information – the site should offer complete coverage of all events, results, schedules and competitors in real-time whenever possible, as quickly as possible.

(4) Fully support London 2012's brand promise – the site should motivate individuals to go beyond their personal best, connect young people to sport and the values that Olympic and Paralympic sport represents by giving a voice to inspiring stories that represent those values, and helping people share them with each other.

(5) Exploit potential of social and mobile media – the site should provide spectators and non-spectators with the information they want, when they want it, where they want it, in the forms they want it.

The Games-Time website is due to launch in May 2012.

## 2 Key challenges

The project faces a number of key challenges, including:

(1) **Management and processing of results data** – London 2012 will be the first Olympic and Paralympic Games to use the new 'Olympic Data Feed' (ODF).

Replacing several and heterogeneous data sources that served past Games, ODF is a new and complex general-purpose standard for sports event-related data, required by the International Olympic Committee and implemented for them by Atos, the IOC Worldwide IT Partner.

ODF collects diverse sources of sport data from the field of play, generated in real time either manually or automatically. It collects them in a consistent and homogeneous, multi-purpose feed of XML messages for client applications to consume, such as the Olympics' own internal applications, or the public website.

The aforementioned messages incorporate live results for every sport and discipline but also their schedule, start lists, athlete biographies and other information. Ingesting, interpreting and relating this data in a meaningful way is a significant challenge, as much as producing the feed itself, especially considering the complex and ever-changing rules and competition formats of the various sports and disciplines.

(2) **Presentation of content** – the Information Architecture of the Games-Time website is very challenging due to multiple simultaneous events, constant real-time updates and a significant amount of information, including live data, editorial content, statistics, and results for 300 events across 26 sports and over 10,500 athletes. All this content contributes to the challenge of presenting it in a relevant, intuitive and highly organised manner that is user-friendly and easily accessible.

(3) **Infrastructure scalability and content delivery** – the Games-Time website will experience billions of page views over the period of the Olympic and Paralympic Games. Not only does the site need to cope with this demand in terms of content delivery, but it will also be required to deliver up-to-date news and data in near real-time to keep up with television and radio broadcasts and other media outlets.

(4) **Multi-platform and multi-device challenge** – users use more platforms and devices than ever before to access online content, including mobiles, tablets, connected TV's, games consoles and other Internet-enabled devices, social media outlets, portals, and other news outlets. Any major website needs to address this challenge both from a user interface perspective and a distribution perspective in order to maximise its reach and audience.

# 3 Project solution

In order to meet the challenges presented above, the Games-Time website is based on a number of innovative technologies and concepts that are gathered under the umbrella name of the Olympic Platform. The Platform consists of the following components and concepts:

(1) Olympic Results Platform (ORP) – the engine that on one side interfaces the LOCOG systems providing the ODF feed, and on the other transforms/pre-processes the data for the use that is specific to the website.

(2) Olympic Pipeline Extension (OPE) – the results publishing engine for the ORP-processed data.

(3) Content Management System (CMS) – the primary tool for managing and maintaining the Games-Time website. The CMS has been designed with scalability in mind, to fulfil the requirements of very high peaks in traffic generated during the Olympics. The web site including the CMS is optimised for CDN caching. In addition the architecture involves the decoupling of the back office activities from the front-end public website. This means that the size of the infrastructure does not need to increase in line with the huge increase in visitors to the website.

(4) Social Media Hub – an extension of the CMS that manages the interaction and integration with social media outlets.

(5) Holistic User Experience (HUX) – a design concept developed by the supplier to ensure a consistent and continuous user experience across multiple platforms and devices (Section 3.5, Fig. 4).

## 3.1 Olympic results platform

The Olympic Results Platform (ORP) is responsible for ingesting and processing ODF. The ORP receives the athlete bios, schedule, start lists, live updates and results messages through ODF and processes them in real-time, as a stream of incoming and outgoing data. The average throughput is thousands of messages per minute.

Processing includes all the logic to both:

- Filter out all data that is not required by the consumer websites, in order to make the stream of data as light and fast as possible (As a general purpose feed capable of serving any Olympic and Paralympic software application, ODF is designed for comprehensiveness more than for speed), while at the same time.

- Normalise and augment data, in order to match the information architecture of the target website, e.g. by associating data elements that are separate in ODF, but displayed as a single element of information on the website.

The result of this process is a streamlined data feed that serves the client applications with exactly the data they need, in the fastest and most effective way possible.

Configuring ORP to achieve the above requires an in-depth knowledge of not only ODF, but of all the sports specifications ODF is designed against (ORIS for the Olympic Games, PRIS for the Paralympic Games).

ORIS stands for Olympic Results and Information Services. In 1993, recognising the high costs and risks incurred in the continual redefinition of requirements about the efficient operation of sporting events, the IOC initiated a pilot project which aimed to define the minimum

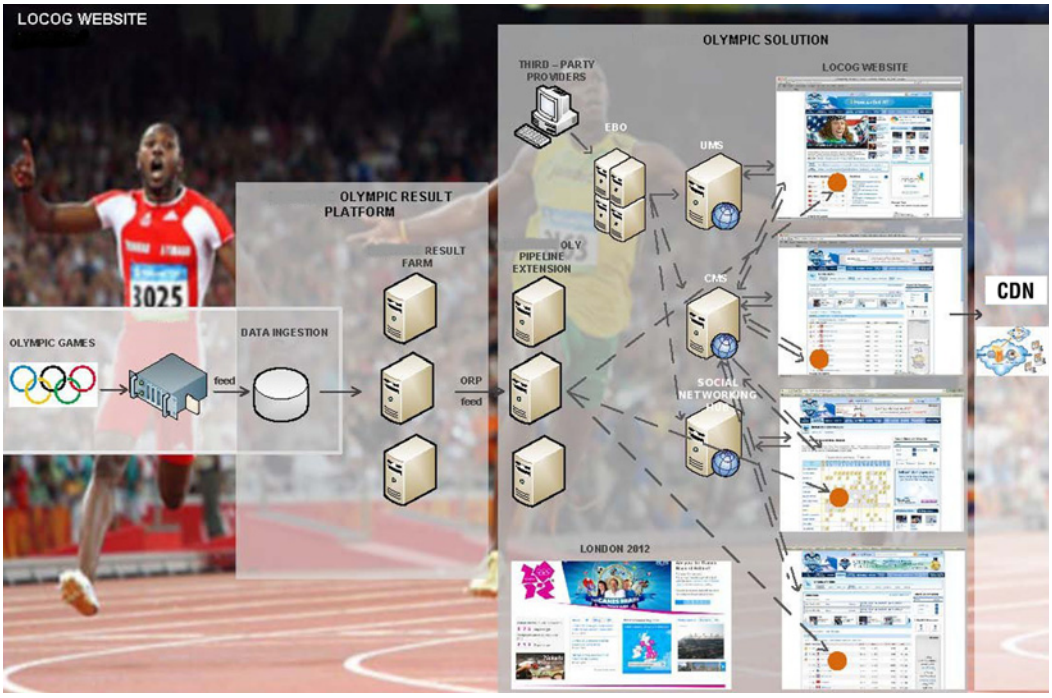


**Figure 1** *Technical Overview of the London 2012 Website*

requirements for Information Technology support at the Olympic Games.

The project was then named ORIS (Olympic Results and Information Services) and had the following objectives:

- Establish and consolidate the IT requirements that an Organising Committee of the Olympic Games (OCOG) will be required to fulfil, in order to meet the needs of the International Sports Federations (IFs);

- Set consistency in the level of IT support across the different sports at the Games;

- Analyse and propose changes to current working practices;

- Document procedures in a readable and user friendly format; and

- Transfer knowledge from one organising committee to the next.

The ORIS documents are now used by the Games organisers and their technology suppliers, in the development of software and planning applications. The IOC and the International Federations use ORIS as a basic reference during the Test Event(s), as well as during the homologation testing process.

Similarly PRIS stands for Paralympic Results and Information Service. In the same way, PRIS documents are used by organisers and their technology suppliers to develop software and applications, whilst the IPC and International Federations use PRIS as the basic reference during Test Events.

The ORP's output feed is presentation-agnostic. While it is designed to include all the required information that needs to be presented to the end user, it is independent of the web page's Information Architecture or design. This is fundamental to achieve complete decoupling of the data and presentation layers, which also achieves:

- The maximum possible degree of freedom for the two to evolve independently; and

- The maximum potential for re-purposing, e.g. for syndication, or alternative end user devices (mobile, tablets...).

During the latest Winter Olympics in Vancouver[2], ODF was not used. The ORP's function was the same as ODF, starting from different data inputs. A detailed analysis of each sport and discipline was required to develop the ORP logic. Just the analysis took several thousand man-days.

From an infrastructure perspective, the ORP architecture is designed to be completely separate from the consumer website. For maximum reliability and high availability, several ORP instances will run simultaneously and from separate, geographically-distributed data centres.

ORP is also designed to process data simultaneously for different target websites. All ODF-licensed consumers, such as Rights-Holding broadcasters for example, can rely on the ORP services together with London 2012's

Games-Time website. When required, data is also logically separated between consumers, e.g. to guarantee that data that is exclusive to LOCOG is not shared with other clients.

## 3.2 Olympic pipeline extension

The Olympic Pipeline Extension (OPE) is the software component that makes ORP-processed data into elements that can be published to the target website, e.g. HTML code.

As with ORP, OPE is designed to process data in real time without relying on permanent storage. Managing data as a stream rather than storing it into a database, as conventional software architecture literature would suggest, significantly reduces both the scale of the required infrastructure and the speed at which the data can be made available to end users.

London 2012 operate a series of dedicated OPE instances, one per data centre.

## 3.3 Content management system

The content management system (CMS) is a bespoke software solution that leverages the latest advancement in software engineering and infrastructure design. It is specifically designed and optimised for the needs and demands of a large scale sports website available to a wide audience, delivering real times results and content, and is subject to significant traffic peaks.

The choice of persevering and developing a bespoke software solution is demanding but necessary. In general, mainstream, out-of-the-box enterprise CMS solutions cannot effectively address the needs described above, which are unique to live sport. Best-in-class commercial CMS products for news organisations for example, have no need to refresh content every few seconds, although may be capable of scaling effectively and coping with peaks of traffic.

When supporting sport events, thousands of page changes, in multiple languages, may need to be delivered as fast as possible, and seamlessly to millions of users. Moreover, sport websites indirectly compete with traditional television and radio coverage of the same events, but cannot compete with speed of information delivery. The delay in observing the same result on TV and on the web must not be substantial for the web to be considered an authoritative source.

In response to all of the above, the CMS used by London 2012 at Games-Time is specifically built to minimise the infrastructure requirements and maximise the use of the Content Delivery Network (CDN), the CDN utilises a system containing copies of data placed at various nodes of the network, which improves access to the data it caches by increasing access bandwidth and redundancy. This is achieved by:

- Pushing to the extreme the granularity of the single element of content that can be changed and pushed to the user, down to snippets of few characters of data or HTML code.

- Rendering and distributing every possible component of the website as static media (static HTML, images etc.)

- Exploiting technology to its limit, pushing dynamic features and content (or the perception thereof) towards the client (e.g. client-side scripting, CDN-based 'server-side includes', or equivalent technology etc.). A close collaboration with the CDN operators is instrumental in achieving this.

The resulting ratio of content delivery network (CDN) hits versus origin, is over 9-to-1, even though live data and breaking news have a very short time-to-live (TTL) on the CDN (less than five seconds).

OPE and CMS push content to the CDN independently from each other. Separation is required to achieve specific characteristics of the data content:

- OPE focuses on results content push to the CDN, with the shortest TTLs.

- CMS specialises on all of the other content and document structures that include the results content produced by OPE. The CMS also contains the function for website implementation 'for desktop' and/or 'for mobile'.

Fig. 2 shows the high level hosting solution. It is noticeable that there are a relatively small number of servers used to run a high traffic web site. The diagram also shows the decoupling of the frontend network, i.e. the servers hosting the websites, from the backend network which hosts the back office applications.

## 3.4 Social media hub

A key objective of the Games-Time website is the integration with social media. Any website that wants to increase its reach and audience needs to embrace it.

The social media scenario is made of several well-consolidated networks (Facebook, Twitter…) and a few emergent ones (Google + …). Such a dynamic context requires an unprecedented degree of flexibility and adaptability. The solution for the Games-Time website lies in relying on a modular software system that is capable of plugging in to the relevant social network and following their changes.

The Social Media Hub component of the Games-Time website was designed to address exactly the issue described above. On one hand, it is capable of social media monitoring, listening to the buzz and intercepting the

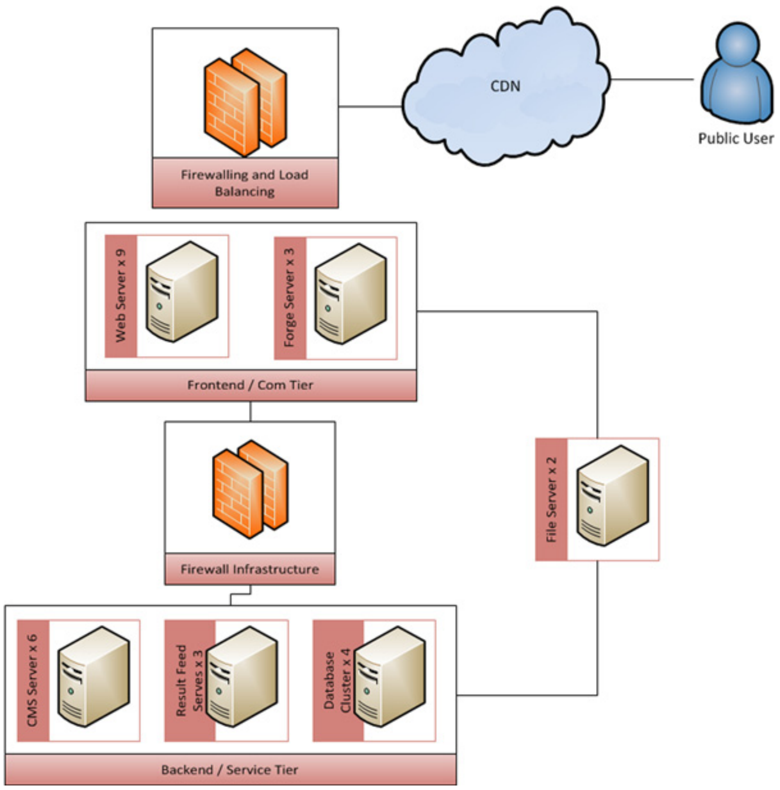


**Figure 2** *Illustrative technical infrastructure for a generic implementation of the supplier's CMS for the Vancouver Winter Olympics*

trends that the London 2012 editors may want to influence. On the other, it can repurpose editorial content to be published not only on the website but also to the target social networks.

At the time of writing, the Games-Time website is currently targeting Facebook and Twitter for integration (Fig. 3).

## *3.5 Holistic user experience*

To address the challenge emerging by end users being more and more used to use multiple platforms and devices, the supplier has developed a design concept named Holistic User Experience (HUX). The aim of HUX is to provide a consistent and continuous user experience for an online offering across all devices and platforms.

- **Consistent** – The key aim of a consistent user experience is to ensure the user is familiar with the interface irrespective of whether they access it from a mobile, tablet, computer, game console, connected TV, portals, social media or other media.

  Targeting a consistent user experience also ensures that users do not need to learn a new user interface or Information Architecture (IA), see section 4.1, for each device or platform.

  The key principle underlying HUX is that the design for each device or platform can no longer be done in isolation. Each needs to be designed with a holistic view.

- **Continuous** – The key aim of a continuous user experience is to assure continuity between what the user was doing when he/she last visited the site and the same content when switching to another platform or device, irrespective of the device or platform.

  For example, a user may be following a particular sport, live at the office on his/her desktop. When the working day is over, the user commutes home and may access the site through a mobile phone while in transit. HUX makes the transition between the devices as seamless as possible by serving the same content when the user accesses the website again (Fig. 4).


**Figure 3** *Social media integration*


**Figure 4** *Traditional design against holistic user experience*

## 4 Best practices

When managing a project of the size and complexity of the Games-Time website, there are a number of best practises necessary to ensure the successful delivery of a project of this nature.

### *4.1 Information architecture*

The Information Architecture (IA) of sports and results visualisation is known to be highly complex. A further challenge of a Games-Time website that is aimed at the public, is making the IA both accessible to the occasional website user, while still engaging to the more expert sport fan (Fig. 5).

The key notion in IA is the display of the most relevant content at any given time. This requires a constantly evolving website. The pre-Games website is radically different from Games-Time or post-Games website. Even during the Games there is a big difference between pre-live, live and post-live, with different content relevant during each period. During the pre-live period for example, the schedule and the news are the most important content. During live, the live data and commentary after a sport event is complete are the most important. During the post-live period, the results, news and reaction are most prominent. This means the site needs to be constantly evolving in order to present to the user the most relevant information at that time rather than forcing them to search for it (Fig. 6).

Developing the IA for such a complex and vast website required the definition of a customised development process that was tailored to London 2012's needs and time constraints, and within which the IA definition was embedded (Fig. 7).

Starting from the hierarchical map, the website was subdivided into 'clusters' of more editorial sections (e.g. 'News' or 'Our Games – Sustainability'). The main clusters and associated work streams aimed at creating original IA, while the side clusters re-purposed the output of the main clusters for other contexts (e.g. mobile). Each cluster had target start and end dates and target resources budget.

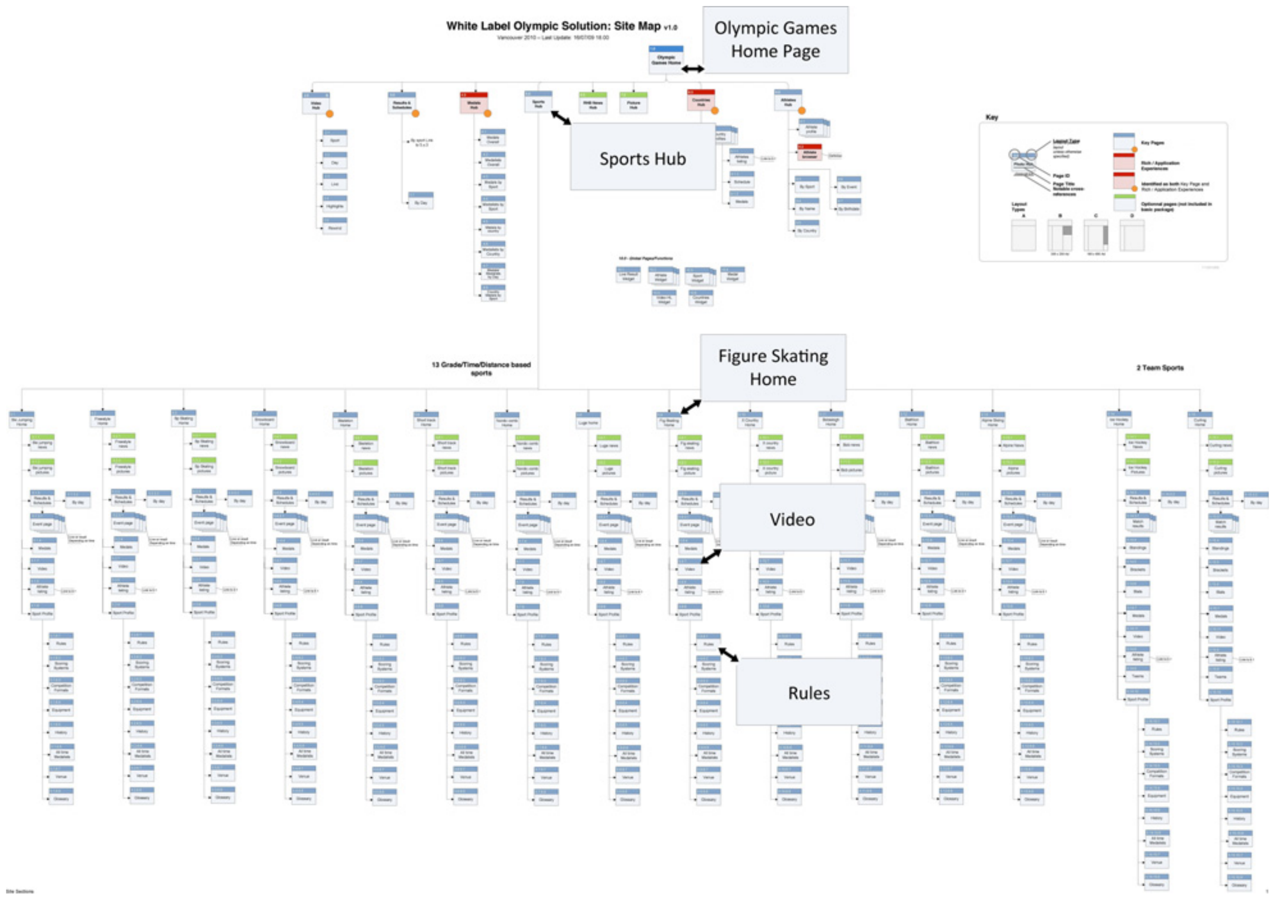


**Figure 5** *Site map from one of the supplier's websites delivered for the Vancouver Winter Olympics*

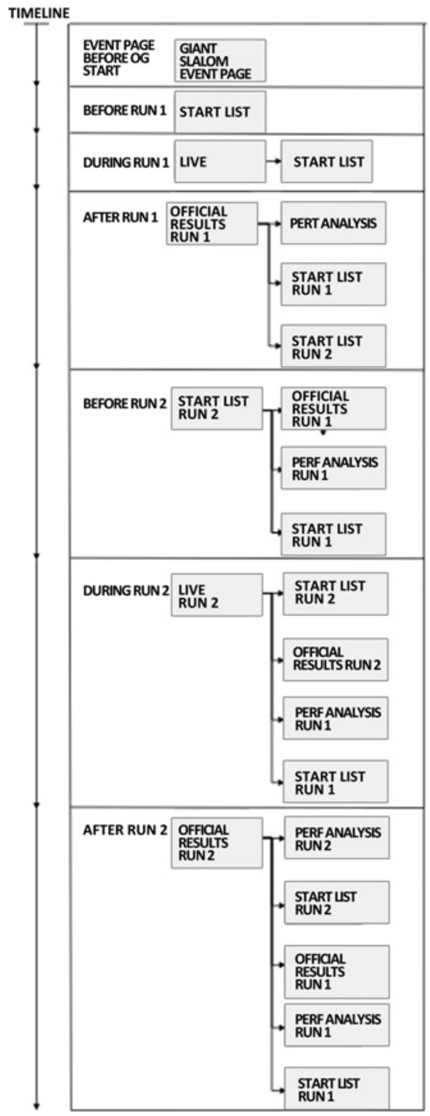


**Figure 6** *Event timeline for the Giant Slalom Event, from one of the websites for the Winter Olympics in Vancouver*

Within each cluster, each web page goes iteratively through five stages: requirements gathering, the core Information Architecture (wireframing and specifications), design, 'stand-alone' development and finally integration with the data sourced from the CMS. Each stage could iterate a number of times to keep within time and budget targets.

## 4.2 User testing of IA and design

When designing a website with a limited lifespan, one which is in the global spotlight from the moment it goes live, there is no room for organic evolution or reactive learning from mistakes. This applies to the website as well as to all Olympic and Paralympic IT systems, The Games-Time website testing joins the impressive 200,000 hours of software testing Atos is performing in the lab for its own London 2012 applications [1].

The Games-Time website's identity, from its strategy down to its design and implementation, must be right first-time. This is typical of websites related to sport events, whose services cannot be released in the context of an uncommitting 'beta' programme, or through 'soft launches'. Any component of the website needs to be thoroughly tested and validated before launch. LOCOG required IA and design to be thoroughly put to the test as much as more traditional testing scopes such as software and infrastructure.

More than one independent third-party has also been brought in to conduct a series of demanding and comprehensive user testing sessions, targeting the website's usability (e.g. how many clicks to get from A to B?) and accessibility (e.g. is the choice of colour suitable for people with visual impairments). Relying on independent parties is instrumental to prevent the tests execution and their results' interpretation from 'contamination' by the tester's expectations and pre-existing knowledge of the website.

## 4.3 Disaster recovery

When approaching a project of the stature and profile of the Games-Time website, nothing can be left to chance. The design implemented ensures that there is no single point of

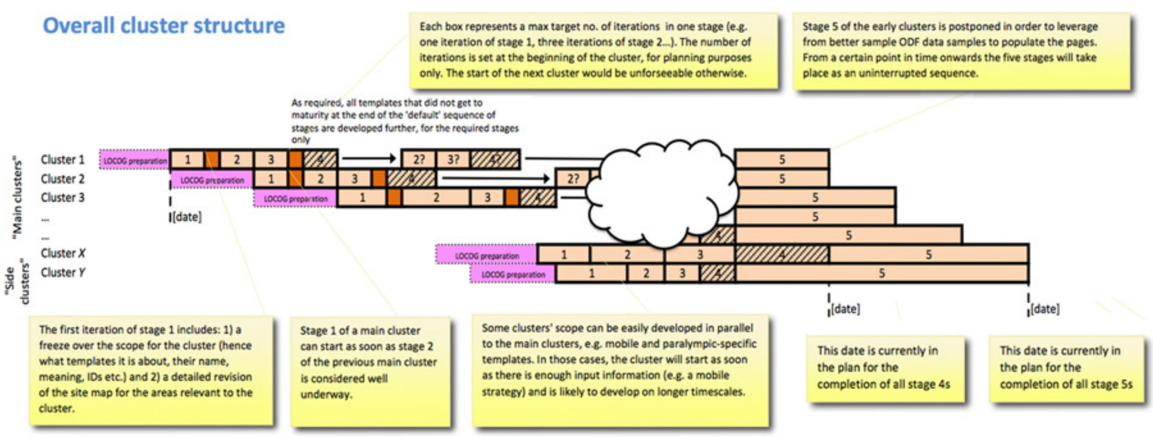


**Figure 7** *Phased and clustered approach to web page development for LOCOG GTW*

failure and that each critical service runs in an active-active configuration across multiple locations.

# 5 Lessons learned

There are a number of lessons to be learned from the Games-Time website, even though the project is only half-way into its life-cycle and it is yet to enter its key phase.

## 5.1 Multiple stakeholders

Major international sports events typically involve a large number of stakeholders. This is particularly true of multisport events such as the Olympics. It is crucial to adopt the correct approach to dealing with multiple stakeholders, and not to underestimate that whilst each is working towards a common goal, everyone equally has their individual strategic and technical objectives and measurements of success and milestones.

## 5.2 Digital is not an after-thought

Following the successful bid, Lord Coe stated that the London Olympics would be 'the first digital Olympics' [2]. The website, mobile website, digital and mobile applications should be viewed as 'core' to the staging of a successful Olympic and Paralympic Games. Too often the digital media offering is secondary to the more traditional features. LOCOG showed that early engagement of the project delivery team enabled greater planning, scoping, stakeholder engagement and ultimately reduce the need for technical changes.

# 6 Recommendation for future projects and programmes

## 6.1 Start early

Even though digital media has grown in importance, it is sometimes treated as an after-thought, as if it was an add-on rather than an integral part to the 'real show' that takes place in the sport venues and on television.

Based on the London 2012 experience, there are significant benefits in considering the digital Olympic offering as a 'core' service along with venue preparation, infrastructure, testing, security and other key Olympic services.

More and more people will experience future Olympics through digital media, perhaps more so than those that will experience them through attendance and traditional broadcast. To adequately service these people, it is therefore essential to properly prepare and plan the digital Olympic offering and include it in the early plans.

## 6.2 Adapt with your audience

User habits are constantly changing and evolving. It is therefore very important that the digital offering of future Olympics evolve with their audiences' habits in order to maximise the reach and engagement of the digital offering. This is especially important to keep the younger generation engaged with the Olympics and turn them into life-long fans.

## 6.3 Take advantage of experience from previous olympiads

An OCOG faces numerous challenges in staging the Olympic Games. LOCOG has met this challenge, in part, by hiring people or companies with experience from previous Olympics. This has been a key success factor for the Games-Time website project.

## 6.4 Abbreviations and definitions table

| | |
|---|---|
| ODF | Olympic data feed |
| ORP | Olympic results platform |
| OPE | Olympic pipeline extension |
| CMS | Content management system |
| CDN | Content delivery network |
| IP | Internet protocol |
| TTL | Time to live |
| ORIS | Olympic results and information service |
| PRIS | Paralympic results and information service |
| HUX | Holistic user experience |

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[2] KELSO P.: 'Olympics inspectors find London well ahead'. London: Guardian; c2011 [updated 2008 Mar 6; cited 2011 Jul 14]. Available from: http://www.guardian.co.uk/uk/2008/mar/06/olympics2012.btgroupbusiness

# Pervasive sensing for athletic training

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**Abstract:** Professional sports are increasingly competitive. The difference between a medallist and a participating athlete is often a fraction of a second. In order to maintain and maximise the marginal gain in performance, it is crucial to understand precisely how an athlete performs. Thus far, most of the quantitative analysis of athletic performance is only carried out in highly constrained laboratory environment, and thus the information captured may not reflect the natural competing environment. The ESPRIT (Elite Sport Performance Research in Training) programme aims to develop pervasive sensing technologies to enable real-time, continuous and quantitative measurement of athletic performance during normal training and competition settings. It is designed not only to help secure a competitive advantage for UK athletes, but also to increase our understanding of the biology of athletic performance, thus leading to improvements in the health and wellbeing of the population at large.

## 1 Introduction

Athletes spend their entire career training under extreme environments aiming to maximise their marginal gain that could lead to successes in major sports events. To maintain their performance gain, athletes increasingly rely on new technologies to help them push their personal best. In recent years, new technologies have contributed significantly to the successes of leading athletes in major international events. These range from new swimsuits and running shoes, to new ways of studying athletes' physiological response and biomechanical parameters, enabling personalised and optimised training programmes. For instance, it is believed that the LZR swimsuit attributed to 94% of the winnings in swimming and led to 23 world records at the Beijing Olympics in 2008 [1, 2]. Aerodynamic design of the bicycle and sportswear also played an important role in the British Cycling success at the Beijing Olympics [3]. The Blackroc sled helped Amy Williams to win the gold medal in bobskeleton at the Vancouver Winter Olympics in 2010 [4]. Within the research community, extensive studies have been carried out to identify factors that could lead to medal positions. For example, Sleivert and Rowlands suggested that optimising swimming economy can lead to significant gain in triathlon performance [5]. Neumayr *et al.* found that high levels of aerobic power and muscle strength are crucial factors impacting the success of alpine skiers [6].

Conventionally, sports science studies and experiments are conducted in controlled laboratory settings due to the high cost and complexity of the measurement equipment. Although studies have shown that laboratory tests are highly correlated to athletic performance [7, 8], especially in endurance sports, such as triathlon, limited understandings of the interplay of complex factors during competition can be achieved. For instance, Riley *et al.* have shown that parameters measured using instrumented treadmills are not directly equivalent to those measured during over-ground running [9]. Furthermore, the high cost of laboratory based analysis has limited the wider adoption of sports technologies.

In situ measurements of athletes' physiological, biochemical, biomechanical parameters during training and competition are essential in revealing the underlining factors affecting training and competition strategies. Recent advances in MEMS (Micro-Electro-Mechanical Systems), biochemical sensing, ultra-low power wireless transceivers, Body Sensor Network (BSN) technologies have facilitated the development of pervasive sensing technologies for healthcare and wellbeing applications [10–13]. Different miniaturised wearable or implantable sensing devices have been developed to provide low cost, continuous, unobtrusive and real-time monitoring.

To address the needs of real-time, continuous monitoring in elite sports, as well as general healthcare applications, the EPSRC (Engineering and Physical Sciences Research Council) and UK Sport have initiated the ESPRIT (Elite Sport Performance Research in Training) research programme (EP/H009744/1) recently. By integrating a multi-disciplinary cohort of scientists in BSN, pervasive computing, biochemistry, biomechanics, mechanical engineering, sports performance research and complex system modelling, the ESPRIT programme aims to develop and apply novel pervasive sensing technologies to improve the understanding of physiology and dynamics of athletic performance in training and competitions. Through the success in elite sport performance research, the ESPRIT programme also aims to translate some of the technologies to the improvement of healthcare and wellbeing of general populations.

## 2 ESPRIT programme

To address the key technological challenges in providing pervasive monitoring for sports training, four core research themes have been defined in the ESPRIT programme. These include:

- G-theme: **G**eneralised Body Sensor Networks
- O-theme: **O**ptimised Sensor Design and Embodiment
- L-theme: **L**earning, Data Modelling and Performance Optimisation
- D-theme: **D**evice and Technology Innovation

### 2.1 G-theme (generalised body sensor networks)

The focus of the G-theme is to develop generalised BSN platforms that can seamlessly integrate both wearable and ambient sensors to provide a holistic, information rich environment to underpin the ESPRIT G.O.L.D themes for deriving detailed physiological, biomechanical indices, as well as accurate localisation and tactical information. The main objectives of the G-theme include:

– Extending the current BSN design [14] and developing novel platform technologies for performance monitoring in elite athletes during training and competitions;

– Developing smart on-node processing algorithms to reduce overall power consumption of the sensor nodes and enabling further sensor miniaturisation;

– Designing new database architecture to allow for both real-time data interrogation and detailed interactive analysis, visualisation and modelling.

### 2.2 O-theme (optimised sensor design and embodiment)

The O-theme aims to develop minimally invasive, subcutaneous biosensors for continuous monitoring of analytes that provide direct measure of physical fitness. Under the O-theme, considerable advances have been made in the development of oxygen, glucose and lactate sensors, with nitric oxide sensor a new target undergoing feasibility studies. The prime objective of this theme is to establish cross-compartmental and temporal correlations, respectively, between athlete outcome and biomechanical and physiological variables. This is achieved by online/offline pervasive monitoring in a range of bodily fluids (sweat, saliva, urine, blood) and using standard sampling methods (venous blood, tissue fluid and muscle biopsy).

### 2.3 L-theme (learning, data modelling and performance optimisation)

The aim of the L-theme is to provide an integrated approach to modelling and performance optimisation by linking biomechanics, exercise physiology, biochemistry and psychology. The objectives of the L-theme include:

– Developing and validating new competition preparation protocols and new methods for competition recovery for repeat performance;

– Validating new sensors for field-based biomechanical assessments and developing real-time diagnostics for salivary biomarkers;

– Deriving new methods for dealing with trans-meridian travel and sleep deprivation;

– Investigating new mechanisms for looking at talent identification and development;

– Developing new methods for training block monitoring and structuring.

## 2.4 D-theme (device and technology innovation)

The D-theme aims to translate the new understanding of the elite athlete in themes G., O., and L. themes to guiding principles of performance optimisation through smart devices and innovative sports technologies. The objectives of the D-theme include:

– Developing autonomic sensing, real-time feedback and adaptation based on an integrated training and novel activity specific equipment;

– Providing enhanced visualisation to support knowledge integration and data mining to extract relevant performance/skill patterns;

– Enabling 'Individualised Optimisation', where the issues will vary between sports, depending on the specificity of requirement;

– Providing a customisation and user-centric focus to ensure solutions can be readily configured and adapted to suit individual needs.

# 3 Sport exemplars

By working closely with sport governing bodies, the ESPRIT consortium has identified a number of sport exemplars for initial validation of the pervasive sensing technologies. A few of these examples are highlighted in the following sections.

## 3.1 Bobskeleton

There is thus far a general lack of knowledge regarding competition preparation in Bobskeleton. In the ESPRIT programme, the G and L-themes have focused on understanding the links between the body, muscle temperature and start performance by monitoring the speed and acceleration profiles of Bobskeleton athletes under different warm-up conditions. Understanding warm-up is a critical part of this sport as it is performed under very cold conditions and success is reliant upon a first phase – referred to as the push – speed and power application. Due to the cold environment, passive warming and heat retention have also been examined. These principles were put into practice in the last winter Olympics. Experiments have also been carried out to study the training and learning progression of talent-selected athletes – athletes with high requisite physical attributes but no experience in this sport – on an accelerated pathway to the next Olympics. Understanding how their physiological systems adapt alongside motor pattern expression is both a novel and pivotal step.

## 3.2 Swimming

A multi-modal sensing environment has been developed under the D-theme to enable full analysis of the start, turns and free swimming elements of a swim. The start elements of the system include multi-axis machine vision, accelerometer, gyroscope and force profiles to produce data rich feedback that allows identification of technique driven performance improvements. Free swimming is analysed by means of a wearable sensor node wirelessly integrated into the over arching sensor system with additional pressure pad data acquired from each end of the pool to assess the turn techniques. These pressure pads are also used in conjunction with novel instrumented start handles for assessment of back and backstroke events. Fig. 2 illustrates the overall system configuration and Fig. 3 demonstrates example outcomes of vision-based measurement of entry angles captured using the system. Fig. 4 shows the presentation of sensor data and performance analysis metrics from the wireless sensor node and the pressure pads.

## 3.3 Rugby Union and League

Research on non-Olympic sports has contributed greatly to the development of new ideas, knowledge and tools that can be directly transferred into Olympic sport. Working closely with various Rugby Union and Rugby Football League teams, the L-theme has been developing various hormonal models for predicting the training and competition outcomes in team sport. These include the testing of testosterone responsiveness to a consistent mid-week exercise stimulus to predict game-ranked performance, and the collection of pre-workout testosterone data to predict the training outcomes of maximal power and strength. Novel strategies have also been developed to deal with sleep deprivation to improve athlete recovery from repeated competition in a tournament situation and to acutely

**Figure 1** *Bobskeleton training of talent athletes in collaboration with the ESPRIT programme*

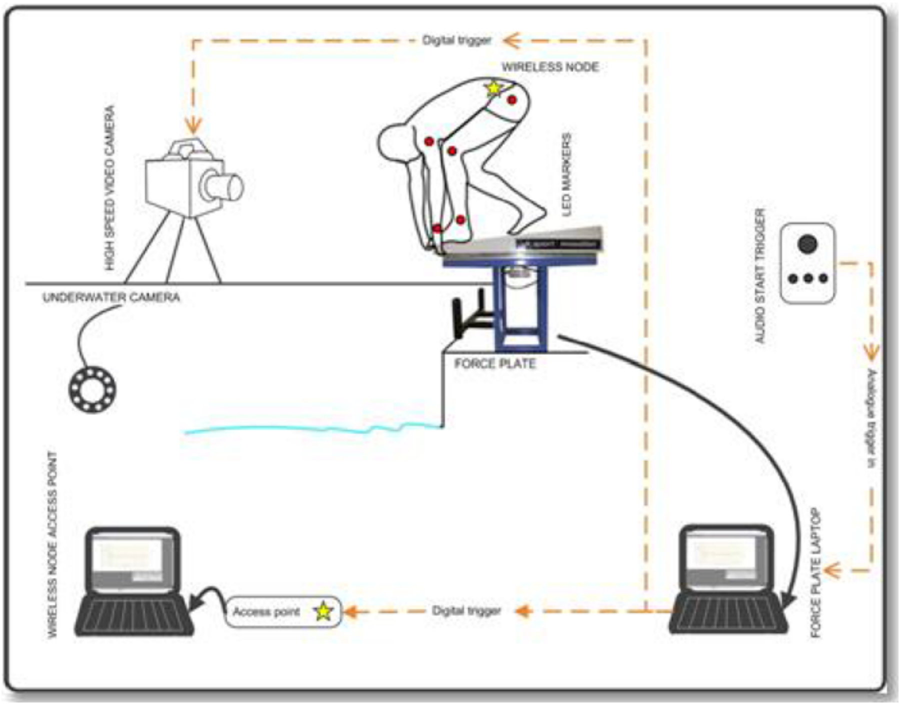


**Figure 2** *Multi-modal sensing for analysing the start element of a swim*

**Figure 3** *Vision based measurement of the water entry angle*

enhance training performance. For example, we found that watching short video clips with different content prior to training sessions can modify testosterone concentrations (both upwards and downwards) and this was mirrored by the subsequent expression of voluntary strength (see Fig. 5).

## 3.4 Wheelchair basketball

For Paralympic events, wheelchair design is crucial to competing athletes. Wheelchair propulsion has been widely studied to define the optimal wheelchair design and pushing mechanism that would lead to maximum performance gain [15–17]. Different instruments have been developed for measuring the wheelchair propulsion and movements. For example, Coutts developed a wheel mounted magnetic based system that can measure the distance travelled of the wheelchair [18]. Moss *et al.* proposed an optical encoder based velocometer that enables the measurement of intra-push velocity [19]. There are also a number of commercially available systems for analysing the wheelchair propulsion for assessing the push velocity, force and frequency of patients [20]. The available systems, however, usually require significant modification of the wheels or the use of special instrumented wheels. Furthermore, most of them are not designed for real-time analysis.

To enable real-time measurement of speed and position of wheelchairs for wheelchair basketball, a wheel-mounted wireless inertial sensor platform called WISDOM (Wheelchair Inertial Sensors for Displacement and Orientation Monitoring) has been developed by the ESPRIT team [21]. As depicted in Fig. 6, the WISDOM platform mainly consists of a miniaturised BSN sensor (programmed using TinyOS, an open source operating system for wireless sensors [22]) that is mounted on the axle of the wheel, and the BSN sensor is integrated with MEMS based 3D gyroscope and 2D accelerometer. By modelling and fusing the inertial sensor information, the instantaneous velocity, heading, ground speed covered and

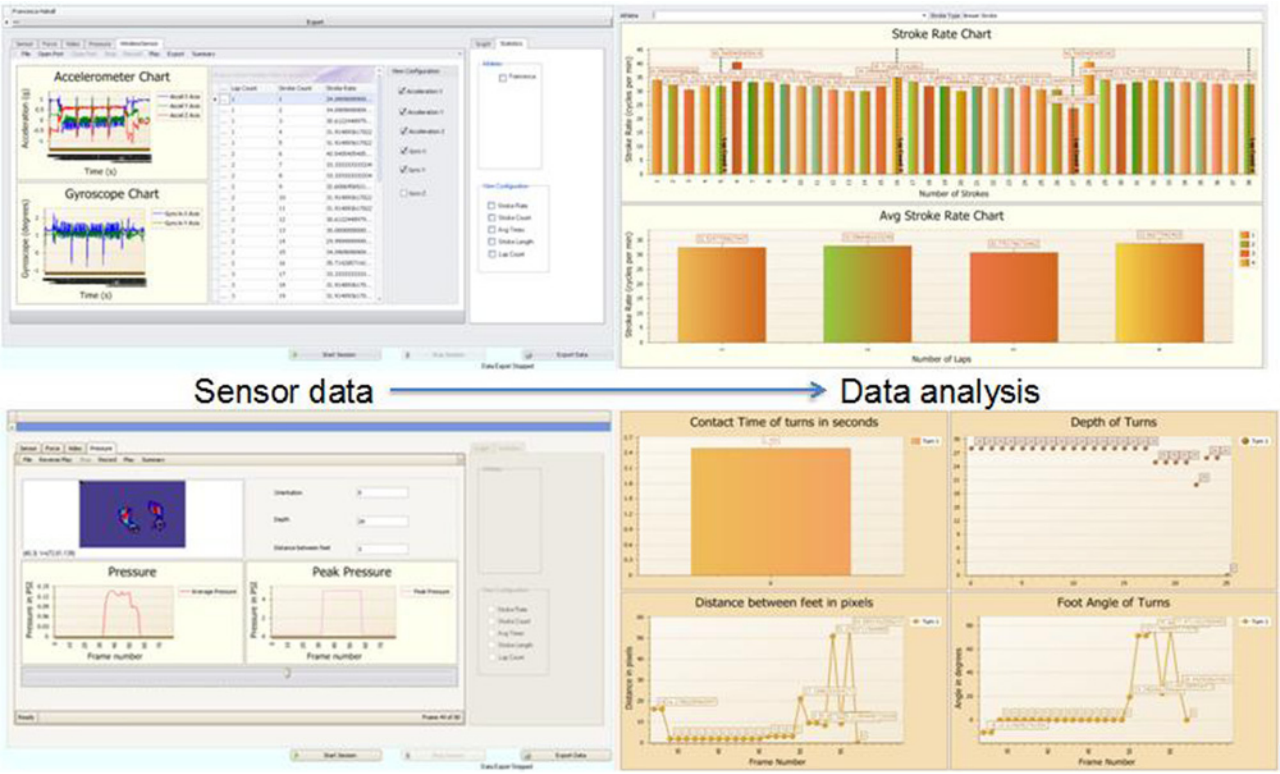


**Figure 4** *Sensor data convergence in swimming data analysis system*

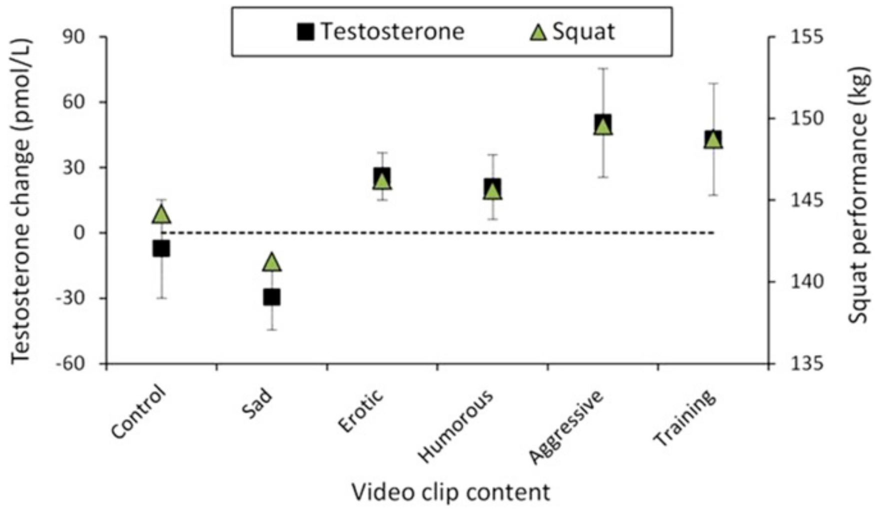


**Figure 5** *Testosterone change and voluntary strength of athletes after watching video chips*

motion trajectory of the wheelchair can be accurately reconstructed. Extensive experiments were conducted to assess the accuracy of the WISDOM platform, where nine subjects were asked to use the sensor equipped wheelchair to perform a series of movements at different speeds. It was found that the average ground distance estimation error is less than 18 mm, and the average positional error is less than 1% of the trajectory length [21]. Compared to conventional velocity measurement instruments, the WISDOM platform is much smaller, lighter and easier to install, and the negligible size and weight of the sensor imposes minimal performance disturbance to the athletes. The platform can be deployed to collect real-time measurements in training and competition. In addition, the WISDOM platform permits accurate localisation of the wheelchair in 2D space, and thus can be used to capture speed and location of multiple wheelchair athletes. The system is therefore valuable for studying team dynamics and tactics of the players.

## *3.5 Rowing*

For professional rowing, quantitative analysis is mainly carried out in laboratory settings by using ergometers, as it

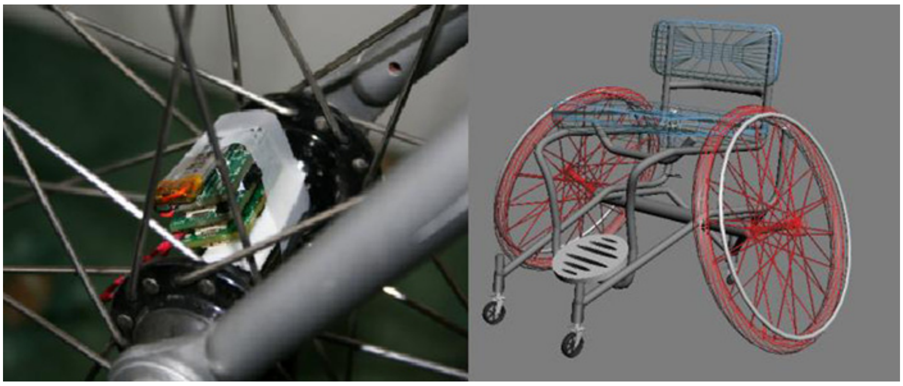

**Figure 6** *WISDOM: wheelchair inertial sensors for displacement and orientation monitoring*

is difficult to instrument a rowing boat with traditional biomechanical and physiological measurement tools [23–26]. Although there are already commercially available devices for training, they do not permit real-time data visualisation and analysis. In addition, only basic measurements such as speed and stroke rate can be captured.

Recent advances in BSN technologies have enabled the development of real-time sensing devices for quantifying rowing techniques during training. For instance, King *et al.* proposed a wearable sensor for measuring rotation of the lower back and femur in the sagittal plane of rowers [27]. Zhang *et al.* later extended the study and demonstrated that detailed angles of the spines and human back can be accurately estimated by using the BSN sensors [28]. The miniaturised BSN nodes can accurately measure biomotion and thus are ideally suited for real-time measurement and feedback.

To facilitate the capturing of real-time information from body worn sensors to boat sensors, an ESPRIT Blackbox is designed under the ESPRIT G-theme. Fig. 7 shows the system design of the ESPRIT Blackbox. The ESPRIT Blackbox mainly consists of a microprocessor, a BSN node, a 3G module, and a flash memory storage unit. Through the embedded BSN node, the Blackbox can manage all the BSN sensors on the rowing boat and capture different motion parameters, such as GPS positions, boat accelerations, and rowers' physical measurements. As shown in Fig. 7, the ESPRIT Blackbox is designed to act as a bridge between the BSN sensors and the Internet via the 3G network, in addition to being a data logger for storing the sensor data.

All sensor data collected by the ESPRIT Blackbox is forwarded to the Sensor Interface Server via the Internet,


**Figure 8** *Web based graphical user interface (GUI) for rowing*

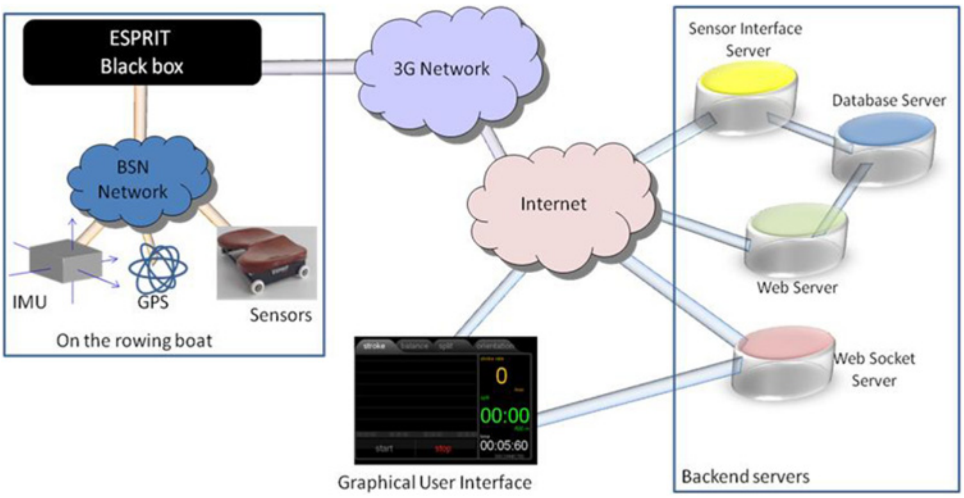


**Figure 7** *ESPRIT blackbox system design*


**Figure 9** *ESPRIT Blackbox for rowing*

and data is real-time archived in the ESPRIT database server. Coaches and athletes can review the performance data via the web interface. A HTML5 Web Socket Server is designed for streaming real-time sensor data to the web based graphical user interface (GUI). Fig. 8 depicts the HTML5 based GUI. As shown in the figure, the acceleration, velocity, stoke rate and various parameters of the rowers and the rowing boat can be visualised and reviewed.

The ESPRIT Blackbox has been extensively tested with elite rowers and Fig. 9 depicts the experimental setup for validating the sensors and the Blackbox. As shown in the figure, the ESPRIT Blackbox can simply be attached to the rowing boat, capturing and transmitting all the wireless BSN sensors data on the boat.

The versatile design of the BSN node facilitates the integration and validation of a range of physiological, biomechanical and biochemical sensors [29]. The ESPRIT Blackbox provides the necessary bridge and logging function for the BSN wireless sensor nodes, thus enabling real-time visualisation and performance profiling. In addition to rowing applications, the BSN sensor nodes and ESPRIT Blackbox can be readily extended to other sports and healthcare applications.

## 4 Translation to healthcare and Olympic legacy

For the general public, a measure of the success of the 2012 Olympics is the legacy that it leaves behind. In the case of ESPRIT, translating research results from sports applications to healthcare and wellbeing is a major focus of the ESPRIT team. To ensure a wider uptake of the ESPRIT technology, significant focus has also been placed on developing open platforms and ultimately standards that can facilitate seamless integration of ESPRIT hardware platforms with existing sensing platforms being used or developed in healthcare. For example, the team has recently announced a new open software development platform BSNOS (Body Sensor Network Operating System). As a Java based system, the BSNOS enables users to program BSN sensors using Java syntaxes and which greatly simplifies the development of BSN applications and eases the translation of sensing technologies from sports to healthcare applications.

There are seamless links between the G., O., L., and D. themes and healthcare. Given the fact that improving the management of chronic disease and elderly care is a key priority of NHS, we have highlighted several areas as the demonstrators for ESPRIT in healthcare.

### *4.1 Rehabilitation after orthopaedic surgery*

More than 165 000 hip and knee replacements were carried out in the UK in 2010, a number that is steadily increasing. In addition to the significant surgical cost, there is an extended economic burden due to continuing care and rehabilitation. In the majority of cases, patients are only able to have 1.4 post-surgery visits with their consultant and need to attend frequent rehabilitation sessions and lab-based gait assessments. Furthermore, over 90% of the joint replacements are due to osteoarthritis, which in an ageing population has a direct relationship to increased mortality and morbidity. The ESPRIT programme aims to transform gait-assessment from costly lab-based assessment to continuous monitoring at home using miniaturised sensors.

A pilot patient trial has been conducted in evaluating the feasibility of using the e-AR (ear-worn Activity Recognition) sensor to quantify the gait improvements after surgery [30]. The e-AR sensor is a bio-inspired designed sensor. By putting the sensor on the ear, the e-AR sensor can emulate the sensory function of the human vestibular system and capture detailed posture, balance, gait and activity information of the user [31–33]. In the trial, 10 patients undergoing total knee replacement were recruited. Their walking patterns were captured pre-operatively and up to 24 weeks postoperatively using the e-AR sensor. From the results, it has been shown that the patient recovery can be classified by using data clustering

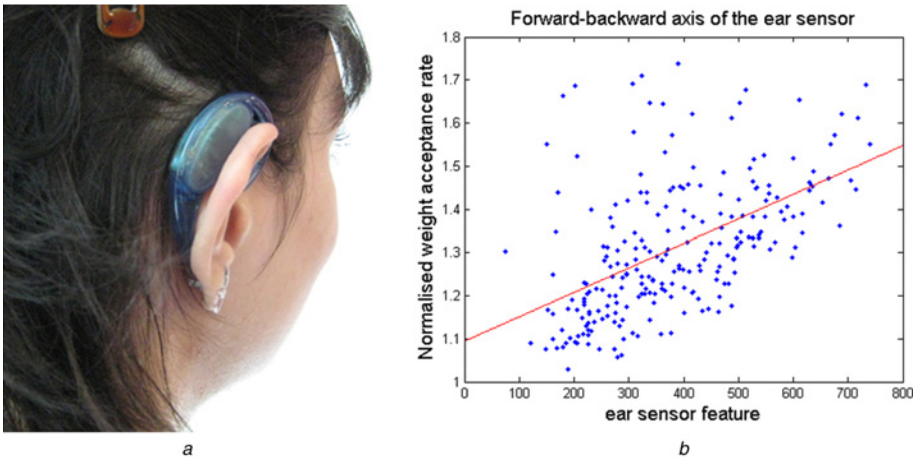


**Figure 10** *a. Ear worn activity recognition sensor used in the orthopaedic study. b. Plot of the maximum amplitude obtained from the e-AR against the normalised weight acceptance rate from 33 subjects. In general, the feature can be used to predict force load*

techniques and wavelet decomposition of the e-AR sensor signals.

In addition, to validate the accuracy of the e-AR in capturing gait parameters, the e-AR sensor has been evaluated using an instrumented treadmill to determine the precision in estimating the gait cycle, weight acceptance and maximal force on each leg, for a large cohort of healthy subjects (N = 40) as well as patients recovering from hip/knee replacement (N = 40). Fig. 10*b* shows a plot of a feature obtained from the e-AR sensor versus the normalised weight acceptance rate from the treadmill for the healthy cohort. From the scatter plot of Fig. 10*b*, it can be seen that the feature can be used to predict force load.

### 4.2 *Chronic obstructive pulmonary disease (COPD)*

Physical activity is an important parameter in COPD. It reduces oxidative stress, has an anti-inflammatory effect, reduces the frequency of upper respiratory tract infections and is associated with a decreased risk of disease progression and hospitalisation [34, 35]. Accurate monitoring of activity in COPD may be useful, both for clinical assessment and to assess response to treatment. Several activity monitors have been used in COPD, however, wearability and miniaturisation remain important issues to address when long term patient studies are concerned.

Given the importance of energy expenditure prediction, the e-AR sensor was validated with a commercially available wearable calorimetry device for 25 subjects performing a range of everyday activities [36]. Intelligent pattern analysis techniques were deployed to predict the type of activity performed and the energy expenditure per minute of activity. Fig. 11 shows the averaged energy expenditure in METs (Metabolic Equivalent of Task)

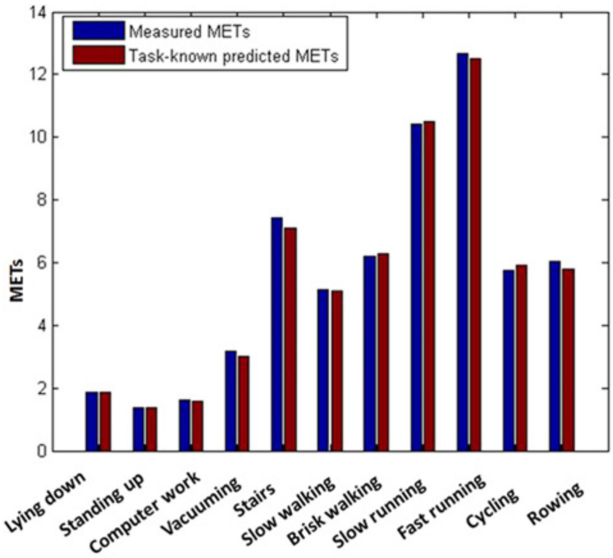


**Figure 11** *Measured METs from both the e-AR sensor and a commercially available $VO_2$ sensing device for a range of daily activities. This indicates that the sensor can be used at home for detecting minute by minute activity levels*

predicted from the e-AR sensor measurements as well as that measured directly using the $VO_2$ (Volume of Oxygen ) calorimetry device.

Pilot studies were conducted with COPD patients, and the results have shown that there is a good correlation between the e-AR sensor measurements and the METs measured using conventional wearable calorimetry devices.

## 5 Conclusions

Through close collaborations with coaches and athletes, several novel sensing platforms have been developed by the

**Table 1** Table of Abbreviations

| Abbreviations | Definitions |
|---|---|
| BSN | body sensor network |
| BSNOS | body sensor network operating system |
| COPD | chronic obstructive pulmonary disease |
| e-AR | ear-worn activity recognition sensor |
| EPSRC | Engineering and Physical Sciences Research Council |
| ESPRIT | Elite Sport Performance Research in Training |
| GPS | global position system |
| GUI | graphical user interface |
| HTML5 | hypertext markup language version 5 |
| IMU | inertial measurement unit |
| MEMS | micro-electro-mechanical systems |
| MET | metabolic equivalent of task |
| $VO_2$ | volume of oxygen |
| WISDOM | wheelchair inertial sensors for displacement and orientation monitoring |

ESPRIT team. Most of the sports exemplars discussed above have already been developed and trialled with elite athletes. It is apparent that the ESPRIT technologies not only enable the collection of performance indices in sports but also provide further understanding of human physiology under different levels of stress. The new findings made available by technological advances will facilitate not only sport research, but also healthcare and wellbeing applications. With the goal of translating our research results to healthcare applications, the ESPRIT programme is expected to play an important role in the future development of healthcare technologies.

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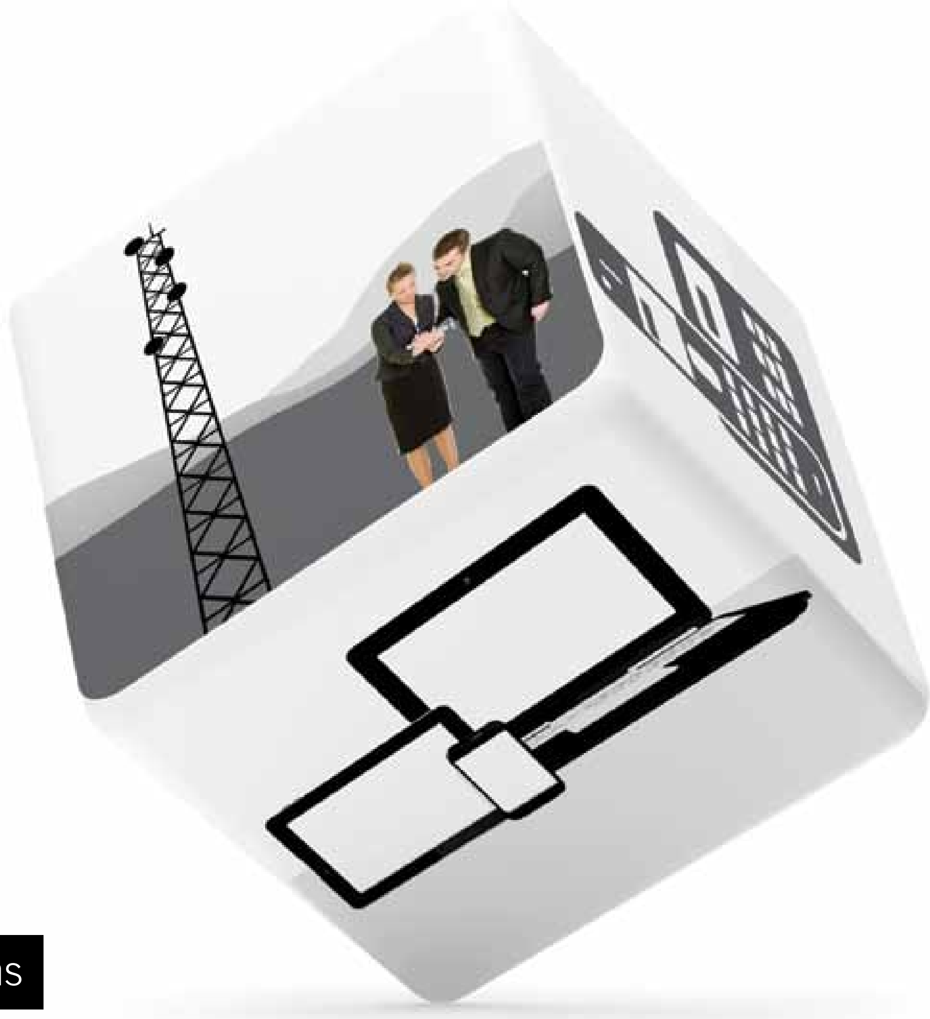

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