Report for Ofcom

Review of Civils Technology and Adoption

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1 Executive summary

This document is the final report of a study carried out by Analysys Mason on behalf of Ofcom to review the various technologies and deployment techniques used in next-generation access network deployment in the UK and in several other countries.

A very significant proportion of the costs associated with deploying next-generation access networks relates to civil engineering and related works, hence this study has focused on those related areas where there may be potential to realise cost savings.

We have carried out interviews with experts in the field of access infrastructure, from a variety of different types of organisations. The specific organisations were:

- civils companies and passive component manufacturers: Corning Cable Systems, Emtelle, Maxcell, Prysmian
- operators/infrastructure providers: BT (UK), Chorus (NZ), KCom (UK), ONI (Portugal), Primetel (Cyprus)
- other key industry organisations: FTTH Council.

We also supplemented the interviews with desk research. We have found that the key recent and expected developments are evolutionary rather than revolutionary, but taken together have the potential to make a material impact on lowering the costs and increasing the speed of roll-out. The likely impact of developments in terms of cost and speed is summarised for each area in the following table:

Figure 1.1: Relative impact of developments in each area on cost/speed of roll-out [Source: Analysys Mason, 2012]

Low impact	Medium impact	High impact
Duct and sub-duct	Cable design	Civils (excavation techniques)
VDSL cabinets	Cable installation techniques	Fibre jointing
	Fibre specifications	Aerial cables
	Flexibility points	

This shows that several areas are expected to have developments with a relatively high impact, namely civils (faster mole-ploughing techniques), fibre jointing (pole-top fusion splicing) and aerial cables (slimmer and lighter ADSS cables with improved reliability). Other areas are also expected to have important developments, such as fibre specifications (the use of bend-insensitive optical fibres in outdoor cables and components).

The development of faster mole-ploughing techniques and improved aerial cables will be particularly relevant for rural fibre deployments in the UK. The realisation of benefits arising from the use of aerial infrastructure is dependent on the relaxation of current restrictions in this area, which include the requirement that telecommunications providers must install their lines underground, except where overhead installations already exist or there is no viable alternative. Government and Ofcom should consider if any additional policy developments in this area would be appropriate.

We have estimated the cost reduction that could be realised from adopting slot-cutting, optimised mole-ploughing and aerial cables on a wide-scale in the UK. As a baseline, we have taken Analysys Mason's estimate for the cost of nationwide FTTP GPON coverage from the work we did for the Broadband Stakeholder Group, namely GBP24.6 billion. That total is based on the use of traditional civils techniques, and includes assumptions on duct re-use, volume of new-build, and unit costs for traditional install in different kinds of terrain.

By modifying the unit install costs (estimated using information received from interviewees during the course of our study) and also applying a 'real-world' deployment factor to reflect the fact that in practice each technique can only be applied to a percentage of eligible areas[1], we have estimated the potential benefit of the three techniques above, and these are shown in the table below. The revised unit costs are expressed as an 'effective unit cost reduction' with respect to the traditional techniques and the total saving in deployment cost from the baseline case is shown in the right-most column.

Figure 1.2: Potential reduction in cost of deployment of GPON FTTP across the UK delivered by widespread use of slot-cutting, optimised mole-ploughing, or aerial cables [Source: Analysys Mason, 2012]

Civils technique	*% of total network route that is new build*	*Total civils cost for the new build routes using traditional techniques (£bn)*	*Effective unit cost reduction from the traditional install technique (%) [A]*	*Proportion of new build routes to which new technique can be applied [B]*	*'Real world' factor (%) (to allow for fact that not all routes will be viable using new techniques) [C]*	*Overall cost saving (%) [A x B x C]*	*Total civils cost for the new build routes using new techniques (£bn)*	*Total cost saving over traditional techniques (£bn)*
Slot	45%	15.2	-38%	66% (hard surface only	80%	-20%	12.2	3.0
Mole-plough	45%	15.2	-50%	34% (soft surface only)	80%	-10%	13.8	2.0
Aerial over hard ground	45%	15.2	-69%	66%	80%	-36%	9.7	5.5
Aerial over soft ground	45%	15.2	-50%	34%	80%	-14%	13.1	2.1

According to our assumptions, the use of slot-cutting in hard surfaces could potentially deliver a cost saving of GBP3 billion (12% of the total cost), whilst mole-ploughing could deliver a saving of GBP2.0 billion (8% of the total cost). If aerial cables were to be used instead of slot-cutting and mole-ploughing in new build routes, a maximum cost saving of 5.5 + 2.1 = GBP7.6 billion (31% of the total) could be realised if aerial was used everywhere. However, it is questionable whether aerial could be used at such scale efficiently, and this would represent a major change in current policy which favours underground installation. It is important to note that the indicated cost savings could only be delivered if the techniques were adopted by industry on a widespread basis,

1 For example, slot-cutting can only be used in hard surfaces, typically roads or footpaths, but in some real situations neither may be suitable.

and this would require the successful commercialisation of the relevant recent or expected technical developments.

Future work could investigate in more detail the potential cost and time savings across different geographies that could be realised from using the various technologies and techniques identified in this study.

2 Introduction

2.1 Context

A key determinant of a viable business case for a fibre-to-the-home (FTTH) project is the cost and speed of roll out of the infrastructure. These two factors are highly sensitive to the civils technologies and techniques that are employed, especially in rural areas where distances between customers and existing telecoms locations can be large. Since there has been an increased number of fibre deployments over the last two to three years, both in the UK and across the rest of the world, it is timely that a comprehensive review of such practices and technologies is undertaken, which is the subject of this report.

2.2 Objectives and scope

In accordance with Ofcom's specifications, this report reviews the civils infrastructure technologies and techniques currently available to infrastructure providers considering deploying next-generation access (NGA) networks. The scope of this study concerns outdoor plant and covers civils, ducts and sub-ducts, cable designs, cable installation techniques, fibre specifications, fibre jointing, flexibility joints and aerial cables. For each of these areas, the report aims to:

- highlight significant developments that have occurred in the field over the past two to three years
- identify any new technologies or techniques that may become available commercially in the next few years
- outline the key benefits that could result for providers in terms of costs, deployment timescales, or other pertinent aspects
- assess the adoption of practices and technologies around the world
- consider the compatibility of key techniques or technologies with current UK planning and construction regulation and guidelines
- identify the key factors that influence communications provider (CP) and contractor adoption and use of innovative techniques and technologies
- set out the changes to network architecture or topology that the adoption of such techniques may favour or require.

The report also aims to highlight which technologies and techniques may be particularly attractive to infrastructure providers in the UK.

Our approach to the study was to undertake interviews with a suitable mix of passive component suppliers, a major civils company, and a variety of operators based both in the UK and overseas. The specific organisations are listed below:

- civils companies and passive component manufacturers: Corning Cable Systems, Emtelle, Maxcell, Prysmian

- operators/infrastructure providers: BT (UK), Chorus (NZ), KCom (UK), ONI (Portugal), Primetel (Cyprus)
- other key industry organisations: FTTH Council.

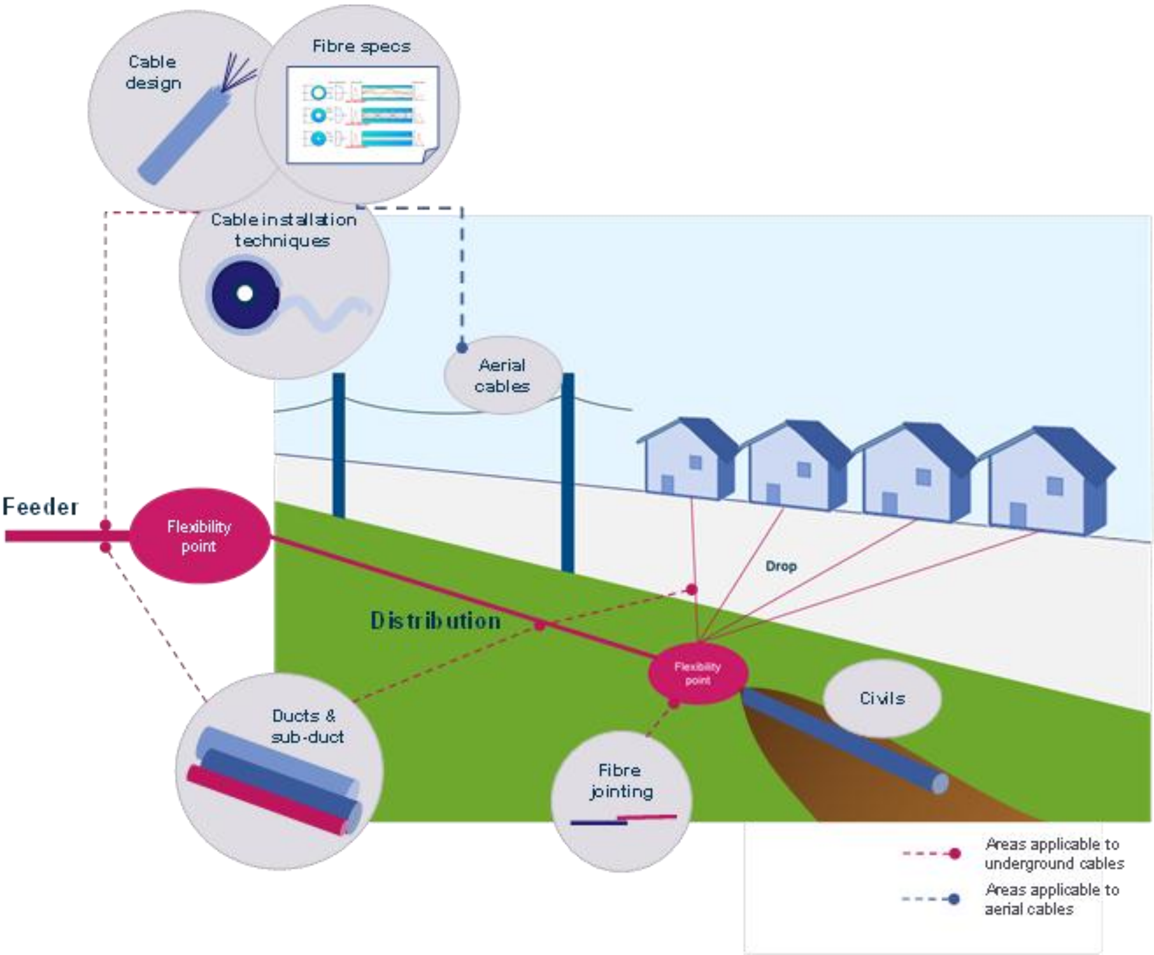
The information collected from each of the interviews was supplemented with desk research.

Since the field of civils infrastructure technologies and techniques is large in scope, we segmented it into a number of key areas as follows:

- **Civils,** which are the excavation techniques which accompany the deployment of underground ducts and/or cables.
- **Ducts and sub-ducts,** which are the conduits into which optical cables are installed.
- **Cable designs,** which are the different ways that optical fibre is incorporated into protective structures.
- **Cable installation techniques,** which are the ways that cables are actually placed into the access network.
- **Fibre specifications,** with reference to International Telecommunications Union (ITU) standards.
- **Fibre jointing techniques** i.e. ways to physically connect separate sections of fibre.
- **Flexibility points,** which provide fibre routing options typically between incoming larger cables are smaller outgoing cables (this section also includes items such as joint enclosures and boxes).
- **Aerial cables,** which are cables supported on raised infrastructure, typically poles.

A schematic diagram showing the location of these areas is presented below:

Figure 2.1: Access network showing location of key areas [Source: Analysys Mason, 2012]



2.3 Report structure

The report is structured around the following technology/technique areas:

- **Section 3** covers civils
- **Section 4** covers ducts and sub-ducts
- **Section 5** covers cable designs
- **Section 6** covers cable installation techniques
- **Section 7** covers fibre specifications
- **Section 8** covers fibre jointing
- **Section 9** covers flexibility points
- **Section 10** covers aerial cables.

Each of these main sections has the following sub-sections:

- **Key points** which summarises the main findings from the study
- **Introduction**, which includes a high-level summary of the costs, benefits, and risks/issues associated with each of the approaches currently employed by civils companies and operators

- **Significant recent developments**, which provides a summary of the key developments in the particular field over the past two to three years
- **Future developments**, which provides a summary of expected future developments that may result in new technologies or techniques that may become available commercially over the next few years
- **Key benefits**, which contains a summary of the benefits of recent and expected future developments
- **Adoption of technologies/techniques around the world**, which highlights key practices undertaken by some overseas operators that are different from those typically used in the UK
- **Compatibility with current UK planning and construction regulations/guidelines**, which briefly assesses whether the above developments and overseas practices identified above are compatible with UK regulations
- **Key factors that influence adoption of new technologies/techniques**, which considers the key factors that determine whether new approaches are adopted by civils companies and infrastructure providers
- **Impact on network architecture**, which addresses the changes to network architecture or topology that adoption of new approaches may favour or require.

Note that supplementary material describing each of the current technologies and techniques can be found in the *Fibre To The home (FTTH) Handbook*, which is published by the FTTH Council.[2]

Finally, **Section 11** gathers together the conclusions of the study. The report also includes an annex that contains a detailed impact analysis of recent and expected developments on three key parameters: cost, speed and quality of infrastructure deployment.

2 'FTTH Handbook', Fibre to the Home Council Europe, February 2012.

3 Civils

Key points:

- The most common civils techniques used are open cutting, mole-ploughing, directional drilling and slot-cutting.
- There have been no significant developments in the field during the past two to three years.
- There was no evidence that radically new techniques will become commercially available in the next few years. Rather, continuous improvement of existing techniques will occur.
- Better quality of backfill and reinstatement could make slot-cutting more widely used in the middle mile. Recently issued guidelines from DCMS in the UK provide a valuable contribution to the discussion on the use of micro-trenching. However, there is still some way to go in this area before approval can be granted for use of the technique by the Highway authorities.
- Faster mole-ploughing techniques will speed up the deployment of optical cable in soft verge in rural areas.
- One overseas infrastructure provider is using water jetting to open cut (waste is removed by vacuuming) – the technique can also be used for micro-trenching.
- In order to become widely adopted, new civils techniques should be faster and/or offer lower costs than existing approaches, and they should offer adequate reliability of installation.

3.1 Introduction

In this section, 'civils techniques' refer to the excavation techniques which accompany the deployment of underground ducts and/or cables. Note that civils techniques which accompany the deployment of overhead cables are much more limited and are therefore not discussed here. Civils companies and operators choose from a set of conventional excavation techniques depending on the particular situation (predominantly the nature of the surface). The techniques are:

- **Open cutting**. This is the basic trenching method, in which a trench is dug, then a duct (or sometimes just a cable) is laid, and finally the trench is re-filled. The three stages are typically undertaken separately.
- **Mole-ploughing**. This is a trenchless method for installing cable in which a tractor carrying a coil of cable and a cutting blade simultaneously digs and installs the cable and the ground then re-closes automatically, so there is no need to undertake any re-filling. The technique is typically used where there are no hard surfaces, where no other underground infrastructure will be encountered e.g. in rural areas (across rural verges or farmland), and where there is no rocky or very stony terrain.

- **Directional drilling**. This is a method of installing ducts or cables by using an underground drill. Initially, a pilot hole is drilled along the desired route and then a second drilling operation enlarges the hole. Finally, the duct (usually a micro-duct into which cables are later blown) is drawn in. The drilling machine can be steered, and the technique is used for passing under major obstacles, such as roads and streams.

- **Slot-cutting**. This is a fast method of installing ducts or cables, in which a vehicle carrying a rotary blade cuts a slot in an existing, hardened surface of sufficient depth, such as a road. Some types of surface such as concrete, which tend to crumble, are unsuitable. The duct or cable is then laid into the slot, which is then re-filled with a special compound. Alternatively a duct can first be laid into the cut slot to accommodate the cable, giving it greater protection. The width of the slot can be varied via the selection of a suitable blade.

The following table shows where in the access network each of the above techniques is typically used.

Figure 3.1: Application of civils techniques in various sections of the access network [Source: Analysys Mason, 2012]

Technique	Feeder	Distribution	Drop
Open cutting	Yes	Yes	Yes
Mole-ploughing	Yes – but only in cases where there is soft ground (typically in rural areas)	Yes – but only in cases where there is soft ground (typically in rural areas)	Yes – but only in cases where there is soft ground (typically in rural areas), and where the route lengths are long, e.g. across farms
Directional drilling	Yes – but only in cases where obstacles occur (most commonly roads)	Yes – but only in cases where obstacles occur (most commonly roads)	Not generally applicable
Slot-cutting	Yes – but only in cases where there is a suitable, pre-hardened surface, such as a bitumen-covered roadway	Yes – but only in cases where there is a suitable, pre-hardened surface, such as a bitumen-covered roadway	Yes – but only when the physical stability of reinstatement (i.e. quality) improves over time

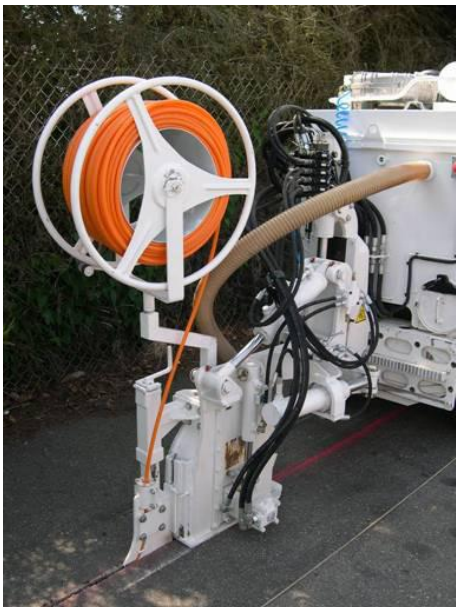


Figure 3.2: Slot-cutting in a previously hardened surface [Source: Emtelle, 2012]

A summary of the high-level costs, benefits and risks/issues of existing techniques is presented in the following table:

Figure 3.3: High-level summary of cost, benefits and risks/issues [Source: Analysys Mason, 2012]

Technique	Relative cost	Benefits	Risks/issues	Other comments
Open cutting	Medium	Results in the most robust installations. Many civils companies and infrastructure providers are familiar with the technique and have the necessary equipment	Causes highest levels of disruption to the local environment during digging	Most common technique
Mole-ploughing	Low	Simultaneously digs and installs the cable and the ground then re-closes automatically, so there is no need to undertake any re-filling	Requires soft verge Not really suitable for urban or suburban areas	Most promising technique for deploying optical cables in rural areas. Typically used where there are no hard surfaces, and where no other underground infrastructure will be encountered (e.g. in rural areas across rural verges or farmland), and where there is no rocky or very stony terrain

Technique	Relative cost	Benefits	Risks/issues	Other comments
Directional drilling	High	Minimises disruption to the local environment during installation. No requirement for road-opening permits to be obtained	Requires highly skilled field engineers and expensive equipment	Used relatively infrequently – mainly to overcome obstacles on fibre routes
Slot-cutting	Medium	Relatively small excavation volume means the technique has the potential to be fast	There are concerns about reliability since the ducts are installed just below the surface. There are also quality issues relating to backfill and surface reinstatement	Technique which currently attracts the most attention

Reliability concerns over slot-cutting

Whilst all of the civils techniques described above have been in use for many years, slot-cutting is the most recent of them, made possible by the development of small-diameter duct, and cables with high fibre counts. However, reliability concerns exist, since the ducts are installed just below the surface, are very small, and are much more prone to damage during street works than traditional duct, which is installed at a deeper level. Further, the technique can only be used when conditions are suitable, i.e. in hard surfaces that do not crumble when cut such as carriageways that have a sufficient 'bound' layer. There are also quality issues relating to backfill and surface reinstatement. These issues, combined with the fact that slot-cutting has the potential to significantly reduce civils costs, means that this technique is attracting a lot of attention across the industry. Notably, DCMS has recently issued a useful advice note to local authorities, which has made a valuable contribution to the discussion in this area.[3] However, there is still some way to go before approval can be granted for use of the technique by the Highway authorities.

3.2 Significant recent developments

There have been no significant developments in the field of civils during the past two to three years. The techniques currently in use were all developed a number of years ago, and most developments have been around incremental improvements, rather than the introduction of radical new ones. However, as described above, slot-cutting has recently attracted a great deal of attention.

[3] 'Micro-trenching and street works: an advice note to local authorities and CPs', DCMS, November 2011.

3.3 Future developments

No radically new technologies or techniques are expected to become available commercially during the next few years. However, there are expected to be some further developments to some existing techniques.

Slot-cutting

Improvements are expected to the slot-cutting technique. As described above, the quality of installations has proved to be highly variable, for example with regard to reliability of the backfill and the aesthetic appearance of surface reinstatements. Consequently, a number of local authorities have become resistant to the use of the technique.

Mole-ploughing

Developments are also expected to the mole-ploughing technique. One passive component vendor highlighted that they are working with a civils company to increase the speed of mole-ploughing and thereby lower the cost of deployment of fibre cables, principally in rural areas where much soft surface digging is undertaken. This will be done by, for example, using smaller ducts, thinner, more flexible cables, and therefore smaller machines (although it is debatable whether this will reduce the number of people required). Some respondents thought the best use of the mole-ploughing technique involves laying multi-tube micro-ducts, which can be continuous for many kilometres.

3.4 Key benefits

Slot-cutting

Due to the relatively small volume of excavation involved, the slot-cutting technique is inherently fast compared to other techniques (the relatively small volume of re-instated material required also serves to lower cost). The challenge in this area is now to sufficiently improve the quality of installations without compromising speed, as speed translates directly into reduced labour costs, which is the biggest cost driver in cable deployments. Therefore, the main benefit that will be delivered will be the adoption of a technique onto the accepted list of standard civils techniques which will be both relatively fast and low cost. There is also an environmental benefit due to the lower volume of material that is extracted and deposited at backfill sites.

However, slot-cutting may not be suitable for all locations within the access network. For example, there is some apprehension about using it for drop connections. This is due to the lack of construction in such areas and the subsequent reliability of the completed installation. This applies to all areas other than the very remote, as accidents (and subsequent claims) caused by imperfect reinstatement is a subject of major concern to local authorities. Also, it is currently not considered to be suitable for all types of road surface (such as concrete). Therefore, slot-cutting is considered to be particularly appropriate for surfaces that have a suitable construction i.e. sufficiently solid that the slot will be clean and the walls of the slot will not collapse – typically a bitumen road surface – but not suitable in pavements, as the top surface is likely to be too shallow. Furthermore, the location of existing buried infrastructure may limit its deployment opportunities.

Mole-ploughing

Mole-ploughing is seen as the preferred technique for use in soft surfaces, which are most common in rural areas. Further developments are in the pipeline that will speed up and lower the cost of the deployment of fibre cables in rural areas.

3.5 Adoption of technologies/techniques around the world

One overseas infrastructure provider uses water-jetting to open cut in difficult areas e.g. around trees with preservation orders (to avoid damage to trees). The waste is then removed by vacuuming. This 'Hydrovac' technique can also be used for micro-trenching (100mm wide × 450mm deep) but the volumes are still too small to achieve low prices.

3.6 Compatibility with current UK planning and construction regulations/guidelines

Slot-cutting

The recent and expected future developments in slot-cutting are unlikely to result in technologies or techniques that are incompatible with UK planning and construction regulations/guidelines. Recently issued guidelines from DCMS provide a valuable contribution to the discussion on the use of micro-trenching. However, there is still some way to go in this area before approval can be granted for use of the technique by the Highway authorities

Mole-ploughing

It is likely that the developments to speed up the deployment of optical cables using smaller, more flexible passive components will involve smaller volume excavations in the ground. Therefore, such developments are unlikely to result in technologies or techniques that are incompatible with UK planning and construction regulations/guidelines.

Further, the overseas practice described in the previous section is likely to be compatible with UK planning and construction regulations/guidelines.

3.7 Key factors that influence adoption

The key factors that influence adoption of new civils techniques by both communications providers and civils companies are that the candidate technique must offer both improved speed and cost, which are both related. The next most important factor was considered to be reliability, which is important to an infrastructure provider since it is a key driver of maintenance opex. The relative importance between cost, speed and quality (which includes reliability) depends on the degree to which an operator is driven by deployment cost, rather whole-life cost, and this was found to differ slightly between the operators that we interviewed.

3.8 Impact on network architecture

The widespread use of reliable slot-cutting and faster mole-ploughing techniques is unlikely to favour or require significant changes to access network architecture or topology. However, such techniques may favour an increasing occurrence of fibre-optic connections in existing parts of the network. For example, slot-cutting may be ideal for commercially viable deployments of new fibre-optic cables to connect service providers' PoP to the local exchange, or local exchanges to the cabinet. Mole-ploughing can be optimised to favour the deployment of more fibre-optic cables in both feeder and distribution networks in rural areas.

4 Ducts and sub-ducts

Key points:

- The most common technologies used are rigid duct and micro-duct. Flexible duct is also used, and copper cable de-coring is available but rarely used.
- There have been no significant developments in the field during the past two to three years.
- There was no evidence that any radically new technologies or techniques will become commercially available during the next few years.
- There will be some incremental improvements to existing technologies, such as the development of ducts with lower-friction liners.
- The diameter of ducts/sub-ducts will track the decreasing diameter of optical cables to increase the number of cables that can be deployed in a route.
- In cases where flexible ducts are justified, the use of blown light pulling ropes to pull in flexible ducts will reduce disturbance to previously installed live cables.
- One overseas infrastructure provider stated that it has extensively used flexible ducts to maximise duct occupancy, and has successfully floated cables i.e. with water into 32mm diameter sub-duct.
- In order to become widely adopted, new technology should both reduce costs and enable more rapid deployment. Ease of maintenance is also important.

4.1 Introduction

Civils companies and operators choose from a set of conventional solutions depending on the particular situation. These solutions are:

- **Rigid duct**. This is the traditional type of underground duct. Here, a rigid main duct made of uPVC or HDPE, and with a diameter of around 95mm to 110mm, is installed underground, along with a number of smaller rigid sub-ducts of around 15mm to 40mm in diameter. Optical cables are then either blown or pulled into the sub-ducts.

- **Micro-duct**. This is a small-diameter version of the traditional rigid duct solution. Small, flexible tubes (around 5 to 10mm outer diameter) are blown or pre-installed into a larger sub-duct. There is a variety of different types of micro-ducts, including tight-bundled (where micro-ducts are pre-installed in a standard duct) and thick-walled (which do not need to be placed inside another tube).

- **Flexible sub-duct**. This is a textile, multi-celled, flexible sub-duct. The soft material adjusts to the cable placement and thereby uses less space than a rigid sub-duct.

- **De-cored copper cables**. This is a copper cable re-use method. First, a special fluid is pumped into the space between the core and the sheath in the previously installed copper cable. Next, the copper core is extracted and, simultaneously, a new duct is pulled into the existing sheath. The greatest benefits are realised when de-coring *large diameter* copper cables.

Figure 4.1: A flexible sub-duct (indicated), containing an optical cable, housed in a rigid duct [Source: Maxcell, 2012]

The following table shows where in the access network each of the above techniques is typically used.

Figure 4.2: Application of ducts and sub-ducts in various sections of the access network [Source: Analysys Mason, 2012]

Technique	Feeder	Distribution	Drop
Rigid duct	Yes	Yes	Yes
Micro-duct	Yes-will be used here increasingly in future using typically 10-12 mm diameter tubes & high-fibre count mini-cables that can be blown	Yes- has been often used here to date using 3.5 mm diameter tubes & blown mini-cables or blown fibre bundles	Yes – has been often used here to date using 3.5 mm tubes with blown fibre bundles

Technique	Feeder	Distribution	Drop
Flexible sub-duct	Not generally applicable as there is usually available duct space in the feeder section. However, can be used to segregate a number of cables in a single 110mm rigid duct, thereby maximising the use of duct space	Yes	Not generally applicable
De-cored copper cables	May be useful in niche applications e.g. congested ducts containing large (very heavy) copper cables that cannot be extracted	May be useful where existing cables are direct buried, so cannot be extracted easily. However, distribution cables are not large, and so the benefits realised are not significant	Not applicable

A summary of the high-level costs, benefits and risks/issues of the existing techniques is presented in the following table:

Figure 4.3: High-level costs, benefits and risks/issues [Source: Analysys Mason, 2012]

Technique	Relative cost	Benefits	Risks/issues	Other comments
Rigid	Medium	Offers significant protection to cables, especially if one cable is installed per sub-duct	Cables can become entangled if more than one cable installed in a sub-duct	The most established technique. Method includes both cable blowing & pulling.
Micro-duct	Medium	Deployment of fibre can be deferred until required. Increased installation distances. Particularly useful in the distribution and drop parts of the access network, although it is used in the feeder section as well.	Requires blowing machines and specially trained staff. Also requires duct network to be contiguous and air-tight	High-count, multiple tubes well suited to the topology of the access network. Has become increasingly popular over the past few years Micro-duct is best suited for fibre to the home networks where high volumes of fibre are required to serve a high-density of customers.

Technique	Relative cost	Benefits	Risks/issues	Other comments
Flexible	Low	Maximises the number of cables that can be installed in a duct. Enables easier removal of old cables.	The flexible duct doesn't offer much mechanical protection	There have been a small number of some deployments
Copper cable de-coring	High	Does not require expensive digging. Provides an option in cases with very congested ducts e.g. central London	To justify approach, requires larger cables, which tend to be installed in duct.	New duct needs to be pulled in to sheath of existing copper cable in order to provide adequate strength Suitable in only very specialist circumstances

We found that operators which have an established duct network with space available for new cables do not have to resort to using the more radical techniques such as installation of flexible ducts or de-coring of copper cables. In Europe, flexible ducts have been used most in France (by France Telecom). Also, one operator in Qatar in the Middle East has used flexible ducts as a way of installing micro-duct over relatively long distances, when it would normally become distorted if 'pulled-in' in the conventional way.

4.2 Significant recent developments

There have not been any significant developments in the field of ducts/sub-ducts during the past two to three years. Most developments have been around incremental improvements to existing techniques, rather than the introduction of radical new ones. For example, the diameter of ducts has steadily decreased to match the reducing size of optical cables. In the case of flexible ducts, modifications such as the use of blown-in small, light ropes which are then used to pull in the flexible duct, complete with a cable draw-in rope, have been developed.

4.3 Future developments

There are not expected to be any radically new technologies or techniques that will become available commercially during the next few years. However, there are expected to be some incremental improvements to existing technologies. These include the further development of lower-friction liners for the inner duct wall, and changes to the materials used for construction e.g. the use of low-, medium- and high-density polyethylene.

4.4 Key benefits

The key benefit arising from the decreasing diameter of sub-ducts to support the significantly decreasing diameter of optical cables has served to drive down space requirements in the duct network. The key benefit arising from the use of blown-in light ropes for pulling in flexible duct is a reduction in the disturbance to previously installed live cables in the congested ducts where flexible ducts are most often used.

4.5 Adoption of technologies/techniques around the world

One infrastructure provider stated that it has extensively used flexible ducts to maximise duct occupancy. The technology was found to be effective, but it would be a more competitive option if material costs were to fall. The provider has also used thick-walled micro-ducts with a thin outer sheath for ease of stripping, and successfully floated cables with water into 32mm diameter sub-duct.

4.6 Compatibility with current UK planning and construction regulations/guidelines

The recent and expected future developments in ducts/sub-ducts and practices adopted overseas are not expected to result in technologies or techniques that are incompatible with UK planning and construction regulations/guidelines. Further, the overseas practices described in the previous section are likely to be compatible with UK planning and construction regulations/guidelines.

4.7 Key factors that influence adoption

The key factors that influence adoption of new duct/sub-duct technologies by both communications providers and civils companies are that the new technology must offer both reduced cost and faster speed of deployment. Ease of maintenance was also cited as being important. The adoption of new duct technologies will also be influenced by the availability of skilled contractors who have suitable plant to install the ducts/sub-ducts. An increasingly competitive supplier market should serve to drive down prices and improve quality.

4.8 Impact on network architecture

None of the recent or expected future developments are expected to significantly favour or require changes to the network architecture or topology.

5 Cable designs

Key points

- The most common cable designs are multi-loose tube and central loose tube. Slotted core cables are also available but are not commonly deployed in the UK.
- The cables typically contain single fibres. Ribbon fibres are available but are not commonly used in the UK.
- The trend for smaller diameter cables will continue, and will help to increase the usable space in existing duct networks. One major operator stated that it intended to discontinue the use of standard mini-cable.
- Bend-insensitive cables will speed up deployment and also support the development of more compact cable joints.
- Very high fibre-count cables (e.g. up to 1000 fibres) will offer lower installed cost per fibre, and can be useful in large point-to-point deployments. However, due to the large impact of cable cuts, such cables are unlikely to be widely deployed in access networks, particularly not in those employing PON architectures.
- Multi-functional cables will allow operators to purchase in greater volumes, thereby driving down costs. Operators will also be able to use fewer different types of cable, which means that infrastructure providers will not have to operate so many internal management processes.
- One overseas operator that we interviewed uses exclusively single fibre at present, but is considering the use of ribbon fibre for cables with few fibres.
- In order to become widely adopted, new cables should offer lower costs and easier handling (e.g. sheath stripping) than existing designs. Reduced physical size, increased fibre capacity and improved blowing performance are also important.

5.1 Introduction

Operators currently select from a wide variety of cables for outdoor deployments in the feeder, distribution and drop sections of the access network. The generic types are direct buried (e.g. armoured) cables, cables suitable for use in standard ducts and mini cables that are suitable to be blown into micro-duct (refer to Section 4 for a description of micro-duct). In the feeder section of the network, where several rigid sub-ducts are often deployed, a number of smaller diameter cables with a capacity of around 200 fibres are usually installed. In the distribution section of the network, cables are typically ducted or arranged in a common micro-duct bundle. Medium-count cables are usually installed that supply capacity for a particular geographic area. Direct buried is also an option but is unpopular due to difficulty in accessing and therefore maintenance. In the **drop** section of the network, underground drop cabling is usually deployed within micro-ducts, small ducts, or by direct burial. Aerial drops are also commonly deployed (refer to Section 11 on aerial cables for further details). The main types of cable design include:

- **Multi loose tube (containing single fibres or fibre ribbons).** This contains a number of tubes distributed around a central strength element. In addition, the tube contains a gel to prevent the ingress of water. Since the tube is not in direct contact with the fibre, no stress is transferred to it. The cables are designed with an outer sheath, generally made of polyethylene, to resist abrasion, temperature variation, and crushing.

Figure 5.1: Stranded multi-loose tube outdoor cable [Source: Corning Cable Systems, 2012]

- **Central loose tube (containing single fibres, fibre ribbons, or micro-bundles).** This is a low-fibre-count version of the above cable (up to around 12 fibres), and uses just a single gel-filled tube.

Figure 5.2: Armoured central loose-tube cable [Source: Prysmian, 2012]

- **Slotted core (containing single fibres or fibre ribbons).** Slotted core cables comprise narrow slots that are grooved out of a central cable element in which the fibres are located.

Figure 5.3: Slotted-core ribbon cable [Source: Prysmian, 2012]

A summary of the high-level costs, benefits and risks/issues of the existing techniques is presented in the table overleaf.

Figure 5.4: High-level costs, benefits and risks/issues [Source: Analysys Mason, 2012]

Technique	Relative cost	Benefits	Risks/issues	Other comments
Multi-loose tube	Medium	Robust. Used in all parts of the network	Larger cables with gel-filled tubes are time consuming to terminate	The most common cable design deployed in the UK
Central loose tube	Low	Simple design, used to make small-diameter cables, e.g. mini-cables	Unsuitable for large, high fibre-count cables	Most popular for lower fibre counts (1–12)
Slotted core	Medium	Dry core simplifies termination	Identification and splicing of fibre is less straightforward. In high-fibre count versions, cable diameters can become large	Uncommon in the UK

Each of the above designs can contain ribbon-fibre or single fibres. However, ribbon-fibre cables are uncommon in the UK, possibly due to the high costs associated with the changeover to ribbon technology.[4] None of the above designs was developed specifically for access networks.

With regard to blown cables, one major operator stated that on balance, the use of blown fibre bundles satisfies a wider range of deployment scenarios than blown cable. Also, the robustness of mini-cable (which the operator had deployed in its distribution network) was a concern, and the company intended to switch to using 7- and 12-tube micro-duct plus blown fibre or mini-cable. The operator was also trialling the use of micro-duct for slot-cutting and also for ‘community deployments’.

5.2 Significant recent developments

The most significant recent development in the field of cable design has been the commercial deployment of small-diameter, high-fibre-count cables. This has resulted in the development of so-called ‘mini-cables’, achieved by reducing the diameter of the tubes (normally stranded) within a cable. The industry standard is now a cable with outside diameter of 1.6mm to 2.5mm that contains a single 12-fibre tube.

4 However, fusion-splicers are available with interchangeable heads for splicing either single or ribbon fibres.

5.3 Future developments

Some of the key future developments in cable designs that may become commercially available in next few years are:

- cables that are less sensitive to being bent
- very high fibre-count cables which, for example, can accommodate up to 1000 fibres
- smaller-diameter cables
- low smoke (LSOH) cables for use in outdoor as well as indoor environments
- multi-functional cables, which can be used in a variety of situations
- ribbon-fibre cables, where the fibre can be separated easily.

5.4 Key benefits

Bend-insensitive cables

Cable products that use bend-insensitive fibre will be easier to install into enclosures, thereby speeding up deployment timescales. They will also allow the development of more compact cable joints which can be more easily fitted into congested manholes and jointing chambers. Initially, these cables will probably be sold at a price premium to standard fibre cables, but prices should fall to those for standard cable over the next 12–18 months. The cables should be particularly useful for use in the distribution and drop sections of the network, where the deployment conditions tend to be the most demanding.

Very high fibre-count cables

Very high fibre-count cables (e.g. containing 1000 fibres) are most suitable for the feeder section of the network, for example for the cables that enter/exit the aggregation point as used in the preferred BT FTTH architecture. However, some respondents considered it unlikely that they will be deployed in the access network, due to the severe impact of any cable cuts on service availability. Additionally, were a 1000-fibre cable to be used in the feeder section of a network based on a shared PON architecture, then the cable would be carrying some 32 000 customer lines and a cable cut would be catastrophic.

Smaller-diameter cables

Smaller-diameter cables will deliver a wide variety of benefits when deployed in the various sections of the network. One example is the reduced space required in ducts, thereby effectively increasing duct availability and avoiding the need for expensive civils work. Another example is where cables need to be stored at the customer's premises or at some other location in the network, a situation which usually occurs when installing cables that are pre-connectorised at both ends.

Multi-functional cables

Operators prefer to purchase cables which can be deployed into variety of situations, rather than specialist designs. This allows them to purchase in bulk and requires fewer internal management processes to be operated. This will be especially pertinent in the drop section of the network, which presents a greater variety of situations than the feeder and distribution sections. For example, drop cables are now available that can be used in both aerial and underground (duct and direct-buried) deployments.

5.5 Adoption of technologies/techniques around the world

One overseas operator that we interviewed uses exclusively single fibre at present, but is considering the use of ribbon fibre for low fibre-count cables.

5.6 Compatibility with current UK planning and construction regulations/guidelines

The recent and expected future developments in cable design are not expected to result in technologies or techniques that are incompatible with UK planning and construction regulations or guidelines. Further, the overseas practices described in the previous section are likely to be compatible with these regulations and guidelines.

5.7 Key factors that influence adoption

Cost was cited by most respondents as the key factor that influences CP and contractor adoption of innovative techniques and technologies. Many other factors were thought to be important, but in most cases could be linked to their impact on reducing either deployment or operational costs. For example, cable sheaths that can be more easily stripped speed up the installation process. Small-diameter cables are desirable as they effectively increase the available duct space, thereby reducing the need for expensive civil. Another example is more reliable cables, which generally reduce maintenance opex. Although operators are always interested in employing initiatives for cost reduction, they will remain a top priority as long as the business cases for fibre remains marginal or uncertain.

5.8 Impact on network architecture

The majority of expected developments in cable design are not expected to favour or require changes to network architecture or topology. However, if very high fibre-count cables are deployed, costly cable redundancy schemes will be needed, in order to mitigate the very large impact of cable failures on service provision.

6 Cable installation techniques

Key points

- Pulling by hand or winch, or cable-blowing are the preferred approaches to cable installation. Cable floating with water, direct-burying and directional drilling techniques are also available, but as yet are rarely used in the UK.
- 'Self-rodding' cables which are stiff enough to be pushed short distances can help to speed up the installation of drop cables, but they are more costly to procure and are often associated with pre-connectorised cables of standard lengths.
- Increasing the distances that cables can be blown will help to reduce the number of joints and jointing chambers required in greenfield installations.
- New fibre clamping techniques are thought to help to improve the reliability of aerial cable installations by preventing the fibres from 'creeping' along the cable and straining the fusion splices.
- Cable over-blowing, in which cables are blown over existing cables in sub-duct, will serve to increase the available duct space.
- In order to become widely adopted, new cable installation techniques should offer reduced cost and increased installation speeds. Reduction of strain on the fibres during installation is also important, both within the cable being installed and in the live cables already installed.

6.1 Introduction

Operators can choose from a number of standard cable installation techniques:[5]

- **Pulling by hand or winch.** This involves pulling in a cable using a pre-installed draw-rope, either by hand or using a winch. As such, they are complimentary techniques. Ideally, a fuse should be attached which is adjusted to be just below the cable's tensile strength rating, as well as a swivel to enable the cable to twist unhindered. Increased installation lengths are often achieved by 'fleeting' the cable (laying figure-of-eight loops of cable on the ground) at intermediate points to avoid the occurrence of excessive tensile forces.
- **Blowing cables into ducts/sub-duct/micro-ducts.** This involves blowing cables into airtight ducts using air. A cable-blowing head is required; this not only blows in the cable, but also pushes it in in order to avoid friction over the first few hundred metres.
- **Floating cables into ducts/sub-duct/micro-ducts.** This uses the same machinery as for blowing, but uses water instead of air.

5 See also EC specification 60794-1-1, Annex C: Guide to Installation of Optical Fibre Cables.

- **Direct burying of cables (mini cables or fixed fibre strand cables).** This involves laying a suitable ruggedized cable structure into a trench.

Figure 6.1: Equipment for blowing fibre installation [Source: Emtelle, 2012]

A summary of the high-level costs, benefits and risks/issues of the existing installation techniques is presented in the following table:

Figure 6.2: High-level costs, benefits and risks/issues [Source: Analysys Mason, 2012]

Technique	Relative cost	Benefits	Risks/issues	Other comments
Pulling by hand or winch	Medium	An effective method for installing underground drop cables where distances are relatively short	Fuses are often required to ensure that the strain on the cable and fibres does not exceed a maximum value	Time to install each metre of cable reduces with length of route (due to reducing friction between cable and other surfaces). Therefore, pulling by hand is highly suitable for the installation of drop cables. When new cables are to be installed next to existing live cables, the hand-pulling technique usually causes less disturbance than winching*

Technique	Relative cost	Benefits	Risks/issues	Other comments
Blowing cables into ducts/sub-duct/micro-ducts	Medium	Fibres experience less strain during installation compared to the (hand or winch) pulling method. Allows increased fibre installation distances and rapid deployment of fibre/fibre-cables into previously installed empty micro-ducts when required †	Requires air-tight duct network to be in place. Blowing pressure must be carefully controlled to avoid damaging the cable	If the cable is too small or flexible, a shuttle (parachute) must be used to assist the blowing process. Although actual blowing times are relatively short, a sub-duct and/or micro-duct must first be installed
Floating cables	Medium	Increased installation distance. Safer technique than air-blowing for removing cables from duct	Floating cables is unpopular due to the need to transport and dispose of water. Survey results provided no evidence of the use of this technique	Distances that can be achieved are not commonly required in access networks
Direct burying of cables	Medium	Does not require ducts to be installed	Difficult to maintain cables or recover old cables. Provides no opportunities for installing new cables, unless cable de-coring is used	–

* Hand-pulling is often quicker than winching, due to the minimal set-up times involved. However, for longer distances winching has to use larger forces to overcome friction, etc. Since the relevant distances in access networks are typically less than 1km, most cables can potentially be hand-pulled.

† However, the prior installation of sub-ducts (which must be winched) and micro-ducts (which can be winched or blown-in) serves to increase the overall deployment time for the blown-fibre system

One respondent stated that floating with water had been very problematic in hilly areas and could therefore only really be used in flat or downward-sloping terrain.

6.2 Significant recent developments

The most significant recent developments in cable installation techniques are considered to be:

- development of stiff, so-called 'self-rodding' cables
- increases in distances achieved via cable-blowing
- improvements in installation techniques for aerial cables.

6.3 Future developments

No radically new developments in cable installation techniques are expected to become available commercially in the next few years. Developments cited by respondents were:

- Over-blowing of cables, whereby cables are blown into already occupied sub-duct.
- Over-ground identification or tracing of underground optical cables. One approach involves incorporating a metallic tracer element in the optical cable. Another potential option that is being discussed is the use of near-field identification technology, as used in other applications such as logistics management.

6.4 Key benefits

'Self-rodding' cables

The use of self-rodding cables, which are made to be stiff enough to be pushed into underground ducts, can replace the use of the standard technique of rodding (to install a rope) followed by cable-pulling. The main benefit is that the speed of deployment is increased. However, this approach can only be used over relatively short distances and is therefore only really suitable for the underground drop.

Cable-blowing

There have been incremental increases in the distance over which cables can be blown, and the technique can now handle most of the distances typically encountered in UK access networks.

Installation techniques for aerial cables

The main development has been the use of fibre-clamping in blown-fibre solutions, specifically in drop section of the network (refer to Section 10 on aerial cables).

Cable 'over-blowing'

Cable over-blowing will serve to increase the available duct space in existing networks.

Tracing of underground optical cables

The elimination of metallic tracer elements in optical cables means that they can be installed in the proximity of electricity cables and will experience no risk of damage due to lightning strikes. This technique is most useful for the longer sections of the network, i.e. the feeder and distribution sections.

6.5 Adoption of technologies/techniques around the world

One overseas operator has implemented cable blowing in a tandem arrangement, rather than fleeting (which is more common), in order to maximise daily installation capacity.

6.6 Compatibility with current UK planning and construction regulations/guidelines

The recent and expected future developments in cable installation are not expected to result in techniques that are incompatible with UK planning and construction regulations or guidelines. Further, the overseas practices described in the previous section are likely to be compatible with these regulations and guidelines.

6.7 Key factors that influence adoption

Cost and speed of installation were cited by most respondents as the key factors that influence CP and contractor adoption of innovative cable installation techniques. Speed not only drives cost itself, but also the time taken to roll out a fibre network, and the quality of service, e.g. the time to provide a customer connection. Also cited as important was the reduction of strain on the fibres during installation, both within the cable being installed and those in already installed live cables.

6.8 Impact on network architecture

The majority of recent or expected future developments in cable installation techniques are not anticipated to favour or require changes to network architecture or topology. An exception is the increase in the distance over which cables can be blown, which will tend to reduce the number of jointing chambers that will be required in greenfield deployments.

7 Fibre specifications

Key points

- Fibres that conform to the ITU-T G.652D standard are by far the most common type of fibre deployed in access networks in recent years. Bend-insensitive fibres that conform to the ITU-T G.6547A1 standard are starting to appear in outdoor cables, and in some cases at no extra cost.
- Bend-insensitive fibres will result in cable products with improved mechanical performance that can be installed more easily, and will also mean more compact flexibility points.
- Smaller-diameter (e.g. 200 micron) fibres will lead to the manufacture of slimmer loose tubes, resulting in cables with improved mechanical performance.
- One overseas operator has taken the decision to adopt G.657.A2 bend insensitive fibre for future deployments, which they perceive will deliver significant benefits.
- In order to become widely adopted, new types of fibre should be backwards-compatible e.g. should allow splicing with existing types of fibre.

7.1 Introduction

The most popular fibre that is used in the access network conforms to the ITU-T G.652D standard, and is considered to provide sufficient bandwidth capacity to accommodate traffic growth in the long term.

7.2 Significant recent developments

The most significant development in this field over the past 2–3 years is considered to be the appearance of bend-insensitive fibre. Although such fibre was initially targeted at indoor applications, the variant G657.A1 (which has a minimum bend radius of just 10mm, as opposed to 15mm for conventional fibre), is starting to appear in outdoor cables, and sometimes at no extra cost.

7.3 Future developments

There was no evidence that new types of fibre will become available commercially in the next few years to complement existing G.652 and G.657 fibres for use in the access network. However, manufacturers are working to reduce the optical loss of existing fibres, for use in longer-reach solutions or PONs that have higher split ratios (e.g. 128-way instead of the typical 32- or 64-way).

7.4 Key benefits

Bend-insensitive fibres

Cable products that use bend-insensitive fibre can be installed into enclosures more easily, thereby speeding up deployment timescales. They also support the development of more compact cable joints, which can be more easily fitted into congested manholes and jointing chambers. Also, smaller optical distribution frames (ODFs) within exchanges can be used.

The new variant of bend-insensitive fibre that is starting to appear in outdoor cables is backwards-compatible with existing G.652 fibre types. This is important, as existing splicing practices and equipment can continue to be used. Initially, these cables will probably be sold at a price premium to standard fibre cables, but prices should fall to those for standard cable over the next 12–18 months. The cables should be particularly useful for use in the distribution and drop sections of the network, where the deployment conditions tend to be the most demanding.

7.5 Adoption of technologies/techniques around the world

One overseas operator has taken the decision to adopt G.657.A2 bend-insensitive fibre for future installations, having negotiated prices that are similar to the previous cost of G.652D fibre. The company believes that this will deliver significant benefits, such as the use of smaller ODFs inside exchanges, more compact joints, and the use of smaller manholes.

7.6 Compatibility with current UK planning and construction regulations/guidelines

The recent and expected future developments in fibre specifications are not expected to result in technologies or techniques that are incompatible with UK planning and construction regulations or guidelines. Further, the overseas practices described in the previous section are likely to be compatible with these regulations and guidelines.

7.7 Key factors that influence adoption

Mechanical and optical performance were cited by most respondents as the key factors that influence CP and contractor adoption of innovative fibre technologies. It is especially important that new fibres are backwards-compatible with existing fibres. There are no other types of fibre that respondents have seriously considered but did not adopt.

7.8 Impact on network architecture

The majority of recent or expected future developments in fibre or fibre specifications are not anticipated to favour or require significant changes to network architecture or topology.

8 Fibre jointing

Key points

- The most popular option for jointing fibre is fusion-splicing. The next popular option is jointing via the use of factory-assembled connectors. Two other options are available – mechanical splicing and jointing via field-assembled connectors – but are considered too unreliable for the outdoor environment.
- New fusion-splicing machines may become available that use sophisticated fibre-alignment techniques, and which can be used safely and easily up a pole, to enable the deployment of pole-top-mounted optical components. (Nevertheless, there remain health and safety issues associated with the practice of fusion-splicing at pole-top height.)
- Some overseas operators are using, or plan to use, factory-assembled connectors in their networks.
- In order to become widely adopted, new fibre-jointing techniques and technologies should offer the same (or better) reliability than existing techniques. The cost and time taken to joint cables are also important.

8.1 Introduction

The main options for terminating or joining fibres in the outdoor environment that are considered by civils companies and operators are:

- **Fusion-splicing** in which two sections of optical fibre are fused together using specialist equipment. The process involves removing the fibre coatings, cleaving the ends of the fibre, fusion splicing, and then protecting with a heat-shrink sleeve.
- **Mechanical splicing** involves 'semi-permanently' aligning two cleaved ends of fibre using a small mechanical assembly.
- **Factory-assembled connectors** which attach FC or PC-type connectors in a controlled environment to one or both ends of an optical cable (such as a drop cable), or to optical components (such as the power splitters used widely in GPON networks).
- **Field-assembled connectors.** Same as above, but the operation is carried out in the field. Products have been developed to speed up the process that do not require fixing the fibre within the connector using epoxy, or polishing the end faces to reduce optical loss.

Figure8.1: Environmentally hardened single-fibre connector (for use in the drop section of a pre-connectorised solution network) [Source: Corning 2012]

A summary of the high-level costs, benefits and risks/issues of the existing techniques is presented in the following table:

Figure 8.2: High-level costs, benefits and risks/issues [Source: Analysys Mason, 2012]

Technique	Relative cost	Benefits	Risks/issues	Other comments
Fusion-splicing	High	Offers highest levels of reliability	Requires expensive splicing machines and suitably skilled field staff	Most popular approach in the UK (and generally with Tier 1 operators)
Mechanical splicing	Low to medium	Fast process to joint fibres	Reliability is perceived to be poor	Unpopular option for outdoor environments
Factory-assembled connectors	Medium	Speeds up time to joint fibres in the field	Requires pre-set lengths, and excess installed cable has to be managed. Some parties have concerns about cost and long-term reliability	Speed of connection is especially useful in providing single customer drops
Field-assembled connectors	Medium	Fast connection time in case of customer drop. No excess installed cable to manage	Reliability is perceived to be poor	Unpopular option for outdoor environments

One major operator stated that it would continue to use only fusion splicing in its network; it had trialled mechanical splicing and connectors, but rejected these technologies on reliability grounds. However, the operator would re-consider them should there be significant improvements (although pre-connectorised drop cables would also be re-considered if costs were to fall significantly).

8.2 Significant recent developments

All of the technologies in use were developed more than three years ago. However, there have been some incremental improvements in fusion-splicing machines, which have become easier to use and more portable.

8.3 Future developments

The key future development in fibre jointing that may become available commercially in the next few years is anticipated to be high-performance, portable fusion-splicing machines that are light enough and easy enough to be used up a pole.

8.4 Key benefits

Fusion-splicing machines

Improved fusion-splicing machines would offer significant benefits to operators, particularly machines that use sophisticated fibre alignment techniques (i.e. alignment of fibre cores) which are capable of being used safely and easily up a pole. Such technology would allow, for example, optical components such as splitters to be located at a safe height above ground (at present they have to be housed in less secure pedestals, or in more costly underground enclosures). Machines are currently available which can be used in this environment, but they use the less precise cladding-alignment technique. Notably, some overseas and smaller UK operators are mitigating the health and safety risks through the use of elevated platforms for technicians, who can carry out the splicing at mid-pole height. Also, BT has now developed in the laboratory an above-ground, secure box for splicing on poles at a height of 2 metres – drop fibres can then be blown from this point when an end-user requests a connection. The solution is particularly useful for use at the very many distribution points, where splicing is most likely to be undertaken.

8.5 Adoption of technologies/techniques around the world

Although fusion splicing is the most popular outdoor fibre jointing technique in the UK, Verizon in the USA has extensively used pre-connectorised, environmentally hardened connectors (EHCs) within outdoor plant in its FTTH network, i.e. on splitters and drop cables. Also, in Australia, NBN Co has placed a contract for this type of solution which it intends to use in its national fibre roll-out programme. One overseas infrastructure provider that we interviewed currently favours fusion splicing wherever possible, but will move to pre-connectorised cables at the cabinet, which it states can become untidy when fusion splicing is done piecemeal (although it considers the use of fusion splicing as part of cabinet construction by contract in bulk to be acceptable). The operator does not experience any cable management issues, as its architecture is such that it blows fibre from the cabinets to end-user premises (the cable is then cut to length and fusion spliced). However, it does not use field-assembled connectors as these are perceived as too unreliable.

8.6 Compatibility with current UK planning and construction regulations/guidelines

The recent and expected future developments in fibre jointing are not expected to result in technologies or techniques that are incompatible with UK planning and construction regulations or guidelines. However, there would be health and safety issues associated with the practice of fusion-splicing at pole-top height, unless improved splicing machines were licensed for such use.

The overseas practices described in the previous section are likely to be compatible with UK planning and construction regulations and guidelines.

8.7 Key factors that influence adoption

Reliability is cited by most respondents as the key factor that influences CP and contractor adoption of innovative fibre jointing techniques and technologies. The perceived superior reliability of fusion splicing probably explains why this approach is currently favoured by operators in UK and Europe. Some operators that we interviewed said that they had seriously considered the use of connectors within outdoor plant, but had decided not to adopt the technology. Other factors cited as important were cost and time taken to joint cables.

8.8 Impact on network architecture

The majority of recent of expected future developments in jointing techniques are not anticipated to favour or require significant changes to network architecture or topology. The development of effective and safe pole-top fusion splicing will favour the deployment of overhead (pole-top-mounted) optical components such as splitters and fibre distribution points. This may increase the number of viable architectural options available for operators, such as cascaded splitter architectures which involve the placing of splitters close to the end-user premises.

9 Flexibility points

Key points:

- Operators can choose from a variety of flexibility points, such as underground joint enclosures, pole-mounted joint enclosures or boxes, street cabinets, or small overground pedestals.
- More compact flexibility points will increase the usable space in underground deployments and reduce the cost of new-build underground enclosures.
- Units with improved aesthetic appearance will support overhead deployments. They will also support the deployment of façade distribution and drop cables and components (these are used in the UK in linked housing, shop fronts and some business premises).
- New types of flexibility point that act as 'mutualisation points' will appear in access networks where there is duplicated, separately owned fibre infrastructure. Access seekers will be able to gain access to common infrastructure inside buildings such as multiple dwelling units (this model has been adopted in France, but not in the UK).
- Time taken to install, ease of use, reliability, security, fibre capacity and flexibility are important factors affecting adoption of new types of flexibility point. Some operators are prepared to pay a premium to ensure high reliability and reduce maintenance opex.

9.1 Introduction

The types of flexibility point that are considered by operators for current FTTH deployments are:

- underground joint enclosures
- pole-mounted joint enclosures or boxes
- street cabinets
- small overground street pedestals.

Figure 9.1: Blowing from a BT underground flexibility point [Source: Analysys Mason, 2012]

A summary of the high-level costs, benefits and risks/issues associated with the existing technologies is presented in the following table:

Figure 9.2: High-level costs, benefits and risks/issues [Source: Analysys Mason, 2012]

Technology	Relative cost	Benefits	Risks/issues	Other comments
Underground joint enclosures	High, due to labour required	Underground environment is protected from vandalism. Not visible	Underground location is prone to flooding and so must be completely resistant to dust and water (i.e. IP68-rated)	Must be resistant to immersion in water. Usually used for the primary or secondary flexibility point*
Pole-mounted joint enclosures or boxes	Medium	Relatively secure from vandalism. Not highly visible	Health and safety issue associated with the practice of fibre splicing at pole-top locations	Can be used for the primary or secondary fibre flexibility point. Most common use is as a distribution point in underground distribution network and overhead final drop
Street cabinets	Low to medium	Overground version is a cost-effective solution as they are easy to install. Allow for regular access	Regular accesses can drive up faults and opex. Overground installations are liable to vandalism or damage from vehicles	Can be placed overground (most common) or underground, but this is very expensive. Smaller in volume than VDSL cabinets. Usually used for primary flexibility point

Technology	Relative cost	Benefits	Risks/issues	Other comments
Small overground street pedestals	Low	Small profile and low cost to install	Overground installations are liable to vandalism or damage from vehicles. Ease of access encourages interventions, which lead to faults	Most often used at the secondary flexibility point

* Primary flexibility points in an FTTH network are defined to be the concentration points between feeder cables and smaller distribution cables. Secondary flexibility points are defined to be concentration points between distribution cables and smaller drop cables. Refer to the *FTTH Handbook*.

One major operator stated that it had consistently found commercially available joints for its access network to be sub-optimal in terms of physical size and functionality. The company subsequently drove the development of a completely new range of products. The re-designed products should become available in around six months.

Operators select particular types of flexibility point depending on the type of network they intend to deploy, and this decision is taken during the development of their strategic plans for the NGA network. The choice of optical architecture – i.e. point-to-point or PON (cascaded, distributed etc.) – is a key element of the network specification that influences the types of flexibility point deployed.

Also, where this choice is available, a high-level decision is taken on whether to use overhead or underground flexibility points. As described above, underground elements are generally more secure, but can involve higher deployment costs where new-build civil works are required; indeed, much like the case with cables and duct, operators often prefer to locate flexibility points in existing enclosures to avoid the high cost of such civil works. Where no space is available in existing underground enclosures, over-ground deployments are often cheaper to deploy and easier to access but can be less secure. However, planning procedures have the potential to slow down and potentially halt the roll-out of networks with high volumes of overhead cables and poles, or over-ground flexibility points.

9.2 Significant recent developments

The most significant development in this field in the last two to three years is considered to be the availability of units that:

- are more compact
- have improved aesthetic appearance
- enable the practical deployment of ‘mutualisation points’ (discussed in Section 9.5 below).

9.3 Future developments

Some of the key developments in flexibility points that may become available commercially in the next few years are expected to include more-compact enclosures, especially those that accommodate bend-insensitive fibres. Also over-ground, secure boxes to enable splicing on poles at a height of two metres are expected. See also comment in Section 9.1 above.

9.4 Key benefits

The key benefits that providers may obtain from recent and expected future developments are as follows:

More-compact flexibility points

The development of more-compact flexibility points delivers several benefits, including greater potential to re-use existing underground manholes and chambers and avoid costly new-build civil works. One passive component company is currently developing flat joints, which can be laid on top of existing cables or in small chambers. However, there is a lower limit on the size of units, which is defined by the size of splice protectors and the diameter of the tubes that house the optical fibres, and the requirement to house spare fibre for re-jointing.

Units with improved aesthetic appearance

Although the ability to make industrial components that have high aesthetic appeal is rather limited, there is scope for improvements to many existing products for overground applications. This is especially pertinent in deployments of façade cables and components, but such deployments are less common in the UK, being only found in some linked housing, shop fronts and business premises.

Joint boxes at two-metre heights on poles

These units will enable splitters to be located overground on distribution poles. Drop fibres can then to be blown from this point when an end user requests a connection.

9.5 Adoption of technologies/techniques around the world

In countries such as France where there are high levels of duplication of outdoor infrastructure in the access network, flexibility points have been developed to support the concept of 'mutualisation points', where access seekers can terminate their access fibres in order to gain access to 'common' infrastructure inside buildings such as multiple dwelling units (MDUs), i.e. to enable the unbundling of communications infrastructure inside buildings. The mutualisation point may be located in the basement of buildings, or outside in the street in order to serve a number of different buildings.

9.6 Compatibility with current UK planning and construction regulations/guidelines

The development of more-compact flexibility points and units with improved aesthetic appearance is likely to result in products that remain compatible with UK planning and construction regulations/guidelines. The development of mutualisation points is not applicable, as the related infrastructure model has not been adopted in the UK market.

9.7 Key factors that influence adoption

Time taken to install, ease of use, reliability, security, fibre capacity and flexibility were all cited as important. Most respondents stated that cost was also important, but less so than in other technology areas. This is due to the relatively small contribution that flexibility points make to total deployment costs. Also, some operators stated that they were prepared to pay a premium to ensure high reliability of units in order to avoid potentially excessive maintenance opex.

9.8 Impact on network architecture

The development of compact flexibility points that can be housed within existing manholes and chambers will favour reduced volumes of overground street furniture. Flexibility points with improved aesthetic appearance will favour overhead deployments and the consolidation of façade cables and components (which will be especially of benefit outside the UK).

Boxes that can accommodate splicing at two-metre pole height will enable the deployment of splitters on distribution poles.

Flexibility points to support the deployment of mutualisation points will favour the concept of duplication of outside infrastructure in access networks, as has occurred in France (although this model currently looks unlikely to be adopted in the UK).

10 Aerial cables

Key points:

- There are a number of cable types that have been developed for backhaul applications, such as aerial dielectric self-supporting (ADSS), wrap, optical ground wire (OPGW), lashed, figure of eight and hybrid plus fibre cable. ADSS cables are the preferred option for aerial cables in the access network.
- Slimmer and lighter cables will make aerial infrastructure more aesthetically appealing, and easier and quicker to install. One operator stated that light (36-fibre, loose-tube) aerial cables will serve to increase the availability of existing pole infrastructure, and therefore reduce the need for civils work on aerial routes, i.e. to provide 'pole-route enhancement'.
- In order to become widely adopted, new aerial cables should have a low deployment cost and be quicker to install than existing designs.
- Comprehensive cost data will become available for overhead optical cables installed in the access network. Operators will then decide whether aerial cables offer reduced whole-life costs compared to underground deployments.
- Aerial optical cables that traverse roads in the UK will be required to break at a specified load if hit by moving traffic, to prevent poles snapping and falling.

10.1 Introduction

Aerial cables in telecoms networks are attached to, and supported by, over-ground poles. They can be deployed in the feeder, distribution or drop sections of the access network. Aerial cables are much less costly to deploy than underground cables due to the lower civils costs associated with erecting poles as opposed to undertaking excavations. The effective space available to accommodate extra cables will depend on the number of cables already installed and the load capacity of the poles. In the UK, aerial cables are commonly found in the drop section of the access network (around 50% of cases). They are also found in the feeder sections (though only very rarely – usually this is in remote areas), and distribution sections (but also rarely – again, typically in rural and remote areas). However, optical cables are unlikely to have been installed to date in the distribution sections of BT's network, as the roll-out of FTTH is still in its very early stages, and in any case is focussed on mainly urban areas. Therefore the discussion around aerial optical cables concerns mainly, but not exclusively, the drop section of the network.

The types of aerial cable that are considered by operators for current FTTH deployments are:

- **All-dielectric self-supporting (ADSS) –** cable which is made of non-metallic materials, so that it can be installed in (low-voltage) power networks. It is also designed to be installed in a self-supporting manner, i.e. without the aid of other elements (wires or conductors)

- **Wrap –** cable which can be wrapped around an earth wire, typically that runs along the top of electricity pylons.
- **Optical ground wire (OPGW)** – cable which replaces the earth wire that runs along the top of electricity pylons. The construction houses a hollow core that contains optical fibres.
- **lashed** – cable that is attached to existing elements (cables), using lashing tapes or clips, for example.
- **'Figure-of-eight' –** cable containing a central tube and fibre, fixed to a steel wire.
- **Hybrid copper plus fibre cable –** cable that contains both optical fibres and copper conductors in the same cable assembly.

Aerial cables come with pre-installed fibre, or as micro-duct versions that require subsequent blowing of fibre bundles or mini-cables. Aerial optical-drop cables tend to be much slimmer and lighter than feeder or distribution aerial optical cables, due to the lower fibre-counts being employed.

A summary of the high-level costs, benefits and risks/issues of the existing techniques is presented in the following table:

Figure 10.1: High-level costs, benefits and risks/issues [Source: Analysys Mason, 2012]

Technology	Relative cost	Benefits	Risks/issues	Other comments
Aerial dielectric self-supporting (ADSS)	Medium	Does not need to be supported with the aid of separate elements, i.e. it is 'self-supporting' Uses similar equipment and techniques for installation to that used for copper cables. Optimised for long spans and has good ice and wind loading characteristics. Lighter than equivalent copper cables	–	Used where electrical isolation from neighbouring electrical cables is key
Wrap	Medium	Can be attached to existing infrastructure (cables) thereby reducing the cost of deployment	Deployment involves specialised wrapping machines	Has been used extensively in power networks
OPGW	High	Offers high reliability		Used where fibre is deployed directly on a power line
Lashed	Low	Allows for simplified cable to be used	The attachment technique may present reliability issues	Conventional cable is attached to a separate catenary member

Technology	Relative cost	Benefits	Risks/issues	Other comments
Figure-of-eight, i.e. central tube containing fibres, fixed to a steel wire	Medium	Allows easy separation of optical section from strength member	Use of metallic components adds to weight of cable	Uses multi-loose tubes
Hybrid copper plus fibre cable	Medium	Contains both optical fibres and copper twisted pairs and so is suitable as a transition drop product for FTTH networks, i.e. where voice continues to be carried via copper	Usually requires existing copper drops to be removed when used as a transition product Use of metallic components adds to weight of cable	Used as drop cables where separate optical and copper access networks are in operation

Note that wrap and OPGW aerial cables are only relevant to deployments over power lines.

Aerial optical cables that traverse roads in the UK are required to break at a specified load if hit by moving traffic, to prevent the poles snapping and falling. One major operator in the UK stated that it was unable to source a cable that met this requirement (probably because of the use of strength members) and would therefore continue to use aerial micro-ducts and blown-fibre bundles (in the drop section).

Openreach (and some other UK-based operators) are currently installing hybrid (copper and fibre) cables when providing customer connections in their small number of FTTH deployments. This is because voice services continue to be provided over the existing copper network, whilst data services (Internet access) are starting to be provided over the new fibre access networks. However, this is considered to be a short-term solution, and Openreach is likely to use a slimmer, lighter all-optical drop cable after the launch of a fibre voice product.

10.2 Significant recent developments

The most significant developments in aerial cables over the last two or three years are considered to be:

- reduced mass per metre and thinner aerial ADSS cables
- use of clamping techniques to prevent fibre creepage in blown solutions.

10.3 Future developments

The main developments in aerial cables that may become available commercially in the next few years are anticipated to be even slimmer and lighter cables.

10.4 Key benefits

The key benefits that may result for providers from recent and expected future developments are as follows:

Reduced mass per metre and thinner aerial ADSS cables

Reducing the mass of aerial optical cables will make the cables easier to install, and may require fewer personnel. This is important in the case of drop cables, which make a significant contribution to deployment costs. Thinner optical cables will also improve their aesthetic appearance, which is important for aerial infrastructure. These developments have been helped by the removal of steel strength/catenary wires and the use of a non-metallic method for gripping the cables.

Use of clamping techniques to prevent fibre creep age

There is a risk that movements in aerial cables will cause a drag on fibres which, for example, may be transferred to joint boxes and reduce the reliability of joints. This can be eliminated through the use of clamping techniques applied to the cable materials. The impact can be potentially significant in longer drop sections, and in other sections such as the distribution network.

10.5 Adoption of technologies/techniques around the world

There are no technologies in use overseas that are significantly different from those in use in the UK.

10.6 Compatibility with current UK planning and construction regulations/guidelines

There are restrictions on the deployment of overhead telecoms cables in the UK, although a consultation is currently being held that proposes the relaxation of such restrictions. The development of slimmer ADSS cables will improve the aesthetic appearance, and over time will strengthen any case for aerial deployments. New aerial optical cables that traverse roads in the UK will be required to break at a specified load if hit by moving traffic to prevent poles moving significantly (which would constitute a hazard to other structures and to people).

10.7 Key factors that influence adoption

The key factor that influences CP and contractor adoption of innovative techniques and technologies cited by most respondents was capex and speed of installation. Compatibility with UK planning and construction guidelines was also cited as important, as currently the deployment of overhead infrastructure is not allowed in new build deployments by local authorities in the UK. There was only one case where an operator considered a new type of aerial cable but did not use it, but this involved the use of a figure-of-eight cable (which contained a metallic element) on an overhead electricity line.

10.8 Impact on network architecture

The recent and expected future developments in aerial cables will favour the deployment of overhead infrastructure in all parts of the network. However, operators are still unsure whether the whole-life costs of overhead infrastructure are significantly lower than those for underground installations. This is because although overhead infrastructure has significantly lower deployment costs, the fact the cables are less protected can drive up maintenance opex.

11 Conclusions

BT is investing GBP2.5 billion to roll out its superfast broadband network to two-thirds of the UK population by 2014, primarily using fibre to the cabinet (FTTC). FTTH is significantly more expensive than FTTC: Analysys Mason's estimates for the Broadband Stakeholder Group (BSG) indicated that rolling out FTTP to the whole of the UK could cost between GBP24.5 billion and GBP29 billion, with the majority of the cost relating to civils and fibre infrastructure.[6]

Furthermore, the cost rises significantly in rural areas, due to an increase in the distances involved and a reduction in demand density. It was evident from our BSG work that the 'final third' of the UK would cost significantly more than the first two-thirds, and this led the UK government to implement a new policy to fund the roll-out of next-generation broadband in rural areas, under the control of BDUK (part of DCMS). There is greater potential for new technologies and techniques to reduce the costs associated with roll-out in the final third, and hence the present report should be read with this in mind.

Since the deployment costs are so significant, as shown in above figures, we have undertaken a comprehensive review of the infrastructure deployment technologies and techniques, which are a significant driver of the costs. This review is especially timely, as the number of fibre deployments has risen during the last two to three years, both in the UK and around the rest of the world.

We have undertaken this study by conducting interviews with a suitable mix of passive component suppliers, a major civils company, and a variety of operators based both in the UK and overseas. We also supplemented the interviews with desk research.

We have found that the key recent and expected developments are evolutionary rather than revolutionary, but taken together they have the potential to make a material impact by reducing the costs and increasing the speed of roll-out. The likely impact of developments in terms of cost and speed is summarised for each area in the following table:[7]

Figure 11.1: Relative impact of developments in each area on the cost/speed of roll-out [Source: Analysys Mason, 2012]

Low impact	Medium impact	High impact
Duct and sub-duct VDSL cabinets	Cable design Cable installation techniques Fibre specifications Flexibility points	Civils (excavation techniques) Fibre-jointing Aerial cables

6 We estimate that the cost of digging new ducts contributes 64% to total deployment costs, whilst the cost of optical fibre materials and installation contributes a further 30% to the total deployment costs.

7 A detailed impact analysis is provided in Annex A.

This shows that there several areas that are expected to have developments with relatively high impact, namely civils (faster mole-ploughing techniques), fibre-jointing (pole-top fusion splicing), and aerial cables (slimmer and lighter ADSS cables with improved reliability). Other areas are also expected to have important developments, such as fibre specifications (the use of bend insensitive optical fibres in outdoor cables and components).

The development of faster mole-ploughing techniques and improved aerial cables will be particularly relevant for rural fibre deployments in the UK. The realisation of benefits arising from the use of aerial infrastructure is dependent on the relaxation of current restrictions in this area, which include the requirement that telecommunications providers must install their lines underground, except where overhead installations already exist or there is no viable alternative. Government and Ofcom should consider if any additional policy developments in this area would be appropriate.

We have estimated the cost reduction that could be realised from adopting slot-cutting, optimised mole-ploughing and aerial cables on a wide-scale in the UK. As a baseline, we have taken Analysys Mason's estimate for the cost of nationwide FTTP GPON coverage from the work we did for the Broadband Stakeholder Group, namely GBP24.6 billion. That total is based on the use of traditional civils techniques, and includes assumptions on duct re-use, volume of new-build, and unit costs for traditional install in different kinds of terrain.

By modifying the unit install costs (estimated using information received from interviewees during the course of our study) and also applying a 'real-world' deployment factor to reflect the fact that in practice each technique can only be applied to a percentage of eligible areas[8], we have estimated the potential benefit of the three techniques above, and these are shown in the table below. The revised unit costs are expressed as an 'effective unit cost reduction' with respect to the traditional techniques and the total saving in deployment cost from the baseline case is shown in the right-most column.

Figure 11.2: Potential reduction in cost of deployment of GPON FTTP across the UK delivered by widespread use of slot-cutting, optimised mole-ploughing, or aerial cables [Source: Analysys Mason, 2012]

Civils technique	% of total network route that is new build	Total civils cost for the new build routes using traditional techniques (£bn)	Effective unit cost reduction from the traditional install technique (%) [A]	Proportion of new build routes to which new technique can be applied [B]	'Real world' factor (%) (to allow for fact that not all routes will be viable using new techniques) [C]	Overall cost saving (%) [A x B x C]	Total civils cost for the new build routes using new techniques (£bn)	Total cost saving over traditional techniques (£bn)
Slot	45%	15.2	-38%	66% (hard surface only	80%	-20%	12.2	3.0
Mole-plough	45%	15.2	-50%	34% (soft surface only)	80%	-10%	13.8	2.0
Aerial over hard ground	45%	15.2	-69%	66%	80%	-36%	9.7	5.5
Aerial over soft ground	45%	15.2	-50%	34%	80%	-14%	13.1	2.1

8 For example, slot-cutting can only be used in hard surfaces, typically roads or footpaths, but in some real situations neither may be suitable.

According to our assumptions, the use of slot-cutting in hard surfaces could potentially deliver a cost saving of GBP3 billion (12% of the total cost), whilst mole-ploughing could deliver a saving of GBP2.0 billion (8% of the total cost). If aerial cables were to be used instead of slot-cutting and mole-ploughing in new build routes, a maximum cost saving of 5.5 + 2.1 = GBP7.6 billion (31% of the total) could be realised if aerial was used everywhere. However, it is questionable whether aerial could be used at such scale efficiently, and this would represent a major change in current policy which favours underground installation. It is important to note that the indicated cost savings could only be delivered if the techniques were adopted by industry on a widespread basis, and this would require the successful commercialisation of the relevant recent or expected technical developments.

Future work could investigate in more detail the potential cost and time savings across different geographies that could be realised from using the various technologies and techniques identified in this study.

Annex A Impact analysis of technical developments

Figure A.1: Impact analysis of technical developments [Source: Analysys Mason, 2012]

Area	Cost	Impact on cost	Speed	Impact on speed	Quality	Impact on quality	Overall impact
Civils	No significant developments	○	Streamlined mole-ploughing techniques will speed up the deployment of optical cable in rural areas	◕	Better quality of backfill and reinstatement will make slot-cutting widely used in the middle mile	●	◕
Duct and sub-duct	The diameter of duct/sub-duct will continue to track the decreasing diameter of optical cables, increasing the number of cables that can be deployed in a route	◔	No significant developments	○	The use of blown light pulling ropes to pull in flexible ducts will reduce disturbance to previously installed live cables	◑	◔
Cable designs	Smaller-diameter cables will help increase usable space in existing ducts and reduce the need to dig trenches. Multi-functional cables will require infrastructure providers to operate fewer internal management processes and will allow bulk purchasing	◑	'Pull-back' cables which involve cutting a window in the cable sheath will allow contents to be accessed quickly and easily	○	No significant developments	○	◑

Cable installation techniques	Increased cable-blowing distances will help to reduce the number of joints required in greenfield installations. Cable over-blowing, where cables are blown over existing cables within a sub-duct, will serve to increase the available duct-space	◑	'Self-rodding' cables which are stiff enough to be pushed short distances will be used for drop cables. Cable over-blowing will serve to increase available duct space	◑	The use of new fibre-clamping techniques will help to improve the reliability of aerial cable installations	◔	◑
Fibre specifications	Bend-insensitive fibres deliver a variety of benefits, e.g. compact flexibility points that increase usable space in existing underground enclosures and reduce the need for civils work, and allow smaller ODFs inside exchanges.	◑	Bend-insensitive fibres will deliver a variety of benefits, e.g. cable products that can be installed more easily	◑	Smaller-diameter (200 micron) fibres will result in the manufacture of slimmer loose-tube units to give cables with improved mechanical performance	◔	◑
Fibre jointing	New fusion-splicing machines based on suitably sophisticated fibre-alignment techniques, and which can be used safely and easily up a pole, will enable the deployment of pole-top-mounted optical components	◕	Environmentally hardened connectors will encourage the use of pre-connectorised drop cables that can be quickly connected to the end user	◑	Environmentally hardened connectors will improve the reliability of fibre joints that use factory-assembled connectors	◑	◕

Flexibility points	More compact flexibility points will increase the usable space in underground deployments and decrease the cost of new-build underground enclosures	◑	No significant developments	○	No significant developments	○	◑
Aerial cables	Comprehensive cost data will become available for overhead optical cables installed in the access network. Operators will then decide whether aerial cables offer reduced whole-life costs compared to underground deployments	●	Slimmer and lighter aerial cables will become easier and quicker to install	◕	Slimmer aerial cables will be more aesthetically appealing.	◔	●

Key:

○ Development likely to have small impact on cost/speed of roll-out ● Development likely to have large impact on cost/speed of roll-ou