DEVELOPMENT OF AN INTERNET PROTOCOL BASED INFRASTRUCTURE FOR TRAFFIC MANAGEMENT

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ABSTRACT

Historically, in the UK transmission of communications signals (including data, video and voice) across roadside communications infrastructure has been carried out on a system by system basis. The potential benefits of a common infrastructure based around the Internet Protocol (IP) have led the Welsh Assembly Government to adopt this as the common medium for transmission of all communications signals, within transmission buildings and control offices, on trunk routes and out to roadside equipment. This approach has been coupled with some novel cabling techniques to provide a low cost, flexible communications infrastructure. This paper discusses the issues that have arisen during the implementation, and the benefits that these approaches have brought.

SYNOPSIS

The paper will discuss the benefits that have been accrued by the implementation of a converged Internet Protocol (IP) infrastructure for voice, video and data in Wales. It will also highlight the new approaches to the physical cable infrastructure that, when coupled with the converged infrastructure model, have driven down costs and improved flexibility. The improved infrastructure can now be used for providing traditional network management Intelligent Transport Systems (ITS) services, such as Closed Circuit Television (CCTV) and emergency telephony, but is also capable of supporting emerging telematic's requirements, such as vehicle to infrastructure communications.

CONVERGED NETWORK INFRASTRUCTURE

The worldwide acceptance of Ethernet and IP products, and their consequent availability, pricing, reliability and ubiquity have for some time made a compelling case for their acceptance in the area of trunk communications. To this end, the Welsh Assembly Government have installed a Gigabit Ethernet communications network, servicing all major nodes on the motorway network and now extended to serve individual roadside devices. The network has been augmented by the provision of an IP telephony (IPT) system, and the trunk transmission of CCTV video streams from around 250 cameras over the network using a number of standards based encoding techniques.

A converged infrastructure has been designed and implemented across the network. Using this infrastructure, solutions have been delivered to the following roadside systems:

- Emergency Telephones
- Closed Circuit Television (CCTV)
- Buried Inductive Loops (MIDAS)
- Matrix Signals and Message Signs (NMCS2)

The core network comprises Ethernet switches, carrying out layer 3 (IP) routing. The switches are connected in a series of interlinked rings. At layer 2 the network operates in excess of 50 VLANs. At layer 3 a range of subnets have been declared, approximating to the VLANs at layer 2. Interconnections between switches operate at Gigabit Ethernet speed over the Assembly's own fibre optic infrastructure. This runs parallel with over 300Km (18%) of the Assembly's road network.

Where Assembly owned roadside cable is not available, the core network has been augmented and extended by the use of a third party telecoms provider's MPLS (Multi Protocol Label Switching) network. This allows data, including CCTV images, to be transferred to and from remotes sites, at relatively low cost, based on ADSL (Asynchronous Digital Subscriber Line) uplinks.

The converged infrastructure approach was adopted for a variety of reasons as summarized below:

- Common infrastructure for all services
- High bandwidth achievable
- Will provide support for next generation roadside services
- Industry standard, widely available, cost effective (IP and associated protocols are not licensed so equipment from many vendors can inter-operate successfully)
- In-built fault tolerance
- Disaster recovery
- Fibre economy
- Improved services
- Allows commercial off-the-shelf systems (eg automatic numberplate recognition cameras) to be added easily

It is not within the scope of this paper to describe each of the above in detail, but when considered as a whole the benefits formed a compelling case for the Welsh Assembly Government to adopt this approach for all inter-urban ITS communications.

EXPERIENCE OF INSTALLED INFRASTRUCTURE

The Assembly have now been operating a converged infrastructure since Spring 2003. Since that time CCTV, telephony and data services have been operating over the network. The following sections describe the primary services that are delivered over the converged infrastructure.

It is worth noting an example of the flexibility of adopting the converged network approach. In early 2005 a need was identified to provide a standby control office facility. Had the ITS road management systems been deployed in the traditional way, this would have taken many months of planning, reorganising and implementing, and would have attracted significant costs. However, because of the free access from any point that is a feature of IP, the facility was made operational within a month of a suitable site being made available. The site has full access to all CCTV pictures, emergency telephone and signal/sign setting equipment.

Digital CCTV

In order to capitalise on the network benefits outlined above, the Assembly have adopted a digital CCTV approach, with the video data transported over the converged infrastructure. This effectively leverages all of the network's benefits to the CCTV system. It also allows pictures to be delivered, viewed or controlled from any network connected location, including the internet or an external network such as a service provider's MPLS infrastructure.

The Assembly's core infrastructure carries digitised CCTV pictures encoded using two techniques; motion JPEG (MJPEG) and MPEG2. These transmission formats are augmented by digital video recording, which again uses MJPEG techniques.

MJPEG is the basic transmission mode, and provides internet and local PC access to any one of the CCTV cameras installed across the Welsh motorway and trunk road network. Every camera is directly fed into an input on a low cost commercially available MJPEG server. This solution was chosen because of its low cost, simplicity, compatibility and the ease with which the video can be displayed at the remote user's terminal, without the need for high-end PCs, sophisticated decoding software or dedicated high bandwidth communications links. Consideration has been given to MPEG4 as a long term successor technology.

As configured, the technology delivers up to two frames per second of video, which is sufficient for radio broadcasters, motoring organisations, trunk road agents, contractors and others ascertain directly current traffic conditions on the road network. MJPEG servers are widely available from various manufacturers, and products from two different vendors have been successfully deployed in the Welsh infrastructure. The pictures are accessed via a series of custom built extranet web pages that allow a user to select their desired camera pictures.

MPEG2 is used where sufficient bandwidth is available to deliver near broadcast quality, PAL resolution, 25 frames per second video to control centres and other nodes directly connected to the core gigabit Ethernet network. MPEG2 was chosen for this purpose because it is standard's based, widely used and available from a variety of manufacturers. In order to reduce latency we are using only 3 frames between each I (reference) frame. This leads to a high bandwidth consumption (6 Mbits/second) but with a latency of only around 180-200 ms. When compounded with control system latency, this gives a total system latency of around 400ms – noticeable, but not sufficient to cause operational issues.

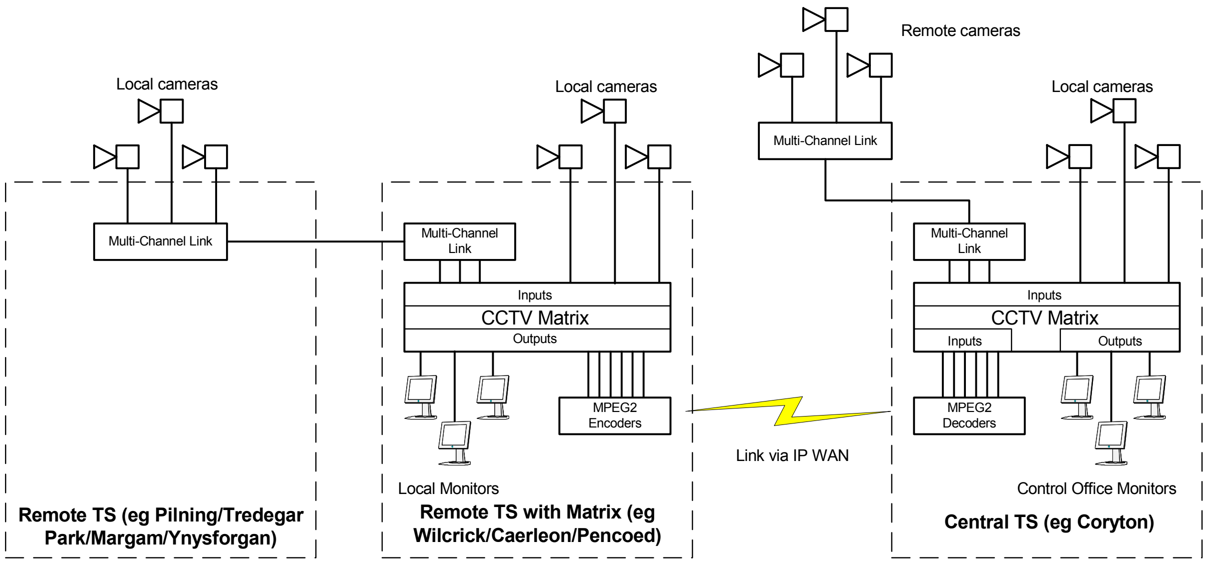

Figure 1 – Interim hybrid MPEG2/analogue CCTV transmission

The MPEG2 technology was first introduced to facilitate the migration of services to the Welsh Assembly's new traffic management centre in Cardiff. A digital solution was selected because the pre-existing analogue transmission network had reached its expansion limit – trunk connections were carried via fibre hungry single-vendor point to point multiplex analogue links. The addition of a new monitoring node would have required many more such links. MPEG2 was chosen, and initially used to replace these multiplex links, resulting in an interim hybrid solution, as shown in figure 1 above.

Both MPEG2 and MJPEG video streams need to be decoded before they can be viewed. Whilst MJPEG video is universally available via the Traffic Wales extranet, MPEG2 can only be viewed at core network sites due to bandwidth limitations. In our environment both encoding techniques are decoded by PCs, by hardware decoders (and fed into CCTV matrix inputs) or directly by the Dynamic Display System (DDS) video wall in the Assembly's new traffic management centre.

At sites beyond the range of the core Gigabit network, bandwidth is not available to deliver MPEG2 video. Instead video from these sites is directly encoded as MJPEG, and streamed to a central recording/relay portal over the telco's MPLS network. Video from all remote sites is universally available from the portal, to internet connected users, or to internal users via PCs, conventional CCTV monitors or the control room DDS.

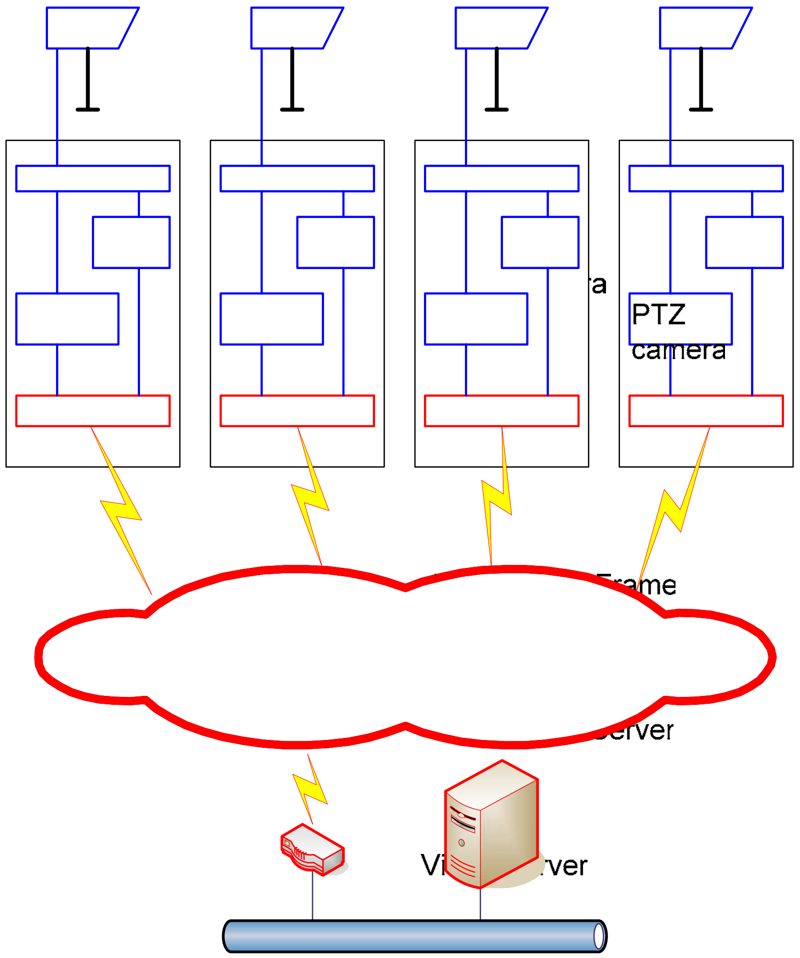

Figure 2 – CCTV transmission from sites beyond the core Gigabit infrastructure

In those areas where the core Gigabit infrastructure is available, future expansion of the digital CCTV principle will be based around encoding CCTV pictures at collection nodes (transmission stations) rather than at the camera site. This was because of the requirement to deliver MPEG2 and MJPEG video, as well as recording the video from each camera at 2 frames per second. The available technology to carry out these three discrete functions was not felt to be sufficiently mature to install at the roadside, where accessibility and reliability issues are paramount considerations.

Accordingly, on the core network video is digitised into the two formats and concurrently recorded at the collection nodes (transmission stations). These are in off motorway buildings where access is easy, and where environmental controls (such as uninterruptible power supplies and air conditioning) are in place. In order to achieve this aim the final connection leg from each camera is retained as an analogue link, and fed into the inputs of the DVR, MPEG2 and MJPEG codecs at the collection nodes.

A number of sites on the core network have now been upgraded in this way. The term “Edge of Network” (EON) has been used to describe cameras connected at these sites. It is a strength of this approach that not only have MJPEG codecs from multiple manufacturer’s been used, but so too have MPEG2 codecs. In both cases extensive testing has been carried out to ensure compatibility between equipment from different vendors, with the software and hardware decoders and the DDS, and to demonstrate that the user’s experience is such that one is unaware that multiple vendor's equipment has been used to deliver the service.

A schematic describing the simple EON video transmission approach at each site is given below:

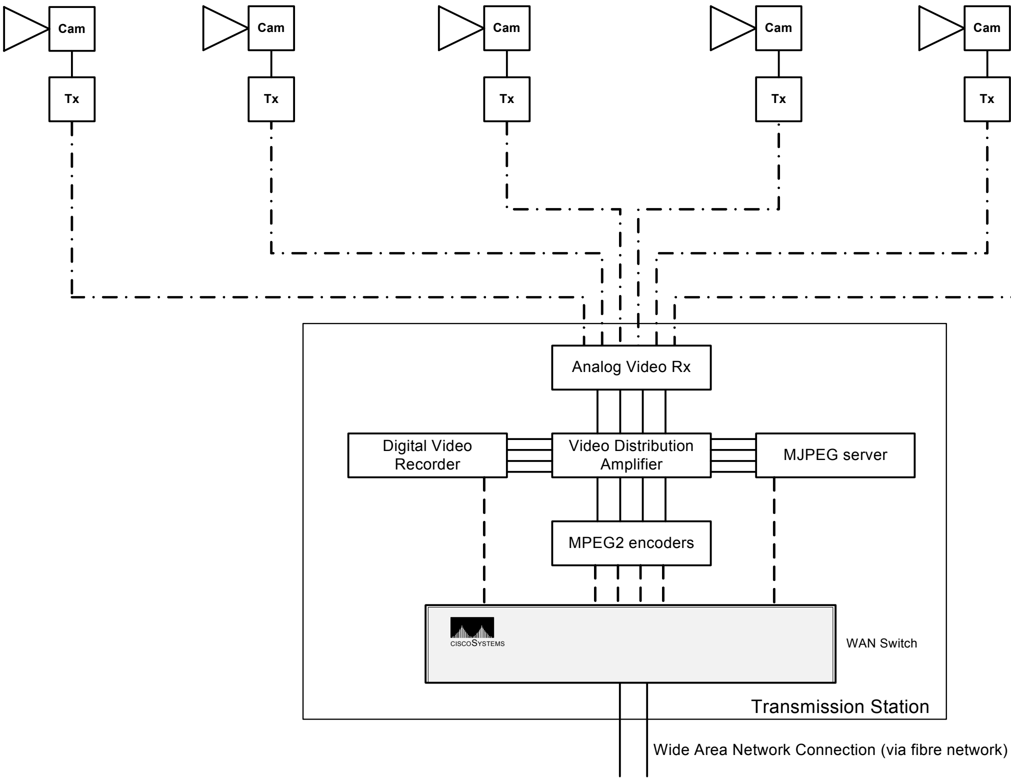

Figure 3 – Typical Edge of Network site, showing MPEG2, MJPEG and DVR devices

Around 10% of the Assembly's traffic cameras have now been upgraded to EON, with the plan to complete this roll-out over the next three to five years. The approach will yield a fault tolerant, open standard based CCTV system that will facilitate unlimited, supplier independent expansion across all of Wales.

IP Telephony

An IP telephony system has been installed, that provides a fault tolerant internal phone network wherever the core IP Ethernet infrastructure extends. In south Wales the system features dual redundant Call Managers (PC based private branch exchange - PBX), dual redundant public telephone network gateways, messaging servers, call recording, automated attendant and a billing/reporting service, the core functions are mirrored in north Wales, as illustrated in figure 4 overleaf.

IP telephony allows fallback sites to be used for disaster recovery purposes – any site with a high bandwidth network connection (including sites with a broadband Virtual Private Network (VPN) connection) can be used to answer incoming calls, or to place the outgoing calls. The IP technology, combined with dual redundant public telephone network (PSTN) connections and dual redundant Call Managers ensures that failure of the PBX, or of a PSTN connection, or of a prolonged power outage at the control office, etc. does not cause all phone services to be lost. Inter-node calls do not attract any call charges. Since the network extends across Wales, and to all of the main Police and Assembly control centres, this realises tangible financial benefits.

The system was designed to allow the technology to be rolled-out to include the SOS emergency telephones at the roadside. At the time of writing just over half of the nearly 500 roadside phones has be upgraded to benefit from the new technology backbone. This has been achieved by replacing the bespoke roadside bridging units (each capable of concentrating connections from up to sixteen handsets) with commercial off-the-shelf (COTS) routers connected to the fibre optic network by a COTS switch, located in an existing roadside cabinet. Not only has voice quality dramatically improved, but system complexity has been reduced and ease of maintenance improved.

The roadside telephones are connected to a dedicated roadside infrastructure, which runs in parallel with the trunk links of the core Gigabit Ethernet. The roadside infrastructure is directly connected to the core network at each transmission station. A trial roadside infrastructure has been in place since late 2003, using primarily non-environmentally hardened equipment. The purpose of the trial (which encompassed around 15 switches, and 10 remote nodes) was to establish the viability of using office specification equipment at the roadside, rather than the significantly more expensive industrial specification equivalents. At the time of writing there have been no failures attributed to the installation environment. The success of the trial has allowed the roadside telephone infrastructure to be implemented at minimal risk. The model adopted has also allowed other technologies to be put in place, to provide additional services, for example:

- Real-time vehicle-by-vehicle can be collected from the existing 500m spaced inductive loops, rather than the amortised data currently collected, to enable more accurate travel time and congestion estimation.
- Roadside message signs can be interrogated, upgraded and maintained more easily (with fewer visits to site).
- Automatic Number Plate Recognition cameras have been installed across the network, without the need for a dedicated communications infrastructure.
- Wireless Access Points have been installed to communicate with IT systems in vehicles at the roadside.

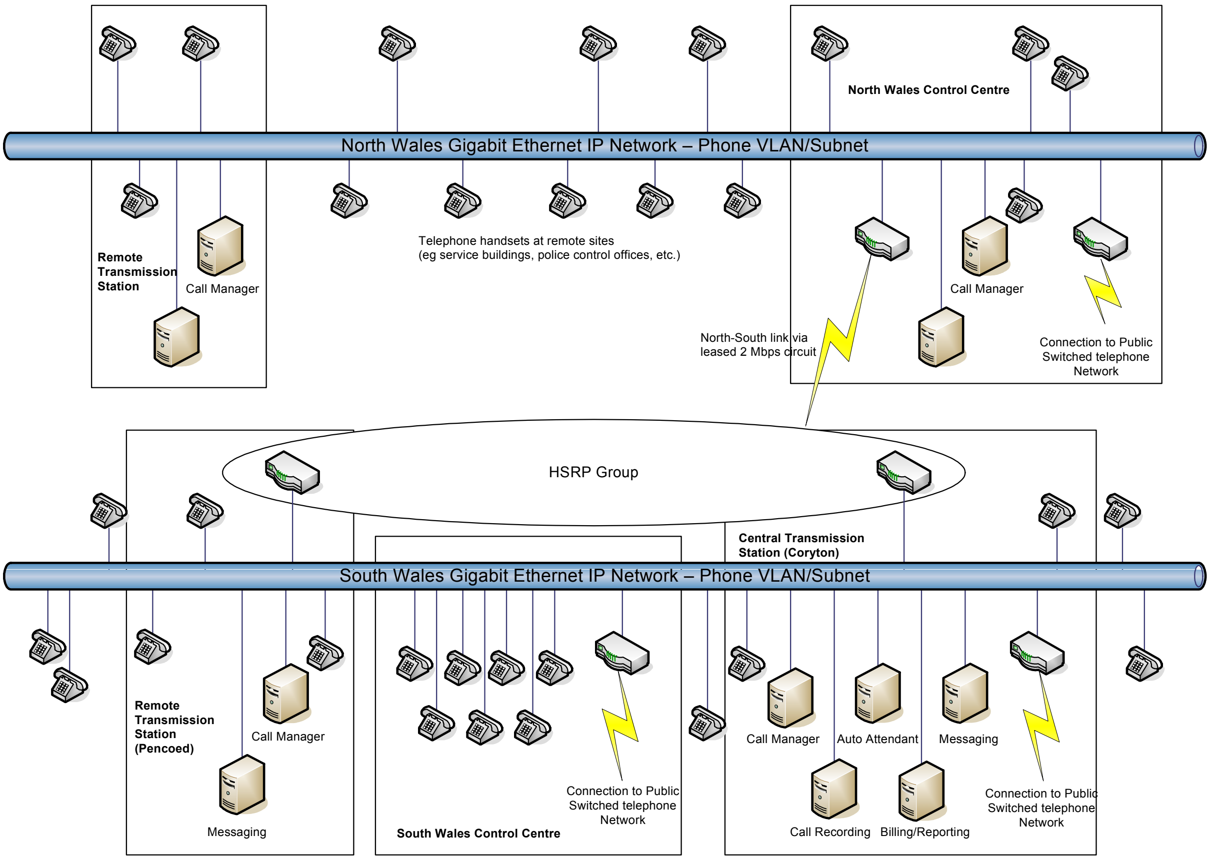

Figure 4 – IP telephony system

One of the gateways to the PSTN is capable of routing both voice and video, and so incorporates video conferencing into the converged network. Not only does this provide conventional office type video conference facilities, but it also allows third parties to access real-time CCTV video. A specific example of this being one of the 24 hour TV news channels, who provide half hourly traffic bulletins, using video directly obtained from our system. This standards based solution allows the broadcaster to select a camera for display directly from the Traffic Wales extranet. It is simple to use, and straightforward for third parties to interconnect with.

NEW APPROACHES TO CABLE INFRASTRUCTURE

In order to expand the geographic scope of the services that can be delivered using the common infrastructure, the Welsh Assembly Government have re-evaluated the way in which their core cable infrastructure is provided. Following the wide acceptance by the UK's telecommunications sector of blown fibre as an alternative to traditional cabling techniques, this new approach has been successfully trialed and rolled out on the Welsh highway network.

Blown Fibre is a fibre solution which works on the basis of pre-installing tubes, made to contain fibre bundles, which can be blown in at a later point in time.

The technique provides the highway authority with substantial benefits when compared with the traditional approach. In the UK, the approved method comprises direct buried/ducted cables and above ground cabinets at 1000m intervals, at which cable joints/terminations can be made. The cabinets all require access steps, handrails and safety barrier, and as such are both costly to install and visually intrusive. The traditional approach relies on future-proofing the installation by guessing how many fibre cores, and of which type (eg standard 62.5/125µm or 50/125µm fibre, laser optimised (OM3 grade) fibre, singlemode fibre, or a combination of any of the above) will be required in future, and then installing sufficient "dark fibre" to meet any future need. Some of these fibre cores may never be used, but the expense of installing, splicing and testing them is met at time of cable installation.

With a blown fibre infrastructure, it is possible to install the actual fibres required when they are required thus taking the guess work out of planning. The flexibility of the blown fibre approach allows new equipment (for example a CCTV camera) to be installed without the need to install cable back to the nearest joint cabinet. The new cable can be jointed with the longitudinal blown fibre cable at its nearest point.

The key benefit derived from this type of installation is its level and degree of flexibility, resulting in benefits such as:

- Simplified planning - Blown fibre is perfectly suited to projects that are implemented in phases, or, where business needs for the cabling infrastructure are not determined at the outset. The network is built according to today's needs. The fibre count can be increased as demand grows.
- Cost effective - The blown fibre specifier can enjoy budgetary benefits from the fact that the fibre is deployed as and when required (pay as you grow) - thereby spreading payment across different budgetary periods. Blown fibre also obviously eliminates the need for "dark" fibres. It minimises branching and splicing of traditional networks, thus reducing engineering costs. The repair and upgrade of blown fibre can be achieved at far lower cost, and with less disruption, than with traditional fibre.
- The network is future-proofed - The versatility of blown fibre makes it both simple and easy to upgrade the network. New roadside equipment can be added as and when required and existing fibre links can be re-routed to alternate equipment. Networks are easily upgraded, branched or extended, giving maximum flexibility and uninterrupted fibre blowing right to the destination. Simplified emergency restoration.
- Reliability of installation - Dragging a traditional cable causes tension that may damage the fibre, especially for complex routes involving corners and risers. With a blown-fibre installation, however, only the plastic tubes are pulled and these are unaffected by stretching. The fibre itself is pushed in using compressed air and is not under any tension as the force acts equally along its entire length.

The tubing used for blown fibre connection is generally inserted in sections and then clipped together, allowing long lengths of fibre (up to 6km) to be installed without the need for splicing. On the Welsh highway network, this means that all roadside plant can be reached either from an intermediate splice or directly from one of the transmission buildings described above.

The new technique eliminates the need for much of the street furniture and the time it takes to install, and hence some of the cost, visual impact and potential for traffic disruption of the traditional approach.

Since September 2004 the Welsh Assembly have installed approximately 30km of blown fibre cable. This has been either direct buried or pulled through existing ducts. However, the technique also lends itself to novel installation techniques. For example, the Assembly have recently completed the installation of a 4km section of blown fibre cable installed in an 80mm deep, 20mm wide slot cut in the road surface.

Because the time spent on site is significantly less with this approach, costs are about 50% of those that would be expected on a traditional UK highway cable installation.

The Assembly have also pioneered the used of prefabricated transmission buildings. Typically sited at 20km intervals, these premises are normally constructed using traditional brick/blockwork. The prefabricated buildings, constructed in a factory off-site from glass reinforced polymer (GRP), arrive on site fully laden with building services, cabling, and equipment, minimising the mobilisation time, and allowing the newly installed blown fibre cable to be placed into service far quicker than would otherwise be the case.

CONCLUSION

The above illustrates the reasons why the Welsh Assembly has chosen to adopt the wider IT and telecoms industry principles of a converged network running over a flexible cable infrastructure, and has also demonstrated that the benefits that are now being derived from this approach, notably reduced dependence on specific suppliers, access to a wider market for equipment and skills, for fault tolerance and to make better use of the installed asset base.

The Welsh Assembly have made policy of making best use of their installed assets, this includes the communications infrastructure of both fibre cables and IP infrastructure. As such, services have been developed, and are currently being rolled out, to deliver on this commitment. For instance, freeing up fibre cores for other uses by use of a converged core network (as described above), or delivering services to the public or stakeholders via the converged network/internet.

The expanded infrastructure has now been made available as a telematic's test track, covering approximately 100km of road, which is now being used for a variety of academic and commercial research projects.