Loughborough College two-hop 802.11 wireless link to remote centre

Edward Wincott, Janet

Paul Taylor, Loughborough College

Tom Franklin, Franklin Consulting

Overview

This paper describes the implementation of a long distance 11.5km (7 mile) wireless connection between Loughborough College and one of the college's outreach centres using 802.11 technology. It describes problems encountered in the selection of a suitable solution due to funding constraints, and in its deployment. The eventual solution involved two wireless bridges as there was no direct line of site between the main campus and the outreach centre. The link has been highly successful, providing sufficient bandwidth for 30 PCs together with VoIP (Voice over IP) telephony, and has operated very reliably (99.7% availability). Although later generations of 802.11 systems are now available, 802.11b systems are still being installed, offering low cost wireless solutions. Having been installed in 2001, costs in this paper relate to that period of time. This case study looks at the issues involved in planning and implementation, and assesses the long-term experiences of this technology.

Executive Summary

A long-range 802.11b wireless bridge solution was introduced to link Loughborough College to an outreach centre to save on the high ISDN-2 (Integrated Services Digital Network connectivity at 128kbit/s) call costs of the previous system. This project was part funded by the EU, which only paid capital costs.

Other solutions such as ADSL (Asymmetric Digital Subscriber Line or broadband) were considered but were ruled out for technical or geographical reasons.

The wireless bridge solution has worked well for the college, providing sufficient bandwidth for 30 PCs used for LearnDirect at the outreach centre. The college has implemented some VoIP over the link as well and is looking at QoS (Quality of Service) at present.

Introduction

Loughborough College is an FE establishment which shares its present campus with Loughborough University and the RNIB (Royal National Institute for the Blind) Vocational College. The college addresses its aim of widening participation in education by the provision of courses in the workplace, learning facilities at community outreach centres and through

distance learning. In 2002/03, a total of 9740 students were enrolled.

One of its outreach centres is Beaumont Lodge, which is 11.5 km (7 miles) in a direct line from the main campus, and is used, in part, as a LearnDirect centre. When this was originally set up in 1999, the site was linked to the college using an ISDN-2 line connecting to a US Robotics Edge Server in the main college. Due to the call costs which apply to ISDN connections, this system was expensive to use and

also not totally reliable. With a single ISDN-2 line it also provided only limited bandwidth – 2 x 64kbit/s. This was acceptable for e-mail and Internet access but insufficient for serious access to main campus college filestores and LAN (Local Area Network) resources. There was therefore a clear need to upgrade this connection.

In 2000 the college gained some funding from the EU to connect Beaumont Lodge and other centres to the college network.

Service Requirements and Constraints

The EU funding was specifically for capital items and a key constraint in selecting a preferred solution was that there should be minimal recurring costs. Ongoing costs such as maintenance and any licensing costs would have to be funded from general college course provision income.

Another major requirement was that significant bandwidth should be provided to satisfy the demands of a LearnDirect centre. A need for at least 2Mbit/s was identified to support traffic from the projected 30 PC workstations at the remote centre. The link also had to provide significantly greater reliability than the ISDN-2 connection.

To summarise:

- Link required to replace existing ISDN-2 based 2 x 64kbit/s connection
- Greater bandwidth needed (2Mbit/s or more) to support 30 PCs at the LearnDirect centre
- High reliability
- Low ongoing costs
- Initial capital outlay not an issue provided a business case could be made

Identification of Possible Solutions

The following technologies were considered:

- Standard BT Megastream leased line
- LearningStream leased line
- ADSL Internet / VPN (Virtual Private Network)
- EPS 8
- IR laser
- 802.11b wireless

Land Lines

The initial intention had been to use a standard BT Megastream type leased line as this would have provided the requisite bandwidth and reliability, but it was thought that this would be very

expensive.

The educational sector LearningStream product was also considered because it was normally ideal for connecting two or more remote centres to a ‘hub’ site. The solution was inexpensive to install, at £600 per remote end and £600 for the hub site. However annual rental costs, although offering good value for 2Mbit/s circuits, still represented a considerable recurring cost. (Note: these costs were quoted in 2001.)

The college looked at a variety of alternative solutions, including the use of ADSL for direct Internet access and/or for a VPN connection to the main college network, and BT EPS 8, and EPS 9 direct copper ‘analogue’ links. (For more information on these solutions, refer to the following case study: West Cheshire College low cost 2 Mbit/s connection using 'Baseband' EPS 8 links [1].)

All the above contenders were unlikely to provide a satisfactory solution, either because the recurrent costs were too high, the technology was unavailable or not reliable, or the sites did not use the same BT exchange. The college decided to look at alternative solutions and, in particular, wireless networking.

Wireless Options

IR laser offered excellent bandwidth capability, but range limits and sensitivity to adverse weather meant that this technology would not be suitable.

The ISM (Industrial, Scientific and Medical) radio bands of 2.4GHz and 5.8GHz can be used without the need for a radio licence, so long as the equipment itself is licensed. At the time of the project, 802.11b was the de facto standard for wireless networks and short-range point-to-point wireless links. This technology seemed promising as medium-length range, acceptable bandwidth and low recurrent cost should be achievable.

A possible solution was found in the form of the Wavelength Solutions Aries 2.4GHz Wireless Ethernet Bridge product. The Aries system offers transparent bridging to 16 km, with dynamic operation and bandwidth allocation (i.e. it will adjust the bandwidth to the maximum achievable at the time, up to 11Mbit/s).

Cost/Technical Comparisons

Technologies	**Estimated Cost install/rental excluding routers**	**Considerations**
Standard BT Megastream leased line	£4,250	Acceptable full-duplex 2Mbit/s bandwidth. Requisite high reliabili
	£8,120 pa	Moderate installation a recurrent cost

LearningStream leased line	£1,200	Acceptable full-duplex 2Mbit/s bandwidth. Requisite high reliabili
	£8,770 pa (1)	Low installation but too cost
ADSL Internet / VPN (2Mbit/s / 1Mbit/s)	£1,060	Bandwidth only just ac 2Mbit/s / 1Mbit/s, but a asymmetric upload/do capacity. Reliability not sufficien
	£2,040 pa	Low installation, mode cost. Not available at time o
EPS 8	£1,080	Acceptable full-duplex 2Mbit/s bandwidth. Requisite high reliabili line quality.
	£640 pa	Low installation, mode cost. Sites did not share BT distance too great.
IR laser	£15,000 / link	Acceptable full-duplex 10Mbit/s bandwidth. Weather affects reliab
	Maintenance only	High installation, low r Distance too great for no line of sight.
802.11b wireless	£12,440 (2)	Acceptable half-duplex 6Mbit/s bandwidth. Acceptably high reliab
	Maintenance only	High installation but lo cost. Line of sight required a exist.

[1] Includes 4-port hub site rental. [2] Final two-hop link cost, single hop cost estimate would have been £8,000.

Table 1: Cost comparison of possible solutions in 2001

Feasibility

Land Lines

The Standard BT Megastream type leased line and the LearningStream product were rejected as the recurrent costs for both were considered too high.

ADSL for direct Internet access and/or for a VPN connection to the main college network was considered, but ruled out because the local exchange for Beaumont Lodge had not been enabled for ADSL.

BT EPS 8 and EPS 9 direct copper ‘analogue’ links can be used to provide highly cost effective solutions, but for a circuit capable of supporting high bandwidth digital signals, both site ends need to be connected to the same BT exchange. This was not the case here so that possibility was also rejected.

Wireless Options

The college initially looked at the Cisco® Aironet® 340 series 802.11b wireless bridge (now superseded by the 350 series which features greater radio power and in-line power capability), because this product was supported by the existing networking supplier. It offered a theoretical 11Mbit/s throughput over short to medium distances, but due to signal attenuation over the required distance, parabolic dish antennae and line of site would be required to achieve acceptable throughput. It seemed unlikely that this solution would work over the required 11.5km and the college was not convinced that it would be possible to achieve even 2Mbit/s, despite assertions in Cisco® sales literature.

A key factor in the range of a wireless system is the power output of the radio system combined with the gain and directionality of the antennae. Most sales literature is produced for the US market where the permitted power for unlicensed usage of the 2.4 GHz frequency band is higher than that in Europe. Therefore in the USA it is possible to achieve greater ranges for a given data rate by using higher power settings or higher gain aerials. The 2.4GHz band in Europe is limited by ETSI (European Telecommunications Standards Institute) regulations to 20dBm (decibel milliWatt) (100mW) EIRP (Emitted Isotropic Radiated Power), whereas in the Americas this tends to be 36dBm (4W).

Note: EIRP=Output power of access point/bridge or card in dBm - cable loss in dB (decibel) - connector losses in dB + aerial gain in dBi (decibel isotrope).

dB	The difference (or ratio) between two signal levels; used to describe the effect of system devices on signal strength.

dBm	A signal strength or power level; 0 dBm is defined as 1 mW (milliWatt) of power into a terminating load such as an antenna or power meter.
dBi	The gain a given antenna has over a theoretical isotropic (point source) antenna.

Table 2: Definition of EIRP terms

For online guides to antennae and radio power combinations see the following links:

- Cisco outdoor bridge range calculation utility: http://www.cisco.com/en/US/products/hw/wireless/ps458/products_tech_note09186a008009459b. [2]
- http://www.wireless.navigator.co.uk/useful_tools.htm [3]

It became apparent that the Cisco® equipment would not provide a solution working within the power limits for unlicensed use in the UK. It would have been possible to apply for a licence for higher power usage, but the granting of a licence was not guaranteed and would have been expensive and time consuming to pursue. The solution was finally ruled out when the college's application for planning permission to locate the parabolic dish at Beaumont Lodge was rejected as it is a listed building.

An alternative and acceptable solution was found in the Wavelength Solutions Aries 2.4GHz Wireless Ethernet Bridge.

Site surveys were then required to establish implementation feasibility i.e. line of sight and antennae mounting sites. A preliminary survey at the end of 2000, using a video camera, concluded that direct line of sight existed between the two buildings and that the distance was 11.5km. This indicated that the Aries solution would be effective and the project was given the go-ahead on the basis of a single, long range link.

During the final pre-installation survey however, it transpired that to achieve connectivity to Beaumont Lodge, a two-hop signal path was necessary – the first link from Beaumont Lodge to the university accommodation block and the second link from the university to the college main campus. The college had to negotiate permission from the university to site a repeater configuration of equipment on the accommodation block roof. This led to a big increase in cost, but capital funding was in place and over a two year period the solution was still less expensive than a leased line.

Technical Details of Solution

Product Details

The following product details are based on information from Wavelength Solutions™ Ltd's website:

The Aries Wireless Ethernet Bridge enables high-speed data links to be established between buildings with line of sight up to distances of 15 km. The use of 2.4 GHz direct sequence spread spectrum technology provides robust, reliable, and secure transmissions under all weather conditions.

The Aries Wireless Ethernet Bridge can be configured to operate in either a point-to-point or point-to-multipoint mode. The latter is ideal where groups of buildings are required to be interconnected with a LAN link.

The system comprises an antenna, a radio/bridge unit with an output power up to 100mW and a downlink cable which runs to a power supply/Ethernet connection unit (which should be mounted indoors). The radio/bridge unit itself is robust and weather-proof and can be mounted on the exterior of a building or on an antenna mast. Antennae are available in a range of gains; 4, 7, 8.5, 14.5 and 18dBi. Network connectivity is via 10BaseT. External power is required is provided to the radio unit via the downlink cable, which can be up to 90m in length. The unit is remotely manageable over the Ethernet connection.

For further details of the product see the Aries product sheet at:

`http://www.wavelengthsolutions.co.uk/products/pdfs/Aries.pdf`

and the antenna product sheet at:

`http://www.wavelengthsolutions.co.uk/products/pdfs/Antennae.pdf.`

Solution Details

The equipment required for the project was:

- 4 x Aries Wireless Ethernet Bridges
- 2 x 8.5 dBi Gain Antennae for the short hop: college - university accommodation block
- 2 x 18 dBi Gain Antennae for the 11.5 km hop: accommodation block - Beaumont Lodge
- Associated installation equipment - antennae masts, fitting and downlink cables

The total price for the two links, including installation, was £12,440 (in 2001).

Project Planning

Project planning started in 2000 when the grant from the EU was approved. The technology options were reviewed and at this early stage the various forms of land line were ruled out. The wireless technology option using Cisco® Aironet® was selected in the winter after the initial line of sight was demonstrated. The equipment choice was however subsequently rejected when it was realised that a licence would be required to operate the wireless equipment in this country at the power required. The alternative lower power solution Aries equipment was then selected. Finally, in early 2001 following the pre-installation survey when line of sight problems became apparent, the project was re-planned with a two-hop signal path using the University of Loughborough's accommodation block as a staging post.

Procurement and Implementation

Historically the college had used European Electronique (http://www.euroele.com [4]) as the preferred supplier of networking products, but at the start of this project European Electronique did not support Aires equipment and so Cisco® equipment was considered. As Wavelength Solutions™ Ltd's Aires equipment was selected for the solution, the first link from Beaumont Lodge to the university building was therefore installed by another company.

Although the original site survey had indicated that only a single direct link would be required, as the weather improved in the spring and installation got underway, it became clear that the line of sight ran not to the 6-floor high college buildings, but to a 31-floor high accommodation block building owned by the University of Loughborough. The situation was also complicated by the existence of a small hill between the college and Beaumont Lodge. The installation engineers were unable to 'bend' the signal and so a second hop was needed to complete the wireless connection from the accommodation block to the college.

Once the initial installation had been completed, it required several visits by the engineers to get everything absolutely right. Once it had been properly set up and tuned, the system worked very well, offering the full advertised 11Mbit/s half-duplex between the wireless bridges. There were however some teething problems due to the way in which that part of the LAN had been configured, resulting in a reduction in effective bandwidth. Once these issues had been resolved there was an effective throughput of up to 8.5Mbit/s.

Regulations restrict the EIRP of a wireless system, so selection and mounting of antennae and configuration of power output of the radio transmitters were crucial to the effectiveness of this solution. For the short hop to the University of Loughborough an 8.5dBi antenna was sufficient, while the long reach to Beaumont Lodge required an 18dBi antenna.

Antenna	**8.5 dBi**	**18 dBi**
Type	Directional	Directional
Polarisation	dual 45 degrees L/R	Linear, vertical
Gain	8.5 dBi	18.0 dBi
3 Db beam width	75° x 60° (HxV)	20° x 20° (HxV)
height	102 mm	502 mm

width	95 mm	385 mm
total depth	32 mm	Not known

Table 3: Antennae specifications

Project Timescales

The project started with the procurement of funds in 2000 and implementation was completed in the spring of 2001. Live use of the link started in September 2001.

Operational Performance and Reliability

Initially the performance of the system was superb.

However, after a year or so there was quite a marked decline in stability and throughput. It was found that by trying other channels and tweaking channel usage it was possible to make substantial improvements. The final improvement came when the bandwidth setting was reduced to 5.5Mbit/s. This returned stability to the link and has resulted in it being fully operational.

It is suspected that the cause of the problems, after the initial excellent performance, was down to the growth in use of wireless network equipment using the 2.4GHz band. With the link operating at close to its extreme range, the additional, though very minor, interference caused by the growth in use of the band was sufficient to reduce the effective signal strength at the receivers. As the radio equipment does not demand such a high signal strength at lower bandwidth rates, more reliable and stable operation could be achieved by limiting bandwidth to the lower rate.

On a couple of occasions the power supplies have failed, but these were replaced the next working day. The college now holds a full spare system, which is considered to be cheaper than maintenance charges for the six systems they now have. (Further wireless links have been installed to provide access to some of the student accommodation buildings.)

Overall, reliability has been around 99.7%.

Benefits of Project

The project has enabled Loughborough College to run Internet based courses, including a number from LearnDirect, at their Beaumont Lodge centre at an affordable price.

In addition to this, the wireless link extension of the network has allowed an IP telephony service to be provided at Beaumont Lodge to supplement the existing analogue telephone service. This has resulted in considerable call cost savings as internal phone calls between Beaumont Lodge and the college main campus are effectively free. IP telephony has also obviated the need to install additional analogue lines: instead, additional value has been leveraged from the already installed LAN wiring.

Lessons Learned

Knowledge of the effectiveness and benefits of a wireless inter-campus link would have resulted in the earlier deployment of such solutions for a number of other inter-site/inter-building links in the college's WAN (Wide Area Network). In particular, the college had installed a 10Mbit/s laser link to the cyber café, but had wireless bridge technology been known about at the time, it would have been seriously considered. In the college's experience, wireless links are not affected by fog or snow to the same degree as laser.

However, its use might have been precluded by the tightness of line of sight access. There are several chimneys and air vents very close to the line of sight and the potential antenna location at the cyber café end. So it is likely that signal propagation and Fresnel zone (a circular zone centred around the path between a transmitter and receiver) constraints would probably prevent a microwave link of this type from working in this instance.

The college has first hand experience that wireless bridges are a viable alternative to leased lines and have much smaller recurrent costs in terms of rental charges and maintenance fees. Furthermore, on the whole it has been found that cost savings can be achieved by buying an extra set of equipment, which can be swapped in by college IT staff themselves when faults develop, rather than paying for on-site hardware maintenance services. This becomes increasingly attractive as the number of wireless links grows.

The requirement for the second hop to circumvent the hill between the college and Beaumont Lodge had not been anticipated and could have affected the budget planning of the project.

Further Work and Future Plans

The 802.11b wireless link has provided sufficient bandwidth for 30 PCs and VoIP telephony. It has worked very reliably and has proved to be a cost-effective solution, and the college decided to use the same solution to link up one of its student halls. Fibre optic cable installed in a duct below ground was considered, but would have necessitated digging a trench across a university car park (not owned by the college) to reach the student accommodation.

The Aries equipment for the short link to the college accommodation block was purchased from European Electronique and because the link distance was relatively short, installation was carried out by the in-house college computer services team. The equipment was installed at the time the building was being erected, using the scaffolding to provide access for mounting the wireless bridge and antenna. In the absence of scaffolding, there is a maintenance problem as a mobile platform has to be hired to be able to reach it. On the plus side, because the equipment is difficult to access, it is also secure from tampering.

The IP telephony deployment has also been successful so the college has plans to slowly extend this network as new phone extensions are needed.

Summary

The project has been a success and has met all the stated needs. The college would implement the same solution in the future where line of sight exists and where it is impractical or distance is too great to dig a trench for a fibre optic cable.

Links
[1] http://community.ja.net/library/advisory-services/west-cheshire-college-low-cost-2mbits-connection-using-%E2%80%98baseband%E2%80%99-eps-8
[2] http://www.cisco.com/en/US/products/hw/wireless/ps458/products_tech_note09186a008009459b.shtml
[3] http://www.wireless.navigator.co.uk/useful_tools.htm
[4] http://www.euroele.com/