TechLearn

Technical Report

Wireless Local Area Networks in Education

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Executive Summary

This report is intended for IT service staff planning enhancements to their network, and for learning technologists who want to understand the ways in which wireless local area networks (LAN) can be used to enhance the learning process for students at their institutions.

The report does not require a technical understanding of LANs and anyone who is not interested in the various standards can skip section 2, Types of Wireless LAN.

It is hoped that IT and network managers will not only gain an understanding of some of the technical issues involved in implementing a wireless LAN, but that they will also appreciate the ways in which a wireless LAN can enhance educational processes for students (and staff). It is also hoped that they may consider installing wireless LANs in areas which already have adequate wired LAN facilities, and using wireless LANs when extending or enhancing existing LANs.

Educational technologists will want to consider how the use of wireless LANs can enhance education and, in particular, what staff development is required to help make effective use of the new opportunities that wireless LANs offer.

A wireless LAN is a method of linking computers together without using cables. Until recently computers could only be effectively networked using wires. However, this can now be done using radio signals or infrared light.

This report discusses what a LAN is and the issues which are involved in determining whether a wireless LAN is appropriate for any institution. It describes how to go about implementing a wireless LAN and looks at the educational opportunities which the use of wireless LANs open up for colleges and universities. It also considers how this affects the way in which wireless LANs are implemented.

- Wireless local area networks (LAN) can be installed where there are economic or educational benefits for so doing.

  There are likely to be economic benefits where there is not already a good existing LAN and one is needed. This is especially true in buildings where it is difficult to lay cables, for example in listed buildings where consent is required or because there is asbestos in the building and drilling through walls or floors may be prohibitively expensive.

  Wireless LANs also provide enhanced flexibility. With a wired LAN any tables that have network connections have to be fixed to the floor or walls so that the wires are not pulled out. This means that the room cannot be re-arranged in the way that the teacher might want. Wireless LANs also enable the provision of ‘computer carts’. A computer cart is a trolley with a number of laptops and a wireless access point which can be wheeled into the room where it is required. This means that all teaching spaces can become computer rooms. This can include laboratories and even outdoor spaces. This can reduce space requirements as there is less need for specialist computer labs for teaching. It also eases timetabling.

  The educational benefits of wireless LANs are most likely to accrue in courses which require all students to have a laptop or personal digital assistant (PDA) such as a Palm or iPaq. While few colleges or universities within the UK currently offer courses which mandate these, this is already common in the US and is likely to become more so in the UK soon. This so-called ‘ubiquitous computing’ with wireless connectivity opens up new educational possibilities which are beginning to be explored. Evidence suggests that this technology enhances collaborative work and is bringing new teaching methods into the classroom.

- In almost all situations wireless LANs will be used in conjunction with wired LANs to maximise the benefits for the college or university.

  A wireless LAN requires a 'backbone' to connect the parts together and in most cases this will be wired (though point-to-point wireless connections can also be used). However, there are locations where wiring makes sense. Examples of this include computer laboratories where data cables can be laid at the same time as power cables are laid and at litte expense, and the density of computers and bandwidth requirements make wired LANs the most sensible solution.

- Great care needs to be taken with the management of the wireless network if reasonable security is to be achieved. Here, 'reasonable' means that the wireless part of the network is no more vulnerable than the wired parts of the network to hackers.

  Wireless networks are inherently more vulnerable for two reasons. Firstly, the hacker does not even need to enter the premises to be able to gain access to the network from inside any institutional firewall, as radio signals will pass through walls. Secondly, it is easier to monitor the radio signals compared to those in a wired LAN.

  To overcome this, a standard called wired equivalent privacy (WEP) has been developed. Though this has been dogged by serious flaws, it is currently undergoing improvments. A number of proprietory solutions are also available.

  To put the security issue into perspective, it should be remembered that in most colleges and universities it is not difficult for anyone to walk in and start using a computer in one of the labs. If security is not set up correctly, hackers can monitor traffic on the network and learn user names and passwords. This is a major problem.

- Wireless LANs do have a role to play in creating a good network in colleges and universities, particularly where a college or university may be wish to extend the network into additional buildings or parts of buildings, or where 'flood wiring' is being considered.

  However, care is needed in designing the network as the available bandwidth is lower (11–650 Mb/s depending on the technology and the number of access points used) and is shared between all the users.

- Wireless LANs can use either radio frequencies or infrared light to transmit signals. While infrared networks are considerably cheaper to install, since many devices (such as most laptops and PDAs and many printers) already have infrared (IrDA) ports, the limitations (low bandwidth and the need for line of sight) mean that it will rarely be the system of choice. Radio frequency (RF) comes with a number of restrictions as most of the available frequencies are licensed for television, radio and mobile phone use. There are currently two bands which can be used freely, but this means that the available space is also used by other devices such as cordless telephone handsets, garage door openers and Bluetooth-enabled devices, which may cause interference.

- When choosing a technology for wireless it is important to consider not only the installation costs but also the upgrade possibilities of any technology. Currently there two major families of wireless LAN technologies, and they are incompatible with each other as they work in different parts of the radio frequency spectrum. In most cases colleges and universities will want to use the technologies in the industrial, scientific and medical (ISM) band as these are better established, cheaper, offer greater security and require less equipment. Their

drawback is that the available bandwidth is less (but rapidly growing) and there is more likely to be interference from other devices (especially Bluetooth).

Currently wireless LANs should be built using Wi-Fi certified 802.11b equipment
This will ensure that they will work with equipment from any supplier and will provide a simple upgrade to equipment meeting the new 802.11g standard as that becomes available.

- Determining exactly how to install a wireless LAN is more complex than installing a wired LAN since the way the radio signals travel in the buildings needs to be carefully examined. This is because wiring, plumbing and building materials can all affect how the signal travels. It is essential to undertake site survey to determine how the LAN should be installed. Failure to do so will probably result in areas where no service is offered and the need for additional equipment to give sufficient coverage. Without a survey planned growth will also be more difficult.
- Wireless LAN use will continue to grow and become more important over the next five years, by which time it will be as unthinkable for a college or university not to have a wireless LAN as it is for a college or university not to have a LAN now. They will continue to supplement wired LANs which will always have an important role to play, both providing the backbone within campuses and serving key areas such as computer labs, where a large concentration of computers requires high bandwidth.

The report looks at each of these issues and will help determine the most appropriate form of wireless LAN for your college or university.

1 Introduction

This section introduces wireless LANs for the layperson. It avoids jargon and technical details as far as possible while explaining what wireless LANs are, the different types of wireless LAN and the issues in determining the suitability of wireless LANs for particular environments and applications.

The report goes on to look in some detail at the various types of wireless LAN and the issues surrounding each of them, and how one can select the best technology.

The subsequent two sections look at how individuals are currently using wireless LANs and how wireless LANs can assist learning and teaching.

The report concludes with an at-a-glance comparison of the various wireless LAN technologies, a glossary and an annotated bibliography.

1.1 Wireless Basics

This section introduces some of the concepts involved in wireless LANs which are necessary to understand any discussion about wireless LANs.

There are five guiding principles that determine the way in which wireless communications work.

- Bandwidth is scarce
  Wireless communication requires radio (or infrared) spectrum, and while the number and type of applications are increasing rapidly the available bandwidth is severely constrained. As bandwidth is scarce it is very expensive in line with the laws of supply and demand (hence the multi-billion£ sales for third generation (3G) mobile telephony licences). While the cost of providing bandwidth is falling the price of processing and storage is falling much faster, which

means that data requirements are currently growing much faster than the rate at which the available bandwidth is growing. The cost of wired access is falling much faster than the cost of wireless bandwidth, with the result that the cost gap between wired and wireless communications is currently growing and is likely to continue to do so. On the other hand because the cost of processing is falling faster, improved compression and other techniques can be used to help make better use of the available bandwidth.

- Complete coverage of a campus is hard
  Wireless signals of the type used for wireless LANs decay rapidly (with the square of the distance from the transmitter at best); this means that many access points (LANs) or base stations (mobile telephony) are needed. Also, the higher the frequency, the faster signals decay, the more base stations are needed and the greater the cost. To complicate matters further, the higher the frequency, the greater the bandwidth available, but the faster the signal decays, and these considerations need to be balanced when designing a network.

- The environment is hostile
  Wire and fibre provide an excellent medium for signals. The air through which wireless signals must travel is a very poor environment due to echoes off obstacles, humidity, etc. This means that complex error correction systems are needed which are not only expensive to design and build but also require additional bandwidth.

- Power consumption in mobile devices
  Mobile devices are restricted by the problem of battery power. The greater the distance of communication, the greater the signal power required and hence the size and weight of the battery. This places a major constraint on both the signal strength and the processing used to encode and decode signals.

- Cost
  Increasingly devices are mobile, and if they are to include wireless connections the costs need to be kept very low so as not to inflate the overall cost; this means that design and building costs must be low. One of the design criteria for Bluetooth was that the chipset needed should cost around $5 so as not to inflate the price of devices using Bluetooth.

A variety of different modes of wireless interconnection have been developed. They can be divided roughly into personal area networks (PAN), local area networks (LAN) and wide area networks (WAN). Figure 1 shows the ways in which the various different types of wireless network may be used together to provide the best performance and mobility. The figure shows a student with a PDA (which could as well be a laptop) and mobile phone. When students are on campus, they would normally use the wireless LAN from their PDAs to access the college or university intranet and the Internet. They might also exchange data between a desktop PC (used perhaps for some specialist purpose) and their PDA using Bluetooth rather than using the LAN. This is particularly likely in computer labs where the computers would be on a wired LAN and there may be no wireless LAN available. At home students might plug their PDAs into a network or dock, but in the future they may well dock

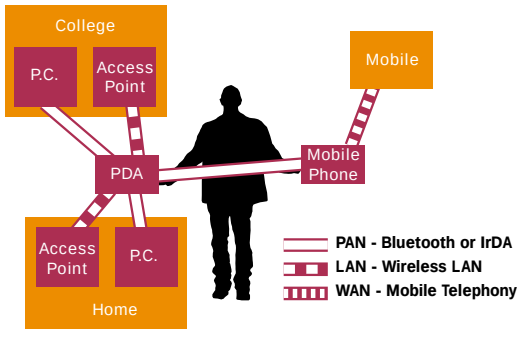

Figure 1. Wireless uses in differing environments

their PDAs to computers using Bluetooth, or if they have laptops, they may have a wireless LANs at home. On the move they can send and receive data via their mobile phones, using Bluetooth to send the data from the PDAs to the mobile phones.

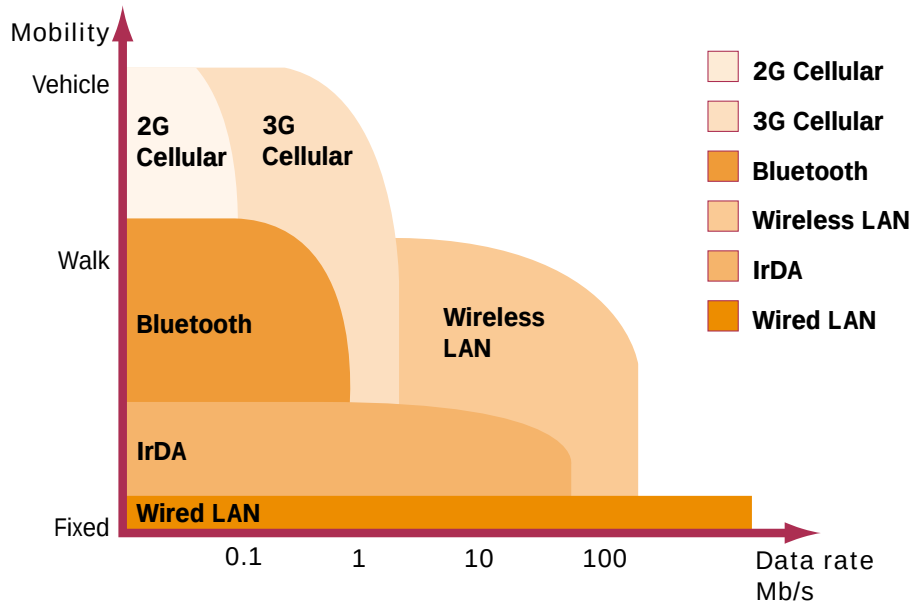

Figure 2. Data rates and mobility for communication types

Figure 2 shows the various types of wireless communication, their data rates and mobility. From this it can be seen that there is a balance to be struck between performance and mobility, and that there will always be a mixed environment as each communication offers different advantages. While some offer good data rates (measured in Mb/s) others offer better geographic coverage.

The function of any LAN is to enable computers to communicate with each other. In this respect a wireless LAN is no different. Fundamentally, it needs to be able to send and receive data, and to ensure that the sent data has been correctly received. Beyond this there are a range of considerations in building a usable network. These include addressing (how to know where to send the data), reliability, bandwidth and security. Many of these functions are identical in a wired and wireless LAN. The way that some of the issues are resolved have to be different because air is a less reliable and secure medium than wire (or fibre).

A wireless LAN consists of a number of access points linked to the wired LAN backbone.[1] The access points provide a wireless service to the users and connect this into the LAN. The access point can communicate with all devices within range that are using the same standards. The range is determined by the type of technology, the power of the signal and the environment in which it is being used. Typically this is around 10m for Bluetooth to around 50m for wireless LAN technologies – though higher bandwidth technologies are likely to offer a maximum bandwidth of about 15–20 m. Although radio waves will penetrate walls they do lose some of their power, and hence the distance they can travel. Wires, metal grills, pipes, even shelves of books and trees all absorb some of the signal and so reduce its range.

Each device using a wireless LAN needs a wireless card to send and receive signals from and to the access point. A variety of different types of wireless card are available for laptops and PDAs. It is important to remember that the wireless LAN needs power to send and receive signals, so using a wireless LAN will flatten the

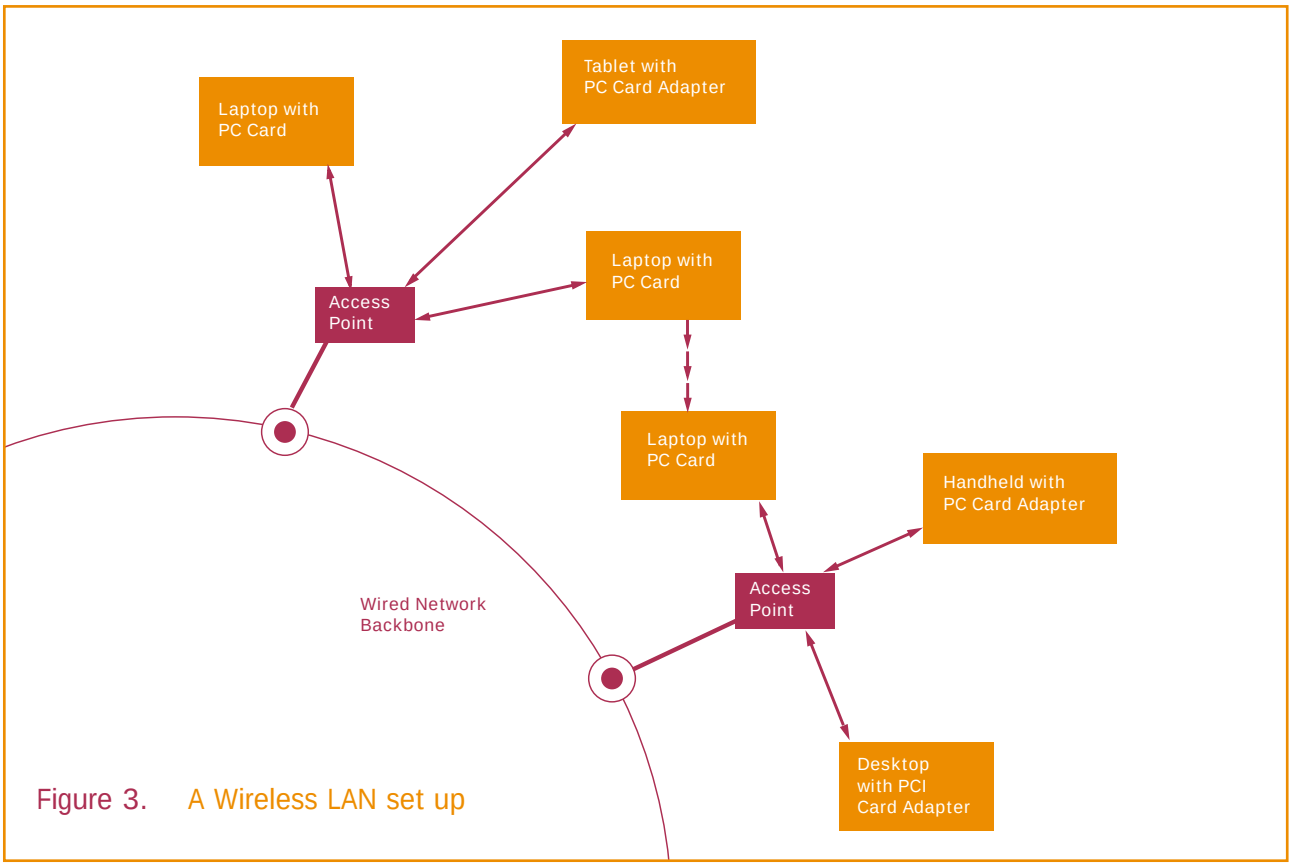

Figure 3. A Wireless LAN set up

computer's battery more quickly unless it has its own power source. Roll on wind up computers.

1.2 What is a LAN

A Local Area Network or LAN is simply a way of connecting computers together within a single organisation and usually in a single site (which may comprise many buildings such as a college campus). A LAN can be thought of as an intranet, although the term intranet often includes the computers, servers and the software systems attached to it. A LAN normally connects to the Internet and for colleges and universities this means connection to the SuperJANET network, and thence to the rest of the Internet.

Construction of a wired LAN

These days the LAN is of such importance to institutions that issues like security and availability are very important. A LAN will normally have a firewall between it and the Internet to protect the intranet from unauthorised external use. Users are expected to 'log in' to the intranet with a user name and password.

Building a LAN, and especially a wired LAN, is expensive. Servers and routers must be bought and cable must be laid wherever access to the network is required. While cable and sockets are cheap the cost of laying cable is high due to the labour involved and the disruption caused by moving furniture, drilling walls and installing trunking and wiring.

Construction of a wireless LAN

An alternative to this is to build a wireless LAN. A wireless LAN comprises a number of 'access points' linked into the main campus network

backbone. An access point is a piece of equipment which acts as a bridge between the wired and wireless parts of the LAN. Typically only one or two access points will be needed in a room (depending on the size of the room, the expected number of users and its construction). By contrast, a wired LAN will need one port for each computer connected to the network. The access points are radio transmitters and receivers which communicate with the computers in range and with the LAN backbone. Unlike the wired LAN ports there is considerable flexibility about where the access points are located. Typically this is near the ceiling, so many of the problems associated with deciding where to locate ports are avoided.

With a wireless LAN each computer will require a wireless card to be installed. These are available for desktop PCs, laptops and PDAs. Many laptops now carry these pre-installed or offer them as an option.

A wireless network does not completely eliminate the need for wiring. It does reduce the number of wires that are needed and provides flexibility is locatinf of PCs and access points.

There are four families of standards for wireless LANs, not all of which are compatible. Three use radio and one infrared light. Each has benefits and disadvantages and it unlikely that any of them will disappear in the next five to ten years. All four are currently being developed and are likely to see improved bandwidth (speed), security and other features. They are discussed in section 2.

1.3 Benefits of wireless LANs:

- Reduced installation effort and costs
  Cabling up a wired LAN can be very expensive and disruptive. It is likely to require drilling through walls, putting ducting along walls, etc. This may mean moving all the furniture in each room to be cabled. This is time consuming and the material costs rapidly mount up. Where wireless LANs require the installation of a small number of access points, there is considerable flexibility concerning their location, so the installation costs are lower than wired LANs.

- Flexibility of room layout and use
  Unlike wired LANs, wireless LANs do not have specific locations where computers must be plugged into the LAN. This means that they are much more flexible in terms of both the location and the number of computers which can be used in an area. When 'flood wiring' a space (that is providing sufficient network ports for all expected use), it is necessary to cable up as many ports as you believe are required and in the locations that they will be needed. One has to balance the cost of installation against the flexibility of the system, as installing additional ports increases the cost of the network, but with the risk that the additional ports will never be needed. Equally, it is difficult to determine the best locations for the ports as this depends on how the space is used. This is likely to change with time and more frequently than a room is re-cabled. Most people have encountered rooms with long trailing cables where the original wiring is no longer suited to a new room layout, where the space is not optimally arranged, or where the room has had to be re-cabled to meet changing circumstances. None of these problems occur with a wireless LAN.

  There is another advantage with wireless LANs. If a classroom is wired then the desks must be fixed as the wiring has to go to each desk and moving the desks will wrench out the wires. With wireless, the class layout is completely unrestricted since desks can be moved, which means that

space can be used flexibly and efficiently. Because wireless LANs are comparatively cheap to install it becomes feasible to provide LANs in more parts of the campus so that computer use is not restricted to a small number of places.

- Extended coverage to new locations
  The user can be anywhere, including places that might never have been wired, such as corridors, cafés and even outdoor spaces. Many institutions that use wireless LANs have included coverage in cafés and (weather permitting) outdoors. Experience shows that this is very popular with students and that they do make effective use of these spaces for online learning.

- Use of student-owned computers
  Increasingly students bring their own computers to college and university (whether laptops, PDAs or smart phones) and expect to use them when they are on campus.

  Providing sufficient network points in places where they wish to use their computers in libraries, study areas, classrooms and cafés is expensive. From the student's point of view, sitting by the port to use his or her computer can be difficult. The problem is exacerbated when students want to work together and each needs to connect their computer to the network.

  Providing a wireless LAN means that when the computer is switched on, wherever the student is, the computer is connected to t he LAN.

  Incidentally, it is worth noting that when students have wireless LAN cards in their computers they can share data between the their computers even in the absence of a network by using 'peer-to-peer' networking – where computers talks directly with each other without going via servers and routers. This is a similar model to Napster.

1.4 Disadvantages of wireless LANs

- Less secure than wired LANs.
  Wireless introduces some additional security problems beyond those associated with a wired network (which a wireless LAN shares). Considerable effort has gone into providing security to meet these problems, and a more detailed discussion is provided below. Some of the key issues are highlighted here.

  The signal from a wireless LAN will pass through walls, which means hackers do not even need to be inside the premises to access the LAN. If they can make use of the wireless LAN they are on the college or university network.

  Once inside, hackers can monitor the traffic on the network and so acquire user names and passwords. These are normally encrypted, but there are some doubts about the effectiveness of encryption.

- Standards are still evolving
  The standards for wireless LANs are still rapidly evolving and not always compatible with one another. A number of different standards are used or defined by organisations which sometimes communicate only with themselves. Europe has been working on some standards for use in the EU, while the IEEE, based in the US, has been defining worldwide standards. Japan is also working in this area. The major standards are described overleaf:

- Management of the network is more complex
  There are a number of issues associated with managing wireless networks which add to the complexity of network management in a mixed wireless and wired LAN environment. These include the need to manage the wireless LAN as a single subnet if roaming is to work,

Standard	Standard body	Spectrum	Date	Continued development	Where used
802.11	IEEE	2.4 GHz	1999	Superseded by Wi-Fi	Worldwide
802.11b (Wi-Fi)	IEEE	2.4 GHz	1999	Will probably be superseded by 802.11g	Worldwide
802.11g	IEEE	2.4 GHz	Probably 2003	Yes	Subject to approval worldwide
802.11a	IEEE	5 GHz	1999	Yes adapting of features from HiperLAN/2	USA but moving to worldwide
HiperLAN/1	ETSI	5 GHz	1998	Superseded by HiperLAN/2	Europe
HiperLAN/2	ETSI	5 GHz	2000	Yes will be replaced by 802.11a	Europe
Bluetooth	Bluetooth	2.4 GHz	1998	Yes	Worldwide
IrDA	IrDA	350 THz	1994		Worldwide

Table 1. Some wireless LAN standards

These standards, how they are being developed and their respective advantages are discussed below.

- Cost of network cards

While cards for wired Ethernet start at around £10, wireless cards start at around £60. Although they will become cheaper, they will never be as cheap as wired LAN cards because they are inherently more complex.

how the wireless part of the LAN relates to the rest of the network and managing security. With modern wireless LANs management is for the most part undertaken centrally. However, some changes need to be made at the acess points themselves.

- Network performance degrades with additional users
  If many users are connected to the LAN via the same access point, the performance of the LAN can degrade quite rapidly by comparison with wired Ethernet systems. This is because the available bandwidth is shared between all the users, and because of the nature of the communications protocols needed to support wireless working. The overheads associated with setting up each message are much larger for wireless LAN than for a wired LAN, and the protocols enforce waiting times (of microseconds) at certain points. The decline in network performance is particularly great when two PCs are hidden from each other (for instance at opposite sides of the cell) but both are trying to communicate with the access point at the same time, so corrupting each other's messages.

- Interference from other devices
  The frequencies that wireless LANs use are part of the unlicensed spectrum, which means that many different types of devices also share the spectrum. These include cordless telephones, garage door openers, microwave cookers and Bluetooth. So far this does not seem to be a great problem, but as the number of wireless devices grows there is the potential for increased problems.

2 Types of Wireless LAN

There are a variety of wireless LAN technologies. Most are based on radio frequencies, although some are based on the infrared spectrum.

The radio frequency (RF) wireless LANs of interest all use the unlicensed radio frequencies. There are two radio bands here: 'Industrial, Scientific and Medical' (which uses the 2.4 GHz frequency band) and a more recent addition at 5 GHz (sometimes referred to by its US name as the Unlicensed National Information Infrastructure – UNII). These bands are used because the wireless LAN user does not need a licence to operate the equipment so long as it meets the regulations on its use. Other frequencies can be used but require licences or that the service is provided by the license holder. Some mobile telephony service providers have just spent billions on licences and are looking at providing private data networks as additional way of increasing revenue.

There are no license requirements on the use of infrared, but there are health and safety issues. Infrared light can damage eyes and there are therefore safety limits on the strength of the signal, which in turn limits the effective working range for an infrared LAN to around 10m.

2.1 Standards

Wireless LANs suffer from a surfeit of competing standards, a situation unlikely to improve much in the next few years. Currently there are at least seven standards in use, some only in Europe, others only in the US, while Japan has its own, closely related to the European standards (see Table 1, Some wireless LAN standards, for some of the standards and where they currently apply). Many observers expect a convergence of standards. Some will become legacy standards which new equipment will support, enabling it to work with older equipment. There will be at least four standards in use over the next five years, and if LANs based on 3G telephone systems arrive, this number will only rise.

Different wireless frequencies have different behaviours, so a standard which works well at

one frequency will not work in another. Logically, this would lead to the development of at least three standards at the moment for the ISM (2.4 GHz), the UNII (5 GHz) and the infrared bands. However, standards are optimised for different functions, and mobile telephony, wireless LANs and PANs all have different requirements. For instance, there is a balance to be struck between the cost and the power requirements of equipment and the area that they can cover. The cost of building wireless chips rises much faster than the range they can cover, so that these have to be carefully balanced.

To add to the complexity, the standards are produced by several different standards bodies, some of which are international bodies with a remit to develop standards (IEEE, ETSI) and others which are associations of suppliers whose equipment must work together (Bluetooth, IrDA, WECA). The latter tend to work much faster as they do not have to go through the complex procedures used by organisations such as the IEEE to build consensus. Conversely, their standards have no particular standing and there have been many such standards which have disappeared. Equally, the production of a standard by one of the standards bodies is no guarantee that the standard will be adopted, as it is often the large vendors who determine which standards are actually adopted. However, in the case of wireless LANs, governments have a considerable say in the standards used as they can allow or diallow particular technologies to be used.

There is every reason to suppose that all the standards discussed here will continue to be important for at least the next five years, with the possible exception of Bluetooth, but may not achieve what their adherents claim.

The remainder of this section looks briefly at each of the major standards, their scope and their geographical coverage, and who is responsible for defining them.

This information is summarised in Table 1, Some wireless LAN standards, and Table 2, Comparison of different wireless LAN technologies.

If you are not interested in the individual standards you should skip to section 3, Regulatory issues.

2.2 IEEE 802.11

The Institute of Electrical and Electronics Engineers (IEEE) is an international professional organisation for Electrical and Electronics Engineers, with formal links to the International Standards Organisation (ISO). They have been defining standards for LANs and MANs for many years, including some for wireless LANs. The IEEE group tasked with developing standards for LANs and MANs is called 802.

Within 802 are a number of working groups looking at different aspects of LANs and MANs, and working group 11 is looking at standards for wireless LANs, hence 802.11. The 802.11 group has felt it necessary to set up a range of task groups (a–h plus x) and the standards that they define are suffixed by the task group letter. Hence 802.11a, 802.11b, etc.

802.11 defines the way in which wireless LANs, both radio frequency (RF) and infrared (IR), work. The standards are constrained to the unregulated radio frequencies (2.4 GHz and 5 GHz). While there are no frequency constraints on the use of infrared there are health and safety limits on the power that any signal can provide.

There are four standards within the 802.11 family that are relevant here, three of which work in the 2.4 GHz ISM band and one which works in the 5 GHz UNII band.

Three of the standards work in the ISM band, and are licensed for use in Europe, the US and Japan. They follow on logically from one another and provide greater bandwidth. The three are 802.11 (2 Mb/s), 802.11b (11 Mb/s) and 802.11g (34

Mb/s). 802.11 is not very relevant now that 802.11b (also often referred to as Wi-Fi) is established, which is primarily the standard now sold. 802.11g has not been ratified yet, but is expected to be approved in 2003 now that most of the contentious issues have been resolved. However, even when 802.11g is approved as a standard it will need regulatory approval before it can be used in this country. It is worth noting that considerable effort has been made to ensure that these three will work together, so that investment in 802.11b will not be wasted when 802.11g is sold. 802.11g access points will work with Wi-Fi wireless cards and Wi-Fi access points will work with 802.11g wireless cards.

Finally there is 802.11a, which works in the UNII 5 GHz frequency band. This offers 54 Mb/s and competes with HiperLAN/2 from ETSI (see Section 2.6 HyperLAN/2). 802.11a equipment is now being shipped in the US, but the market is still very immature and it has only just been licensed in the UK. However, the licence regulations will almost certainly change when 802.11h (which defines power levels and frequency) is approved. If you buy 802.11a at the moment you should seek guarantees from vendors that they will upgrade any equipmnent to meet the new standards.

2.3 Bluetooth

Bluetooth is a trade association that uses a system originally designed by Ericsson for cable replacement. If you look at your desk it is almost certainly cluttered with cables to the keyboard, mouse, speakers, possibly a printer, a PDA synchronisation cradle, etc. Bluetooth was designed to replace these with what is often referred to as a personal area network (PAN), which means that it was originally designed with a very short range (maximum 10m) for ad hoc low bandwidth networks. One of the major goals in the short range was to keep the cost down. It has always been one of the goals of Bluetooth to develop systems which cost under $5, and so can be incorporated intp other systems (mobile phones, PDAs, keyboard, mice etc.) without pricing them out of the market.

Bluetooth, having been adopted by a large number of manufacturers, is now promoted for purposes other than those for which it was created. It is not clear whether it is suitable for building LANs because of the short design range, the low data rates of 4 Mb/s (although these will no doubt increase in newer versions) and because its design may not be suitable for building high performance networks. There are also major problems with interoperability as not all vendors have implemented it in the same way.

Bluetooth, like Wi-Fi and 802.11g, works in the 2.4 GHz range, and this means that the networks may interfere with each other. Whether this will cause problems is yet to be determined and a subject of active research. However we will not know until Bluetooth is in widespread use and we begin to see what effect it has on LANs.

Current predictions suggest that Bluetooth will be important and this may have an influence on the design of LANs which work in the ISM 2.4 GHz band.

2.4 WECA

The Wireless Ethernet Compatibility Alliance (WECA) is another trade association. Unlike the other bodies listed here, WECA does not define standards. It certifies that equipment from different suppliers will interoperate successfully. To do this it has created a trademark – Wi-Fi – for equipment that it has tested as meeting a common interpretation of the 802.11b standard.

It is important to note that while products which have been certified as Wi-Fi by WECA are interoperable with each other, product specific features may not interoperate (and this may include some security features when interoperating with different manufacturers equipment).

Without interoperability between manufacturers (or even different products from the same manufacturer) users would have to buy all their supplies from a single supplier. This might sound good from the supplier's perspective, but in fact it would cause them many problems too. For instance if you use your laptop in several areas you might have to have several wireless cards to work which is impractical for users and would remove many of the advantages that wireless LANs offer. Wi-Fi ensures that you will at least get the minimum service if you are using an approved card if the card is using the 802.11b standard.

Anyone creating a wireless LAN based on the 802.11b standard should buy only Wi-Fi equipment as this will allow them to intermix equipment from other suppliers. This is important for the college or university when it extends its equipment, but it is also important for students who arrive with their own equipment and will not want to keep changing their wireless LAN card depending on location.

2.5 IrDA

The Infrared Data Association (IrDA) is yet another trade association which has been defining standards for infrared communication for many years. Infrared is a technology which has moved in and out of favour over time. It has some advantages; notably that it is cheap and there are many devices which already include infrared, such as most laptops, PDAs, and some printers. Before the advent of radio frequency, LANs and infrared LANs were built with some success.

The main problems with infrared centre around the way the signals propagate in a building. There are two apparently contradictory problems. To get a good signal for sending data, 'line of sight' should be established between the communicating devices. This means that computers need to be orientated towards the access point and that there should be no objects between the computer and the access points, such as other computers or partitions. The other problem results from echoes as the signal bounces off walls etc., which can cause problems with reception. These, together with the shorter distance and the inability of signals to go through walls, means that radio frequency tends to be the technology of choice for LANs.

In many ways IrDA is a competitor to Bluetooth. They are both cheap, short-range technologies likely to be incorporated in handheld devices.

In the end it is likely that Bluetooth (or its successors) will win out over IrDA for building personal area networks (PAN). These allow an individual's devices, such as PDA and mobile phone, to communicate with each other because there is no need for line of sight, so that one device could be in your pocket while you use the other. For example, your PDA could send emails via your mobile phone.

2.6 ETSI

The European Telecommunications Standards Institute (ETSI) says: 'HiperLAN/ 2 is a flexible Radio LAN standard designed to provide high speed access up to 54 Mb/s to a variety of networks including 3G mobile core networks, ATM networks and IP-based networks, and also for private use as a wireless LAN system. Basic applications include data, voice and video, with specific Quality of Service (QoS) parameters taken into account. HiperLAN/2 systems can be deployed in offices, classrooms, homes, factories, hot spot areas like exhibition halls and more generally where radio transmission is an efficient alternative or a complement to wired technology.'[2] It is worth noting that HiperLAN/ 2 was developed in conjunction with the Japanese standards body, the Association of Radio Industries and Broadcasting.

HiperLAN/2 offers a number of advantages over 802.11a (the alternative from IEEE 802.11, see above) in that it incorporates quality of service (QoS) features. However, there is a long tradition of Europe developing standards which are not adopted because the US does something different.

HiperLAN/2 will loose out to 802.11a, but some of the features developed by ETSI will be incorporated in revised versions of the 802.11 standards in 802.11h.

2.7 Wireless telephony

Wireless telephony is only included here for completeness as it cannot be used to build LANs at the moment, nor is it likely to be able to in the next three years, as current technologies (GSM and GPRS) do not offer sufficient bandwidth.

Wireless telephony networks are likely to form a major part of networking once 3G networks are widespread, but that will not be for a few years. There are a number of serious technical issues which will have to be resolved before wireless telephony networks can be used effectively for data networks.

The service providers have spent enormous sums buying licences and even more on installing the necessary infrastructure and persuading people to move from their current mobile telephone systems. It is likely that they will therefore be interested in building private networks within buildings or campuses based on piconets (tiny areas covered by each base station to provide sufficient bandwidth in a densely used area). The advantage here is that a single technology would then work for both the LAN within the campus and for wide area calls from anywhere. This will happen, provided the cost and technology issues can be solved before it is overtaken by some other technology.

3 Regulatory issues

Once again there are differences between infrared and wireless.

Broadcasting has long been regulated by governments worldwide. Originally regulation was a way of controlling the use of wireless. Today, regulation is also used as a means of raising very large sums of money by selling off frequencies. There have also been moves to make some bandwidth freely available. For radio frequencies there are two bands which have been made available for unlicensed use. However, this does not mean that there are no regulations. Equipment has to meet stringent regulations about what frequencies it uses and even how it uses them.

3.1 Radio Frequencies

Radio frequency transmissions are very strongly regulated by governments worldwide through both national laws and international agreements. Wireless bandwidth is a very valuable commodity and the channels available to wireless impose limits on the technology.

Many channels are reserved for particular purposes, such as TV and radio broadcasts, CB radio, police and military use.

There are currently two bands which have been freed of most regulations and which can therefore be used by anyone (subject to the rules discussed below) for any purpose. This means that many different types of users will be competing for the same bandwidth whether they are using cordless telephone, garage door opener or a wireless LAN. With most frequencies the end user has to get a license to use that frequency, and will have to use appropriate equipment. With the unlicensed bands, the equipment will need to be approved (much like the green triangles on telephone equipment which may plugged into the BT network), but no additional licensing is required to use it.

Health and Safety

The safety issues relating to electro-magnetic radiation from mobile phones have been widely discussed, so it is worth commenting on these concerns in relation to wireless LANs which do emit electro-magnetic radiation. There are three points which attest to the saftey of wireless LANs.

- Firstly, wireless LANs operate at a power of 35 mWatts, compared to 600 mWatts for mobile phones, or about one twentieth of the energy emitted by mobile phones.
- Secondly, they are not held against the head as mobile phones are and the amount of energy is inversely proportional to the square of the distance, so that the amount of energy reaching the head will be less again.
- Thirdly, wireless LANs transmit in bursts and only when they have data to transmit, so if a user wishes to transmit 100 MB of data per day then the transmission time will be about ten minutes.

Together these factors indicate that any dangers which exist are trivial by comparison with mobile phones, and even here it is strongly disputed that the danger really exists.

2.4 GHz – Industrial, Scientific and Medical (ISM)

The 2.4 GHz frequency band has been available for some time and there are many products made for it besides the wireless LAN. These include cordless telephones, garage door openers and Bluetooth. The current generation of wireless LAN equipment uses a method called direct sequence spread spectrum, but this is unsuitable for the higher data transmission rates that are now being developed within the 802.11g standard. These will use orthogonal frequency division multiplexing (OFDM). At the moment there is some doubt over whether the current licence arrangements do cover 802.11g, but most commentators do not think that there will be a problem.

5 GHz – Unlicensed National Information Infrastructure (UNII)

Both 802.11a and HiperLAN/2 work in the 5 GHz band, as shown in Figure 4. The frequencies available and the terms under which they can be used vary from country to country. Different countries have released different parts of the spectrum for unlicensed use. This makes the design of equipment more complex and thus more expensive as mobile equipment needs to work out what environment it is operating in and so which rules it needs to follow. There are moves afoot to bring the available frequencies in line one another, although dates for this (if it succeeds) have not been decided.

3.2 Infrared

There are no regulations controlling the use of infrared for data transmission because infrared is obstructed by walls, and signals will only travel for a relatively short distance outdoors (around 10m with permitted power levels). There are health and safety issues which limit the amount of energy (power of the signal) as intense infrared light can damage eyes. This then limits the power of signals and therefore the distance at which the user can be from the access point, hence the problems associated with using infrared to build wireless LANs.

4 Security

Security is a serious issue with any kind of network these days. Networked computers are now critical to the efficient running of any college

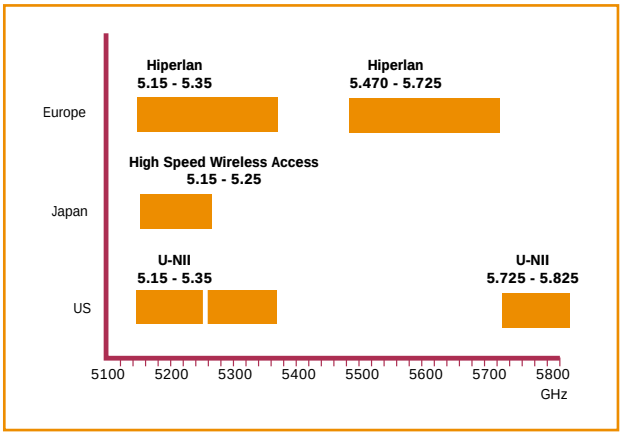

Figure 4. Licensed bandwidth in the 5 GHz band

or university and it is imperative that unwanted intruders (hackers) neither access or damage data on the systems nor prevent systems being used through denial of service attacks. This is not the place to discuss the general issues about network security, although there are additional issues which arise with wireless LANs. Some of these issues are less important for colleges and universities because they are such open institutions. Whereas in most corporations it is not easy to wander in and start using a computer, colleges and universities have rooms devoted to this activity – PC labs. This means that the problems associated with being able to hack into the network from off the campus are little different to the problems of strangers wandering in to the site and using the network, probably on college or university equipment.

The other great problem is that it is easier to monitor traffic on wireless LANs than on other network technologies, and so learn user names and passwords. This information is transmitted in encrypted form but is not very secure. However, if you want to learn a user name and password, by far the easiest thing to do is sit down at a computer in one of the computer labs, look lost and then turn to your neighbour and say 'I have forgotten my password – could I use your username and password as I just need to check the course timetable'. The chances of being given the required data are remarkably high.

Having said that, many companies which take security seriously are using wireless LANs. However, it should be borne in mind that it does take more care and thought to reach the same level of security.

Anyone who wants to breach security on a wired LAN either has to be on the premises using a computer attached to the network or, if they are outside the institution, must come through the 'firewall'. A firewall is a piece of software or hardware which checks all traffic coming into the network from outside or leaving it and verifies that it meets specific criteria to ensure the secure and effective running of the network. With a wireless LAN the user can listen to anything on the network so long as they are in range, even if they are off the premises.

Many suppliers also provide their own additional proprietary security features that will work with their equipment. However, if students are permited to use their own equipment, they will want to use it everywhere. With part-time students or staff this could include other wireless locations such as their place of employment that may require the use of a wireless card with a different standard. This means that you cannot reasonably specify that they will use a particular card which may have additional security features. To do so would would mean that they would have to keep changing the card and reconfiguring their computer depending on the location.

To address the security issues, a standard called wired equivalent privacy (WEP) has been developed. Unfortunately, there are a number of serious security lapses within WEP which mean that it has been relatively easy for a hacker to crack the security and gain access to the LAN. The IEEE has developed 802.1x (NB NOT 802.11x) to provide the necessary level of

security for wireless LANs. Some vendors are now offering 802.1x based security solutions.

There are a number of solutions to this problem, several of which are vendor specific. See the security section of the bibliography for a selection of papers on the issue.

In September 2001, WECA produced a set of recommendations on the use of Wi-Fi.[3] They noted that the greatest threat to security is the failure to use any form of security. They recommended six procedures for improving security in smaller offices range from turning WEP on and managing the WEP keys properly through to using a virtual private network (VPN). Where greater levels of security are required, additional security methods are needed such as RADIUS or Kerberos.

5 Mobility

Mobility comes in two forms; itinerancy, the ability to use computers wherever you happen to stop; and roaming, the ability to use computers on the move (or more to the point perhaps, not having to log in each time you have moved but to continuing from where you left off). Both can be provided by wireless LAN, though roaming is more complex.

5.1 Itinerancy

Students will use their own PCs in ever increasing numbers in the future on and off campus. In a few years time it is likely that they will preferentially choose colleges and universities where this is possible.

Many staff work part-time and may posses their own laptops which they may then wish to use when they are at their college or university.

Wireless LANs make this easier to support. Students are not required find ports but can instead use their computers wherever they are on campus. This increases flexibility of use for the student and eases planning problems for the college or university. Students can find a free space and still use their computer rather than having to jockey to use the limited spaces where wired ports are available.

Wireless LANs can be installed in the home for around £200. This is not yet common in the UK but will become increasingly so as homes have more than one computer, with a single fast Internet connection which can easily be shared among them. Although it is more expensive than wiring a LAN, users can install it themselves without having to rip up floors and drill walls to lay cables.

Companies are now starting to install wireless LANs and supply their staff with wireless-enabled laptops. These users will want to use their laptops while at college or university to support their studying. They will then put pressure on their college or university to supply wireless LAN facilities. Institutions which do offer this facility are likely to have a competitive edge.

5.2 Roaming

Wireless LANs allow anyone at college or university to move around with their computer while remaining connected to the network, and therefore without having to keep logging on. This means that a student who has started some work in class can continue working on it afterwards in the library, study area, café or anywhere else that happens to be free, without having to leave their work, log off and start again when they reach their next destination.

This is not a particularly important function of wireless LAN, but rather a benefit of installing the system.

Roaming requires considerable thought in regards to how it is set up. Typically it is achieved by making the wireless LAN a single

separate sub-net. But as it is likely to work across many parts of the LAN this requires care in setting up if it is to work and not create other problems – including security problems.

6 The US position

Wireless LANs will become more common. We are already seeing some American universities using the presence of Wireless LANs as a marketing tool, in the way that well-cabled universities were a few years ago. It is not long until we see some American community colleges following suit.

The dynamics in the UK are of course different. Laptop universities (where all students are issued with or are required to have a laptop) are not uncommon in the US – especially as the cost can be included in the part of the fees which are eligible financial support. The requirement for a PC already exists on some Open University courses and this is likely to increase. It cannot be long now until some UK universities make possession of a PC, or even a laptop, a requirement for at least some courses.

Once all students have laptops (either across the university or college or just on some courses) the use of wireless LANs makes a great deal of sense. There is no need to calculate exactly how many ports are needed in any area. With wired ports one needs to calculate for the expected maximum and either provide for that or accept that some needs will go unmet. With wireless, as more people use a space, the service is shared more thinly so that quality declines but the service continues to function.

Students do not need to plug their laptops in to be connected to each other, the teacher or the Internet, and despite the cost of wireless LAN cards it is much cheaper to deploy wireless LANs than flood wiring an institution.

6.1 Costs of wireless versus wired LANs

It is not possible to give anything other than indicative costs for the various types of LANs. The costs will depend on the infrastructure already in place, the configuration of the campus including the number of buildings, the building materials used and of course the coverage that the LAN is expected to provide.

However, the costs reported by some of the institutions which have deployed wireless LANs are discussed here. It is worth noting that these are particularly successful and that the scale of savings may not be as great as in these examples.

The University of Akron, Ohio

The University of Akron needed to upgrade their entire LAN and had been looking to do so over several years because of the cost. They had costed wiring the library alone at $800,000, because of the disruption and the high cost of drilling the reinforced library walls and floors. Installing wireless in the library only cost one tenth of this at $80,000 and they used a further $200,000 to buy 100 laptops for use in the building. The laptops are lent out fully charged, with either a single or dual battery so that they have a life of two to five hours. In this particular case students are not allowed to remove the computers from the library.

Buena Vista University, Iowa

Buena Vista University wanted to rewire 41 classrooms which it estimated would cost at least $5,000 per classroom (ie. $205,000), and would have to be done over three years because of the disruption that it would cause. Instead they installed a wireless LAN over the entire campus, with most of the installation work being done in a two-week period during the summer.

Putting one or two access points in each classroom worked out considerably cheaper than drilling out the walls and floors and adding sufficient wall jack ports.

They spent $152,000 on 130 access points to cover the entire campus (fewer than half of these were used in the classrooms) and $225,000 to buy 1,500 wireless cards for laptops.

It is interesting to note that in both these cases (and others), although the cost of installing the LAN falls significantly, the installation brings other costs with it, such as wireless LAN cards which must be acquired for PCs. It is the success of the projects which tends to raise expectations and requires additional resources to meet these as a result. This includes extending the wireless LAN to areas which had not initially been planned for (or possibly not even considered in the original plans) and in several cases, such as Akron, buying additional wireless-enabled laptops for loan to students.

Conclusion

Wireless LANs are considerably cheaper to deploy than flood wiring. Cost savings of up to 90% are not uncommon if considering only the networking costs. However, the increased flexibility that wireless LANs provide also creates greater demand so that some of the savings may be needed to meet this. The end result will still be a cheaper, more pervasive and more useful network.

7 College and University drivers

The use of wireless LANs in the UK needs to be considered in relation to the main drivers for change in colleges and universities. There are many drivers and here we only consider some of the main ones coming from the government and the funding councils.

- Widening participation

  Fifty percent of school leavers are expected to experience some form of higher education by 2010. Young people are encouraged to remain in learning and increase their attainment.

  An increasing number of students will have their own laptops and this will include school leavers. Some will have been given them, but an increasing number will be getting their hands on their own laptops through school-based schemes. Many of these children will keep these laptops when they leave school and will want to use them at their college or university. Wireless LAN provides a simple way of achieving this.

  We will also see an increasing number of colleges and universities offering laptop loan schemes – both short term for a few hours (until the battery goes flat) and for whole modules or courses – as a way of encouraging students to become more technically literate. It is important that these computers can access the network, and the easiest way to achieve this on campus will be through the use of wireless LANs.

- Involvement with industry and the community,

  including maximising the contribution of education and training to economic performance.

  Wireless LANs can help with this in two ways. First, by helping workers in industry and the community who are already working with wireless-enabled laptops and PDAs to make use of their equipment in their learning as well. This will help to strengthen ties between colleges and universities and the communities that they serve through use of the same equipment in both environments. This has the added advantage of helping to locate learning in a work context.

Second, it will act as an example to local industry of what wireless LAN technology has to offer and so help to move industry forward in this important area.

- Quality and Standards
  Raising standards in teaching and learning.

  There is a growing body of evidence that suggests that the implementation of wireless LANs leads to changes in student activity which improves learning. In particular, it leads to more collaborative learning and to learning in a wider variety of contexts in colleges and universities.

- Reducing costs
  Wireless LANs can be considerably cheaper than extending wired LANs to new areas, and should be considered in any expansion or renewal of the existing LAN. This issue is covered in more detail in Costs of Wreless versus Wired LANs on page 3.

8 Wireless LANs: The future

What is the future of wireless LANs and how will they affect colleges and universities? It is important to remember that any discussion of the future of wireless LANs is speculative.

Wireless LAN use will continue to grow and become more important over the next five years, by which time it will be as unthinkable for a university or college not to have a wireless LAN as it is for a college not to have a LAN now. They will continue to supplement wired LANs which will always have an important role to play, both providing the backbone within campuses and serving key areas such as computer labs where large numbers of computers needing high bandwidth are found.

Within five years we will see colleges and universities which have wireless LANs deriving a market advantage from them, with work-based students and students with their own laptops expressing a preference for places which offer good wireless coverage. Clearly this will not be a key determinant in students' choices, but there is evidence from the US that some colleges and universities are heavily promoting their wireless LANs because they believe that this attracts students.

The future needs to be looked at in terms of wireless LANs and convergence with other forms of mobile communication, most notably third generation (3G) mobile telephony.

For the next two or three years, at least, Wi-Fi (802.11b) and its faster successor 802.11g will be the most important wireless LAN technologies. There are a number of reasons for this assertion.

Firstly, there is already a large user base installed which will want to continue to use their equipment. Wi-Fi wireless cards will work with 802.11g access points and 802.11g wireless cards will work with Wi-Fi access points. This provides a migration strategy whereby Wi-Fi can be upgraded in key areas to 802.11g without having to re-equip the entire campus. While Wi-Fi offers 11 Mb/s, 802.11g offers up to 34 Mb/s at the moment, and developments are already underway which will increase this to 54 Mb/s or even to 108 Mb/s.

Secondly, Wi-Fi will continue to be cheaper than 802.11a for quite a while not only because much of the research and development cost of Wi-Fi has already been recovered, but more importantly, because the ISM band has a greater reach than the UNII band so that fewer access points will be required. 802.11a will require anything from two to seven times as many access points as Wi-Fi, with a commensurate increase in costs.

Thirdly, Wi-Fi is now a reasonably well understood technology by many network managers, and while there are undoubtedly problems with it (including

security and performance in a noisy environment), solutions to many of the problems are known and understood.

Nevertheless, over the next few years it is possible that interference from other devices using the same bandwidth – notably Bluetooth – will begin to interfere with the wireless LAN use of the ISM spectrum. If Bluetooth does take off (and it is not clear yet that what was designed as a cable replacement technology clear the desktop clutter of mouse and keyboard cables, etc., will have a wider role to play) then, in three or four years' time, we may see a concerted move from the ISM band for wireless LANs to some other frequency space, and this will almost certainly be the UNII band at 5 GHz which is used by HiperLAN/2 and 802.11a.

We will also see some mixed environments in a couple years where most individuals will be using Wi-Fi, but a few with particularly high data requirements in the same area will be using 802.11a. Some suppliers are already providing access points with two slots to meet exactly this requirement.

Bluetooth may establish a place in the so-called small office / home office (SOHO) market for LANs, but because of its small reach (about 10m) and limit of seven devices attached to any device, it is unlikely to be used for LANs in offices or colleges or universities. This does not mean that it will not play a part in campus networking for personal area networks (PANs) and ad hoc use, though it will not be used to create LANs. It was never designed for this, but as a cable replacement technology to tidy up the desktop.

It is unlikely that 3G-based LANs will be available in the next few years. 3G will be used for data communication, but only for remote use for sometime to come. We will begin to see 3G service providers moving into this area as quickly as possible to maximise their return on investment. For some, especially smaller colleges or universities, this may be a sensible route, as 3G service providers are likely to offer a managed service. However, it is not possible to predict costs or data rates.

While IrDA may be used to build LANs in a few places it is unlikely to be used widely because the computer and the access point need to be pointing at one another. IrDA, like Bluetooth, will have a place to play in ad hoc computing, for instance for walk up printing, where the user takes their laptop or PDA to the printer, points their machine at the printer and start printing.

9 Pedagogy

One of the areas in which wireless can have the greatest impact is in conjunction with universal provision of PDAs or laptop computers to all staff and students (ubiquitous computing), and this is discussed at the end of the section. First, let's look at what wireless LANs have to offer without this.

9.1 Wireless enabled teaching

Wireless LANs provide great flexibility, especially in conjunction with laptops because this combination allows computers to be used anywhere. The computers go to the teaching rather than the teaching to the computers, so that any place – including laboratories, classrooms and even outdoors – can be used to teach with computers.

This has several advantages. Firstly, as already suggested the computer can be used where the teacher wants. Secondly, laptops used where they are needed, not where they happen to be installed or can be plugged in, are much less intrusive to the rest of the teaching. Thirdly, it allows more efficient use of resources because computers can be used in the numbers needed – not the numbers that have been installed in a

room, and special rooms do not need to be set aside when computers are required in teaching.

Computer carts

A computer cart is secure cart or trolley that can hold enough computers for a class as well as an access point. When not in use, the cart is plugged in and the computers are charged. To use the computers the cart is unplugged, wheeled into the classroom and the computers handed out. If the classroom is not within a wireless cell then the access point will need to be plugged in (but note that for this only one wired port is needed, and it can be located where it is most convenient.)

Computer carts of this type have been being used in schools, colleges and universities in the US for a couple of years, and teachers find that it greatly increases productivity.

'Probably the most intriguing use of wireless is not in whole building implementations but in "wireless à la cart". In such uses, a rolling cabinet with twenty or so portable computers and a wireless bridge [access point] is rolled into a seminar or classroom, and the bridge is plugged in to the lone Internet connection in the room. The portables are detached from the built-in chargers and are used throughout the room by students in teams of two or three.'[4] The report goes on to say that since this system was installed, 'productivity went sky-high!'.

The use of carts allow computers to go to the students, rather than students to the computer. This permits more efficient use of both computers and space. It also gives the teacher complete flexibility with regards to how the computer is used. Carts can be used in any room which can then be laid out according to the teacher's requirements with the minimum of fuss.

Students' computers

More students now bring their own laptops with them to college and university. This began in business courses but has spread quickly to other areas. Students want to be able to make full use of their computers at their college or university. Clearly, students can always use the computers as stand-alone systems, but that denies them much of the power and utility that computers afford. Some colleges and universities allow students to plug their computers into the wired network but this causes many problems. Students must be in a location where there are points to plug in their computers and these are often not where the students want to be. There may not be enough points available. Moreover, these points are expensive to install and are easily damaged. Wireless LANs allow students easy access to the campus network from a position of convenience.

Colleges and universities which have installed wireless LANs for student use say that they see students working together much more than before and that the system fosters collaborative working. However, it is, as yet, hard to find anything beyond anecdotal evidence.

9.2 In conjunction with universal PDA / laptops

Once all students have their own computer or PDA, a range of exciting possibilities exists for their use in teaching, and many of these are only possible with wireless LAN or can be greatly enhanced by its use. A good analogy is reading. If all the students can read, then written material (books, hand-outs, etc.) can be used in teaching and learning. If even 10% cannot read then it becomes necessary to read to the students. The same applies with laptop provision. If all the students have laptops, they can be fully integrated into the course. If only one student does not, none of the students can use the system.

In the US there are already many 'laptop universities' and 'laptop colleges' where all students are required to have a laptop, usually provided by the institution but charged to the student (and eligible for financial aid). There are several models for achieving this and different suppliers offer different models. Approaches range from the supplier doing everything (which tends to suit small colleges or universities) to training college staff in everything including warranty repairs. Suppliers also promote a range of financial models from lease to lease-purchase to purchase. IBM claims that over 130 universities have signed up to its Thinkpad University scheme, with around 30 of these having gone wireless, while Dell claims over 100 institutions are using its equivalent scheme. Several other suppliers are also active in this field. Many of the colleges and universities that have laptop programmes have already installed wireless LANs covering part or all of their campuses, with others moving rapidly towards wireless LANs as the best method of supplying network access to all their students.

In Britain we are already beginning to see courses which require students to have access to a PC or a laptop as a condition for doing the course. Examples include some business schools (eg. London Business School) which require their MBA students to have a laptop. The Open University now has a requirement for access to a PC for several of its courses and the number of such courses is growing. Whether the computer is the student's own or one which they lease or borrow from their college or university is a separate issue and not part of this paper. It cannot be long now until we see some universities and colleges requiring students to bring laptops with them on at least some courses (likely courses include computing, business and medicine). Colleges and universities will need to have the infrastructure and policies in place to support their use before they can reasonably make such a requirement. By using wireless LAN technology, the college or university creates flexibility in use, since computers can be used anywhere on the site. Wireless LANs are also significantly cheaper than the wired alternative.

Wireless LANs are a relatively new development and much of the work on how they can enhance teaching and learning is anecdotal or experimental with very little hard data to show what the impact has been. This does not mean that wireless LAN technology does not enhance learning, only that it is currently new and that evidence is still hard to find.

We now look at some of the ways in which the combination of ubiquitous computing and wireless LANs are being used, as well as some of the evidence that it leads to improvements in the educational experience of students.

Mobile access to information

At Wake Forest University Medical School medical students need access to vast amounts of information to make diagnoses, determine drug doses and see patient notes. The medical students are given PDAs, which allow them to access this information where they need it – on the wards, giving students control over information they need, when they need it. Not only does this mean that students do not need to memorise so much information, they are also developing skills which they can use in their work after graduation.

Clearly, there is scope for similar use in any field where large amounts of information are accessed or where information is continually being updated. Before the advent of wireless LANs, this information was memorised or available only where computers could be plugged in. This can be extremely limiting. This method of providing unpredictable information where and when it is needed can greatly enhance the learning experience and be a valuable skill for the workplace.

Feedback in class

One application which seems to be gaining ground is the use of wireless-enabled laptops as a method of improving interaction with students during class, especially with large classes. When teaching large classes it can be a major problem to gauge how well the students understand the material under discussion. Teachers have used a variety of different methods to try to discover how well the students understand, but many of these involve very limited sampling. Some lecturers are using the availability of wireless laptops to get feedback.

The use of the computers for this can be initiated by both the teacher and the student. During class sessions, students can use their computer to indicate whether they understand the lesson or to ask questions without the embarrassment of revealing to their colleagues that they do not understand (when apparently everyone else does).

Equally, teachers can ask a few short questions to poll quickly students understanding – these can be either to test their understanding or to ask students, 'Do you want me to go over that again?' The advantages of using laptops to communicate with the class is that it eliminates the embarrassment for a student of saying that he or she does not understand, with the result that students are more likely to be honest about their degree of comprehension. It is also easier to get more complex responses (either a range or a list of options).

Experience with these techniques so far is mixed, with some lecturers finding it helpful and others not liking it at all, finding it an intrusion into the way they teach.

In-class tests

Several colleges and universities are using the presence of wireless computers to conduct tests or 'quizzes' in class. These can be of the feedback-in-class type discussed above or they can be much fuller tests. Either way, one of the key advantages is that the results can be collated immediately and fed back to the teacher.

At Wake Forest University they have taken this one stage further and a number of the lecturers are experimenting with the use of their wireless PDAs as web servers for in class tests. At the appropriate time the quiz is enabled on the web server and the entire class can take the test without disrupting the teaching. The teacher can then collect all the results immediately and thus gets instant feedback on the students' understanding.

Data capture

Much scientific equipment these days produces electronic input and output which can be fed straight into computers. The use of wireless LANs can facilitate this in both the laboratory and the field. It also means that where an experiment is being demonstrated, students can capture the live data for analysis. One of the great advantages this offers is the ability to network mobile equipment – including devices such as pH meters, digital cameras and digital thermometers. Transferring data directly to the computer means that it can be viewed immediately and using wireless LANs means that there are no trailing cables to get in the way.

Course updates

Course updates of any kind can be broadcast to students and they will receive them as soon as they come within range of an access point. This could be a new piece of work, feedback on existing work, changes to the course schedule, etc.

Many of the colleges and universities which have installed wireless LANs in conjunction with ubiquitous computing comment on the usefulness of this facility, and student comment seems to be universally favourable. It is really

an indication of usability. When students have to go to a computer that is networked and log on they often do not bother to do it for several days until they have some pressing need to do so. With a computer in their hand connected to a wireless LAN, they are much more likely to check in more often and therefore get updates more quickly.

Collaborative working

Encouraging students to collaborate on work is often difficult. It may be difficult to find places where they can do the work together, especially when this involves using computers. With wireless LANs the students can work online together wherever and whenever suits them.

Several universities have reported significantly increased collaboration in terms of both the quantity and the quality of collaboration achieved, with comments like 'you see students working together much more often, now that there is a wireless network'.

Conclusion

Wake Forest University, which has done more work in this area than most, claims the following for their use of ubiquitous computing with wireless LANs:

- enhanced collaboration among learners
- more frequent student–staff dialogue
- prompter feedback
- better application of theory
- more student initiative
- more personal and individual teaching

Leading to

- better SAT (standard attainment test) scores and class ranks
- enhanced retention and graduation rates
- more satisfaction and learning

This is an impressive list of advantages.

10 Some College Experiences

At the end of 2001 two members of TechLearn went to the United States and examined in detail some of the experiences there. Three of these are discussed below.

10.1 State University of New York, Morrisville

The college

State University of New York (SUNY) Morrisville, which started as a College of Agriculture and Technology, is a two-year college. These are two-year, post-secondary educational institutions which offer: certificate programmes (less than two years of work), professional technical programmes (associate degrees) and transfer programmes (Associate of Arts and Associate of Sciences degrees). It has 3,000 students and two campuses: Morrisville has 2,500 students of which approximately 1,750 reside on campus, and a second campus at Norwich with 500 students about 30 miles away. It is a Public Sector college subject to cost reductions, and therefore needs to be creative in finding resources and in establishing mutually beneficial partnerships with industry.

The college formerly used the Top Class VLE but has recently converted to Web CT to integrate the on-line learning environment with their (Banner) administration systems.

In the spring of 1998, teaching staff became interested in the concept of the IBM ThinkPad University. In the autumn of the same year a new

college president arrived with a strong technical background and entrepreneurial outlook who backed the idea of becoming a Thinkpad University.

A pilot project was established to invite proposals from faculties. Proposals had to be supported by analysis of needs, assessment of likely impact and 100% endorsement by teaching staff within the curriculum area submitting the proposal. Funds were available for four projects. In the event thirteen proposals were received. IBM Thinkpads were bought and loaned to 100 students on the four selected courses. Extensive campus wiring was installed to make access ports available in teaching, social and residential areas. A 'Laptop lounge' was created in every residence comprising fifteen to twenty ports, but not 'one port per pillow'.

The network

In 1999 the project was scaled up to include more courses and 1,000 laptops. ThinkPads bought in bulk at discount by the college were provided to students as part of the course fee package, paid for in four instalments over four semesters. This arrangement made the costs eligible for financial aid, which was important because a high proportion of the students are on grant support. Students are offered virtually unlimited network file space, a two-year maintenance/ repair warranty, network and wireless cards, and technical support. Faulty machines were originally just replaced, now students are offered loan machines while their own is repaired. Students are discouraged from supplying their own, non-standard PCs. Those with non-standard machines are helped with configuration for running on the college network but not given machine–specific hardware support.

Planned extensions to the wireless network include the equine and dairy farming locations, where it will become possible to link data collection from PDAs to the main database, eg. data on individual horses and milk yields.

The basic college network is a 1 Gb/s Ethernet backbone, with 100 Mb/s per building, further split down to 10 Mb/s to ports, but individual ports can be given 100 Mb if necessary, eg. for AutoCAD. All buildings are supplied with single and multimode fibre.

11 Mb/s (802.11b) access points were rejected in favour of 2 Mb (802.11) because although bandwidth is initially lower, the loss of bandwidth is less severe with distance from the access point using 802.11. All access points have their own separate power supply and provide connectivity in a 500ft radius indoors and 1,000ft outdoors. The college will probably upgrade directly to 54 Mb (802.11a) in two years, recognising that this will require at least a doubling of access points (and in reality anything up to seven times as many access points) to maintain coverage. However at present the main bottleneck is not access point bandwidth but the 1.544 Mb/s of the college T1 Internet connection. The wireless network covers much but not all of the two campuses, including many open spaces because of leakage from surrounding buildings. It is possible to walk across campus without losing connection. If the connection is lost, eg. when changing floors within a building, it is automatically restored without needing to log on again.

Motivation for introducing a wireless LAN

Laptop-based study is perceived as more flexible and convenient for campus-based students and good preparation for the realities of mobile computing in real working life.

Wireless networking is perceived as offering even greater flexibility than flood wiring and as being cheaper. Some of the older buildings were too costly to wire due to construction, too dangerous due to the presence of asbestos materials, or unsuitable because of the impact of trunking on visual appearance.

Impact

Students on ThinkPad courses are perceived to

work together more, both physically and virtually, and to have changed their working patterns, studying at a wider range of times and in a wider range of locations. Students use the technology to develop relationships spontaneously. Apparently there is no need any longer to run ice-breaker parties for freshers in residences for example. Staff perception of wireless is that it is just an access technology and that the major pedagogical change was the move to laptops. There seems little apparent thinking about new pedagogical opportunities created by mobile computing, although some developments in Equine Studies, using PDAs to collect data and feed it into the network, are evidence of creativity.

10.2 Seton Hall University

Background

Seton Hall is a medium-sized (5,000 undergraduates and 6,000 graduates) private Catholic college in New Jersey. About 50% of its students live on campus with most of the remainder commuting. It is a four-year college and charges substantial fees.

Seton Hall now offers an IBM Thinkpad to all students and has wireless networking across the campus

History of networking

In 1995 an IT plan was developed which was based on the lack of common standards and facilities across disciplines in computing and networking. Some disciplines were reasonably well served, while others had few resources. There was also a lack of support for staff and it was even worse for students, as, for instance, some computer labs insisted that you could only work from that department on their computers. This was exacerbated by the lack of no central support, eg. for email, so that each department ran its own (often incompatible) system, while students do modules from several departments.

At this stage a mobile computing pilot was run involving 20 business honours students. In 1996 this was extended to the MBA programme.

In 1997 all the departmental servers – around 40 – were consolidated, with the aim of providing staff and students with a single account across the campus. This was based on the premise that all students worked in several departments and 'even a math major may only take 25% of their courses in their home department'.

At this stage they felt able to make ThinkPads mandatory on some courses. The courses picked were Business Studies and Biology.

In 1998 the ThinkPad programme was made mandatory for all new students by which time the campus was flood wired with all the lecture theatres having multiple ports and even some of the benches on the college green having ports.

The wireless programme started in 2,000 with about 350 faculty and students. The wireless LAN was installed in the library, student centre and about six classrooms. The pilot went sufficiently well for the wireless to be rolled out during 2001 and all freshmen and juniors (years 1 and 3) now have wireless enabled laptops; from next year all students will have wireless-enabled laptops.

Laptop Programme

All new students are issued with a wireless-enabled laptop. This is replaced after two years and the student keeps the machine on graduating.

To fund this students pay a $650 technology fee per semester. This covers the lease on the systems, insurance, maintenance, networking and support. (If the student is providing their own machine they pay an access fee of $200 per year to cover the labs.)

The machines are ThinkPads and include an 802.11b aerial built into the monitor. They also have network and modem ports.

The machines are 'heavily insured' and Seton Hall is a licensed IBM repair centre, which means that they can repair the systems on site and then reclaim the cost from IBM. To provide a good service to students repair is done by replacement (swapping the hard discs if possible).

Other students can provide their own laptop and wireless card and get the software and service set identifier (SSID) which is used for security purposes to ensure that only registered laptops use the network, through there is little demand for this.

The college is currently looking to acquire software to 'lock down' the PCs (ie. control what applications students can use) during class or exams as some teachers do not like students using instant messaging or reading their email in class.

The network

The campus is heavily wired, which supplements wireless technology. However wireless was chosen for two reasons:

- it is cheaper than wired network to install
- it is more flexible

It was not chosen for educational reasons, and at this stage the university does not have any projects that take advantage of the itinerancy that mobile computing offers.

There are about 7,000 ports wired across the campus, including one port per pillow in the bedrooms and large numbers in other places. Approximately one-third of the teaching areas have one port per seat and all classes have at least one port. There are also ports in public areas and the library, and even some on benches on the college green outside.

Wiring was installed in all buildings where this was a simple affair, for example all the classrooms with hollow walls.

The mobile network is 802.11b offering a nominal 11 Mb/s shared between all the users in the area. The university has installed 200 access points covering about 90 classrooms and most public spaces. The total cost has been about $300,000, or $1,500 per access point. This has been achieved in part by using power over Ethernet. Symbol was chosen as the supplier and undertook the site survey to determine where to put the access points.

Determination of the location of the access points will be one of the most important factors in the success of rolling out wireless networking. The characteristics of the signal are not sufficiently understood for it to be possible to work out where to site the access points without a survey. The building layout and building materials can have a major impact on the signal, which may be affected by things like bookshelves. Because the signal (and therefore bandwidth) decays quite rapidly the location of access points has a marked effect on performance.

Support

To be effective the network needs to be supported by

- faculty and curricular support
- network support

A help desk is staffed by a team of seven support staff and ten students. Walk-up help is available from 7am to 1am during the week, with help available at the weekends. From August to October 200–400 calls per day are received, mostly from new users and this then tails off. Most of the requests come by phone with just 2–3 by email. A significant number of the problems are caused by signal loss as one gets further from the access points.

Use of mobile and itinerant computing

The college has found that mobile computing changes where and when computing is done,

increasing flexibility in the classroom and allowing tutors to rearrange furniture to suit different modes of working.

Administrative functions have not yet been made mobile (eg. for registration).

Staff involvement

All staff involved in the pilot were given a $1,000 dollar bonus to pay for the additional effort involved in participating.

Wireless in action

Seton Hall is moving from Lotus to Blackboard because it integrates with their record system (Banner from SCT) and this allows them to populate courses in the virtual learning environment (VLE) with registration information on the students.

However, the Blackboard roll out was seen as premature and is not popular with many students due to its unreliability.

We observed one class where wireless is used. In fact, this was not an officially wireless classroom although there was sufficient bandwidth available from 'bleeding' through the wall. Interestingly, the tutor – who is strongly in favour of wireless – does not use it when teaching because he says that while it is not too intrusive if the connection fails on a student's machine, it is too disruptive when this happens on the tutor's machine. Moreover, several students had chosen to plug their machines in rather than rely on wireless.

The tutor reported that wireless LANs made it easy to reconfigure the classrooms and to move around to see what the students are doing. He said that this meant that he is able to see more students in a session.

Students said that carrying the laptop around is not a problem, and no different from carrying books. The battery life of about two hours was also not seen as a problem.

10.3 Carnegie-Mellon University, Pennsylvania

History of networking

Carnegie-Mellon University (CMU) already had a team researching LANs in the early 1990s and a group within the team wanted to look at wireless LANs. In 1994 they approached the National Science Foundation (NSF) and were awarded a grant of over $500,000 to implement a wireless LAN.

In 1988 they wanted to 'refresh' the network, and the IEEE wireless standard 802.11 had recently been approved. AT&T's wireless division, which had become Lucent, was looking for a test site for their 802.11 products. So, in 1988 Lucent granted CMU 400 access points and some cards.

This allowed the university to expand the coverage to a wider range of buildings – covering almost all of the academic buildings (teaching, research and administrative buildings, but not the student accommodation), amounting to three million square feet of interior space and a significant amount of the exterior space through leakage. It took eighteen months to deploy the 350 required access points and this was achieved by June 1999. This represented a significant increase in coverage and required a site survey to ensure that there was full coverage of the intended area with no blind spots.

The only way to undertake such a survey is to walk around all the areas with temporary aerials and monitor the signal strength. The survey was described as more of an art than a science in that it cannot be predicted from the building plans. Fixed devices, such as wiring and water pipes as well as the precise composition of the walls, affect the way that the signal propagates.

During this time 802.11b was approved, and the cards in the access points were swapped

from 802.11 to 802.11b. As the site survey had been undertaken for 802.11, which has a longer range than 802.11b, the full 11 Mb/s is only achieved close to the access point and falls away to the 802.11 bandwidth of 2 Mb/s quite rapidly.

Once the campus was cabled up students began asking for it to be extended to their accommodation so that they could use roaming. Lucent granted another 60 access points and these cards were powered over the Ethernet cable. The dormitories are much smaller than the other building, with 30 buildings covering less than one million square feet. At first, it was thought that approximately 150 access points would be required to cover this, but in the end only 250 access points were needed. In part, this was because a true 11 Mb/s design was undertaken, so that each access point would not reach as far as originally planned and in part because of the building design. Dormitories have more bathrooms and the pipes than teaching spaces and ceramic installations also block signals, as do fire doors. Some buildings use a wire-lathe-covered-in-plaster form of construction which could act as a Faraday cage and severely affect signals.

Managing wireless networks is still a major task as they have been designed by radio engineers, not network engineers and insufficient thought has gone into the management issues, so that access points have to be 'touched' (ie. visited) to update the software or configuration. For instance, CMU recently found that the access points in the academic buildings don't work properly with Windows-XP. The drivers had to be updated, which took around eight hours over three days to achieve.

The Graduate School for Business Administration was one of the first buildings to be wired and now requires its students to have laptops. Many of the 800 students are now moving to wireless, though the building was designed for 2 Mb/s. They have sixteen access points in the building but are looking to redesign the network. However, 802.11b uses direct sequence spread spectrum (DSSS) whereas 802.11 uses frequency hopping spread spectrum (FHSS). It is easier to overlay access points using the latter as there are fifteen hopping algorithms which can be overlaid in a shared space. With DSSS the network has to be more carefully planned.

The current cost of installing access points is $1,000 to $1,500 where the access point itself costs $500–800 depending on the degree of remote management and number of slots in the access point. Cabling and installing the card is another $500, as is the power supply if AC mains cable has to be fed to the access point. This falls to around $100 when power over Ethernet is used.

When CMU first installed wireless they did not entirely trust it. They therefore laid a separate backbone for it and created a separate subnet. This proved to be a very good solution as it allowed roaming without the complications which ensue if more than one subnet is involved.

CMU does not run a network which they consider insecure and if data security is important, the user must encrypt it. Kerberos is used to secure passwords. It is hoped that 802.1x will provide the security needed in the future.

For other useers, wireless has been easy. Wireless is just another network type. CMU has ten times as many problems with DSL users as wireless, in part because they issue a CD with all the software and drivers needed for wireless operation at the beginning of each year.

There has as yet been little work to make effective use of wireless in teaching as the initial motivation was wireless LAN research and even then it was seen as just one form of commodity network.

11 Conclusion

Wireless LANs have an important part to play in the development of IT infrastructure in colleges and universities over the next few years. They will be especially important for those colleges and universities which are in the process of extending the reach of their network, whether this is to increase the area covered by the network or to improve availability to students. This paper has shown that wireless LANs are likely to be the most cost effective way of extending the reach of the college or university network both to new areas and increasing the number of people who can use it simultaneously. Cost savings are likely to be especially great in areas that are difficult to wire because of the nature of the existing buildings. This includes listed buildings, where permission to install the wiring can be difficult to obtain and where the controls on where it can go make it even more expensive. Moreover, buildings with asbestos or reinforced walls can be very difficult to wire and here wireless LANs can be especially beneficial.

Besides the economic advantages, wireless LANs also provide greater flexibility than wired LANs for three reasons:

1. They provide physical flexibility in that the user can log onto the network anywhere within the space. With a wired network it is necessary to decide where computers will be used and then install the ports there. Often the use of space changes with time, and then either the space has to be rewired or long trailing cables must be laid to get from the computer to the port.
2. With a wired network the maximum number of users must be determined when the space is wired and a suitable number of ports installed. This tends to mean either that too many ports are installed, so wasting money, or that there are times when demand exceeds supply and some users are unable to use the network. With a wireless network the performance of the network will deteriorate as the usage increases but unless there is very high demand, all users will be able to access the network.
3. The network can reach places that wired networks cannot, including out of doors, where the signal can reach up to several hundred metres from buildings. Moreover, it is relatively easy to set up an access point linked back to the campus network for use in remote premises.

Wireless LANs can be especially useful in classrooms as these are constantly re-arranged for different purposes – eg. for lectures in one session and then for discussions in another. This is not possible if the desks are wired since this requires them to be secured to the floor. With wireless LANs this issue does not arise. A particularly powerful use of wireless LANs is in conjunction with ‘wireless carts’. These mobile carts with between ten to twenty laptops and an access point can be wheeled into the classroom when they are required, giving the students immediate access to Internet-enabled PCs. This means that all classrooms can be PC labs, including specialist rooms such as chemistry labs.

Institutions which are looking at student ownership and use of laptop PCs and personal digital assistants (PDAs) need to find ways of providing access to the Internet for students’ own machines. Wireless LANs are an easy way to manage this.

However, there are a number of problems with wireless LANs. The two most significant are the rapid evolution of the technical standards and the limited bandwidth available to a wireless network as compared with a wired network.

While standards are moving rapidly, Wi-Fi is well established and many people are already using it, both in industry and education. The next likely standard (called 802.11g) has specifically been designed to be compatible with Wi-Fi, so that investment in Wi-Fi equipment is not wasted. The other main standards, 802.11a and

HiperLAN/2, are more problematic. 802.11a has been in existence for a long time, though there is little equipment that uses this standard. Moreover, it is not yet licensed for use in the UK. HiperLAN/2 is a European standard and has yet to gain ground among suppliers. Some form of merging of the two standards is likely and colleges and universities would be unwise to invest in either until their future is much clearer.

Wireless LAN is a relatively young technology and we are only just beginning to find the educational advantages that it can offer, either with or without ubiquitous computing. It is already clear that there are a number of features that it enables including better collaborative working among students.

In conclusion then, wireless LANs will have a growing place in the IT infrastructure of colleges and universities over the next few years and teachers will begin to make use of them to enhance their teaching.

12 Comparison of Wireless technologies

This table compares the key wireless standards to show how they differ from one other. It does not cover all the standards which could be used to support the development of a wireless LAN. Other features of some of these standards are shown in Table 1, Some wireless LAN standards.

	IrDA	Bluetooth	802.11	802.11b	802.11g	802.11a	HiperLAN/2
Max Bandwidth Mb/s	4 but usually much lower. Work is proceeding on a 16 Mb/s version	4 work is proceeding on a faster version	2	11	34	54	54
Backward Compatible with	-	-	-	802.11b	802.11 802.11b	-	
Wireless type	Infrared	Radio	Radio	Radio	Radio	Radio	Radio
Frequency space (GHz)	850 -900 nm	2.4	2.4	2.4	2.4	5	5
Licensed for use in the UK	✓	✓	✓	✓	Expected 2003-4	Limited licence offered*	✓
Maximum effective Range (metres)	10	10	50	50	50	50	50
Security Provided	No	Some	WEP 802.1x	WEP 802.1x	WEP 802.1x	WEP 802.1x	Some
Designed for	Ad hoc communication	PAN	LAN	LAN	LAN	LAN	LAN

*May change when 802.11h approved

Table 2. Comparison of different wireless LAN technologies

13 Glossary

2G	Second generation of mobile telephones. Capable of data rates of around 9.6 kb/s. WAP was designed to work with this type of data rate, but has not proved successful by comparison with the short message service (SMS) so popular with many mobile phone users.
3G	Third generation of mobile telephony. In 2001 there were auctions for licenses for 3G phone networks which netted £21 billion in the UK alone!
802.11	The basic standard which defines wireless communications for LANs. It works in the 2.4 GHz unlicensed range and provides up to 2 Mb/s. Defined by the IEEE.
802.11a	A version of the 802.11 standard for the 5 GHz unlicensed range, offering 54 Mb/s and 108 Mb/s. It is not compatible with 802.11, 802.11b or 802.11g. Defined by the IEEE.
802.11b	A revised version of the 802.11 wireless standard which works in the 2.4 GHz unlicensed range. It offers 11 Mb/s and is backward compatible with 802.11. Defined by the IEEE.
802.11e	Defines quality of service (QoS) requirements for the 802.11a standard. Example applications include transport of voice, audio and video over 802.11 wireless networks, video conferencing, media stream distribution, and mobile and nomadic access applications. Defined by the IEEE.
802.11g	An extension to the 802.11b standard designed to enhance the performance and the possible applications. 802.11g is backward compatible with 802.11b, offering up to 34 Mb/s. Defined by the IEEE.
802.11h	Enhances 802.11a to provide frequency control and power management. This allows it to meet the different regulatory frameworks in various countries by providing dynamic channel selection and transmit power control mechanisms. Defined by the IEEE.
802.11i	Enhances the 802.11 Medium Access Control (MAC), providing security and authentication mechanisms. Defined by the IEEE.
802.1x	The 802.1X standard is designed to enhance the security of wireless local area networks (WLANs) that follow the IEEE 802.11 standard. 802.1X provides an authentication framework for wireless LANs, allowing user authentication.
access point	A device which links wireless-enabled computers to the network. To create a WIRELESS LAN each computer needs to access the wired LAN. This is the service provided by an access point.
Backbone	A high bandwidth part of the LAN that connects together the branches which go to the user.

Bandwidth	The capacity of a network connection; used as an indication of speed. Normally specified in bits per second, eg. 802.11 works at 2 Mb/s.
Bit	Short for binary digit. The smallest unit of data used in computers. It consists of single 0s or 1s. Eight bits make one byte.
Bluetooth	An industry-defined radio frequency communication technology for short range (10 m) communication between devices such as mobile phones, computers, and personal digital assistants (PDAs).
Bridge	A device that connects network segments together. If information is destined for a user within the sender's own network segment, the bridge keeps the packet there. If the packet is bound for another segment, the bridge passes the packet onto the network backbone. Access points act as bridges in a LAN.
Byte	Eight bits. It is the unit needed to represent letters and digits internally in a computer. It has 256 possible values.
Cart	A secure trolley which contains a number of laptops (typically ten to twenty) and a wireless access point which allows networked computers to be used in any teaching space. The laptops are issued to students and plugged in the access point to the LAN.
Cell	The area covered by a wireless access point (or mobile telephone transmitter). For wireless LAN this is typically a radius of 10 – 50m.
Digital Subscriber Line	DSL is a technology for bringing high-bandwidth information to homes, small businesses, colleges and universities over ordinary copper telephone lines. xDSL refers to different variations of DSL, such as ADSL, HDSL, and RADSL. Typically, individual connections will provide from 1.544 Mb/s to 512 Kb/s downstream and about 128 Kb/s upstream.
Direct-sequence spread spectrum	This is a method of controlling the way that the available bandwidth is allocated for use in wireless LANs, the other being Frequency Hopping Spread Spectrum.
DSL	Digital Subscriber Line.
DSSS	Direct-sequence spread spectrum.
EAP	Extensible Authentication Protocol. EAP is an authentication protocol which supports multiple authentication mechanisms.
Ethernet	The most common LAN technology.
ETSI	European Telecommunications Standards Institute is a membership organization whose mission is to produce the telecommunications standards that will be used for decades to come throughout Europe and beyond. It has over 900 members in 55 countries, and is responsible for the HiperLAN standards.
Extensible Authentication Protocol	EAP is an authentication protocol which supports multiple authentication mechanisms.

FHSS	Frequency Hopping Spread Spectrum.
Firewall	Firewalls are system designed to prevent unauthorized access to private network (intranet or LAN). All messages entering or leaving the intranet pass through the firewall, which examines each message and blocks those that do not meet the specified security criteria.
Frequency hopping spread spectrum	Frequency hopping spread spectrum (FHSS) is one of two basic modulation techniques used in spread spectrum signal transmission. It is the repeated switching of frequencies during radio transmission to minimize the effect of interference from other systems. It is also known as frequency hopping code division multiple access. The alternative is Direct Sequence Spread Spectrum (DSSS).
HiperLAN	High Performance Radio LAN. Developed by the European Telecommunications Standards Institute (ETSI), HiperLAN is a WIRELESS LAN communication standard similar to the IEEE 802.11. There are two versions of the HiperLAN standard: ■ HiperLAN/1: provides communications at up to 20 Mbps in the 5 GHz band. ■ HiperLAN/2: provides communications at up to 54 Mbps in the 5 GHz band. It seems likely that HiperLAN will merge with 802.11a.
Global System for Mobile communication	GSM – the digital mobile telephone technology used in Europe for second generation mobile telephony.
GSM	Global System for Mobile communication.
Industrial, Scientific and Medical	Part of the radio frequency spectrum released by governments in the US, Europe and Japan for unlicensed use. This means that the end user (college or university) does not need a license to use these frequencies. However equipment must meet the regulations (similar to green triangles on telephones which may be plugged into the public network).
IEEE	Institute of Electrical and Electronic Engineers. Responsible for developing many of the international electronic standards. The IEEE has a formal relationship with ISO.
Internet	The worldwide network of computers.
Intranet	A private network. Essentially a synonym for local area network.
IrDA	Infrared Data Association (an industry-sponsored organisation) is one of the various standards which can be used for wireless communication.

	IrDA uses infrared communication links over short distances (up to about 10m), and in later versions up to 16 Mb/s, though most current devices are much slower. Infrared data communication is playing an important role in wireless data communication due to the popularity of laptop computers, personal digital assistants (PDAs), digital cameras, mobile telephones, pagers, and other devices, many of which come with IrDA ports. IrDA can be considered a direct competitor to Bluetooth.
ISM	Industrial, scientific and medical (ISM) band.
ISO	International Organisation for Standardisation. Amazingly, ISO is not an acronym.
LAN	Local Area Network.
Local Area Network	A network or group of network segments confined to a single building or campus. Compare to WAN and PAN.
MAN	Metropolitan Area Network.
MB	Megabyte – 1 million bytes.
Mb	Megabit – 1 million bits.
Metropolitan Area Network	A high-speed network that typically covers a region (originally an urban region, but not necessarily so now) linking together a large number of LANs.
OFDM	Orthogonal frequency division multiplexing.
Orthogonal Frequency Division Multiplexing	A method of splitting up radio signals and using a number of different frequencies as a way of minimising interference.
PAN	Personal area network.
PDA	Personal Desktop Assistant.
Personal Area Network	PAN. Originally conceived for wearable computing as a network of devices worn by an individual, but now extended to those that they might be using. Bluetooth is often seen as the best technology for building a PAN.
Personal Desktop Assistant	A small handheld personal computer such as Palm, Handspring and iPaq.
Piconet	Another term for personal area network.
Power over Ethernet Power	Power over Ethernet eliminates the need for mains power to Wireless Access Points and other network devices on a wired LAN. With Power over Ethernet, system installers need to run only a single CAT 5 Ethernet cable that carries

	both power and data to each device. This can significantly reduce the costs of installing a wireless LAN.
Quality of Service	A set of ideas and tools which can be used to control and monitor use of the Internet to guarantee performance for important traffic (ie. real time traffic such as video conferencing).
QoS	Quality of Service.
RADIUS	Remote Access Dial-in User Service.
Remote Access Dial-in User Service	RADIUS is a client/server protocol that enables remote access servers to communicate with a central server to authenticate wireless LAN or dial-in users and to authorise their access to the requested system or service.
Service Set Identifier	SSID is an identifier attached to packets sent over a wireless LAN that functions like a password for joining a particular radio network. All wireless cards and access points within the same area must use the same SSID or their packets will be ignored.
Short Message Service	SMS is a service for sending messages up to 160 characters to mobile phones that use Global System for Mobile (GSM) communication. GSM and SMS service available primarily in Europe.
SMS	Short Message Service.
SOHO	Small Office / Home Office (also often written as SO/HO).
Specification	A specification is an agreed method for doing something which does not have the formal validity of a standard. Many of them are created by membership organisations, including W3C and IETF which create the specifications used on the Internet. Others include WECA and IrDA which have created wireless communication specifications. These may be adopted as standards later.
SSID	Service Set Identifier.
Standard	Standards are controlled by the International Organisation for Standardisation (ISO) which was set up by treaty in 1947 as a federation of national standards bodies including the British Standards Institute. ISO also works with a number of other organisations including IEEE and the ITU. Other bodies also create specifications.
ThinkPad	IBM Laptop PC.
UNII	Unlicensed National Information Infrastructure.
Unlicensed National	Part of the radio frequency spectrum which has been released by governments in the US (with similar but not identical releases by the governments in Europe

Information Infrastructure	and Japan) for unlicensed use. This means that the end user (college or university) does not need a licence to use these frequencies. However, equipment must meet regulations (similar to green triangles on telephones which may be plugged into the public network).
Virtual LAN	A VLAN is LAN with a definition which maps PCs on a non-geographical basis, for instance by department or access type (so a VLAN might be used for wireless access).
Virtual Learning Environment	A VLE is the system in which learners and tutors participate in 'on-line' interactions of various kinds, including on-line learning.
Virtual private network	A VPN enables IP data to travel securely over a public network by encrypting all traffic from one network to another. A VPN uses 'tunnelling' to route securely encrypted information.
VLAN	Virtual Local Area Network.
VLE	Virtual Learning Environment.
VPN	Virtual private network.
WAN	Wide Area Network. The Internet.
WAP	Wireless Application Protocol
WEP	Wired equivalent privacy
Wide Area Network	The Internet.
Wi-Fi	Wireless Fidelity is another name for IEEE 802.11b standard. The term Wi-Fi was created by the Wireless Ethernet Compatibility Alliance (WECA). Products which have been certified as Wi-Fi by WECA are interoperable with each, though product-specific features may not be available (and this may include some security features).
Wired Equivalent Privacy	WEP is a security protocol for wireless local area networks defined in the 802.11b standard. WEP is designed to provide the same level of security for wireless LANs as are found in wired LANs. Wired LANs are inherently more secure than wireless LANs because wired LANs are inside a building that can normally be protected from unauthorised access. Wireless LANs with radio waves which go through walls are more vulnerable to tampering. WEP aims to provide security by encrypting data over radio waves so that it is protected as it is transmitted from one end point to another.
Wireless Application Protocol	WAP is a specification for access to the Internet by low bandwidth devices such as mobile phones.
Wireless Bridge	Another term for access point. A device which links wireless-enabled computers

	to the network. To create a wireless LAN each computer needs access the wired LAN. This is the service provided by an access point.
Wireless LAN	Wireless Local Area Network. A LAN (see above) which used radio or infrared light to send information.

14 Annotated Bibliography

This is not intended to be a full or academic bibliography, but aims to allow readers to pursue easily the ideas expressed in the paper. With this in mind preference has been given to materials which are available on the Web.

All URLs were checked on 24 November 2002.

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An excellent web resource with an enormous amount of information on each of the standards and a general section. Repays a browse or search.

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