The Application of Wireless Technologies to Data Communications

Venkata K. Josyula
Supervisor: Rick Bunt

Abstract

The need to maintain unrestricted access to information has created enormous demand for wireless data services. The stringent bandwidth limitations and high error rates of the transmission medium pose major technical challenges in the design and deployment of these networks. This paper surveys available wireless technologies such as infrared (IR) and radio frequencies (RF), the various access techniques like TDMA, CDMA and FDMA, and addresses their suitability to computer networks. The limitations of wireless technologies to emerging applications like multimedia services and the issues involved in providing a wireless access to a high speed ATM backbone are also discussed. It is observed that different user requirements are satisfied by different technologies and hence the choice of the transmission technology or an access technique depends on the particular application.

1 Introduction

Computer Networks are providing access to information all around the globe. Now, the need has arisen to maintain uninterrupted access to this information. This has led to the evolution of wireless networks. A similar requirement in the telecommunications industry has led to the evolution of cordless telephones, pagers, cellular systems, and the development of standards for personal communication services (PCS). Cordless telephones satisfy the need for voice communication indoors, whereas cellular technology satisfies voice-oriented requirements of mobile users. There is also a need for high speed data transfer within a building and wireless local area networks (WLANs) target this requirement. Data transfer over wide area is also desirable although the data rate may be compromised in this regard [11]. Improvements in wireless transmission methods and the rapid proliferation of small portable computers provide a greater scope for the development of wireless data services. The stringent bandwidth limitations and high error rates of the transmission medium pose major technical challenges in the design and deployment of wireless networks. Wireless links among existing networks can be provided, or wireless access can be provided to a wired network. Wireless access is provided by means of a wireless interface card that has an antenna. The fixed wireline networks can be provided with these interfaces to service small low-powered portable terminals. Unless otherwise specified, the term wireless networks in this paper refers to networks which facilitate wireless access.

1.1 Why Wireless?

- The main advantage of wireless networks is that they facilitate tetherless access. It is interesting to envision an environment in which a student can take a small portable computer to a classroom or a library and still access a high speed fixed network on the campus.
- The installation costs are low and they provide an attractive alternative where cabling is difficult.
- Wireless LANs can provide temporary access at conventions, seminars and conferences.

- Wireless connection provides new opportunities for mobile computing. This gives rise to a whole realm of applications.

These various user requirements can be broadly divided into two major categories [15]. On one hand, there are requirements for relatively low-speed data services supporting mobile users over wide geographical areas, as provided by mobile data networks. On the other hand, there are requirements for high-speed data services in local areas as provided by wireless LANs. The various classes of applications place different demands on the network which give rise to different system design and performance considerations.

1.2 Current Scenario

Current short range wireless systems are developed to handle mainly voice traffic [17] [21]. They employ circuit-switching technology which is a proven technology for such traffic but regarded as inefficient for handling bursty data traffic. These systems can only support low data-rate applications up to 19.2 kb/s [14] and also involve large message delays. Conventionally, data traffic is considered to be better served by a packet-switching technology. As the need to provide wireless access to data applications is increasing, the possibility of multiplexing voice and data traffic is being explored. This allows different traffic types to share common transmission resources and equipment, while satisfying their individual performance requirements. In addition, packet-switching techniques can make a better use of the talk-spurts/silent-gaps structure of voice sources to increase the capacity of the system. Voice packets are not transmitted whenever the corresponding voice source is in a silent period. This is an important issue in wireless networks since conservation of bandwidth is paramount [9]. The commercially available wireless LANs offer data rates of about 2 Mb/s [8] and the performance is not comparable to their wired counterparts. The more recent studies [13] show (through simulation) the feasibility of wireless LANs at 100 Mb/s but still many issues remain to be resolved. The use of wireless technologies tantamount to more than just replacing the physical layer of the wired networks by the air interface.

The following sections discuss the potential and the limitations of the available frequencies, and access techniques with respect to data communications. Section 2 discusses the inherent limitations of the wireless services and Section 3 describes the existing cordless and cellular systems. Infrared (IR) and Radio frequency (RF) systems are described in section 4 followed by a discussion of multiple access techniques in section 5 with an emphasis on spread spectrum technology. Section 7 addresses the limitations of the wireless networks in providing multimedia services. The issues involved in providing a wireless access to an ATM backbone are discussed in section 8.

2 Limitations of Wireless Services

Wireless networks differ from traditional data networks in several important ways. Wireless networks are considerably slower than current wireline networks, and the disparity in speed makes it difficult to design software that will operate well in either environment [7] [10]. Variations in radio signal quality, make the communication less reliable. The major limitations of wireless communications can be attributed to the non-availability of spectrum and the highly error-prone wireless medium. The new wireless products have to co-exist with the already existing applications and thereby deal with interference effects.

2.1 Spectrum Limitations

The radio frequency spectrum is a valuable and limited commodity. Most countries regulate and license the use of radio frequencies. The frequencies 902-928 MHz, 2400-2483 MHz, 5725-5850 MHz constitute the Industrial, Scientific and Medical (ISM) bands. The propagation characteristics also vary by frequency band. Increase in frequency implies greater *multipath effects*. The transmission range is better for the 915 MHz band when compared to the 5.8 GHz band but the 915 MHz band is more prone to interference. Propagation above 3 GHz is mainly short range and line-of-sight (LOS). However, the higher frequencies offer higher bandwidth and consequently higher data rates (above 5 Mb/s). The 2.4 GHz band is a middle path between the two. Moving up in the frequency band means facing more challenging technology issues. Silicon-based devices can be used in the lower bands whereas the upper band requires gallium arsenide (GaAs) [2]. Silicon devices have higher integration levels and low fabrication costs. From an end-user point of view, devices operating in the 5.8 GHz band will be more expensive than the devices operating in the 2.4 GHz band, which are themselves more expensive than the devices operating in the 915 MHz band. This results in a heavier utilization of the lower frequency bands, giving rise to greater problems of interference at lower frequencies.

2.2 Interference

Unlike physical media, such as copper or fiber, that provide a somewhat predictable and controlled transmission environment, the free-space environment for wireless systems is constantly changing. Radio signals can be distorted by other nearby systems using the same frequencies. This phenomenon is called *co-channel interference*. The simultaneous arrival of signals propagated over different paths with different path lengths gives rise to *multipath interference*. The signal arrives with different path lengths due to reflections from buildings and other structures. When the path lengths differ by half a wavelength (or multiples of half wavelengths), signals arriving over different paths may partially or totally cancel at the receiver. This phenomenon is known as *Rayleigh fading*. Thus interference places a restriction on the maximum transmission rate. This is of major concern when one wants to operate several networks simultaneously in the same place. There are a variety of techniques to combat multipath fading such as diversity, equalization, channel coding, data interleaving, etc.

3 Cordless and Cellular Systems

Cordless and cellular telephones have been among the first wireless products with respect to voice communications. This section describes these two systems and discusses how they can scale up to the requirements of data communications.

3.1 Cordless

The basic cordless telephone provides a wireless counterpart to the standard telephone typically operating within 50 to 100 m of the user's base station [20]. Various applications such as tv-remote controls, wireless keyboards, and wireless mouse fall in this category. The first generation cordless systems were analog systems for voice transmission and had major shortcomings with respect to security, privacy and low user density. The two standards CT-2 and DECT form the second generation systems. CT-2 was originally concerned with digitizing voice but can support data services as well. DECT standard was proposed with both voice and data applications in mind. Cordless standards primarily offer an access technology rather than fully specified networks. Cordless data would encompass any data transfer over relatively short distance such as the infrared beam in the Apple Newton and other Personal Digital Assistant (PDA)-type products. The term cordless is now being used synonymously with all the services which do not employ *frequency reuse* (as explained in the next section). Wireless local area networks can be included in this area as well, because they use radio frequency transmissions that cover only the area of a building.

3.2 Cellular Systems

Cellular systems use many base stations with relatively small coverage radii (on the order of 10 km or less). Each frequency is used simultaneously by multiple users. This *frequency reuse* allows a much higher density of users per MHz of spectrum. As the mobile unit crosses cell boundaries, continuous

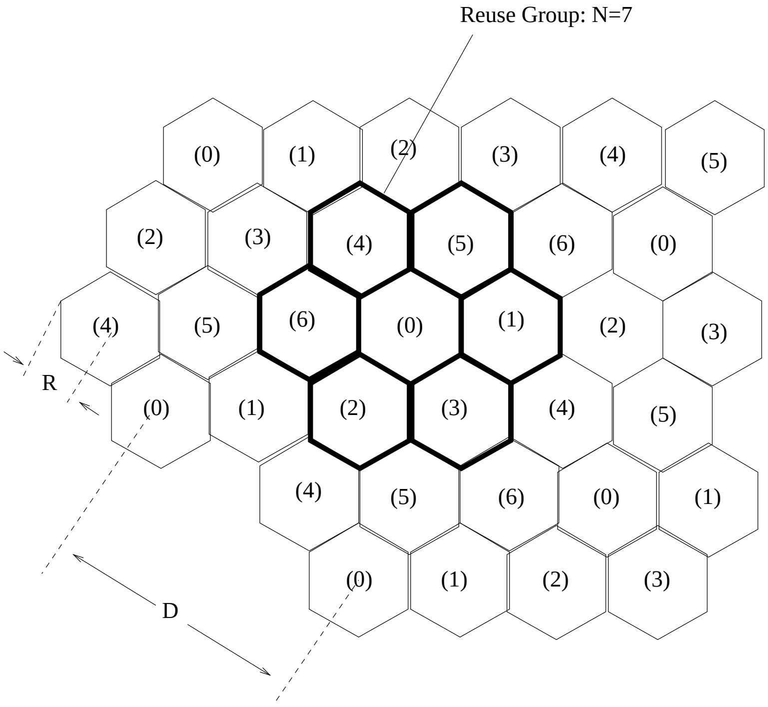

Figure 1: Cellular architecture [6]

coverage is achieved by executing a *handoff* (the seamless transfer of the call from one base station to another) [6]. This requires the mobile to change frequencies under control of the cellular network. Figure 1 shows the cellular architecture. The core of the cellular concept is *spatial reuse*, which exploits the fact that radio waves are significantly attenuated during propagation in a terrestrial environment. If two cells are separated by enough distance, each can use the same frequency bands at the same time without resulting in co-channel interference. Thus extensive frequency reuse becomes possible. This allows the network to achieve spatial multiple accesses. Figure 1 shows the reuse pattern. These patterns are characterized by a frequency reuse factor N, which represents the number of distinct frequency sets that need to be used to cover the entire service area. Instead of one user per frequency band, the network can now support N users per band, where N is the number of cells in the service area using that band. Each user **effectively** consumes **B/N Hz** of bandwidth, where B is the physical bandwidth needed to support transmission, thus increasing overall spectral efficiency. So by minimizing the physical distance D between cells using the same frequency, by reducing the cell size R, greater frequency reuse can be obtained. Typically the range for each cell is about 10 km. The micro-cellular environment has smaller cells and and the pico-cellular environment has still smaller cells (5 to 20 m). As the size of the cells decreases the power required for transmission is also reduced. It is to be noted that most of the traffic in each cell originates at a single site (the cell's base station).

3.3 Comparison

Current cellular systems are limited to voice and low-speed data (19.2 kb/s) within areas covered by the base stations. In contrast to cellular systems, cordless standards primarily offer an access technology rather than fully specified networks. In general, the digital cordless systems are optimized for low-complexity equipment and high-quality speech in a quasi-static environment (with respect to user mobility) [20]. When an application like full motion video is to be supported data rates can easily exceed 2 Mb/s even with the best compression schemes. This data rate may not be required for regular computation tasks such as word processing or spreadsheets. It is a well known fact that the peak data rate required by users will be much larger than the overall data rate. So it is important to minimize overall system bandwidth consumption while supporting a large number of users accessing data simultaneously. This is better provided by the cellular environment. This has also another advantage in the pico-cellular environment since transmit power is scaled down as the cell size decreases. While the existing cellular systems use 1 watt of transmit power for voiceband RF links in 5 mile cells, a system with 5 meter cells requires only milliwatts to maintain the link. Frequency planning is a tough task and this adds to the complexity of the cellular systems. Such complexity may not be required for supporting simple applications. A cellular-like architecture using IR need not have different frequencies for the cells but in the RF configurations the operating frequencies of the neighbouring cells should be different.

4 Physical layer alternatives : IR vs RF

The physical layer refers to the transmission medium which is twisted pair, coaxial cable or fiber in the wired networks. The choice of the transmission medium is a critical design decision. There are two alternatives for wireless communication: infrared (IR) channels or radio frequency (RF) channels.

4.1 Infrared

The frequencies of the order of 10^{12} Hz are in the infrared region. Several features of IR communications are well suited to application in wireless in-building networks. Transmitters and receivers for IR systems use light-emitting diodes (LEDs) and photosensitive diodes. IR transmissions do not interfere with existing RF systems. The IR signal does not penetrate walls, thus providing a degree of privacy within a closed area. IR LANs use either directed-beam or diffused radiation.

4.1.1 Directed Beam Infrared (DBIR)

In directed beam infrared communications (DBIR) the transmitted pattern must be adjusted in the direction of the receiver which may turn out to be a disadvantage. This method can be used for applications in which the terminals are relatively fixed. Higher data rates and better coverage can be achieved by this method. This would be suitable for large-file transfers between servers and fixed terminals.

4.1.2 Diffused Infrared (DIFR)

Diffused infrared (DFIR) radiation does not require a direct line of sight between the transmitter and the receiver; the receiver can collect a transmitted signal through reflections from the walls, ceiling or other objects in the room. Therefore, the installation of the network does not require any alignment to establish the communication link. The disadvantages when compared to DBIR are that it requires higher power to cover a given area. The data rates are limited by multipath and there is also a higher risk for eye exposure. This is more suited for applications demanding portability, like cordless telephones, and communication with lap-top or pen-based computers. A compromise to both the above options is provided by quasi-diffused IR (QDIR) but this is expensive.

4.1.3 Limitations of IR

The major limitations of IR communication are

- interference from ambient light sources (sunlight, fluroscent lamps)
- multipath characteristics of the channel for diffused radiation
- transient characteristics of the IR devices

Although the effects of ambient light can be reduced by modulating the transmitted IR signal, the rise and fall times of the light-emitting diodes (LEDs) limit the data rate to around 1Mb/sec. As the room dimensions become larger, the multipath effects increase and the supportable bit rate is consequently decreased. Considering multipath to be the only limitation on the data rate, results of computer simulations suggest that the theoretical limitation for the baseband transmission rate with diffused IR is 260 Mbit . m/sec [5]. Usually the range obtained is 20m. Many materials are opaque to IR radiation, causing reflection of infrared signals (because the wavelength is small compared to the dimensions of common objects) [4]. This makes IR signals sensitive to the positioning of nearby objects which is an impediment for mobility.

4.2 RF Systems

The primary sources of interference in RF wireless LANs are atmospheric and man-made noise, as well as the noise generated in its own amplifiers and the signals of other intentional radiators (like microwave ovens, diathermy equipment). There are also some unintentional sources of noise such as equipment that uses corona discharge in their operation (copiers, laser printers) or that interrupt high-voltage or high-current circuits (heavy electrical equipment). Several techniques are available to isolate RF transmissions, including the choice of different carrier frequencies and spread spectrum techniques.

4.3 Comparison

IR is suitable for in-room, short-range wireless LANs, while RF is suitable for longer range, high-capacity, full-coverage products like building-wide wireless LANs. The extreme intensity of solar radiation precludes the use of IR outdoors. RF is also used for wide-area wireless networks like data on cellular telephone and packet radio networks. Since the wavelength is very small for IR systems, the channel characteristics cannot be significantly improved against multipath using *antenna diversity* as in RF. IR networks can be isolated through use of different optical frequencies, but optical frequency agility is quite difficult to achieve and limits a user's choice of networks to join. The feasibility of isolating RF networks from each other makes uniform access to the wireless network possible through the use of cellular techniques. This implies that for several networks to operate simultaneously it is advisable not to use IR. Thus IR and RF are complementary and the choice of a particular method is clearly dependent on the application for which it is used.

5 Multiple Access Techniques

In FDMA (Frequency Division Multiple Access) the frequency spectrum is divided and assigned to different users i.e a frequency band is subdivided into channels and each user is assigned a different channel. Hence, the channels are the frequency bands. Although, FDMA can be used with analog as well as digital transmission, it is not flexible enough for wireless LANs. FDMA is also inefficient in spectrum utilization with bursty data traffic. In TDMA (Time Division Multiple Access) each user has the exclusive access of the entire channel periodically for a fraction of time and thus each user's transmission is intermittent. In this case, the channels are the time-slots. With this scheme a remote terminal knows when it is allowed to transmit or receive and it can enter power savings states during the periods when the channel is used by other members of the network.

5.1 Spread Spectrum Techniques

A spread spectrum signal is created by modulating the signal with a spreading sequence (a code consisting of a series of binary pulses), or by *hopping* the frequency of the carrier signal [19]. Many spread spectrum systems can share the same frequency band, provided that each system uses a unique spreading code to reduce interference between the different systems. Only the receiver with the same spreading code as the transmitter can reassemble, or despread, the noise-like signal to recover the broadcasted information. Thus, spread spectrum systems can tolerate a higher level of interference than conventional systems – allowing the same frequency to be reused many times within a given area. This capacity advantage makes spread spectrum ideal for use in environments where the frequency spectrum is congested, such as large cities. The spectrum needed to transmit a modulated signal must be much larger than the bandwidth of the information transmitted. Spread spectrum systems provide large coverage area and are suitable for applications where penetration through building floors is desired. There are two types of spread spectrum techniques: frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS).

5.1.1 Frequency-hopping Spread Spectrum (FHSS)

In an FHSS system, the total available band is split into a set of channels of equal bandwidth. Both transmitter and receiver dwell on one channel for a period of time, and then hop from that channel to another. The pattern of channel usage is referred to as an hopping sequence. The hopping sequence can be either random or deterministic. The time spent on each channel is called a *chip*. The ratio between the chipping rate (also known as the hopping rate) and the data rate differentiates two modes of FHSS: fast and slow frequency hoppers. If the chipping rate is higher than the data rate, then the system is known as a fast frequency hopper, if it is lower than the data rate then the system is called a slow frequency hopper. Fast frequency hoppers are costly and consume greater power. Since the transmitter and receiver should hop together, it is also difficult to achieve synchronization for a fast frequency hopper. Fast hopping at 800-900 MHz is not yet feasible.

5.1.2 Direct-Sequence Spread Spectrum (DSSS)

In these systems a pseudo-random code is used to modulate the transmitted signal. The user data and the sequence can be XOR-ed and the resultant stream is used to modulate a radio frequency carrier. The relative rate between the pseudo-random sequence and the user data is known as the spreading factor. It is between 10 and 100 for commercial DSSS systems, and for military applications it can be as large as 10000. At the receiver, the received radio frequency signal is demodulated, and the resulting signal XOR-ed with the same pseudo-random sequence used on the transmitter side. If the receiver sequence is exactly in phase with the transmitter sequence, the resulting signal obtained on the receiver side is simply the end user data. The limitation is the ability to spread the spectrum using a very high chip rate.

5.2 Code-Division Multiple Access (CDMA)

CDMA employs the DSSS techniques. Each user's digital waveform is spread over the entire frequency spectrum allocated to all users of the network and can be present continuously in time. The spreading is done according to a particular code. This code is known both to the subscriber and the base station's channel unit which communicates with the subscriber. This allows the receiver in both the locations to despread and demodulate the digital signal. The use of CDMA resolves multipath interference and multipath propagation.

5.3 Comparison

The current voice systems using analog FDMA and TDMA are narrow band and typically operate in a large, single cell environment, using the spectrum very inefficiently and also lack privacy. CDMA is more robust in presence of multipath and hence has the potential of allowing more users than either TDMA or FDMA. Compared to the current analog FDMA system, capacity gains on the order of 10-20 are achieved, and the capacity gain is on the order of 4-7 [2] when compared to the TDMA systems. CDMA is interference limited. The number of users that use the same spectrum and still have acceptable performance is determined by the total interference power of all the users as generated

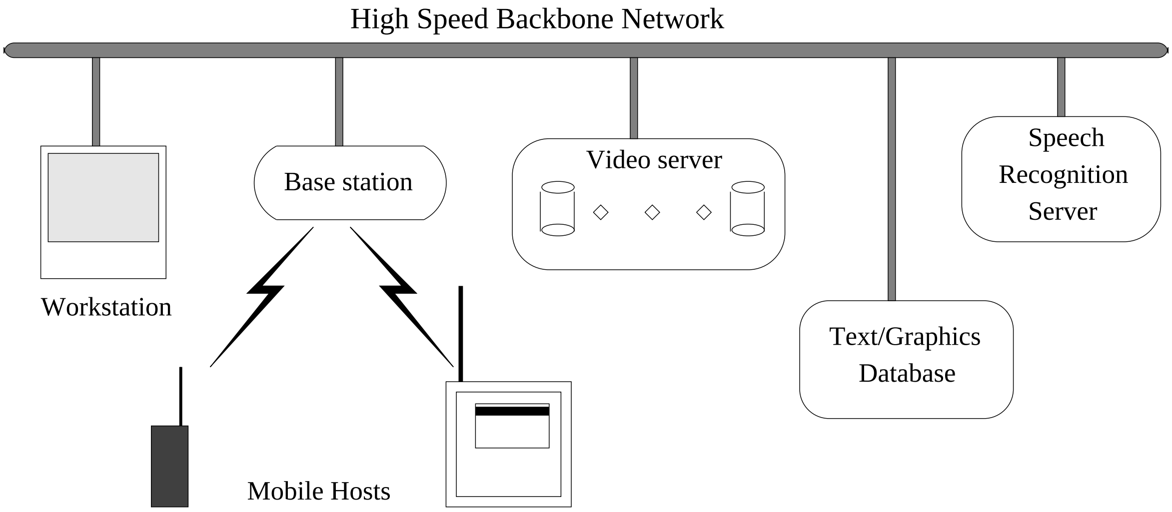

Figure 2: A future multimedia environment

in the receiver. Unless one takes great care in power control, those CDMA transmitters which are close to the receiver will cause an overwhelming problem called the *near-far problem*. In a **mobile** environment the near-far problem can be the dominant effect. It is possible to control the power of each mobile user so that the received power from each mobile user is the same. This technique is called *adaptive power control*. CDMA permits soft handoffs between cells as it moves between the vicinity of one base station to the other [14]. The use of soft handoffs gives certain immediate advantages like greater service quality near the boundary of the cells, virtually eliminating the possibility of dropped calls and annoying gaps in speech and it markedly increases the coverage area of each cell. Since CDMA is able to cope with interference effects, single-cell clusters can be used which avoids the arduous task of frequency-planning. It is possible to control the power of each mobile user so that the received power from each mobile user is the same. This technique is called *adaptive power control*. Numerous field tests involving the use of B-CDMA (Broad band CDMA) for PCS services have demonstrated the transmission of X-ray data at 9.6 kb/sec and video at 64 kb/sec. This also facilitates interoperability with other users and privacy. This might be suitable for future multimedia services since it provides wired line quality voice, privacy and high data rates. B-CDMA permits access within a building as well as outdoors. TDMA has the advantage in that common radio equipment can be shared among the users at a particular frequency. With respect to CDMA, TDMA has the advantage of much less stringent power control requirements, since inter-user interference is controlled by timeslot and frequency allocation instead of by processing gains resulting from coded bandwidth spreading. Though CDMA is advantageous for bursty traffic, TDMA may be preferred when there are different user requirements in terms of service. The complexity and cost of the circuitry involved using CDMA should be considered against the net benefit anticipated in the system. The use of CDMA is not viable in a low-traffic-density area.

6 Limitations for providing Multimedia Services

Multimedia developments will support the ever-growing demand for mixed data, voice and imagery applications. Major research activity will be required to develop the technologies to support ubiquitous access to the evolving network services through a wireless, multimedia terminal [18] [16]. Figure 2 shows a future network environment. Research is needed at all levels, extending from circuit design in the portable units, to the protocols on the high speed backbone networks. The network should provide

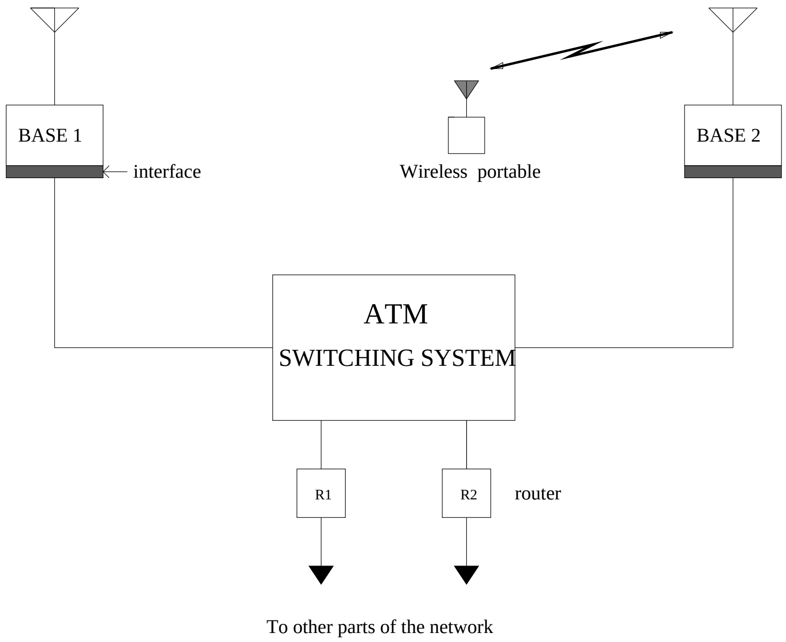

Figure 3: An illustration of wireless base stations connected through an ATM switch.

some guarantees with respect to bandwidth, jitter and latencies. Once again the wireless link design becomes a trade-off between capacity and interference. Spectrum usage is of great concern since per-user data rates can easily exceed 2 Mb/s. This data rate may not be needed on a continuous basis since tasks such as word processing or spreadsheet require only slight screen changes on a frame-by-frame basis. Minimizing over-all system bandwidth consumption while supporting a large number of users simultaneously is very important. This is supported by the cellular networking environment. For an application like video in a wired distributed network the processing required during playback (such as decompression and the associated frame buffering) is performed at the client side to avoid overloading the server [12]. This is not possible in the wireless terminal owing to the low power consumption requirements of the terminal. The host mobility requires *handoffs* whose time should be minimized to minimize the disruptions during video playback. The design of an effective user interface is also a critical issue. Also the communication is likely to be asymmetric, since the user primarily controls the information flow.

7 ATM and Wireless

Asynchronous transfer mode (ATM) is expected to have a strong impact on the concepts and interfaces within the framework of evolution into the third generation mobile systems and personal-mobility services [3]. Currently popular wireless transmission systems using infrared and radio frequencies have radically different multipath and interference properties that are again different from the properties in an ATM network based on point-to-point fiber links. The implementation of connected-oriented ATM services over wireless is a challenging task due to the bandwidth inconsistencies between the fixed and the wireless networks [1]. In addition to the loss and delay constraints the mobility of the end users introduces greater challenges in the ATM environment. Figure 3 shows the general architechture consisting of the ATM switching system and base stations. Although few prototypes have been built to investigate the feasibility of ATM in a wireless environment, the literature emphasizes the following research areas for further investigation.

7.1 Quality of Service (QoS)

ATM allows a quality of service (QoS) to be associated with each connection which should be guaranteed throughout the connection. The frequently changing wireless network conditions and user mobility may necessitate redefining the QoS parameters in the wireless environment. For instance, the user-specified degree of mobility is considered to be one of the most important wireless QoS parameters where the network needs to reserve resources according to the expected number of connection handovers. The handover failure and latency can also be investigated as QoS specifications where the parameters can be chosen based on the specific traffic types and their performance requirements.

7.2 Medium Access Control

The MAC technique used will have a significant impact on user performance, system capacity, and mobile terminal complexity and is therefore an important design parameter [3]. To provide per connection QoS guarantees over wireless, it is necessary to have a MAC protocol with sufficient reservation control on the raw wireless medium resources. To achieve transparency for the ATM applications is a design challenge. The wireless MAC protocols should have mechanisms for handling high error rates, frequent changes in network configuration, overlapping of subnets and security aspects.

7.3 Adaptation Layer

The mobility of users causes a frequent topology reconfiguration, which may cause the ATM cells to arrive out of order. This is also possible during a handover process when the cells of a single connection travel through different paths before and after the handover. The ATM adaptation layer (AAL) proposed for the wired ATM networks, does not specify any protection mechanism for cell out-of-ordering. This may require the consideration of alternative AAL protocols for the support of wireless applications.

7.4 Connection Management

The implementation of ATM in the third generation PCN systems requires careful redesign of the network layer signalling and the connection management services. Routing in a connection-oriented wireless environment needs a radically different approach from the connection oriented IP datagram-oriented designs. Handover is one of the most crucial management operations and providing QoS guarantees during handover is a challenging task. The multiple access nature of wireless networks calls for a resource reservation mechanism which is different from wired networks.

7.5 Viewpoints

The reliability of the wireless transmission link can be increased by per-cell acknowledgements from base stations due to the small round-trip time [3]. This approach certainly leads to further complications when the network is based on explicit handover, when a mobile user passes from one cell to another, most of the network traffic will be due to signalling. An important observation is that for keeping the mobility transparent to the end-points, the virtual circuit identifiers (VCIs) used by the endpoints should not change during a connection handover. Ideally the wireless network should provide the same QoS guarantees as the wired network, but in practice the QoS requirements may be renegotiated. In a mobile environment, more flexibility may be desirable, such as providing a range of acceptable performance values that a circuit can have before the application is notified or the circuit is canceled. Protection against the cell loss cannot be implemented in the AAL since cell loss appears when an ATM-cell header becomes disrupted whereas the measures at AAL level can only protect the ATM-cell payload. Additional measures can be introduced at ATM layer level by which more errors can be corrected in the ATM cell header. This would however require additional cell overhead and would be incompatible with the standardized format of ATM cells. The protection measures can be implemented in the physical layer [3]. In addition, the nature of radio spectrum, cellular division and mobility of the users in wireless networks makes effective traffic control and resource allocation very difficult.

8 Conclusions

Wireless networks are much slower than wireline networks. This manifests as a challenge to the application programmers since users will expect to be able to run the same applications from wireline and wireless terminals. Some of the currently available wireless networks are able to support e-mail within limited geographical areas. Currently very little is known about the demands various applications place on a wireless network. Moreover, applications may change to make the best use of the wireless environment. For example, multicast is an important service provided by wireless networks which can be exploited in designing new applications. Different user requirements are satisfied by different technologies and hence the choice of the transmission technology or an access technique depends on the particular application. The goal of wireless communications is to allow user access to the capabilities of the global network at any time without regard to location or mobility. This requires ubiquitous wireless network connectivity, adequate wireless bandwidth, and small portable computing platforms with sufficient functionality. Significant research opportunities exist in this discipline ranging from access and assignment methods to handling real time mobility and call control services. As heterogeneous traffic arises due to multimedia services, there will be more challenging design and traffic problems. Although there are inherent limitations in the wireless medium, various techniques can be developed which can overcome these limitations and thereby increase the achievable data rates [13]. Current trends in the evolution of wireless data services indicate that wireless medium will be used as the "first mile" of the information highway.

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