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Multiple Access Techniques–An Overview

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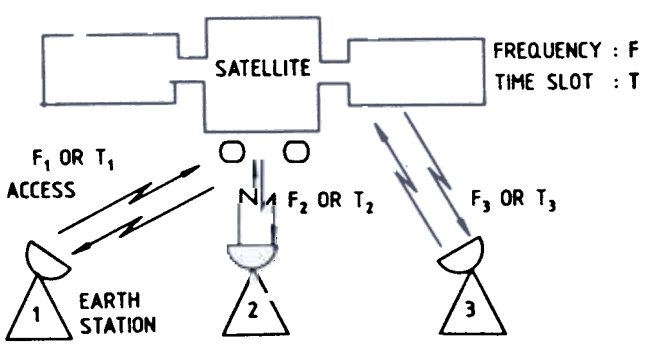
ABSTRACT

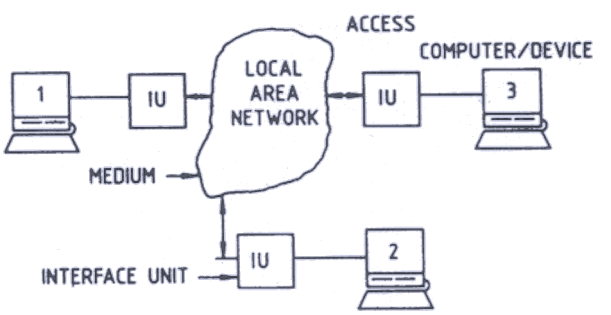
Multiple access techniques provide a means of sharing the network media, nodes, peripheral devices, and information/databases have become very important particularly because of the expansoin in the number and location of users. In this paper an overview of the different resources for multiple access and their optimum use by proper assignment and control has been presented in a unified manner to embrace satellite communications as well as the computer networks.

1. INTRODUCTION

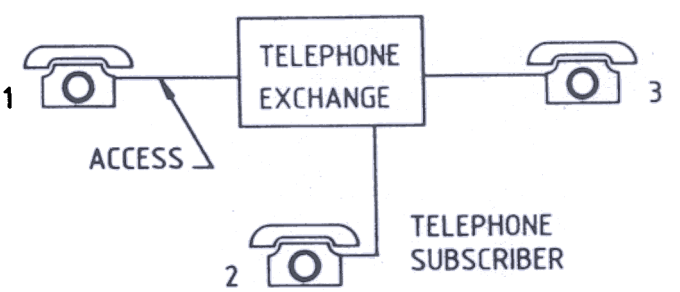
Whenever a large number of geographically scattered users communicate by gaining access to a common point, node, device, centre or medium, it is called multiple access communications. A telephone exchange, a satellite and local area computer networks, (Fig.1) are some of the important examples of multiple access communications. A large number of telephone subscribers first gain access to a telephone switching centre before they communicate with one another. Multiple access become more important when satellites appeared on the communications scene. Different user earth stations are able to communicate via satellites by employing one or the other multiple access techniques. The local area computer networks have further



(a) EARTH STATIONS (1,2,3) ACCESS THE SATELLITE



(b) COMPUTERS (1,2,3) ACCESS LAN TO COMMUNICATE WITH EACH OTHER



(C) TELEPHONE SUBSCRIBERS (1,2,3) ACCESS THE EXCHANGE

Figure 1. Examples of multiple access communications.

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increased the importance of multiple access techniques in the recent times. The different users in a computer network access the common medium in order to transmit information to the destination.

Whatever be the telecommunication application, the basic issues in multiple access communications remain the same. Resources and the control techniques are vital aspects of multiple access communications. The resources play an important role because the large number of users have to really share the same resource in order to communicate. Since the number of users and their demands are continuously increasing while the resources are always limited, it becomes necessary to devise ways and means to make the best use of the resource. This can be done by developing and designing control and assignment techniques. In this paper some important multiple access resources and their control techniques are discussed in a brief and unified manner.

2. RESOURCES

There are primarily three resources which can be used for providing multiple access communication facilities to the users. They are space, frequency and time leading to space division (SD), frequency division (FD) and time division (TD) multiple access (MA) techniques, (Fig.2). In SDMA, a given space is subdivided into smaller segments which are assigned to different users. In a telephone network, the individual subscriber lines to the telephone exchange are laid in space. In satellite communications, many spot beams, each serving a different region, are used on the SDMA basis. Frequency spectrum is another natural resource and is used for providing multiple access. In FDMA, a given frequency band is subdivided (Fig.3), into smaller bands each of which is allocated to a different user. This technique has been used in telecommunications since the beginning of radio communication and broadcasting. In a satellite communication system, a frequency band of 500 MHz is sub divided into 12 bands each with a width of 36 MHz. Each of the twelve transponders is used to serve a different application. The 36 MHz band is further subdivided into smaller bandwidths to be assigned to different users. Thus every user transmits a different carrier frequency in FDMA to avoid interference and overlapping.

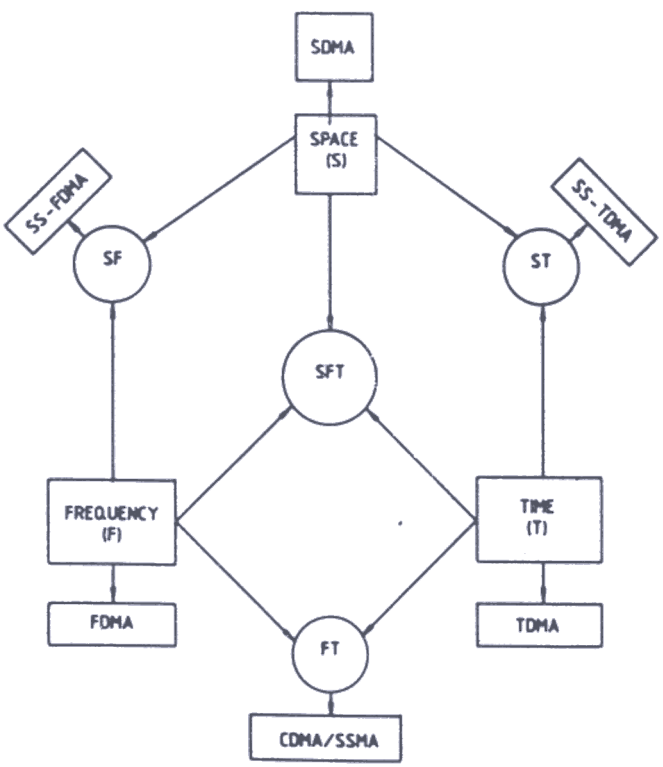

Figure 2. Multiple access resources (W.W.Wu).

The SDMA technique is generally inefficient, inflexible and not cost-effective compared to other multiple access techniques. The FDMA technique, though very popular because of its simplicity to use and operate, is not very flexible. Spectrum and power utilisation are also not optimum in the FDMA systems because of the spectrum wastage due to provision of guard bands between adjacent channels and the low power operation of the amplifiers to prevent inter-modulation products. The use of time for multiple access applications has gained momentum because of the digital technology revolution and the easy availability of the VLSI/IC devices. The TDMA techniques offer greater flexibility and better spectrum and power utilisation efficiencies as compared to both the SDMA and FDMA. The TDMA systems inherently use the digital signals and techniques and therefore, have all the advantages of digital communications. However, they suffer from the stringent requirements of synchronisation among different users. Of course, the problems of synchronisation are getting resolved with the advent of developments in digital signal processing techniques and microelectronics. In order to make use of time for multiple access communications, first a time-frame, (Fig. 3) is defined such that every frame has information signal from a user and at the destination the information from every frame is delivered without any discontinuity in the signal. For

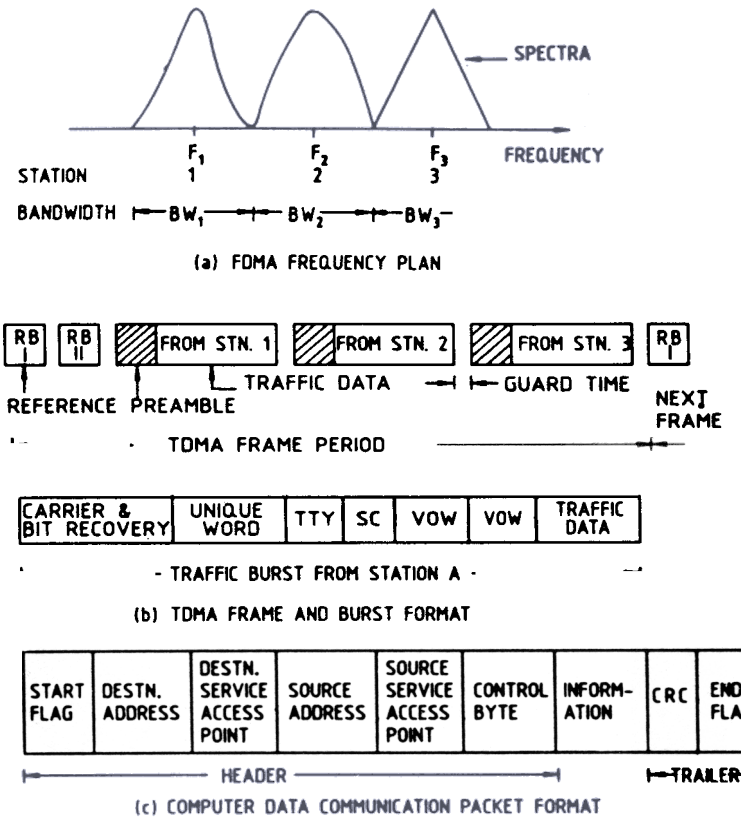

Figure 3. Frequency and time division slots (a) FDMA frequency plan, (b) TDMA frame and burst format and (c) computer data communication packet format.

example, in voice applications, sampling of speech signals at 8 kHz, results in a primary frame period of 125 μ s. In many practical TDMA systems, longer frame periods--multiple of 125 microseconds are taken in order to reduce the overhead bits necessary in each frame for synchronisation, address and control purposes. For example the frame period in Intelsat TDMA systems is 2 ms. The frame period is subdivided into smaller time slots which are then assigned to individual users. Thus no two users transmit at the same time. A guard time is provided between adjacent time slots to avoid overlap between them and to ease stringent requirements of synchronisation. The TDMA techniques find increasing applications in satellite communications and in computer networks, particularly the local area networks (LANs). In fact most of the LANs use primarily TDMA in one form or the other.

So far the use of the three resources have been discussed individually. When there is a greater demand for accommodating more users, two resources are combined together. For example, by combining space and frequency, the number of users can be increased considerably without extending the spectrum further. The same frequency spectrum is reused in different isolated spaces. The number of channels can be increased as many times as the number of reuses. In practice, however, the total number of channels is less because some channels are required to interlink these isolated spots. With the help of isolated spot beams and reusing the given frequency spectrum, the effective bandwidth in satellite communication is increased manifold. Since TDMA has been found to be more efficient and flexible than FDMA, a combination of space and time is considered superior to the space and frequency combination because all the advantages of the TDMA are then available. Once again considering the satellite communications, a large geographical area can be split into many smaller segments each being covered by a separate isolated spot beam. Every segment has user transmitting information using the TDMA mode. The spot beams are interlinked by time switching synchronised with the TDMA. This combination of space and time, known as

satellite-switched time division multiple access (SS-TDMA) is considered to yield high spectrum utilisation efficiency.

In addition to the space frequency and the space time hybrid multiple access resource sharing schemes, the scheme using a hybrid of the frequency and the time is also very attractive. Both the time-frame and the given bandwidth are split into smaller time slots and frequency bands and a multiple access user transmits (Fig. 4) his information at different frequencies during

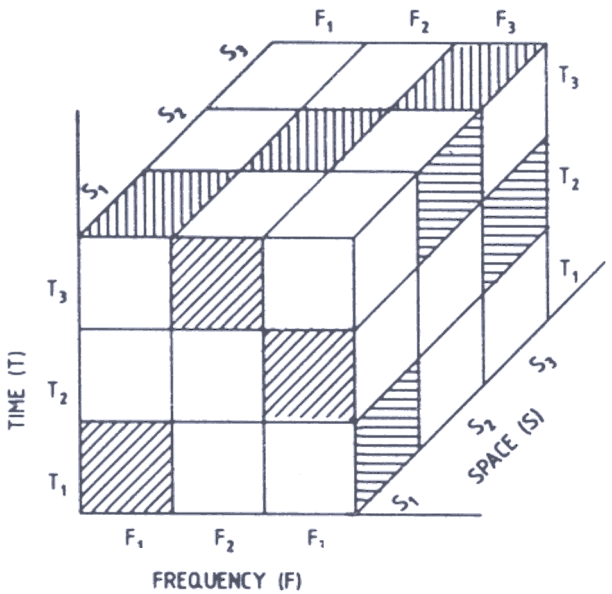

Figure 4. SFT resource cube.

different time slots in accordance with a predetermined code (frequency-time combination). Every user has a distinct code and transmits using the whole bandwidth for the entire frame duration. Thus the time-bandwidth product of the user's signal is much larger than unity unlike the FDMA and the TDMA where it is nearly unity. This multiple access technique is known as spread spectrum (and also F-T matrix) multiple access (SSMA) due to the resultant spectrum spreading of the signal. The SSMA techniques find applications where features like signal hiding, secrecy, anti-jamming, random access and flexible number of users are of paramount importance. Both satellite and fibre-optic networks use the SSMA techniques for special requirements. Direct sequence/binary phase shift keying (DS/BPSK) and frequency-hopping/multi frequency shift keying (FH/MFSK) are the two more generally used SSMA techniques used in radio and satellite networks.

3. ASSIGNMENT AND CONTROL

Resources like space, frequency and time, and their hybrids form the backbone of the multiple access schemes. In order to use these resources properly, it is very important to understand and develop methods of their assignment to different users and to control their use. The problems of assignment and control become very relevant when the resources are limited and the demand is more. Who and how one should get the access to the common resource is a question which needs due attention. The simplest method of assignment would be to allocate separate space, time or frequency slots to different users permanently. This kind of fixed assignment would work well if the number of users is equal to or less than the total number of available slots or channels. When the number of users is more than the number of available channels, alternative schemes have to be developed to satisfy the needs in an optimum manner. Demand assignment techniques have been developed to overcome the difficulty of large number of users. In this scheme, all the channels (resources) are kept in a pool and are allocated to the users on a demand basis. Separate channels have to be kept aside and control techniques are required to be developed to enable users to make requests and to get served. Centralised or distributed control stations are needed to implement the demand assigned system. All these make the system more costly and complex in operation. While fixed assignment is quite suitable when a user has heavy continuous traffic, the demand assignment scheme serves the purpose better in the case of random traffic requirements. In a mixed situation, a hybrid of the fixed and the demand assignment schemes is preferred. In the hybrid scheme, users are assigned specific channels for their heavy and continuous traffic but some channels are kept in a common pool for assignment based on demand. Satellite communication systems use both preassignment and demand assignment schemes in both the FDMA and the TDMA modes. Majority of the time division and the frequency division slots are pre-assigned to take care of the regular heavy traffic between different stations. For the scattered and random users they have single channel per carrier system. The SPADE (single channel per carrier pulse code modulation multiple access demand assignment equipment) is one such famous system where there are 800 carriers in a 36 MHz band each with a bandwidth of 38 kHz to support PCM digital voice at 64 kbps. A

pair of frequencies for bothway communication is assigned to a user on demand for which there is a separate signalling channel based on TDMA. This system is a good example of a hybrid of TDMA and FDMA.

Instead of fixed and demand assignment schemes, it may be preferable to have a random access scheme where a user gains access whenever he requires, without need for making any request. As mentioned earlier, the SSMA provides such a random access capability but the system is quite complex and costly to be commercially viable. Simple random access scheme which does not require any complex demand assignment protocols and equipment has been developed but is useful only for light and bursty traffic as in the case of computer communications. Such a scheme is popularly known as ALOHA, which was developed for computer data communication. In this scheme a broadcast channel is made available to be used by all users. As and when required, a user transmits data packets (Fig. 3). If any other user also transmits at the same time on the channel, the packets collide and are said to be destroyed. If the traffic is random and bursty in nature, then the probability of collision is small. Such a pure ALOHA scheme provides a truely random access capability. While pure ALOHA is quite simple to implement, its throughput is rather small (about 18 per cent). By introducing some kind of a self-control in the form of fixing the epoch of transmission for every user as in slotted ALOHA, the wasted time due to collision is reduced and the throughput is doubled. If throughput has to be further increased, more of self, centralised or distributed control has to be introduced. In the carrier sense multiple access (CSMA) technique, a user listens to the channel before transmission and transmits only when the channel is free. This considerably reduces the chances of collision and thus increases the throughout further. In spite of this care, collisions may take place and to make the channel free, collisions should be immediately detected and a warning signal should be issued to indicate to all users about the collision so that they need not transmit at that time. This scheme, namely the CSMA/CD (collision detection) has become very popular in present day local area computer networks using the bus topology by the trade name of Ethernet. The IEEE 802.3 standard specifies this scheme fully.

The CSMA/CD protocol does not guarantee opportunity to every user who has to depend more on his chance and has to keep on trying to get an access. To obviate this difficulty, the use of a token is suggested on the bus. A token is issued on the bus and a user having the token only can transmit thus avoiding collisions totally. The logical order in which the token should be passed from one user to the next can be decided beforehand, thus ensuring every user the opportunity to transmit. The token-bus protocol has been standarised by the IEEE as 802.4. It should be noted how the token bus has more control in its protocol compared to ALOHA or CSMA.

The idea of token passing is also very popularly used in the ring type of LANs. A token circulates uni-directionally in a ring and a user intending to transmit captures the token and then transmits the data packets. After the transmission, user releases the token. The capture of the token gives the user the right to transmit. The IEEE 802.5 specifies the token ring protocols. Empty slot ring is another version of the token ring where an empty slot instead of the token circulates on the ring. Polling is another controlled multiple access scheme where a central hubnode asks every user in turn whether it has any thing to transmit. Figure 5 shows classification of different multiple access, control and assignment schemes.

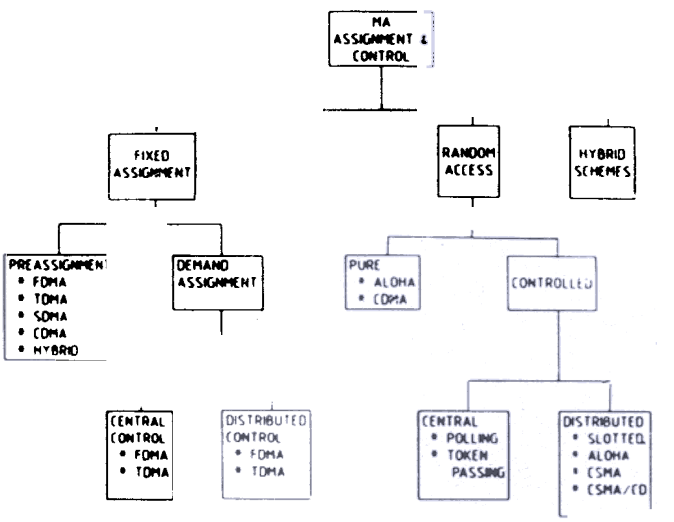

Figure 5. Multiple access control and assignment classification.

It should be noted that the random and the controlled multiple access schemes described above, for the computer data networks, like the pure/slotted ALOHA, the CSMA/CD, the token-bus/ring, and the polling are nothing but some form of the TDMA with

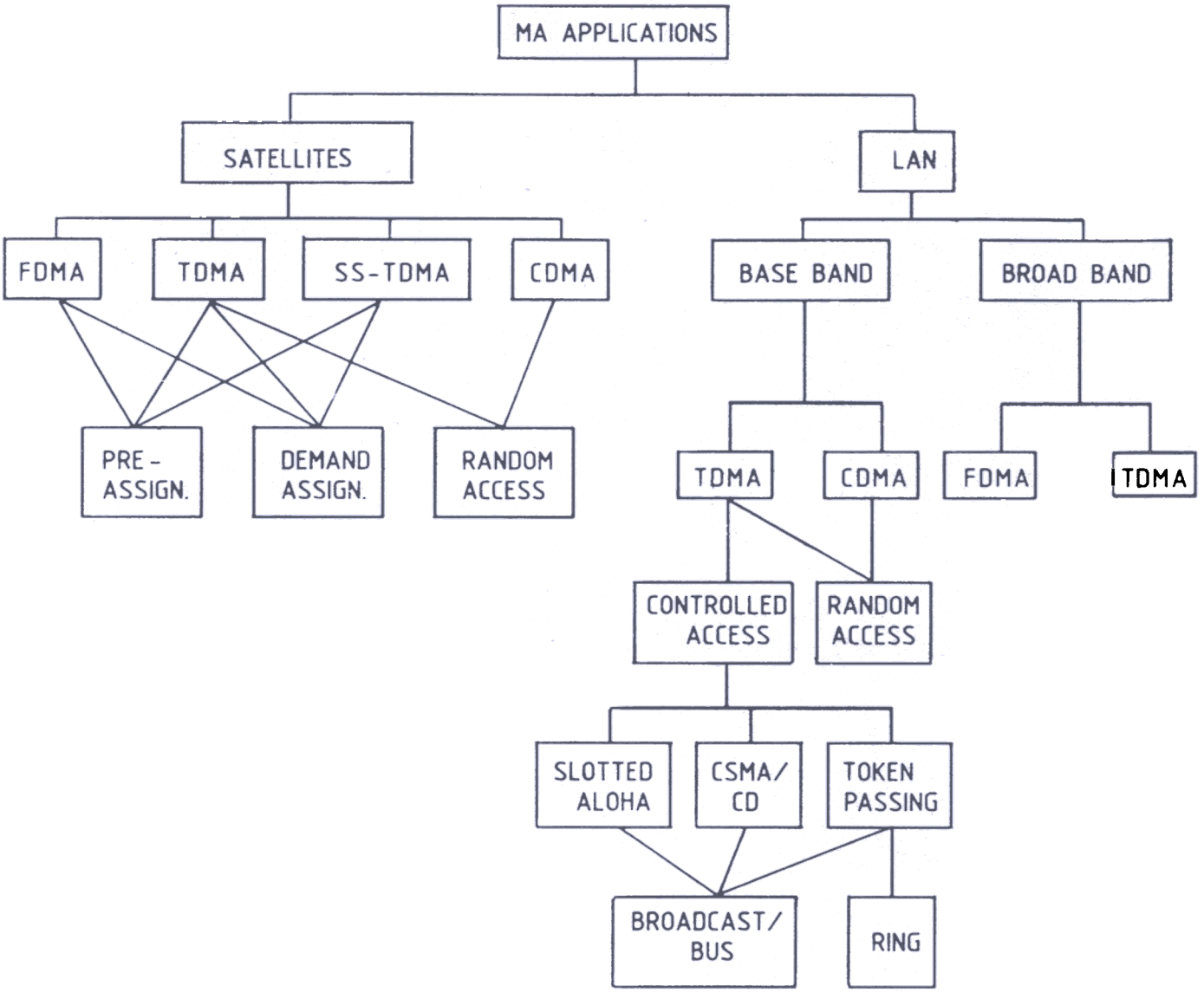

Figure 6. Applications of MA resources and assignment techniques.

variable degrees of control. Like hybrid schemes for sharing the primary resources, hybrid schemes for assignment and control have also been developed for specific applications. Many new multiple access schemes for packet radio and satellite networks have been developed. Different applications of multiple access resources and assignment techniques are summarised in Fig. 6.

4. CONCLUSIONS

Multiple access schemes comprise of two major components, the resources and the assignment and control protocols. The efficacy of a particular multiple access scheme depends on the proper choice of both the components. The resources to be used and how best they can be used have to be decided depending on the needs and applications in mind. Multiple access techniques are fundamental to all telecommunication networks irrespective of the type of signal and the type of medium. The basic concepts, and the design considerations of multiple access communication have been discussed in a unified way with some examples of popularly used techniques. A variety of multiple access systems can be designed considering the basic resources like space, frequency and time; the basic assignment and control requirements like fixed or demand assignment; and random or controlled access, to suit a particular application. The fundamental concepts of the multiple access techniques for both satellite communication and computer networks are the same.