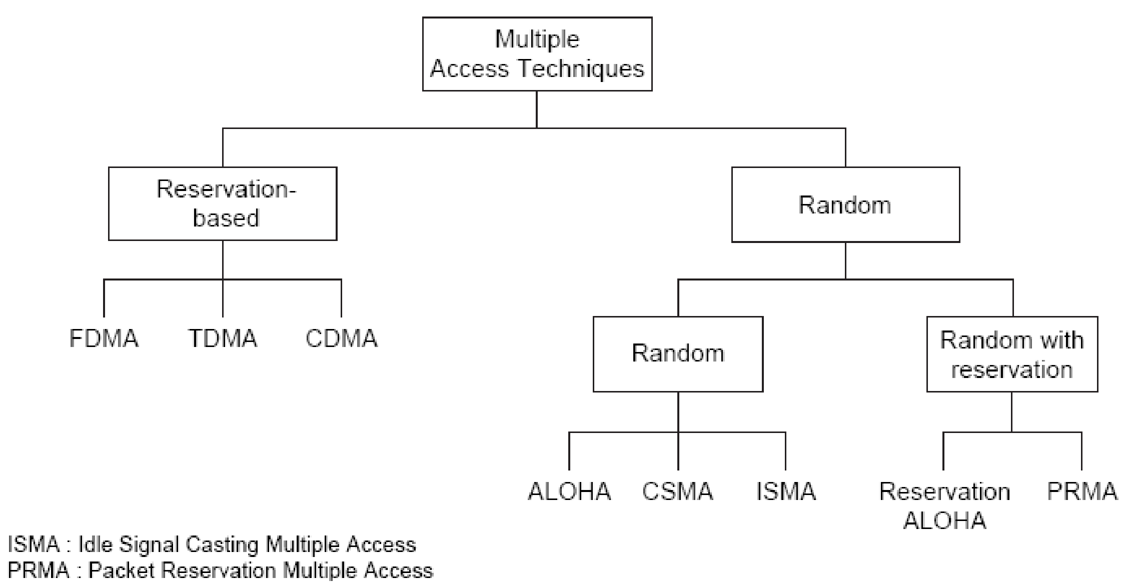
Multiple Access Techniques

In Chapter 5 we discussed that cellular systems divide a geographic region into cells where mobile units in each cell communicate with the cell's base station. The goal in the design of a cellular system is to be able to handle as many calls as possible in a given bandwidth with the specifi ed blocking probability (reliability). Multiplexing deals with the division of the resources to create multiple channels. Multiplexing can create channels in frequency, time, etc., and the corresponding terms are then frequency division multiplexing (FDM), time division multiplexing (TDM), etc. [1,3]. Since the amount of spectrum available is limited, we need to fi nd ways to allow multiple users to share the available spectrum simultaneously. Shared access is used to implement a multiple access scheme when access by many users to a channel is required [13,14,15]. For example, one can create multiple channels using TDM, but each of these channels can be accessed by a group of users using the ALOHA multiple access scheme [8,9]. The multiple access schemes can be either reservation-based or random. Multiple access schemes allow many users to share the radio spectrum. Sharing the bandwidth effi ciently among users is one of the main objectives of multiple access schemes [16,17]. The variability of wireless channels presents both challenges and opportunities in designing multiple access communications systems. Multiple access strategy has an impact on robustness and interference levels generated in other cells. Therefore, multiple access schemes are designed to maintain orthogonality and reduce interference effects [10]. Multiple access schemes can be classifi ed as *reservation-based* multiple access (e.g., FDMA, TDMA, CDMA) [4,5] and *random* multiple access (e.g., ALOHA, CSMA) (see Figure 6.1) [9,23]. If data traffi c is continuous and a small transmission delay is required (for example in voice communication) reservationbased multiple access is used. The family of reservation-based multiple access includes frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA) [6,7,12,21,22]. In many wireless systems for voice communication, the control channel is based on random multiple access and the communication channel is based on FDMA, TDMA, or CDMA. The reservation-based multiple access technique has a disadvantage in that once the channel is assigned, it remains idle if the user has nothing to transmit, while other users may have data waiting to be transmitted.



Narrowband Channelized Systems

Traditional architectures for analog and digital wireless systems are channelized [6,11]. In a channelized system, the total spectrum is divided into a large number of relatively narrow radio channels that are defi ned by carrier frequency. Each radio channel consists of a pair of frequencies. The frequency used for transmission from the base station to the mobile station is called the *forward channel* (downlink channel) and the frequency used for transmission from the mobile station to the base station is called the *reverse channel* (uplink channel). A user is assigned both frequencies for the duration of the call. The forward and reverse channels are assigned widely separated frequencies to keep the interference between transmission and reception to a minimum.

Frequency Division Multiple Access

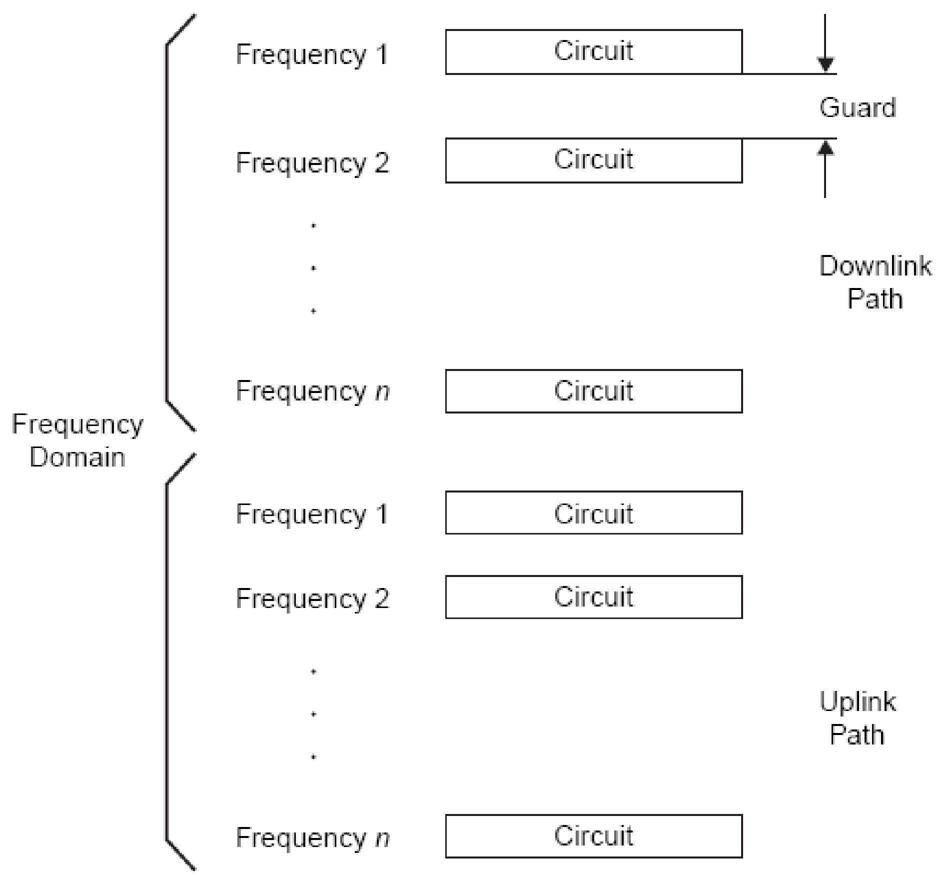
The FDMA is the simplest scheme used to provide multiple access. It separates different users by assigning a different carrier frequency (see Figure 6.2). Multiple users are isolated using bandpass fi lters. In FDMA, signals from various users are assigned different frequencies, just as in an analog system. Frequency guard bands are provided between adjacent signal spectra to minimize crosstalk between adjacent channels. The advantages and disadvantages of FDMA with respect to TDMA or CDMA are:

Advantages

1. Capacity can be increased by reducing the information bit rate and using an effi cient digital speech coding scheme (See Chapter 8) [20].
2. Technological advances required for implementation are simple. A system can be confi gured so that improvements in terms of a lower bit rate speech coding could be easily incorporated.
3. Hardware simplicity, because multiple users are isolated by employing simple bandpass fi lters.

Disadvantages

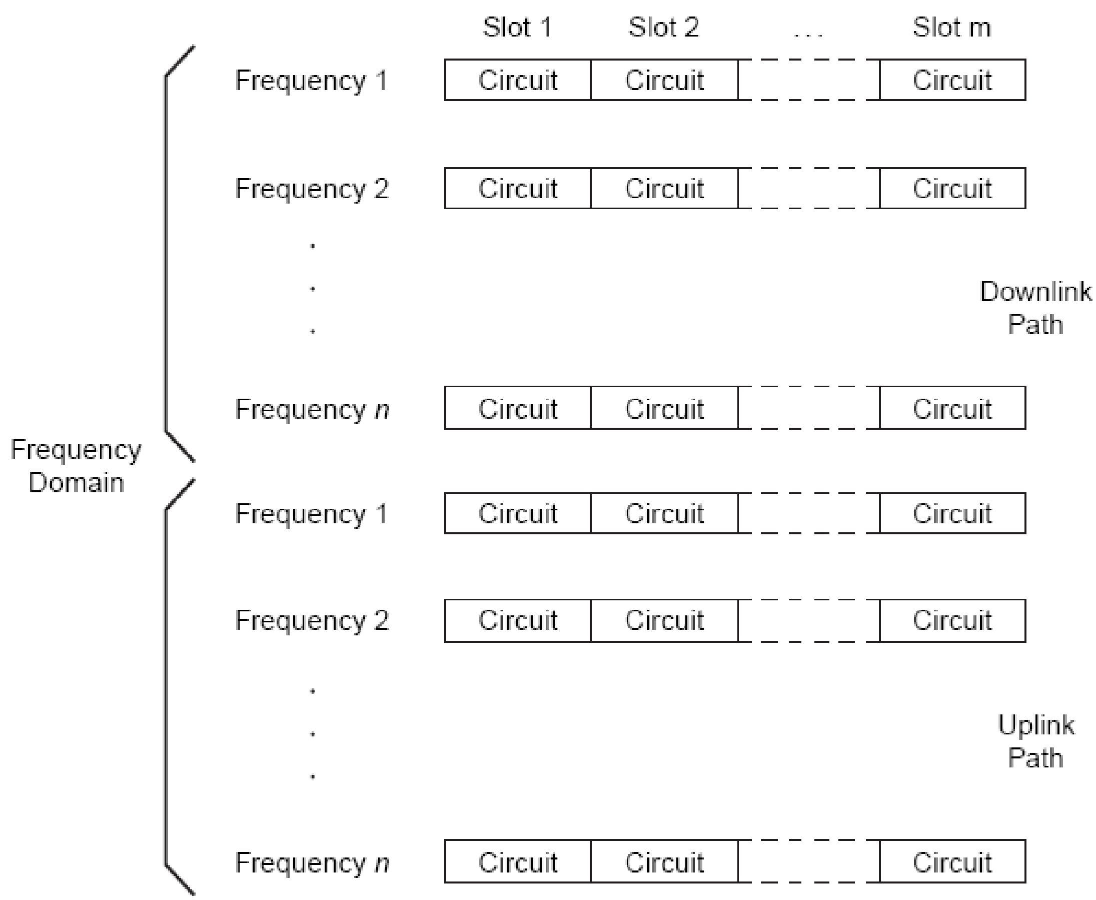
1. The system architecture based on FDMA was implemented in fi rstgeneration analog systems such as advanced mobile phone system (AMPS) or total access communication system (TACS). The improvement in capacity depends on operation at a reduced signal-to-interference (*S/I*) ratio. But the narrowband digital approach gives only limited advantages in this regard so that modest capacity improvements could be expected from the allocated spectrum.
2. The maximum bit-rate per channel is fi xed and small, inhibiting the fl exibility in bit-rate capability that may be a requirement for computer fi le transfer in some applications in the future.



3. Ineffi cient use of spectrum, in FDMA if a channel is not in use, it remains idle and cannot be used to enhance the system capacity.
4. Crosstalk arising from adjacent channel interference is produced by nonlinear effects.

Time Division Multiple Access

In a TDMA system, each user uses the whole channel bandwidth for a fraction of time (see Figure 6.3) compared to an FDMA system where a single user occupies the channel bandwidth for the entire duration (see Figure 6.2) [2]. In a TDMA system, time is divided into equal time intervals, called *slots*. User data is transmitted in the slots. Several slots make up a frame. Guard times are used between each user's transmission to minimize crosstalk between channels (see Figure 6.4). Each user is assigned a frequency and a time slot to transmit data. The data is transmitted via a radio-carrier from a base station to several active mobiles in the downlink. In the reverse direction (uplink), transmission from mobiles to base stations is time-sequenced and synchronized on a common frequency for TDMA. The preamble carries the address and synchronization information that both the base station and mobile stations use for identification.

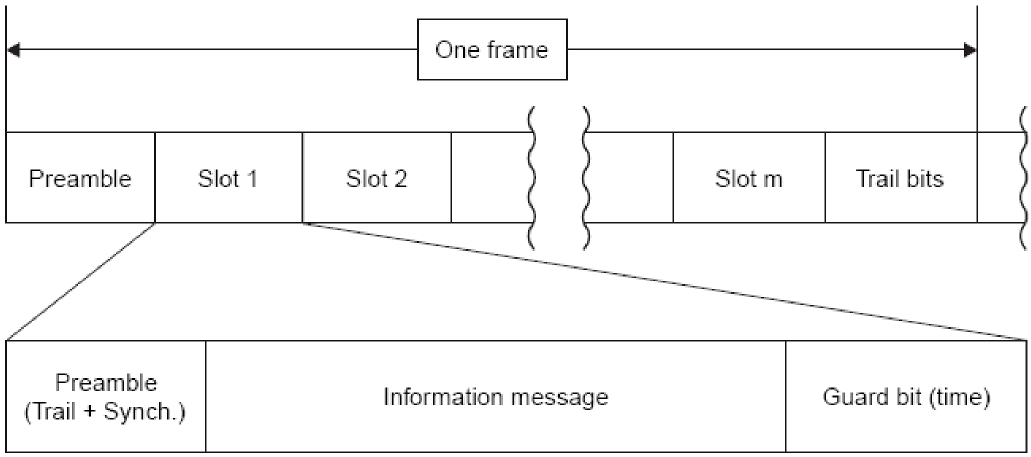


In a TDMA system, the user can use multiple slots to support a wide range of bit rates by selecting the lowest multiplexing rate or multiple of it. This enables supporting a variety of voice coding techniques at different bit rates with different voice qualities. Similarly, data communications customers could use the same kinds of schemes, choosing and paying for the digital data rate as required. This would allow customers to request and pay for a bandwidth on demand. Depending on the data rate used and the number of slots per frame, a DMA system can use the entire bandwidth of the system or can employ an FDD scheme. The resultant multiplexing is a mixture of frequency division and time division. The entire frequency band is divided into a number of duplex channels (about 350 to 400 kHz). These channels are deployed in a frequency-reuse pattern, in which radio-port frequencies are assigned using an autonomous adaptive frequency assignment algorithm. Each channel is configured in a TDM mode for the downlink direction and a TDMA mode for the uplink direction. The advantages and disadvantages of TDMA are:

Advantages

1. TDMA permits a fl exible bit rate, not only for multiples of the basic single channel rate but also submultiples for low bit rate broadcast-type traffic.

2. TDMA offers the opportunity for frame-by-frame monitoring of signal strength/bit error rates to enable either mobiles or base stations to initiate and execute handoffs.
3. TDMA, when used exclusively and not with FDMA, utilizes bandwidth more efficiently because no frequency guard band is required between channels.



4. TDMA transmits each signal with suffi cient guard time between time slots to accommodate time inaccuracies because of clock instability, delay spread, transmission delay because of propagation distance, and the tails of signal pulse because of transient responses.

Disadvantages

1. For mobiles and particularly for hand-sets, TDMA on the uplink demands high peak power in transmit mode, that shortens battery life.
2. TDMA requires a substantial amount of signal processing for matched fi ltering and correlation detection for synchronizing with a time slot.
3. TDMA requires synchronization. If the time slot synchronization is lost, the channels may collide with each other.
4. One complicating feature in a TDMA system is that the propagation time for a signal from a mobile station to a base station varies with its distance to the base station.

Wideband Systems

In wideband systems, the entire system bandwidth is made available to each user, and is many times larger than the bandwidth required to transmit information. uch systems are known as *spread spectrum* (SS) systems. There are two fundamental types of spread spectrum systems: (1) direct sequence spread spectrum (DSSS) and (2) frequency hopping spread spectrum (FHSS) [3,26]. In a DSSS system, the bandwidth of the baseband information carrying signals from a different user is spread by different codes with a bandwidth much larger than that of the baseband signals (see Chapter 11 for details). The spreading codes used for different users are orthogonal or nearly orthogonal to each other. In the DSSS, the spectrum of the transmitted signal is much wider than the spectrum associated with the information rate. At the receiver, the same code is used for despreading to recover the baseband signal from the target user while suppressing the transmissions from all other users (see Figure 6.5). One of the advantages of the DSSS system is that the transmission bandwidth exceeds the coherence bandwidth (see Chapter 3). The received signal, after dispreading (see Chapter 11 for details), resolves into multiple signals with different time delays. A Rake receiver (see Chapter 11) can be used to recover the multiple time

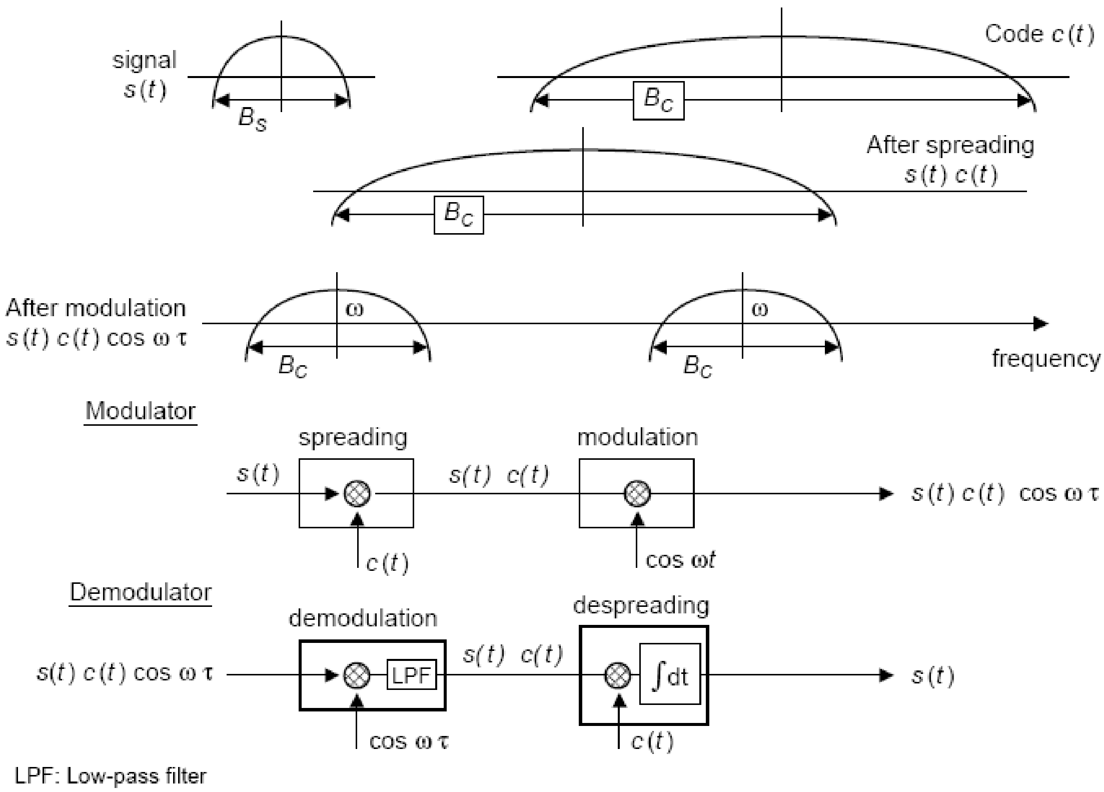


Figure 6.5 Direct sequence spread spectrum.

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