In one sense, the technique used to obtain position information is straightforward: because all GPS satellites orbit in well-known positions, a receiver can determine a unique location on the earth's surface by finding the distance to three satellites. To see why, consider the set of points distance D_1 from Satellite 1. The set defines a sphere. Similarly, the set of points distance D_2 from Satellite 2 defines another sphere. A GPS system that is simultaneously D_1 from Satellite 1 and D_2 from Satellite 2 lies on the circle that is formed by the intersection of the two spheres. If the GPS system is also distance D_3 from Satellite 3, the GPS system will be in the intersection of a third sphere with the circle, which results in two possible points. The satellites are arranged so that only one of the two points lies on the Earth's surface and the other is in space, making it easy to choose the correct point.

To compute distance, a GPS system applies the formula from Newtonian physics that specifies distance equals rate times time. The rate is constant (the speed of light, 3×10^9 meters per second). The time is computed by arranging for each GPS system to compute the local time, and for each satellite to have an accurate clock that is used to include a *timestamp* in the information being sent. A receiver can then subtract the timestamp from the local time to determine the time the information has been in transit.

16.21 Software Defined Radio And The Future Of Wireless

The wide variety of wireless technologies described in the chapter each use special-purpose radio hardware. The antenna, transmitter, and receiver in a given device are designed to operate on predetermined frequencies using specific forms of modulation and multiplexing. A cell phone that can use GSM, Wi-Fi, and CDMA networks must have three completely separate radio systems, and must choose among them.

Traditional radios are being replaced by radios that follow a *programmable* paradigm in which features are controlled by software running on a processor. Figure 16.22 lists major radio features that can be controlled in a *Software Defined Radio* (*SDR*).

The key technologies that enable software defined radios are tunable analog filters and multiple antenna management. Analog chips are currently available that provide tunable analog filters. Thus, it is possible to select frequencies and control power. *Digital Signal Processors* (*DSPs*) are available to handle signal coding and modulation. The more interesting aspect of software defined radios concerns the use of multiple antennas. Instead of merely choosing an antenna to use at a given time, a software defined radio can use multiple antennas simultaneously to provide *spatial multiplexing*, a technique that allows a signal to be transmitted or received from a given direction. We use the term *Multiple-Input Multiple-Output* (*MIMO*) to denote a system that employs multiple antennas for both transmission and reception (i.e., can aim transmission or reception).