mobility, allowing users to maintain their TCP sessions while traveling, for example, on a bus or a train. With sufficiently high upstream and downstream bit rates, the user could even maintain video-conferencing sessions while roaming about. This scenario is not that far-fetched. As of 2012, many cellular telephony providers in the U.S. offer their subscribers a cellular Internet access service for under $50 per month with typical downstream and upstream bit rates in the hundreds of kilobits per second. Data rates of several megabits per second are becoming available as broadband data services such as those we will cover here become more widely deployed.

In this section, we provide a brief overview of current and emerging cellular Internet access technologies. Our focus here will be on both the wireless first hop as well as the network that connects the wireless first hop into the larger telephone network and/or the Internet; in Section 6.7 we'll consider how calls are routed to a user moving between base stations. Our brief discussion will necessarily provide only a simplified and high-level description of cellular technologies. Modern cellular communications, of course, has great breadth and depth, with many universities offering several courses on the topic. Readers seeking a deeper understanding are encouraged to see [Goodman 1997; Kaaranen 2001; Lin 2001; Korhonen 2003; Schiller 2003; Scourias 2012; Turner 2012; Akyildiz 2010], as well as the particularly excellent and exhaustive reference [Mouly 1992].

6.4.1 An Overview of Cellular Network Architecture

In our description of cellular network architecture in this section, we'll adopt the terminology of the *Global System for Mobile Communications (**GSM**)* standards. (For history buffs, the GSM acronym was originally derived from *Groupe Spécial Mobile*, until the more anglicized name was adopted, preserving the original acronym letters.) In the 1980s, Europeans recognized the need for a pan-European digital cellular telephony system that would replace the numerous incompatible analog cellular telephony systems, leading to the GSM standard [Mouly 1992]. Europeans deployed GSM technology with great success in the early 1990s, and since then GSM has grown to be the 800-pound gorilla of the cellular telephone world, with more than 80% of all cellular subscribers worldwide using GSM.

When people talk about cellular technology, they often classify the technology as belonging to one of several "generations." The earliest generations were designed primarily for voice traffic. First generation (1G) systems were analog FDMA systems designed exclusively for voice-only communication. These 1G systems are almost extinct now, having been replaced by digital 2G systems. The original 2G systems were also designed for voice, but later extended (2.5G) to support data (i.e., Internet) as well as voice service. The 3G systems that currently are being deployed also support voice and data, but with an ever increasing emphasis on data capabilities and higher-speed radio access links.

CASE HISTORY

3G CELLULAR MOBILE VERSUS WIRELESS LANS

Many cellular mobile phone operators are deploying 3G cellular mobile systems with indoor data rates of 2 Mbps and outdoor data rates of 384 kbps and higher. These 3G systems are being deployed in licensed radio-frequency bands, with some operators paying considerable sums to governments for spectrum-use licenses. 3G systems allow users to access the Internet from remote outdoor locations while on the move, in a manner similar to today's cellular phone access. For example, 3G technology permits a user to access road map information while driving a car, or movie theater information while sunbathing on a beach. Nevertheless, one may question the extent to which 3G systems will be used, given their cost and the fact that users may often have simultaneous access to both wireless LANs and 3G:

- The emerging wireless LAN infrastructure may become nearly ubiquitous. IEEE 802.11 wireless LANs, operating at 54 Mbps, are enjoying widespread deployment. Almost all portable computers and smartphones are factory-equipped with 802.11 LAN capabilities. Furthermore, emerging Internet appliances—such as wireless cameras and picture frames—will also have small and low-powered wireless LAN capabilities.
- Wireless LAN base stations can also handle mobile phone appliances. Many phones are already capable of connecting to the cellular phone network or to an IP network either natively or using a Skype-like Voice-over-IP service, thus bypassing the operator's cellular voice and 3G data services.

Of course, many other experts believe that 3G not only will be a major success, but will also dramatically revolutionize the way we work and live. Most likely, both WiFi and 3G will both become prevalent wireless technologies, with roaming wireless devices automatically selecting the access technology that provides the best service at their current physical location.

Cellular Network Architecture, 2G: Voice Connections to the Telephone Network

The term *cellular* refers to the fact that the region covered by a cellular network is partitioned into a number of geographic coverage areas, known as **cells**, shown as hexagons on the left side of Figure 6.18. As with the 802.11WiFi standard we studied in Section 6.3.1, GSM has its own particular nomenclature. Each cell contains a **base transceiver station (BTS)** that transmits signals to and receives signals from the mobile stations in its cell. The coverage area of a cell depends on many factors, including the transmitting power of the BTS, the transmitting power of the user devices, obstructing buildings in the cell, and the height of base station antennas. Although Figure 6.18 shows each cell containing one base transceiver station residing in the middle of the cell, many systems today place the BTS at corners where three cells intersect, so that a single BTS with directional antennas can service three cells.

The GSM standard for 2G cellular systems uses combined FDM/TDM (radio) for the air interface. Recall from Chapter 1 that, with pure FDM, the channel is partitioned into a number of frequency bands with each band devoted to a call. Also recall from Chapter 1 that, with pure TDM, time is partitioned into frames with each frame further partitioned into slots and each call being assigned the use of a particular slot in the revolving frame. In combined FDM/TDM systems, the channel is partitioned into a number of frequency sub-bands; within each sub-band, time is partitioned into frames and slots. Thus, for a combined FDM/TDM system, if the channel is partitioned into *F* sub-bands and time is partitioned into *T* slots, then

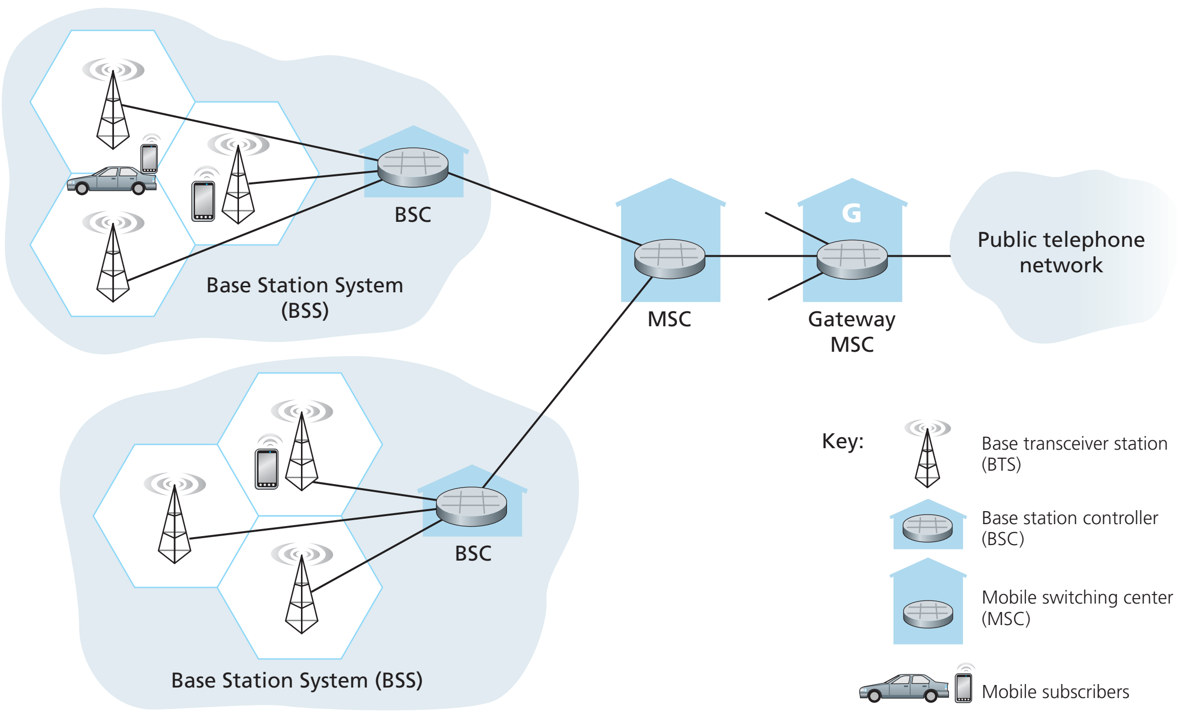

Figure 6.18 ♦ Components of the GSM 2G cellular network architecture