

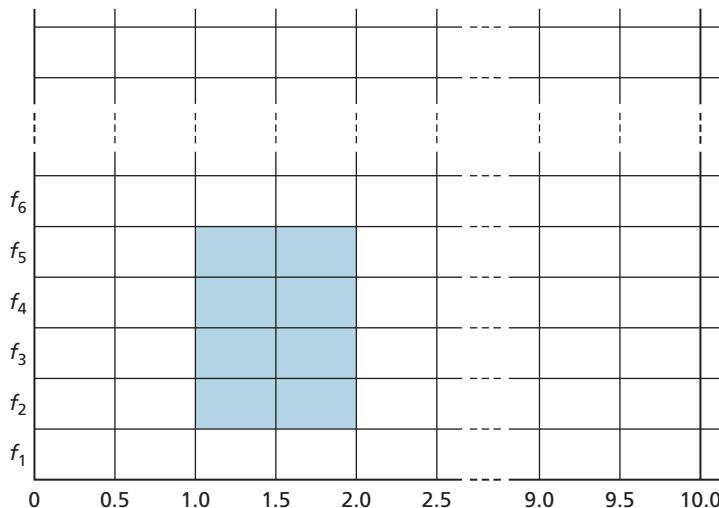
### 6.4.3 On to 4G: LTE

With 3G systems now being deployed worldwide, can 4G systems be far behind? Certainly not! Indeed, the design, early testing, and initial deployment of 4G systems are already underway. The 4G Long-Term Evolution (LTE) standard put forward by the 3GPP has two important innovations over 3G systems:

- **Evolved Packet Core (EPC)** [3GPP Network Architecture 2012]. The EPC is a simplified all-IP core network that unifies the separate circuit-switched cellular voice network and the packet-switched cellular data network shown in Figure 6.19. It is an “all-IP” network in that both voice and data will be carried in IP datagrams. As we’ve seen in Chapter 4 and will study in more detail in Chapter 7, IP’s “best effort” service model is not inherently well-suited to the stringent performance requirements of Voice-over-IP (VoIP) traffic unless network resources are carefully managed to avoid (rather than react to) congestion. Thus, a key task of the EPC is to manage network resources to provide this high quality of service. The EPC also makes a clear separation between the network control and user data planes, with many of the mobility support features that we will study in Section 6.7 being implemented in the control plane. The EPC allows multiple types of radio access networks, including legacy 2G and 3G radio access networks, to attach to the core network. Two very readable introductions to the EPC are [Motorola 2007; Alcatel-Lucent 2009].
- **LTE Radio Access Network.** LTE uses a combination of frequency division multiplexing and time division multiplexing on the downstream channel, known as orthogonal frequency division multiplexing (OFDM) [Rohde 2008; Ericsson 2011]. (The term “orthogonal” comes from the fact the signals being sent on different frequency channels are created so that they interfere very little with each other, even when channel frequencies are tightly spaced). In LTE, each active mobile node is allocated one or more 0.5 ms time slots in one or more of the channel frequencies. Figure 6.20 shows an allocation of eight time slots over four frequencies. By being allocated increasingly more time slots (whether on the same frequency or on different frequencies), a mobile node is able to achieve increasingly higher transmission rates. Slot (re)allocation among mobile nodes can be performed as often as once every millisecond. Different modulation schemes can also be used to change the transmission rate; see our earlier discussion of Figure 6.3 and dynamic selection of modulation schemes in WiFi networks. Another innovation in the LTE radio network is the use of sophisticated multiple-input, multiple output (MIMO) antennas. The maximum data rate for an LTE user is 100 Mbps in the downstream direction and 50 Mbps in the upstream direction, when using 20 MHz worth of wireless spectrum.

The particular allocation of time slots to mobile nodes is not mandated by the LTE standard. Instead, the decision of which mobile nodes will be allowed to transmit in a given time slot on a given frequency is determined by the scheduling algorithms provided by the LTE equipment vendor and/or the network operator. With opportunistic scheduling [Bender 2000; Kolding 2003; Kulkarni 2005], matching the physical-layer protocol to the channel conditions between the sender and receiver and choosing the receivers to which packets will be sent based on channel conditions allow the radio network controller to make best use of the wireless medium. In addition, user priorities and contracted levels of service (e.g., silver, gold, or platinum) can be used in scheduling downstream packet transmissions. In addition to the LTE capabilities described above, LTE-Advanced allows for downstream bandwidths of hundreds of Mbps by allocating aggregated channels to a mobile node [Akyildiz 2010].

An additional 4G wireless technology—WiMAX (World Interoperability for Microwave Access)—is a family of IEEE 802.16 standards that differ significantly from LTE. Whether LTE or WiMAX becomes the 4G technology of choice is still to be seen, but at the time of this writing (spring 2012), LTE appears to have significantly more momentum. A detailed discussion of WiMAX can be found on this book’s Web site.



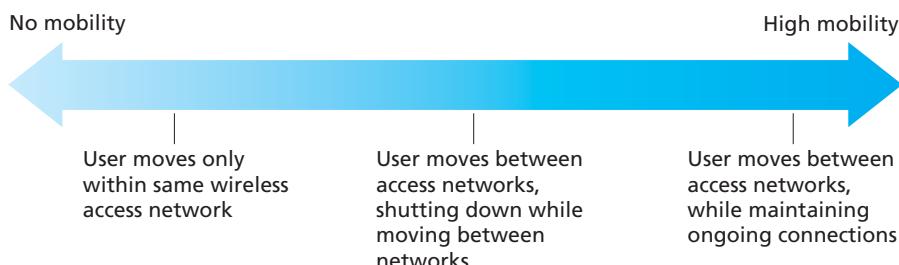
**Figure 6.20** ♦ Twenty 0.5 ms slots organized into 10 ms frames at each frequency. An eight-slot allocation is shown shaded.

## 6.5 Mobility Management: Principles

Having covered the *wireless* nature of the communication links in a wireless network, it's now time to turn our attention to the *mobility* that these wireless links enable. In the broadest sense, a mobile node is one that changes its point of attachment into the network over time. Because the term *mobility* has taken on many meanings in both the computer and telephony worlds, it will serve us well first to consider several dimensions of mobility in some detail.

- *From the network layer's standpoint, how mobile is a user?* A physically mobile user will present a very different set of challenges to the network layer, depending on how he or she moves between points of attachment to the network. At one end of the spectrum in Figure 6.21, a user may carry a laptop with a wireless network interface card around in a building. As we saw in Section 6.3.4, this user is *not* mobile from a network-layer perspective. Moreover, if the user associates with the same access point regardless of location, the user is not even mobile from the perspective of the link layer.

At the other end of the spectrum, consider the user zooming along the autobahn in a BMW at 150 kilometers per hour, passing through multiple wireless access networks and wanting to maintain an uninterrupted TCP connection to a remote application throughout the trip. This user is *definitely* mobile! In between these extremes is a user who takes a laptop from one location (e.g., office or dormitory) into another (e.g., coffeeshop, classroom) and wants to connect into the network in the new location. This user is also mobile (although less so than the BMW driver!) but does not need to maintain an ongoing connection while moving between points of attachment to the network. Figure 6.21 illustrates this spectrum of user mobility from the network layer's perspective.



**Figure 6.21** ♦ Various degrees of mobility, from the network layer's point of view

- *How important is it for the mobile node's address to always remain the same?*

With mobile telephony, your phone number—essentially the network-layer address of your phone—remains the same as you travel from one provider's mobile phone network to another. Must a laptop similarly maintain the same IP address while moving between IP networks?

The answer to this question will depend strongly on the applications being run. For the BMW driver who wants to maintain an uninterrupted TCP connection to a remote application while zipping along the autobahn, it would be convenient to maintain the same IP address. Recall from Chapter 3 that an Internet application needs to know the IP address and port number of the remote entity with which it is communicating. If a mobile entity is able to maintain its IP address as it moves, mobility becomes invisible from the application standpoint. There is great value to this transparency—an application need not be concerned with a potentially changing IP address, and the same application code serves mobile and nonmobile connections alike. We'll see in the following section that mobile IP provides this transparency, allowing a mobile node to maintain its permanent IP address while moving among networks.

On the other hand, a less glamorous mobile user might simply want to turn off an office laptop, bring that laptop home, power up, and work from home. If the laptop functions primarily as a client in client-server applications (e.g., send/read e-mail, browse the Web, Telnet to a remote host) from home, the particular IP address used by the laptop is not that important. In particular, one could get by fine with an address that is temporarily allocated to the laptop by the ISP serving the home. We saw in Section 4.4 that DHCP already provides this functionality.

- *What supporting wired infrastructure is available?* In all of our scenarios above, we've implicitly assumed that there is a fixed infrastructure to which the mobile user can connect—for example, the home's ISP network, the wireless access network in the office, or the wireless access networks lining the autobahn. What if no such infrastructure exists? If two users are within communication proximity of each other, can they establish a network connection in the absence of any other network-layer infrastructure? Ad hoc networking provides precisely these capabilities. This rapidly developing area is at the cutting edge of mobile networking research and is beyond the scope of this book. [Perkins 2000] and the IETF Mobile Ad Hoc Network (manet) working group Web pages [manet 2012] provide thorough treatments of the subject.

In order to illustrate the issues involved in allowing a mobile user to maintain ongoing connections while moving between networks, let's consider a human analogy. A twenty-something adult moving out of the family home becomes mobile, living in a series of dormitories and/or apartments, and often changing addresses. If an old friend wants to get in touch, how can that friend find the address of her mobile friend? One common way is to contact the family, since a