station roaming number (MSRN), which we will refer to as the **roaming number**. Note that this number is different from the mobile's permanent phone number, which is associated with the mobile's home network. The roaming number is ephemeral: It is temporarily assigned to a mobile when it enters a visited network. The roaming number serves a role similar to that of the care-of address in mobile IP and, like the COA, is invisible to the correspondent and the mobile. If HLR does not have the roaming number, it returns the address of the VLR in the visited network. In this case (not shown in Figure 6.29), the home MSC will need to query the VLR to obtain the roaming number of the mobile node. But how does the HLR get the roaming number or the VLR address in the first place? What happens to these values when the mobile user moves to another visited network? We'll consider these important questions shortly.

3. Given the roaming number, the home MSC sets up the second leg of the call through the network to the MSC in the visited network. The call is completed, being routed from the correspondent to the home MSC, and from there to the visited MSC, and from there to the base station serving the mobile user.

An unresolved question in step 2 is how the HLR obtains information about the location of the mobile user. When a mobile telephone is switched on or enters a part of a visited network that is covered by a new VLR, the mobile must register with the visited network. This is done through the exchange of signaling messages between the mobile and the VLR. The visited VLR, in turn, sends a location update request message to the mobile's HLR. This message informs the HLR of either the roaming number at which the mobile can be contacted, or the address of the VLR (which can then later be queried to obtain the mobile number). As part of this exchange, the VLR also obtains subscriber information from the HLR about the mobile and determines what services (if any) should be accorded the mobile user by the visited network.

6.7.2 Handoffs in GSM

A **handoff** occurs when a mobile station changes its association from one base station to another during a call. As shown in Figure 6.30, a mobile's call is initially (before handoff) routed to the mobile through one base station (which we'll refer to as the old base station), and after handoff is routed to the mobile through another base station (which we'll refer to as the new base station). Note that a handoff between base stations results not only in the mobile transmitting/receiving to/from a new base station, but also in the rerouting of the ongoing call from a switching point within the network to the new base station. Let's initially assume that the old and new base stations share the same MSC, and that the rerouting occurs at this MSC.

There may be several reasons for handoff to occur, including (1) the signal between the current base station and the mobile may have deteriorated to such an extent that the call is in danger of being dropped, and (2) a cell may have become

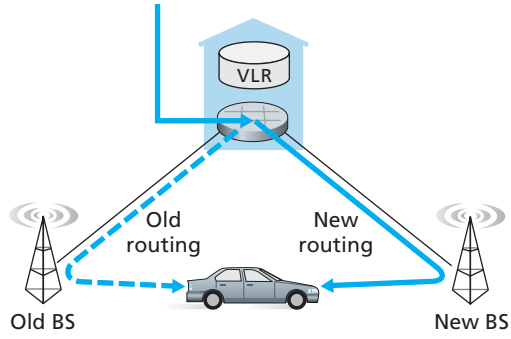

Figure 6.30 ♦ Handoff scenario between base stations with a common MSC

overloaded, handling a large number of calls. This congestion may be alleviated by handing off mobiles to less congested nearby cells.

While it is associated with a base station, a mobile periodically measures the strength of a beacon signal from its current base station as well as beacon signals from nearby base stations that it can "hear." These measurements are reported once or twice a second to the mobile's current base station. Handoff in GSM is initiated by the old base station based on these measurements, the current loads of mobiles in nearby cells, and other factors [Mouly 1992]. The GSM standard does not specify the specific algorithm to be used by a base station to determine whether or not to perform handoff.

Figure 6.31 illustrates the steps involved when a base station does decide to hand off a mobile user:

1. The old base station (BS) informs the visited MSC that a handoff is to be performed and the BS (or possible set of BSs) to which the mobile is to be handed off.
2. The visited MSC initiates path setup to the new BS, allocating the resources needed to carry the rerouted call, and signaling the new BS that a handoff is about to occur.
3. The new BS allocates and activates a radio channel for use by the mobile.
4. The new BS signals back to the visited MSC and the old BS that the visited-MSC-to-new-BS path has been established and that the mobile should be informed of the impending handoff. The new BS provides all of the information that the mobile will need to associate with the new BS.
5. The mobile is informed that it should perform a handoff. Note that up until this point, the mobile has been blissfully unaware that the network has been laying the groundwork (e.g., allocating a channel in the new BS and allocating a path from the visited MSC to the new BS) for a handoff.
6. The mobile and the new BS exchange one or more messages to fully activate the new channel in the new BS.

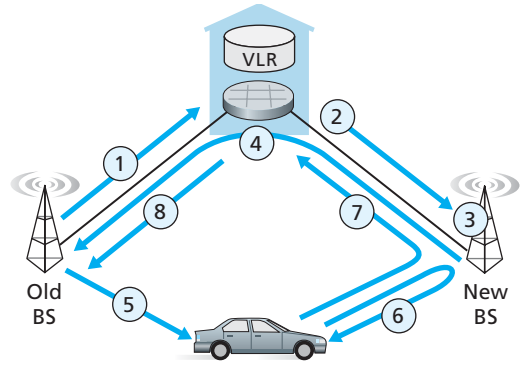

Figure 6.31 ♦ Steps in accomplishing a handoff between base stations with a common MSC

7. The mobile sends a handoff complete message to the new BS, which is forwarded up to the visited MSC. The visited MSC then reroutes the ongoing call to the mobile via the new BS.
8. The resources allocated along the path to the old BS are then released.

Let's conclude our discussion of handoff by considering what happens when the mobile moves to a BS that is associated with a *different* MSC than the old BS, and what happens when this inter-MSC handoff occurs more than once. As shown in Figure 6.32, GSM defines the notion of an **anchor MSC**. The anchor MSC is the MSC visited by the mobile when a call first begins; the anchor MSC thus remains unchanged during the call. Throughout the call's duration and regardless of the number of inter-MSC transfers performed by the mobile, the call is routed from the home MSC to the anchor MSC, and then from the anchor MSC to the visited MSC where the mobile is currently located. When a mobile moves from the coverage area of one MSC to another, the ongoing call is rerouted from the anchor MSC to the new visited MSC containing the new base station. Thus, at all times there are at most three MSCs (the home MSC, the anchor MSC, and the visited MSC) between the correspondent and the mobile. Figure 6.32 illustrates the routing of a call among the MSCs visited by a mobile user.

Rather than maintaining a single MSC hop from the anchor MSC to the current MSC, an alternative approach would have been to simply chain the MSCs visited by the mobile, having an old MSC forward the ongoing call to the new MSC each time the mobile moves to a new MSC. Such MSC chaining can in fact occur in IS-41 cellular networks, with an optional path minimization step to remove MSCs between the anchor MSC and the current visited MSC [Lin 2001].

Let's wrap up our discussion of GSM mobility management with a comparison of mobility management in GSM and Mobile IP. The comparison in Table 6.2 indicates that although IP and cellular networks are fundamentally different in many ways, they share a surprising number of common functional elements and overall approaches in handling mobility.