CHAPTER

19 MULTIMEDIA BROADCAST/ MULTICAST SERVICES

In the past, cellular systems have mostly focused on transmission of data intended for a single user and not on broadcast/multicast services. Broadcast networks, exemplified by the radio and TV broadcasting networks, have on the other hand focused on covering very large areas with the same content and have offered no or limited possibilities for transmission of data intended for a single user. *Multimedia broadcast multicast services* (MBMS) support multicast/broadcast services in a cellular system, thus combining the provision of multicast/ broadcast and unicast services within a single network. The provision of broadcast/multicast services in a mobile-communication system implies that the same information is *simultaneously* provided to multiple terminals, sometimes dispersed over a large area corresponding to a large number of cells, as shown in Figure 19.1. In many cases, it is better to broadcast the information across the area rather than using individual transmissions to each of the users.

MBMS, introduced in LTE release 9, supports transmission of the same content to multiple users located in a specific area, known as the *MBMS service area*, and possibly comprising multiple cells. Two mechanisms for MBMS delivery are available in LTE, s*ingle-cell point to multipoint* (SC-PTM) and *multicast-broadcast single frequency network* (MBSFN).

SC-PTM, introduced in release 13, is in essence very similar to unicast and intended as a complement to MBSFN for services of interest in a single cell only. All transmissions are dynamically scheduled but instead of targeting a single device, the same transmission

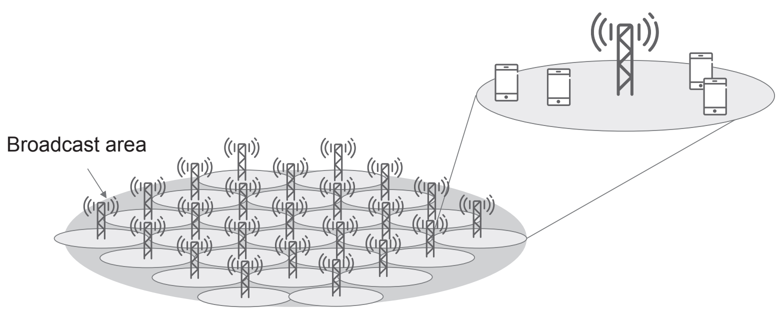

FIGURE 19.1

Broadcast scenario.

4G, LTE-Advanced Pro and The Road to 5G. http://dx.doi.org/10.1016/B978-0-12-804575-6.00019-4

is received by multiple devices simultaneously. SC-PTM is described in more detail in Section 19.4.

MBSFN, introduced in release 9, targets the case when the MBMS service is of interest over a larger area. In such a case, the resources (downlink transmit power) needed to provide a certain broadcast data rate can be considerably reduced if terminals at the cell edge can utilize the received power from broadcast transmissions from multiple cells when detecting/decoding the broadcast data. One way to achieve this and further improve the provision of broadcast/multicast services in a multi-cell network is to ensure that the broadcast transmissions from different cells *are truly identical* and *transmitted mutually time aligned*. In this case, the transmissions received from multiple cells will, as seen from the terminal, appear as a single transmission subject to severe multi-path propagation, see Figure 19.2. As long as the cyclic prefix is sufficiently large, the OFDM receiver can easily handle the equivalent time dispersion "for free" without knowing which cells are involved in the transmission. The transmission of identical time-aligned signals from multiple cells, especially in the case of provision of broadcast/multicast services, is sometimes referred to as single-frequency network (SFN) or, in LTE terminology, MBSFN operation [9]. MBSFN transmission provides several benefits:

- Increased received signal strength, especially at the border between cells involved in the MBSFN transmission, as the device can utilize the signal energy received from multiple cells.
- Reduced interference level, once again especially at the border between cells involved in the MBSFN transmission, as the signals received from neighboring cells will not appear as interference but as useful signals.
- Additional diversity against fading on the radio channel as the information is received from several, geographically separated locations, typically making the overall aggregated channel appear highly time-dispersive or, equivalently, highly frequency selective.

Altogether, this allows for significant improvements in the multicast/broadcast reception quality, especially at the border between cells involved in the MBSFN transmission, and, as a consequence, significant improvements in the achievable multicast/broadcast data rates.

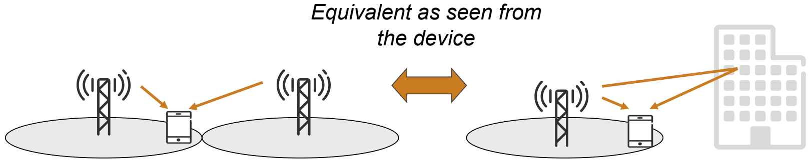

FIGURE 19.2

Equivalence between simulcast transmission and multi-path propagation.

When providing multicast/broadcast services for mobile devices there are several aspects to take into account, of which two deserve special attention and will be elaborated upon later: good coverage and low device power consumption.

The coverage, or more accurately the data rate possible to provide, is basically determined by the link quality of the worst-case user, as no user-specific adaptation of transmission parameters can be used in a multicast/broadcast system providing the same information to multiple users.

Providing for power-efficient reception in the device in essence implies that the structure of the overall transmission should be such that data for a service-of-interest is provided in short high-data-rate bursts rather than longer low-data-rate bursts. This allows the device to occasionally wake up to receive data with long periods of DRX in between. In LTE, this is catered for by time-multiplexing unicast and broadcast transmissions, as well as by the scheduling of different MBMS services, as discussed later in this chapter.

The rest of the chapter focuses on MBSFN transmission, including the overall architecture and scheduling in an MBSFN network, with SC-PTM briefly covered towards the end of the chapter.

19.1 ARCHITECTURE

MBMS services can be delivered using MBSFN or SC-PTM. In the following, the MBSFN mechanisms are described with the release 13 addition of SC-PTM discussed in Section 19.4.

An *MBSFN area* is a specific area where one or several cells transmit the same content. For example, in Figure 19.3, cells 8 and 9 both belong to MBSFN area C. Not only can an MBSFN area consist of multiple cells, a single cell can also be part of multiple, up to eight, MBSFN areas, as shown in Figure 19.3 where cells 4 and 5 are part of both MBSFN areas A and B. Note that, from an MBSFN reception point of view, the individual cells are invisible, although the device needs to be aware of the different cells for other purposes, such as reading

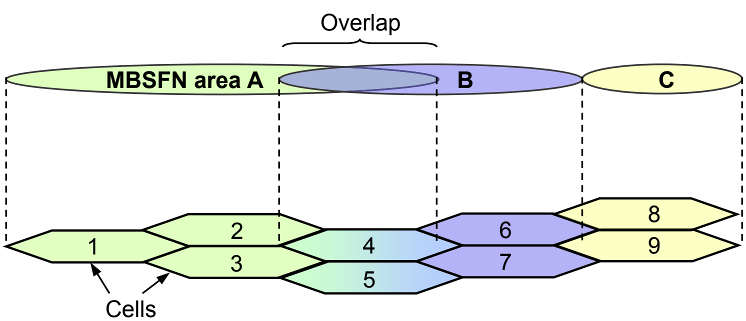

FIGURE 19.3

Example of MBSFN areas.

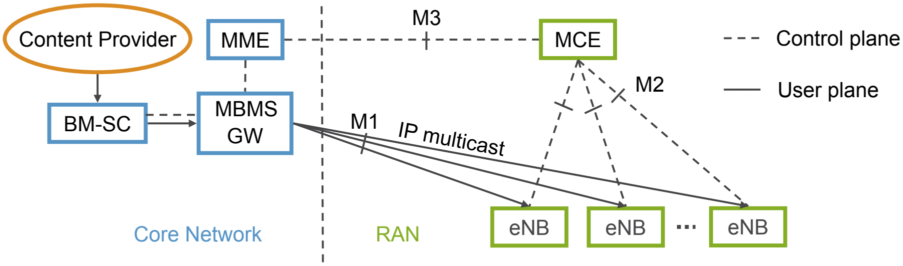

FIGURE 19.4

LTE MBMS architecture.

system information and notification indicators, as discussed in the following. The MBSFN areas are static and do not vary over time.

The usage of MBSFN transmission requires not only time synchronization among the cells participating in an MBSFN area, but also usage of the same set of radio resources in each of the cells for a particular service. This coordination is the responsibility of the *multi-cell/multicast coordination entity* (MCE), which is a logical node in the radio-access network handling allocation of radio resources and transmission parameters (time–frequency resources and transport format) across the cells in the MBSFN area. The MCE is also responsible for selecting between SC-PTM and MBSFN for MBMS services. As shown in Figure 19.4, the MCE[1] can control multiple eNodeBs, each handling one or more cells.

The *broadcast multicast service center* (BM-SC), located in the core network, is responsible for authorization and authentication of content providers, charging, and the overall configuration of the data flow through the core network. The MBMS gateway (MBMS-GW) is a logical node handling multicast of IP packets from the BM-SC to all eNodeBs involved in transmission in the MBSFN area. It also handles session control signaling via the MME.

From the BM-SC, the MBMS data is forwarded using IP multicast, a method of sending an IP packet to multiple receiving network nodes in a single transmission, via the MBMS gateway to the cells from which the MBMS transmission is to be carried out. Hence, MBMS is not only efficient from a radio-interface perspective, but it also saves resources in the transport network by not having to send the same packet to multiple nodes individually unless necessary. This can lead to significant savings in the transport network.

A device receiving MBMS transmission may also receive unicast transmission on the same carrier as MBMS and unicast transmissions are time-multiplexed onto different subframes. This assumes the same carrier being used for both MBMS and unicast transmission,

[1]There is an alternative architecture supported where MCE functionality is included in every eNodeB. However, as there is no communication between MCEs in different eNodeBs, the MBSFN area would in this case be limited to the set of cells controlled by a single eNodeB.

which may limit the deployment flexibility in case an operator uses multiple carriers (multiple frequency bands) in an MBSFN area. In release 11, enhancements were introduced to improve operation in such deployments. Briefly, the device informs the network about its MBMS interest and capabilities. The network can take this information into account and ensure that the device is able to receive the relevant MBMS service, for example, by handover of the device to the carrier providing the MBMS transmission. A carrier-aggregation capable device may receive unicast transmissions on one component carrier and MBMS on another component carrier.

19.2 MBSFN CHANNEL STRUCTURE AND PHYSICAL-LAYER PROCESSING

The basis for MBSFN transmission is the *multicast channel* (MCH), a transport-channel-type supporting MBSFN transmission. Two types of logical channels can be multiplexed and mapped to the MCH:

- *multicast traffic channel* (MTCH);
- *multicast control channel* (MCCH).

The MTCH is the logical channel type used to carry MBMS data corresponding to a certain MBMS service. If the number of services to be provided in an MBSFN area is large, multiple MTCHs can be configured. As no acknowledgments are transmitted by the devices, no RLC retransmissions can be used and consequently the RLC unacknowledged mode is used.

The MCCH is the logical channel type used to carry control information necessary for reception of a certain MBMS service, including the subframe allocation and modulation-and-coding scheme for each MCH. There is one MCCH per MBSFN area. Similarly to the MTCH, the RLC uses unacknowledged mode.

One or several MTCHs and, if applicable,[2] one MCCH are multiplexed at the MAC layer to form an MCH transport channel. As described in Chapter 4, the MAC header contains information about the logical-channel multiplexing, in this specific case the MTCH/MCCH multiplexing, such that the device can de-multiplex the information upon reception. The MCH is transmitted using MBSFN in one MBSFN area.

The transport-channel processing for MCH is, in most respects, the same as that for DL-SCH as described in Chapter 6, with some exceptions:

- In the case of MBSFN transmission, the same data is to be transmitted with the same transport format using the same physical resource from multiple cells typically belonging to different eNodeBs. Thus, the MCH transport format and resource allocation cannot be dynamically adjusted by the eNodeB. As described in the preceding

[2]One MCCH per MBSFN area is needed, but it does not have to occur in every MCH TTI, nor on all MCHs in the MBSFN area.

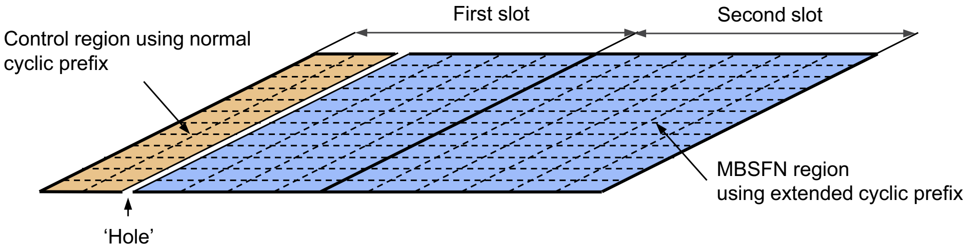

FIGURE 19.5

Resource-block structure for MBSFN subframes, assuming normal cyclic prefix for the control region.

paragraphs, the transport format is instead determined by the MCE and signaled to the devices as part of the information sent on the MCCH.

- As the MCH transmission is simultaneously targeting multiple devices and therefore no feedback is used, hybrid ARQ is not applicable in the case of MCH transmission.
- As already mentioned, multi-antenna transmission (transmit diversity and spatial multiplexing) does not apply to MCH transmission.

Furthermore, as also mentioned in Chapter 6, the PMCH scrambling should be *MBSFN-area specific*—that is, identical for all cells involved in the MBSFN transmission. There are also a number of smaller differences. For example, 256QAM is only supported when the PMCH carries the MTCH and not the MCCH,[3] spatial multiplexing is not supported for the PMCH, nor is any transmit-diversity scheme specified.

The MCH is mapped to the PMCH physical channel and transmitted in MBSFN subframes, illustrated in Figure 19.5. As discussed in Chapter 5, an MBSFN subframe consists of two parts: a *control region*, used for transmission of regular unicast L1/L2 control signaling; and an *MBSFN region*, used for transmission of the MCH.[4] Unicast control signaling may be needed in an MBSFN subframe, for example, to schedule uplink transmissions in a later subframe, but is also used for MBMS-related signaling, as discussed later in this chapter.

As discussed in at the beginning of this chapter, in the case of MBSFN-based multicast/broadcast transmission, the cyclic prefix should not only cover the main part of the actual channel time dispersion but also the timing difference between the transmissions received from the cells involved in the MBSFN transmission. Therefore, MCH transmissions, which can take place in the MBSFN region only, use an extended cyclic prefix. If a normal cyclic prefix is used for normal subframes, and therefore also in the control region of MBSFN subframes, there will be a small "hole" between the two parts of the MBSFN subframe, as

[3]This is a consequence of 256QAM being introduced at a later stage and not supported by all devices while the MCCH burst be received by all devices using MBMS services.
[4]As discussed in Chapter 5, MBSFN subframes can be used for multiple purposes and not all of them have to be used for MCH transmission.

illustrated in Figure 19.5. The reason is to keep the start timing of the MBSFN region fixed, irrespective of the cyclic prefix used for the control region.

As already mentioned, the MCH is transmitted by means of MBSFN from the set of cells that are part of the corresponding MBSFN area. Thus, as seen from the device point of view, the radio channel that the MCH has propagated over is the aggregation of the channels of each cell within the MBSFN area. For channel estimation for coherent demodulation of the MCH, the device can thus not rely on the normal cell-specific reference signals transmitted from each cell. Rather, in order to enable coherent demodulation for MCH, special MBSFN reference symbols are inserted within the MBSFN part of the MBSFN subframe, as illustrated in Figure 19.6. These reference symbols are transmitted by means of MBSFN over the set of cells that constitute the MBSFN area—that is, they are transmitted at the same time–frequency position and with the same reference-symbol values from each cell. Channel estimation using these reference symbols will thus correctly reflect the overall aggregated channel corresponding to the MCH transmissions of all cells that are part of the MBSFN area.

MBSFN transmission in combination with specific MBSFN reference signals can be seen as transmission using a specific antenna port, referred to as *antenna port 4*.

A device can assume that all MBSFN transmissions within a given subframe correspond to the same MBSFN area. Hence, a device can interpolate over all MBSFN reference symbols within a given MBSFN subframe when estimating the aggregated MBSFN channel. In contrast, MCH transmissions in different subframes may, as already discussed, correspond to different MBSFN areas. Consequently, a device cannot necessarily interpolate the channel estimates across multiple subframes.

As can be seen in Figure 19.6, the frequency-domain density of MBSFN reference symbols is higher than the corresponding density of cell-specific reference symbols. This is needed as the aggregated channel of all cells involved in the MBSFN transmission will be equivalent to a highly time-dispersive or, equivalently, highly frequency-selective channel. Consequently, a higher frequency-domain reference-symbol density is needed.

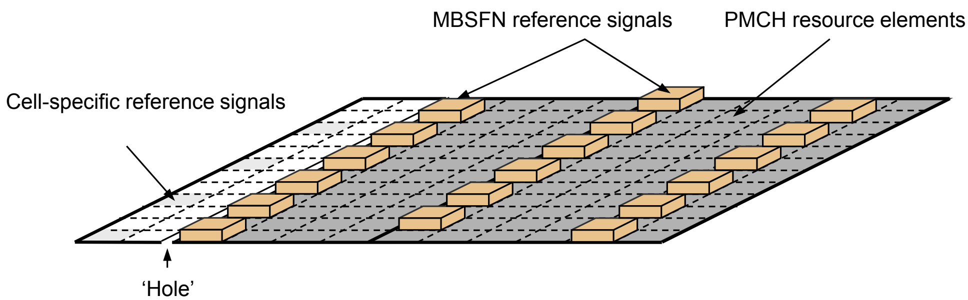

FIGURE 19.6

Reference-signal structure for PMCH reception.

There is only a single MBSFN reference signal in MBSFN subframes. Thus, multi-antenna transmission such as transmit diversity and spatial multiplexing is not supported for MCH transmission. The main argument for not supporting any standardized transmit-diversity scheme for MCH transmission is that the high frequency selectivity of the aggregated MBSFN channel in itself provides substantial (frequency) diversity. Transmit-diversity schemes transparent to the device and hence not requiring any specific support in the specifications can still be applied if beneficial.

19.3 SCHEDULING OF MBSFN SERVICES

Good coverage throughout the MBSFN area is, as already explained, one important aspect of providing broadcast services. Another important aspect, as mentioned in the introduction, is to provide for energy-efficient reception. In essence, for a given service, this translates into transmission of short high-rate bursts in between which the device can enter a DRX state to reduce power consumption. LTE therefore makes extensive use of time-multiplexing of MBMS services and the associated signaling, as well as provides a mechanism to inform the device *when* in time a certain MBMS service is transmitted. Fundamental to the description of this mechanism are the *common subframe allocation* (CSA) period and the *MCH scheduling period* (MSP).

All MCHs that are part of the same MBSFN area occupy a pattern of MBSFN subframes known as the CSA. The CSA is periodic, as illustrated in Figure 19.7. The subframes used for transmission of the MCH must be configured as MBSFN subframes, but the opposite does not

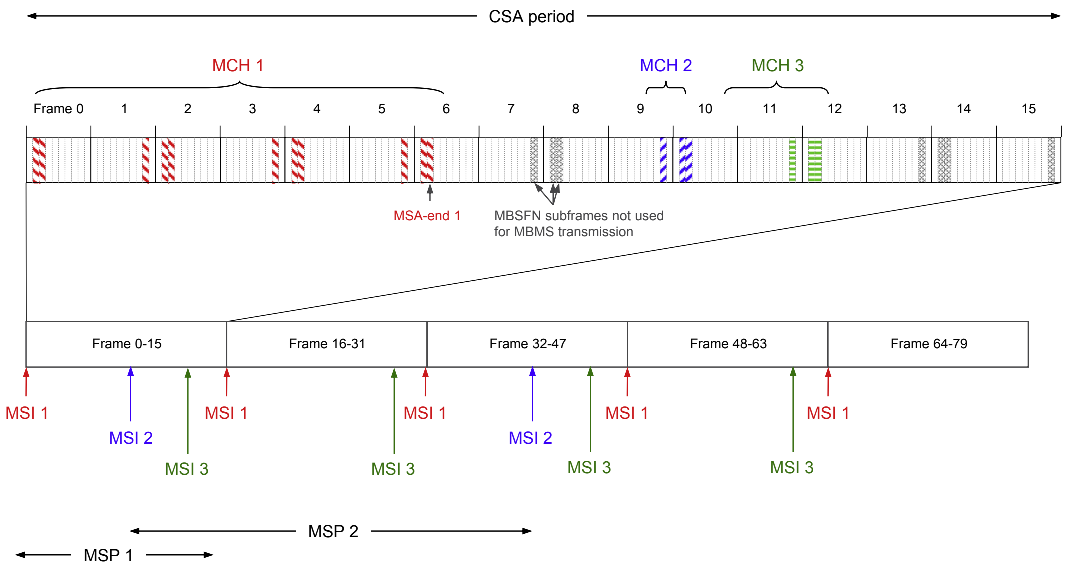

FIGURE 19.7

Example of scheduling of MBMS services.

hold—MBSFN subframes can be configured for other purposes as well, for example, to support the backhaul link in the case of relaying, as described in Chapter 18. Furthermore, the allocation of MBSFN subframes for MCH transmission should be identical across the MBSFN area as otherwise there will not be any MBSFN gain. This is the responsibility of the MCE.

Transmission of a specific MCH follows the *MCH subframe allocation* (MSA). The MSA is periodic and at the beginning of each MCH scheduling period, an MAC control element is used to transmit the *MCH scheduling information* (MSI). The MSI indicates which subframes are used for a certain MTCH in the upcoming scheduling period. Not all possible subframes need to be used; if a smaller number than allocated to an MCH is required by the MTCH(s), the MSI indicates the last MCH subframe to be used for this particular MTCH (*MSA end* in Figure 19.7), while the remaining subframes are not used for MBMS transmission. The different MCHs are transmitted in consecutive order within a CSA period—that is, all subframes used by MCH n in a CSA are transmitted before the subframes used for MCH $n + 1$ in the same CSA period.

The fact that the transport format is signaled as part of the MCCH implies that the MCH transport format may differ between MCHs but must remain constant across subframes used for the same MCH. The only exception is subframes used for the MCCH and MSI, where the MCCH-specific transport format, signaled as part of the system information, is used instead.

In the example in Figure 19.7, the scheduling period for the first MCH is 16 frames, corresponding to one CSA period, and the scheduling information for this MCH is therefore transmitted once every 16 frames. The scheduling period for the second MCH, on the other hand, is 32 frames, corresponding to two CSA periods, and the scheduling information is transmitted once every 32 frames. The MCH scheduling period can range from 80 ms to 10.24 s.

To summarize, for each MBSFN area, the MCCH provides information about the CSA pattern, the CSA period, and, for each MCH in the MBSFN area, the transport format and the scheduling period. This information is necessary for the device to properly receive the different MCHs. However, the MCCH is a logical channel and is itself mapped to the MCH, which would result in a chicken-and-egg problem—the information necessary for receiving the MCH is transmitted on the MCH. Hence, in TTIs when the MCCH (or MSI) is multiplexed into the MCH, the MCCH-specific transport format is used for the MCH. The MCCH-specific transport format is provided as part of the system information (SIB13; see Chapter 11 for a discussion about system information). The system information also provides information about the scheduling and modifications periods of the MCCH (but not about CSA period, CSA pattern, and MSP, because those quantities are obtained from the MCCH itself). Reception of a specific MBMS service can thus be described by the following steps:

- Receive SIB13 to obtain knowledge on how to receive the MCCH for this particular MBSFN area.
- Receive the MCCH to obtain knowledge about the CSA period, CSA pattern, and MSP for the service of interest.
- Receive the MSI at the beginning of each MSP. This provides the device with information on which subframes the service of interest can be found in.

After the second step, the device has acquired the CSA period, CSA pattern, and MSP. These parameters typically remain fixed for a relatively long time. The device therefore only needs to receive the MSI and the subframes in which the MTCH carrying the service of interest are located, as described in the third bulleted item in the preceding list. This greatly helps to reduce the power consumption in the device as it can sleep in most of the subframes.

Occasionally there may be a need to update the information provided on the MCCH, for example when starting a new service. Requiring the device to repeatedly receive the MCCH comes at a cost in terms of device power consumption. Therefore, a fixed schedule for MCCH transmission is used in combination with a change-notification mechanism, as described in the following paragraph.

The MCCH information is transmitted repeatedly with a fixed repetition period and changes to the MCCH information can only occur at specific time instants. When (part of) the MCCH information is changed, which can only be done at the beginning of a new modification period, as shown in Figure 19.8, the network notifies the devices about the upcoming MCCH information change in the preceding MCCH modification period. The notification mechanism uses the PDCCH for this purpose. An eight-bit bitmap, where each bit represents a certain MBSFN area, is transmitted on the PDCCH in an MBSFN subframe using DCI format 1C and a reserved identifier, the M-RNTI. The notification bitmap is only transmitted when there are any changes in the services provided (in release 10, notification is also used to indicate a counting request in an MBSFN area) and follows the modification period, as described earlier.

The purpose of the concept of notification indicators and modification periods is to maximize the amount of time the device may sleep to save battery power. In the absence of any changes to the MCCH information, a device currently not receiving MBMS may enter DRX and only wake up when the notification indicator is transmitted. As a PDCCH in an MBSFN subframe spans at most two OFDM symbols, the duration during which the device needs to wake up to check for notifications is very short, translating to a high degree of power saving. Repeatedly transmitting the MCCH is useful to support mobility; a device entering a

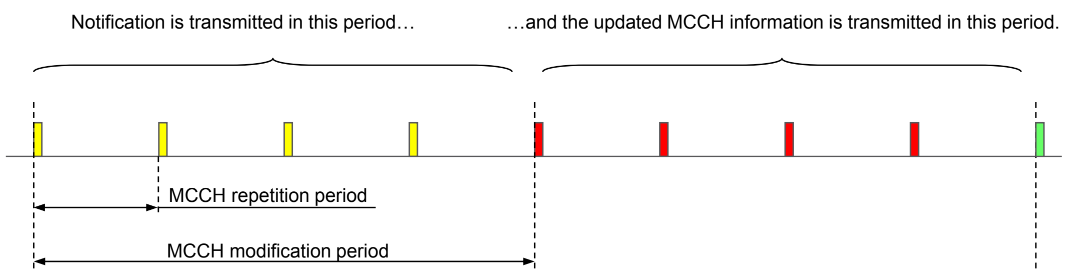

FIGURE 19.8

MCCH transmission schedule.

new area or a device missing the first transmission does not have to wait until the start of a new modification period to receive the MCCH information.

19.4 SINGLE-CELL POINT TO MULTIPOINT TRANSMISSION

Single-cell point to multipoint, SC-PTM, was introduced in release 13 in order to support MBMS services of interest in a single cell (or a small area consisting of a few cells) and complementing the MBSFN transmission scheme described in the preceding section. The same overall architecture is reused with the MCE being responsible for selecting between MBSFN and SC-PTC transmission.

The SC-MTCH, mapped to the DL-SCH, carriers the MBMS information to be transmitted using SC-PTM. The same mechanism as unicast transmission is used—that is, dynamic scheduling of the DL-SCH. This allows efficient support of very bursty traffic compared to the slower scheduling used for MBSFN transmission. Since the DL-SCH transmissions target multiple devices, hybrid-ARQ feedback and CSI reports are not used. Consequently, transmission modes 1–3, which do not rely on feedback, are supported. A new group RNTI, the G-RNTI, is used for dynamic scheduling with a different G-RNTI for each MBMS service.

Control information such as the G-RNTIs used for different MBMS services are provided on the SC-MCCH logical channel type, mapped to the DL-SCH and dynamically scheduled using the SC-RNTI. SIB20 contains information assisting the device to receive the SC-MCCH.