CHAPTER

RELAYING

18

The possibility of a device communicating with the network, and the data rate that can be used, depends on several factors, including the path loss between the device and the base station. The link performance of LTE is already quite close to the Shannon limit and from a pure link-budget perspective, the highest data rates supported by LTE require a relatively high signal-to-noise ratio (SNR). Unless the link budget can be improved—for example, with different types of beam-forming solutions—a denser infrastructure is required to reduce the device-to-base-station distance and thereby improve the link budget.

A denser infrastructure is mainly a deployment aspect, but in later releases of LTE, various tools enhancing the support for low-power base stations were included. One of these tools is *relaying*, which can be used to reduce the distance between the device and the infrastructure, resulting in an improved link budget and an increased possibility for high data rates. In principle this reduction in device-to-infrastructure distance could be achieved by deploying traditional base stations with a wired connection to the rest of the network. However, relays with a shorter deployment time can often be an attractive alternative, as there is no need to deploy a specific backhaul.

A wide range of relay types can be envisioned, some of which could already be deployed in release 8.

Amplify-and-forward relays, commonly referred to as *repeaters*, simply amplify and forward the received analog signals and are, on some markets, relatively common as a tool for handling coverage holes. Traditionally, once installed, repeaters continuously forward the received signal regardless of whether there is a device in their coverage area or not, although more advanced repeaters can be considered as well. Repeaters are transparent to both the device and the base station and can therefore be introduced in existing networks. The fact that the basic principle of a repeater is to amplify whatever it receives, including noise and interference as well as the useful signal, implies that repeaters are mainly useful in high-SNR environments. Expressed differently, the SNR at the output of the repeater can never be higher than at the input.

Decode-and-forward relays decode and re-encode the received signal prior to forwarding it to the served users. The decode-and-re-encode process results in this class of relays not amplifying noise and interference, as is the case with repeaters. They are therefore also useful in low-SNR environments. Furthermore, independent rate adaptation and scheduling for the

4G, LTE-Advanced Pro and The Road to 5G. http://dx.doi.org/10.1016/B978-0-12-804575-6.00018-2

base station—relay and relay—device links is possible. However, the decode-and-re-encode operation implies a larger delay than for an amplify-and-forward repeater, longer than the LTE subframe duration of 1 ms. As for repeaters, many different options exist depending on supported features (support of more than two hops, support for mesh structures, and so on) and, depending on the details of those features, a decode-and-forward relay may or may not be transparent to the device.

18.1 RELAYS IN LTE

LTE release 10 introduced support for a decode-and-forward relaying scheme (repeaters require no additional standardization support other than RF requirements and are already available in release 8). A basic requirement in the development of LTE relaying solutions was that the relay should be transparent to the device—that is, the device should not be aware of whether it is connected to a relay or to a conventional base station. This ensures that release 8/9 devices can also be served by relays, despite relays being introduced in release 10. Therefore, so-called *self-backhauling* was taken as the basis for the LTE relaying solution. In essence, from a logical perspective, a relay is an eNodeB wirelessly connected to the rest of the radio-access network by using the LTE radio interface. It is important to note that, even though the relay from a device perspective is identical to an eNodeB, the physical implementation may differ significantly from a traditional base station, for example, in terms of output power.

In conjunction with relaying, the terms *backhaul link* and *access link* are often used to refer to the base station—relay connection and the relay—device connection, respectively. The cell to which the relay is connected using the backhaul link is known as the *donor cell* and the donor cell may, in addition to one or several relays, also serve devices not connected via a relay. This is illustrated in Figure 18.1.

Since the relay communicates both with the donor cell and devices served by the relay, interference between the access and backhaul links must be avoided. Otherwise, since the power difference between access-link transmissions and backhaul-link reception at the relay can easily be more than 100 dB, the possibility of receiving the backhaul link may be completely ruined. Similarly, transmissions on the backhaul link may cause significant

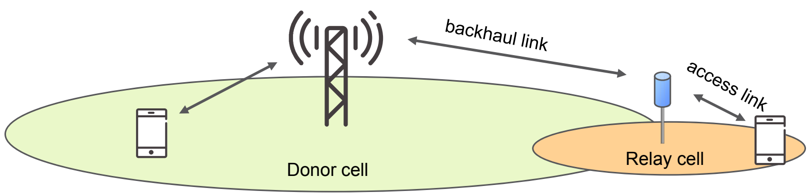

FIGURE 18.1

Access and backhaul links.

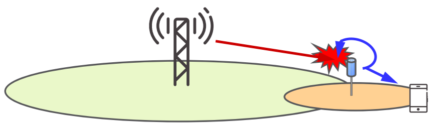

FIGURE 18.2

Interference between access and backhaul links.

interference to the reception of the access link. These two cases are illustrated in Figure 18.2. Therefore, isolation between the access and backhaul links is required—isolation that can be obtained in one or several of the frequency, time, and/or spatial domains.

Depending on the spectrum used for access and backhaul links, relaying can be classified into *outband* and *inband* types.

Outband relaying implies that the backhaul operates in a spectrum separate from that of the access link, using the same radio interface as the access link. Provided that the frequency separation between the backhaul and access links is sufficiently large, interference between the backhaul and access links can be avoided and the necessary isolation is obtained in the frequency domain. Consequently, no enhancements to the release 8 radio interface are needed to operate an outband relay. There are no restrictions on the activity on the access and backhaul links, and the relay can in principle operate with full duplex.

Inband relaying implies that the backhaul and access links operate in the same spectrum. Depending on the deployment and operation of the relay, this may, as the access and backhaul link share the same spectrum, require additional mechanisms to avoid interference between the access and backhaul links. Unless this interference can be handled by proper antenna arrangements, for example, with the relay deployed in a tunnel with the backhaul antenna placed outside the tunnel, a mechanism to separate activity on the access and backhaul links in the time domain is required. Such a mechanism was introduced as part of release 10 and is described in more detail below. Since the backhaul and access links are separated in the time domain, there is a dependency on the transmission activity and the two links cannot operate simultaneously.

The RF requirements for decode-and-forward relays were introduced in release 11. Because of the similarities with operation of the access and backhaul links with base stations and UEs, respectively, the requirements are to a large extent very similar to the corresponding ones for base stations and UEs. This is discussed in more detail in Chapter 22.

18.2 OVERALL ARCHITECTURE

From an architectural perspective, a relay can, on a high level, be thought of as having a “base-station side” and a “device side”. Toward devices, it behaves as a conventional eNodeB using the access link, and a device is not aware of whether it is communicating with a relay or a "traditional" base station. Relays are therefore transparent for the devices and devices from the first LTE release, release 8, can also benefit from relays. This is important from an operator's perspective, as it allows a gradual introduction of relays without affecting the existing device fleet.

Toward the donor cell, a relay initially operates as a device, using the LTE radio interface to connect to the donor cell. Once connection is established and the relay is configured, the relay uses a subset of the "device side" functionality for communication on the backhaul link. In this phase, the relay-specific enhancements described in this chapter may be used for the backhaul.

In release 10, the focus is on two-hop relaying and scenarios with a relay connected to the network via another relay are not considered. Furthermore, relays are stationary—that is, handover of a relay from one donor cell to another donor cell is not supported. The case for using mobile relays is not yet clear, and therefore it was decided in release 10 not to undertake the relatively large task of adapting existing core-network procedures to handle cells that are moving over time, something that could have been a consequence of a mobile relay.

The overall LTE relaying architecture is illustrated in Figure 18.3. One key aspect of the architecture is that the donor eNodeB acts as a proxy between the core network and the relay. From a relay perspective, it appears as if the relay is connected directly to the core network as the donor eNodeB appears as an MME for the S1 interface and an eNodeB for X2 toward the relay. From a core-network perspective, on the other hand, the relay cells appear as if they belong to the donor eNodeB. It is the task of the proxy in the donor eNodeB to connect these two views. The use of a proxy is motivated by the desire to minimize the impact to the core network from the introduction of relays, as well as to allow for features such as tight coordination of radio-resource management between the donor eNodeB and the relay.

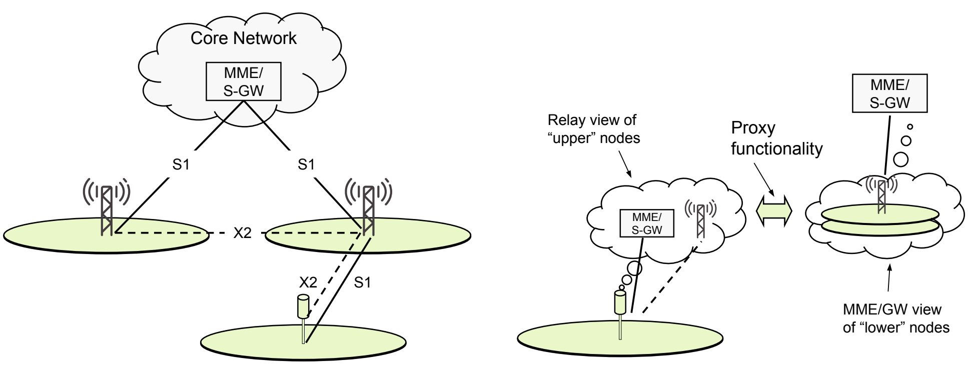

FIGURE 18.3

LTE relaying architecture.

18.3 BACKHAUL DESIGN FOR INBAND RELAYING

In the case of inband relaying, the backhaul and access links operate in the same spectrum. As discussed in the previous section, a mechanism to separate activity on the access and backhaul links in the time domain is required unless sufficient isolation between the two links can be achieved in other ways, for example, through appropriate antenna arrangements. Such a mechanism should ensure that the relay is not transmitting on the access link at the same time as it is receiving on the backhaul link (and vice versa).

One way to handle this is to “blank” some subframes on the access link to provide the relay with the possibility to communicate with the donor eNodeB on the backhaul link. In the uplink, the scheduler in the relay can in principle schedule such that there is no access-link activity in certain subframes. These subframes can then be used for uplink transmissions on the backhaul link as the relay does not need to receive anything on the access link in these subframes. However, blanking subframes on the access downlink is not possible. Although a release 10 device in principle could have been designed to cope with blank subframes, devices from earlier releases expect at least cell-specific reference signals (CRS) to be present in all downlink subframes. Hence, to preserve the possibility of also serving releases 8/9 devices, which was an important requirement during standardization of release 10, the design of the backhaul link must be based on the assumption that the access link can operate with release 8 functionality only.

Fortunately, from the first release LTE included the possibility of configuring MBSFN subframes (see Chapter 5). In an MBSFN subframe, devices expect CRS and (possibly) L1/L2 control signaling to be transmitted only in the first one or two OFDM symbols, while the remaining part of the subframe can be empty. By configuring some of the access-link subframes as MBSFN subframes, the relay can stop transmitting in the latter part of these subframes and receive transmissions from the donor cell. As seen in Figure 18.4, the gap during which the relay can receive transmissions from the donor cell is shorter than the full subframe duration. In particular, as the first OFDM symbols in the subframe are unavailable for reception of donor-cell transmissions, L1/L2 control signaling from the donor to the relay cannot be transmitted using the regular PDCCH. Instead, a relay-specific control channel, the R-PDCCH, is introduced in release 10.

Not only are transmission gaps in the access downlink required in order to receive transmissions from the donor cell, but also reception gaps in the access link are needed in

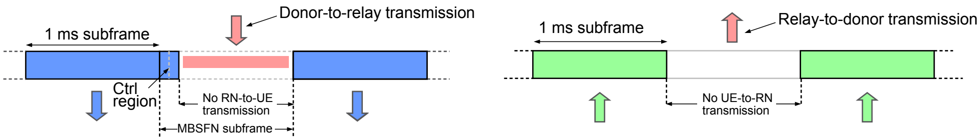

FIGURE 18.4

Multiplexing between access and backhaul links.

order to transmit on the backhaul from the relay to the donor cell. As already mentioned, such gaps can be created through proper scheduling of uplink transmissions.

The detailed specifications of the physical-layer enhancements introduced in release 10 to support the backhaul can be found in [37].

18.3.1 ACCESS-LINK HYBRID-ARQ OPERATION

The access-link gaps discussed earlier, MBSFN subframes in the downlink and scheduling gaps in the uplink, used in order to be able to receive and transmit, respectively, on the backhaul link, affect the hybrid-ARQ operation. Note that hybrid-ARQ is used on both the access and backhaul links. Since compatibility with release 8 was a fundamental requirement in the development of the LTE relaying solution, there are no changes to access-link hybrid-ARQ operation.

For uplink transmissions on PUSCH, hybrid-ARQ acknowledgments are transmitted on PHICH. Since the PHICH can be transmitted by the relay even in MBSFN subframes, the operation is identical to that in earlier releases of the LTE standard. However, although the hybrid-ARQ acknowledgment can be received, the subframe where the retransmission should take place (8 ms after the initial transmission for FDD, configuration dependent for TDD) may be used by the backhaul link and not be available for the access link. In that case the corresponding uplink hybrid-ARQ process needs to be suspended by transmitting a positive acknowledgment on the PHICH, irrespective of the outcome of the decoding. By using PDCCH, a retransmission can instead be requested in a later subframe available for the same hybrid-ARQ process, as described in Chapter 8. The hybrid-ARQ round-trip time will be larger in those cases (e.g., 16 ms instead of 8 ms for FDD).

Downlink transmissions on PDSCH trigger hybrid-ARQ acknowledgments to be sent on PUCCH and, for proper operation, the relay should be able to receive those acknowledgemnts. The possibility to receive PUCCH on the access link depends on the backhaul operation, more specifically on the allocation of subframes for backhaul communication.

In FDD, backhaul subframes are configured such that an uplink subframe occurs 4 ms after a downlink subframe. This is chosen to match the access-link hybrid-ARQ timing relations, where an uplink subframe follows 4 ms after a downlink subframe. As the relay cannot transmit on the access link simultaneously with the backhaul link, there is no access-link transmission in subframe n and, consequently, no hybrid-ARQ transmission in subframe $n+4$. Hence, the inability to receive access-link hybrid-ARQ acknowledgments in some subframes is of no concern as the corresponding downlink subframes cannot be used for access-link transmission anyway. Downlink retransmissions are not an issue as they are asynchronous and can be scheduled in any suitable downlink subframe on the access link.

In TDD, the relay node may not be able to receive hybrid-ARQ feedback on PUCCH in uplink subframes used for transmission on the backhaul link. One possibility is to restrict the downlink scheduler such that no devices transmit PUCCH in uplink subframes the relay cannot receive. However, such a restriction may be too limiting. Alternatively, the relay can schedule without restrictions in the downlink and ignore the hybrid-ARQ acknowledgment. Retransmissions can then either be handled blindly—that is, the relay has to make an educated "guess" on whether a retransmission is required based on, for example, CSI feedback or RLC retransmissions are used to handle missing packets. Another possibility is to configure repetition of the hybrid-ARQ acknowledgments such that at least some of the repeated acknowledgments are receivable by the relay.

18.3.2 BACKHAUL-LINK HYBRID-ARQ OPERATION

For the backhaul link, the underlying principle in the design is to maintain the same timing relations as in release 8 for scheduling grants and hybrid-ARQ acknowledgments. As the donor cell may schedule both relays and devices, such a principle simplifies the scheduling implementation, as scheduling and retransmission decisions for devices and relays are taken at the same point in time. It also simplifies the overall structure, as release 8 solutions can be reused for the relay backhaul design.

For FDD, the subframes configured for downlink backhaul transmission therefore follow a period of 8 ms in order to match the hybrid-ARQ round-trip time to the extent possible. This also ensures that the PUCCH can be received in the access link, as discussed in the previous section. However, as the possible configurations of MBSFN subframes have an inherent 10 ms structure while the hybrid-ARQ timing follows an 8 ms periodicity, there is an inherent mismatch between the two. Hence, as illustrated in Figure 18.5, some backhaul subframes may be spaced 16 ms apart, as subframes 0, 4, 5, and 9 cannot be configured as MBSFN subframes (see Chapter 5). Uplink backhaul subframes follow 4 ms after a downlink backhaul subframe, following the principle discussed in the previous paragraph.

For TDD, there is an inherent 10 ms component in the hybrid-ARQ timing relations, which matches the 10 ms MBSFN structure and makes it possible to keep a regular spacing of the backhaul transmission attempts. Subframes 0, 1, 5, and 6 cannot be configured as MBSFN subframes. Hence, TDD configuration 0, where subframes 0 and 5 are the only downlink subframes, cannot be used in a relay cell since this configuration does not support any MBSFN subframes. For configuration 5, there is only a single uplink subframe and in order to support both the backhaul and access links at least two uplink subframes are needed.

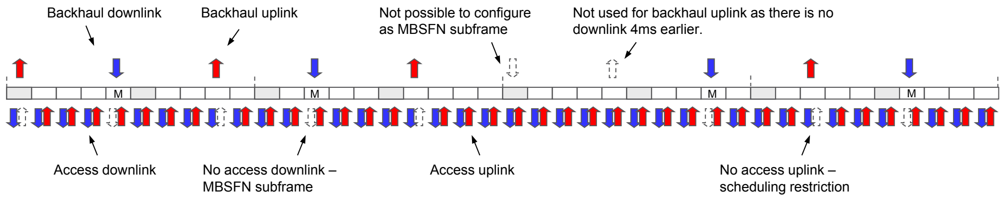

FIGURE 18.5

Example of backhaul configuration for FDD.

Therefore, of the seven TDD configurations supported in LTE, only configurations 1, 2, 3, 4, and 6 are supported in relay cells. For each TDD configuration, one or several backhaul configurations are supported, as shown in Table 18.1.

The underlying timing principles for hybrid-ARQ acknowledgments and uplink scheduling grants are, as mentioned earlier, to keep the same principles as for the access link. However, backhaul transmissions may occur in backhaul subframes only. Therefore, for TDD, the acknowledgment of a transport block on the backhaul link in subframe n is transmitted in subframe $n+k$, where $k \geq 4$ and is selected such that $n+k$ is an uplink *backhaul* subframe if the acknowledgment is to be transmitted from the relay and a downlink *backhaul* subframe if the acknowledgment is transmitted from the eNodeB.

The numbering of uplink hybrid-ARQ processes on the backhaul link is similar to the TDD numbering on the access link, where uplink hybrid-ARQ process numbers are assigned sequentially to the available backhaul occasions as shown in Figure 18.6, taking into account the same processing times as for the access link (see Chapter 8). This is in contrast to the FDD access link, where the uplink hybrid-ARQ process number can be directly derived from the subframe number. The reason for adopting a somewhat different strategy is to minimize the maximum hybrid-ARQ round-trip time. Due to the fact that a pure 8 ms periodicity does not always match the MBSFN allocation, the actual uplink round-trip time, unlike the FDD access link, is not constant but, similar to the TDD access link, is dependent on the subframe number.

18.3.3 BACKHAUL DOWNLINK CONTROL SIGNALING

The gap during which the relay can receive transmissions from the donor cell is, as seen in Figure 18.4, shorter than the full subframe duration. In particular, as the first OFDM symbols in the subframe are unavailable for reception of transmissions from the donor cell, L1/L2 control signaling from the donor to the relay cannot be transmitted using the regular PDCCH.[1] Instead, a relay-specific control channel, the R-PDCCH, was introduced in release 10.

The R-PDCCH carries downlink scheduling assignments and uplink scheduling grants, using the same DCI formats as for the PDCCH. However, there is no support for power control commands using DCI formats 3/3A. The main function of DCI formats 3/3A is to support semi-persistent scheduling, a feature mainly targeting overhead reduction for low-rate services and not supported for the backhaul link.

In the time domain, the R-PDCCH is, as already mentioned, received in the "MBSFN region" of the subframe, while in the frequency domain, transmission of the R-PDCCH occurs in a set of semi-statically allocated resource blocks. From a latency perspective it is

[1]In principle, the PDCCH could be received if the subframe structures of the access and backhaul links are offset by two to three OFDM symbols, but with the drawback that relay and donor cells would not be time aligned, which is beneficial, for example, in heterogeneous deployments.

Table 18.1 Supported Backhaul Configurations for TDD

Backhaul Subframe Configuration	Uplink−Downlink Configuration in Relay Cell	Backhaul DL: UL Ratio	Subframe Number									
			0	1	2	3	4	5	6	7	8	9
0	1	1:1					D				U	
1						U						D
2		2:1					D				U	D
3						U	D					D
4		2:2				U	D				U	D
5	2	1:1			U						D	
6						D				U		
7		2:1			U		D				D	
8						D				U		D
9		3:1			U	D	D				D	
10						D				U	D	D
11	3	2:1				U				D		D
12		3:1				U				D	D	D
13	4	1:1				U						D
14		2:1				U				D		D
15						U					D	D
16		3:1				U				D	D	D
17		4:1				U	D			D	D	D

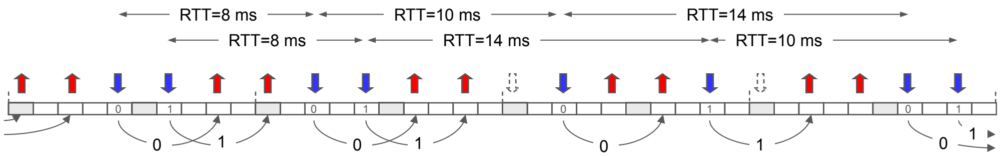

FIGURE 18.6

Example of hybrid-ARQ process numbering for FDD.

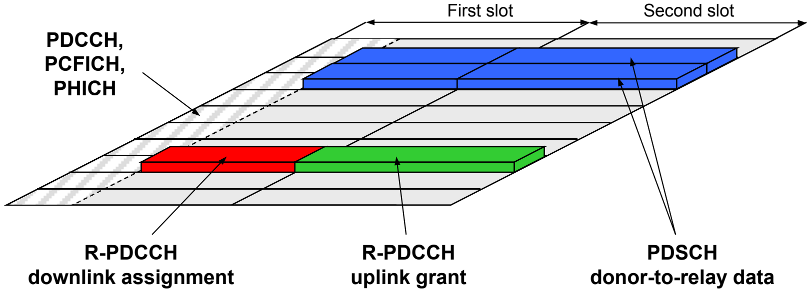

FIGURE 18.7

Example of R-PDCCH transmission.

beneficial to locate transmissions of downlink scheduling assignments as early as possible in the subframe. As discussed in Chapter 6, this was the main motivation for dividing normal subframes into a control region and a data region. In principle, a similar approach could be taken for the R-PDCCH, namely dividing the set of resource blocks used for R-PDCCH transmission into a control part and a data part. However, because it is not possible to exploit fractions of a subframe for transmission of PDSCH to devices connected directly to the donor cell, transmission of a single R-PDCCH could block usage of a relatively large number of resource blocks. From an overhead and scheduling flexibility perspective, a structure where the frequency span of the R-PDCCH is minimized (while still providing sufficient diversity) and resources are allocated mainly in the time dimension is preferable. In the release 10 design of the R-PDCCH, these seemingly contradicting requirements have been addressed through a structure where downlink assignments are located in the first slot and uplink grants, which are less time critical, in the second slot of a subframe (see Figure 18.7). This structure allows the time-critical downlink assignments to be decoded early. To handle the case when there is no uplink grant to transmit to the relay, the R-PDCCH resources in the second slot may be used for PDSCH transmission *to the same relay.*

Coding, scrambling, and modulation for the R-PDCCH follows the same principles as for the PDCCH (see Chapter 6), with the same set of aggregation levels supported (one, two, four,

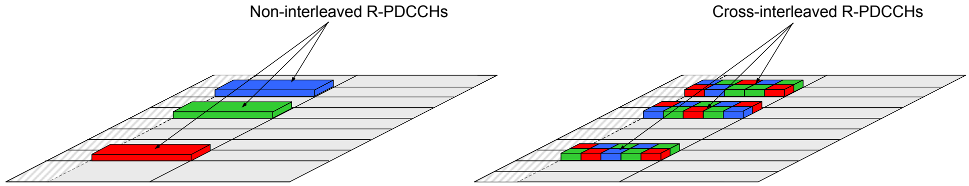

FIGURE 18.8

R-PDCCH mapping types, no cross-interleaving (left) and cross-interleaving (right).

and eight CCEs). However, the mapping of the R-PDCCH to time–frequency resources is different. Two different mapping methods, illustrated in Figure 18.8, are supported:

- without cross-interleaving,
- with cross-interleaving.

Without cross-interleaving, one R-PDCCH is mapped to one set of virtual resource blocks, where the number of resource blocks (one, two, four, or eight) depends on the aggregation level. No other R-PDCCHs are transmitted using the same set of resource blocks. If the resource blocks are located sufficiently apart in the frequency domain, frequency diversity can be obtained, at least for the higher aggregation levels. Non-interleaved mapping is, for example, useful for beam-forming of the backhaul transmissions or when applying frequency-selective scheduling to the R-PDCCH. Either CRS or demodulation reference signals (DM-RS) can be used for demodulation.

Cross-interleaved mapping is similar to the strategy used for the PDCCH and reuses most of the PDCCH processing structures except for the mapping to resource elements. A set of R-PDCCHs is multiplexed together, interleaved, and mapped to a set of resource blocks allocated for R-PDCCH transmission. As transmissions to multiple relays may share the same set of resource blocks, CRS are the only possibility for demodulation. The motivation for this mapping method is to obtain frequency diversity also for the lowest aggregation level. However, it also comes at the cost of blocking additional resource blocks from PDSCH transmission as, even at low aggregation levels, several resource blocks in the frequency domain are used for the R-PDCCH.

For both mapping cases, cross-interleaved as well as non-cross-interleaved, a set of candidate R-PDCCHs is monitored by the relay node. The set of resource blocks upon which the relay monitors for R-PDCCH transmission is configurable by the donor cell by signaling a set of virtual resource blocks using resource allocation type 0, 1, or 2 (see Chapter 6 for a discussion on resource allocation types). The sets may or may not overlap across multiple relay nodes. In the subframes used for backhaul reception, the relay attempts to receive and decode each of the R-PDCCHs candidates as illustrated in Figure 18.9 and, if valid downlink control information is found, applies this information to downlink reception or uplink transmission. This approach is in essence similar to the blind decoding procedure used in the devices, although there are some differences. First, there are no common search

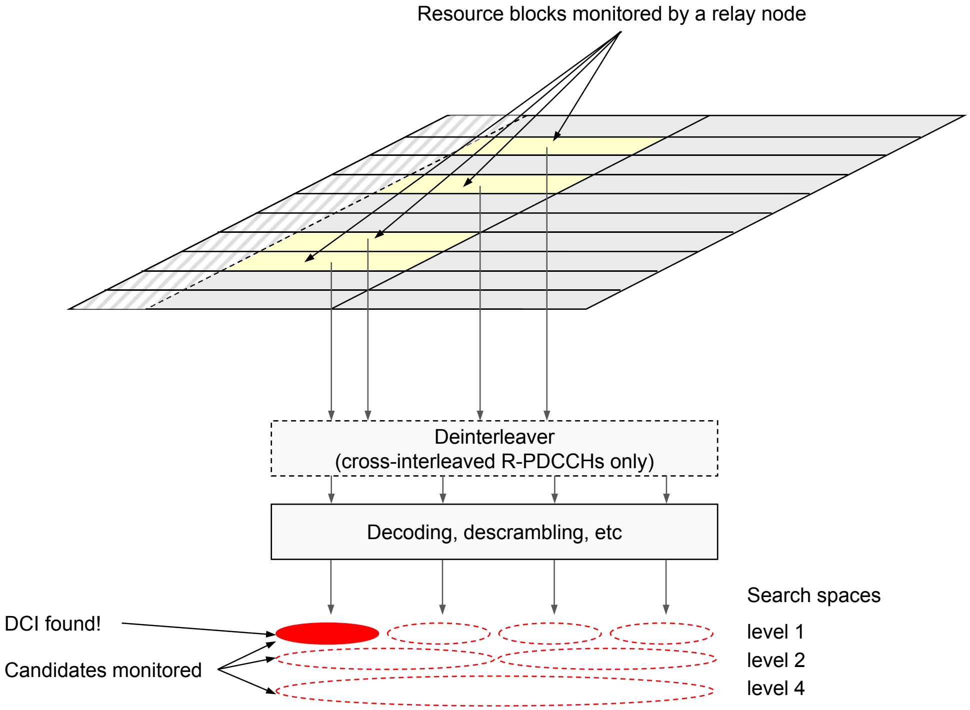

FIGURE 18.9

Principle illustration of R-PDCCH monitoring.

spaces for the relays as there is no need to receive broadcast information. Any information necessary for relay operation is transmitted using dedicated signaling. Secondly, the search spaces for the non-interleaved mapping are not time varying as in devices, but remain static in time.

The number of blind decoding attempts is the same as for a device—that is, six, six, two, and two attempts for aggregation levels one, two, four, and eight, respectively. However, note that an R-PDCCH can be transmitted in either the first or second slot. Hence, the total number of decoding attempts performed by a relay is 64.[2]

No PHICH channel is defined for the backhaul. The main reason for the PHICH in release 8 was efficient support of nonadaptive retransmissions for delay-sensitive low-rate applications such as voice-over IP. The backhaul from a relay, on the other hand, typically uses a higher data rate as multiple devices are served by the relay. Hence, as control signaling overhead is less of an issue, the PHICH was omitted from the backhaul in order to simplify the overall design. Retransmissions are still supported through the use of the R-PDCCH.

[2]Two slots and two DCI formats per transmission mode results in $2 \cdot 2 \cdot (6+6+2+2) = 64$.

18.3.4 REFERENCE SIGNALS FOR THE BACKHAUL LINK

Backhaul reception at the relay can use CRS or DM-RS, described in Chapter 6. Different reference-signal types can be used for R-PDCCH and PDSCH, but if the R-PDCCH is received using DM-RS, then DM-RS should be used for PDSCH as well. This is a reasonable restriction as DM-RS for R-PDCCH is motivated by beam-forming. If beam-forming is used for the R-PDCCH, there is no incentive not to use beam-forming also for the PDSCH. The opposite scenario, CRS for R-PDCCH and DM-RS for the PDSCH, does make sense though. One example is interleaved mapping of the control signaling, where multiple R-PDCCHs are multiplexed and individual beam-forming cannot be used, together with beam-forming of the PDSCH. The different combinations of reference signals supported for the backhaul link are summarized in Table 18.2.

Note also that in the case of (global) time alignment between the donor and relay cell, the last OFDM symbol cannot be received by the relay as it is needed for reception–transmission switching. Hence, the DM-RS on the last OFDM symbols in the subframe cannot be received. For transmission ranks up to 4 this is not a problem, as the necessary reference signals are also available earlier in the subframe. However, for spatial multiplexing with five or more layers, the first set of reference signals in the subframe is used for the lower layers while the second set of reference signals, located at the end of the subframe and that cannot be received, is used for the higher layers. This implies that reference signals for rank 5 and higher cannot be received by the relay, and backhaul transmissions are therefore restricted to at most four-layer spatial multiplexing, irrespective of the timing relation used.

18.3.5 BACKHAUL–ACCESS LINK TIMING

To ensure that the relay is able to receive transmissions from the donor cell, some form of timing relation between the downlink transmissions in the donor and relay cells must be defined, including any guard time needed to allow the relay to switch between access-link transmission to backhaul-link reception and vice versa.

Table 18.2 Combinations of Reference Signals and R-PDCCH Mapping Schemes

Reference Signal Type used for Demodulation of		R-PDCCH Mapping Scheme
R-PDCCH	**PDSCH**	
CRS	CRS	Cross-interleaved or non-cross-interleaved
CRS	DM-RS	Cross-interleaved or non-cross-interleaved
DM-RS	DM-RS	Non-cross-interleaved

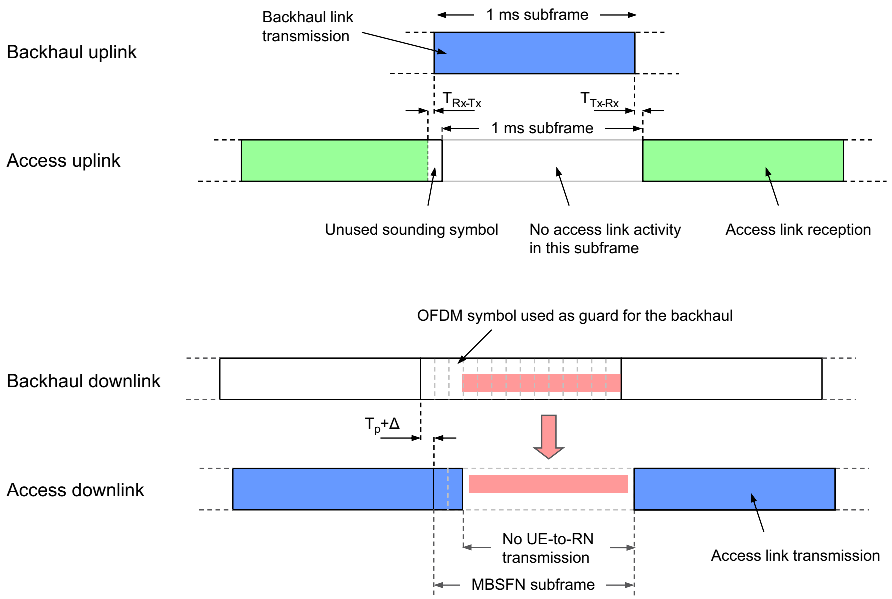

FIGURE 18.10

Backhaul timing relations in case the relay cell timing is derived from the backhaul timing.

A natural choice for the timing of the access link is to synchronize it to the frame timing of the backhaul link as observed by the relay. From this backhaul downlink timing reference, the timing of the access-link transmission is derived as shown at the bottom of Figure 18.10. The backhaul uplink timing is subject to the normal timing advance controlled by the donor cell, ensuring that the backhaul-uplink transmissions are time aligned with other uplink transmissions received by the donor base station.

In the backhaul downlink, the first OFDM symbol in the data region is left unused to provide the guard time for relay switching, and a small time offset is used to distribute the guard between Tx—Rx and Rx—Tx switching at the relay. This case is shown at the bottom of Figure 18.11. Locating the guard symbol at the beginning of the data region instead of at the end is beneficial as the guard symbol is needed at the relay side only and can therefore still be used for transmission of PDCCHs to devices in the donor cell. In principle, the guard time comes “for free” from a donor cell perspective and the freedom in shifting the relay node frame timing relative to the donor cell timing is used to move the “free” guard period to where it is needed.

The backhaul uplink is subject to the normal timing advance controlled by the donor cell, ensuring that the backhaul uplink transmissions are time aligned with other uplink transmissions received by the donor base station. Similarly to the guard time needed to switch from access-link transmission to backhaul-link reception, which influenced the downlink

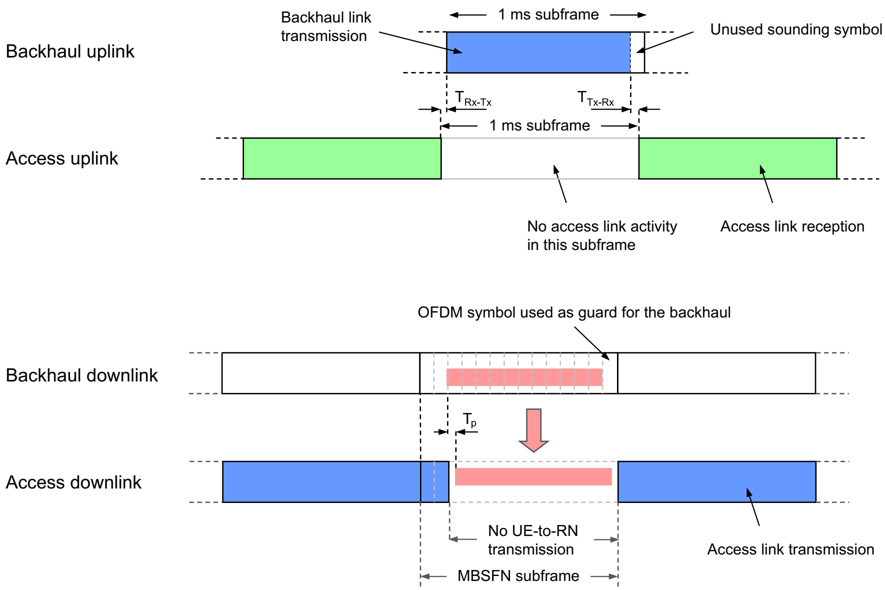

FIGURE 18.11

Backhaul timing relations in access link transmission in the relay and donor cells are time synchronized.

timing relation between the access and backhaul links, there may also be the need for a guard time in the uplink direction to switch from access-link reception to backhaul-link transmission. However, unlike the downlink case, how to handle this is not standardized but left for implementation, noting that functionality already present in release 8 is sufficient for providing the necessary guard time.

In principle, if the relay could switch from access-link reception to backhaul-link transmission within the cyclic prefix, no provisions for additional switching time would be necessary. However, the switching time is implementation dependent and typically larger than the cyclic prefix. For larger switching times, one possibility is to use the shortened transmission format on the access link, originally intended for sounding, as shown in the top part of Figure 18.10. By configuring all the devices in the relay cell to reserve the last OFDM symbol of the preceding subframe for sounding-reference signals but not to transmit any sounding-reference signals, a guard period of one OFDM symbol is created. This guard time can then be divided into Rx—Tx and Tx—Rx switching times through a time offset between the frame timing of the backhaul and access links.

For some deployments, it is desirable to align the access-link transmission timing of the relay with the transmission timing of the donor cell—that is, to use a global timing reference for all the cells. One example hereof is TDD. In such deployments, the necessary guard times are obtained in a slightly different manner compared to the case of using reception timing of

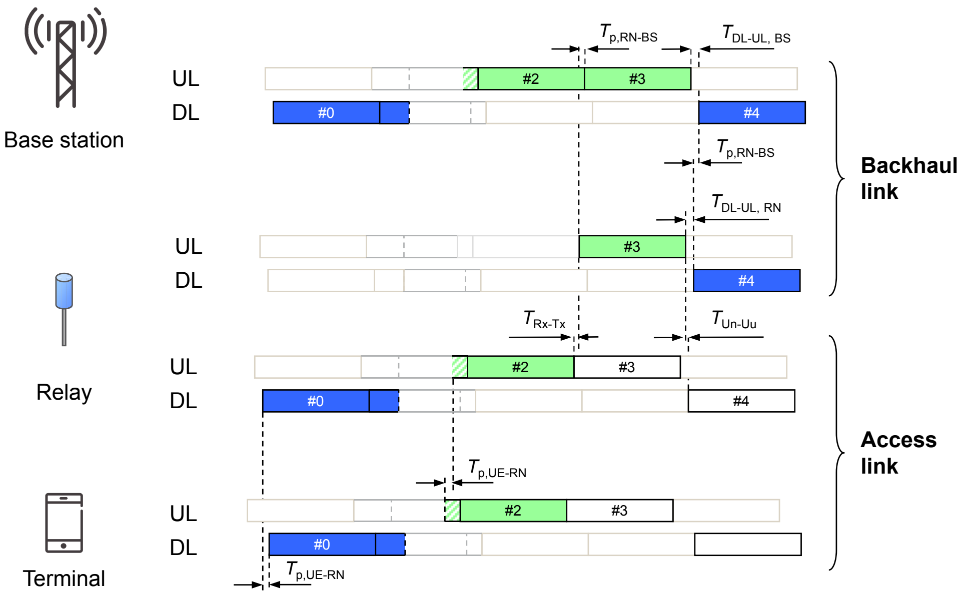

FIGURE 18.12

Example of uplink timing relation for TDD.

the backhaul downlink. In this case it is not possible to obtain the necessary guard time by shifting the subframe timing at the relay. Hence, the guard time for switching from backhaul-link reception to access-link transmission will also be visible at the donor cell, as the last OFDM symbol in the resource blocks used for the backhaul transmission cannot be used for other transmissions in the relay cell. If the time for Tx—Rx switching is longer than the donor-cell-to-relay-node propagation delay, then the first OFDM symbol has to be left unused as well. This case is shown in the bottom part of Figure 18.11.

In the backhaul uplink, the guard time necessary, similar to the previous timing case, is obtained through configuration of (unused) sounding instances. However, unlike the previous case, sounding is configured in the *backhaul* link, as shown at the top of Figure 18.11. Note that this implies that sounding cannot be used for the backhaul link as the OFDM symbol intended as a sounding-reference symbol is used as guard time.

In the case of TDD operation, guard time for the access—backhaul switch can, in addition to the methods discussed earlier, be obtained from the guard period required for TDD operation itself. This is shown in Figure 18.12 and is a matter of using the appropriate settings of timing advance and timing offsets.

Backhaul downlink transmissions consist of data transmitted on the PDSCH and L1/L2 control signaling transmitted on the R-PDCCH, as already discussed. Both these types of transmission must follow one of the timing scenarios discussed earlier. In order to allow for different implementations and deployments, the LTE specifications provide not only the possibility to configure which of the two access–backhaul downlink timing relations to use, but also flexibility in terms of the time span of the channels transmitted on the backhaul link.

PDSCH transmissions intended for a relay can be semi-statically configured to start on the second, third, or fourth OFDM symbol to cater for different control region sizes in the donor cell and relay cells. The PDSCH transmission ends at the last or second last OFDM symbol, depending on which of the two timing cases mentioned earlier is used.

R-PDCCH transmissions intended for a relay always start at the fourth OFDM symbol. A fixed starting position was chosen to simplify the overall structure. Since the amount of resource blocks occupied by an R-PDCCH is relatively small compared to the PDSCH, the overhead reduction possible with a configurable starting position is small and does not justify the additional specification and testing complexity.