CHAPTER

MULTI-POINT COORDINATION AND TRANSMISSION 13

The principle of *spatial reuse* lies at the core of any cellular wireless-access system. Spatial reuse implies that the same communication resource, in the LTE case the same time–frequency resource, can be simultaneously used for communication at different, spatially-separated locations.

Inherently, transmissions carried out on the same time–frequency resource will cause interference to each other. To limit this interference, early cellular technologies relied on a static frequency separation between neighboring cells. As an example, in a *reuse-3* deployment the overall set of available frequency resources is divided into three groups. As illustrated in Figure 13.1, only frequencies of one of these groups are then used within a given cell, with frequencies of other groups being used in the most neighboring cells. Interference from transmissions in the most neighbor cells is then avoided and each communication link experiences a relatively high signal-to-interference ratio (SIR) regardless of the device position within the coverage area.

However, for modern wireless-access technologies such as LTE, which should be able to provide very high end-user data rates when the channel conditions so allow, this is not a good approach. Being hard limited to only a fraction of the overall available spectrum at a given transmission point would reduce the maximum achievable transmission bandwidth that can be used at the transmission point with a corresponding reduction in the maximum achievable data rates as a consequence.[1]

Even more important, in a wireless-access system dominated by highly dynamic packet-data traffic there is frequently no data available for transmission at a given transmission point. Having statically assigned a part of the overall available spectrum to that transmission point with no possibility to use the corresponding frequency resources to provide higher instantaneous transmission capacity at neighboring transmission points would imply an inefficient use of the available spectrum. Rather, in order to maximize system efficiency, as well as to enable end-user data rates as high as possible, a wireless-access technology should be deployed such that, fundamentally, all frequency resources are available for use at each transmission point.

[1]Instead of "cell" we here use the more general term "(network) transmission point." For a homogeneous deployment, which is the focus of this chapter, one can typically assume that each "transmission point" corresponds to a "cell." For the case of heterogeneous deployments, which is the topic of the next chapter, the distinction will in some cases be more important.

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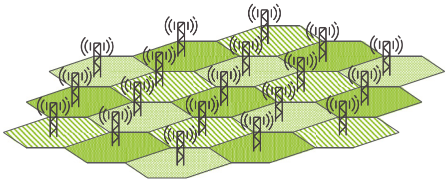


FIGURE 13.1

Reuse-3 deployment.

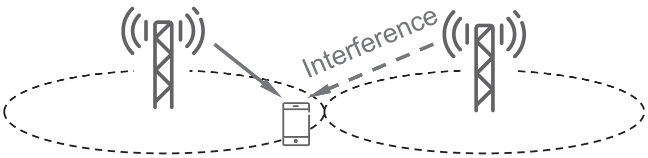


FIGURE 13.2

Downlink interference to device close to the border between two transmission points.

At the same time, for the specific case of transmission to a device close to the border between the coverage areas of two transmission points, see Figure 13.2, end-user quality and overall efficiency would be further improved if interference from the neighboring transmission point could be avoided.

Thus, even if all frequency resources should fundamentally be available for use at each transmission point, coordination across the transmission points can be beneficial. Such coordination could, for example, imply avoiding transmission, or transmitting with lower power or in a different direction (beam-forming), on a certain time–frequency resource in order to reduce the interference to devices served by other, neighboring transmission points if such a device would otherwise experience severe interference.

In certain cases one could even consider using both transmission points for transmission to the same device. This would not only avoid interference from the neighboring transmission point but would also boost the overall signal power available for transmission to the device.

The preceding discussion implicitly assumed downlink transmission with device reception being interfered by downlink transmissions from other network transmission points. However, the concept of coordination between network points as a means to better control the interference levels is applicable also to the uplink, although the interference situation in this case is somewhat different.

For the uplink, the interference level experienced by a certain link does not depend on where the transmitting device is located but rather on the location of the *interfering* devices, with interfering devices closer to the border between two, in this case, network *reception points* causing more interference to the neighboring reception point, see Figure 13.3. Still, the

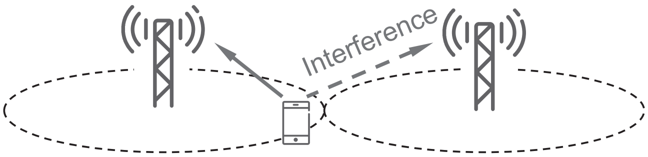


FIGURE 13.3

Uplink interference from device close to the border between two reception points.

fundamental goal of uplink coordination is the same as for the downlink, that is, to avoid the most severe interference situations.

One can envision two main deployment scenarios when considering coordination between network points:

- Coordination within a *homogeneous deployment*, for example between nodes in a macro deployment.
- Coordination within a *heterogeneous deployment*, such as between a macro node and under-laid lower-power nodes.

The focus of this chapter is on the first type of coordination—that is, coordination within homogeneous deployments. Heterogeneous deployments will create additional challenges and corresponding need for coordination between transmission points. This is further discussed in the next chapter as part of a more general discussion on heterogeneous deployments.

One factor that impacts the possibilities for coordination between network points is the available backhaul connectivity and especially its associated latency. Highly dynamic coordination requires low-latency connectivity between the points to be coordinated. One case when this is definitely available is when the points to be coordinated correspond to sectors of the same site ("intrasite coordination"). However very-low-latency connectivity may be available also in the case of geographically separated transmission points, especially if there are direct physical links (for example optical or wireless links) between the points. In other cases, only not-so-low latency internode connectivity, for example connectivity with latency in the order of several tens of milliseconds or more, may be available in which case one is limited to less dynamic coordination.

The 3GPP activities related to coordination between network points for LTE can be divided into two phases:

- Release 8 activities on *inter-cell interference coordination* (ICIC), primarily focusing on inter-eNB (X2) signaling to assist such coordination
- Release 10−13 activities on multi-point coordination/transmission targeting more dynamic coordination and focusing on new radio-interface features and device capabilities to enable/improve such coordination

Furthermore, as is discussed in the next chapter, additional schemes for interpoint coordination have been defined as part of enhancements for heterogeneous deployments.

13.1 INTER-CELL INTERFERENCE COORDINATION

The potential gains of coordination between transmission/reception points were extensively discussed in the early phase of LTE standardization with focus on coordination within homogeneous macro deployments. More specifically, the focus was on defining X2 signaling that could be used to enhance such coordination between cells corresponding to different eNodeB.[2] As the X2 interface is typically associated with not-so-low latency, the focus of the release 8 activities was on relatively slow coordination.

In the case of scheduling located at a higher-level node above the eNodeB, coordination between cells of different eNodeB would, at least conceptually, be straightforward as it could be carried out at the higher-level node. However, in the LTE radio-network architecture there is no higher-level node defined and scheduling is assumed to be carried out at the eNodeB. Thus, the best that can be done from an LTE specification point of view is to introduce messages that convey information about the local scheduling strategy/status between neighboring eNodeBs. An eNodeB can then use the information provided by neighboring eNodeBs as input to its own scheduling process. It is important to understand though that the LTE specifications do not specify how an eNodeB should react to this information. Rather, this is up to scheduler implementation.

To assist uplink interference coordination, two X2 messages were defined as part of LTE release 8, the *high-interference indicator* (HII) and the *overload indicator* (OI), see also Figure 13.4.

The *HII* provides information about the set of resource blocks within which an eNodeB has high sensitivity to interference. Although nothing is explicitly specified on how an eNodeB should react to the HII (or any other ICIC-related X2 signaling) received from a

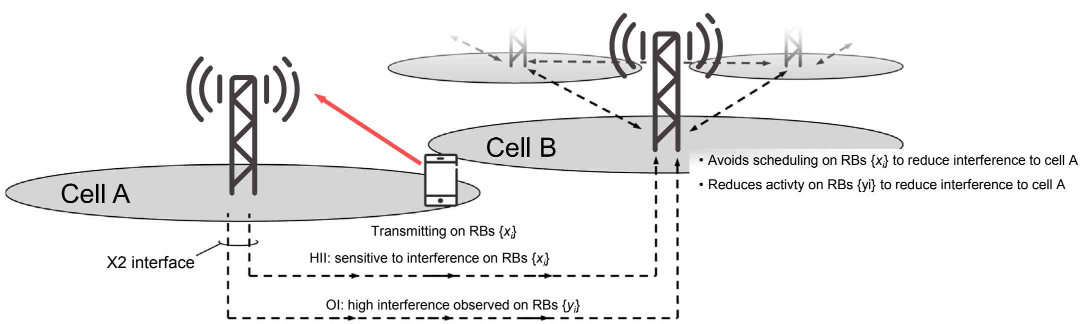


FIGURE 13.4

Illustration of uplink ICIC based on the HII and OI X2 signaling.

[2]As the focus was on X2, that is, inter-eNodeB signaling, the transmission/reception points relevant for the coordination would inherently correspond to different cells.

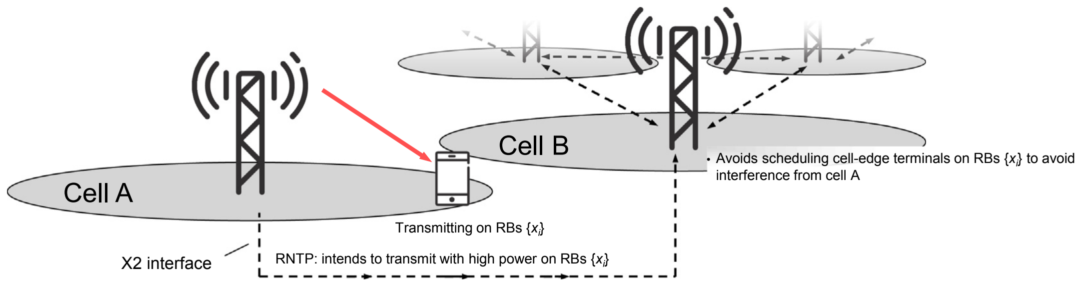


FIGURE 13.5

Illustration of downlink ICIC based on RNTP X2 signaling.

neighboring eNodeB, a reasonable action for the receiving eNodeB would be to try to avoid scheduling its own cell-edge devices on the same resource blocks, thereby reducing the uplink interference to cell-edge transmissions in its own cell as well as in the cell from which the HII was received. The HII can thus be seen as a *proactive* tool for ICIC, trying to prevent the occurrence of *too-low-SIR* situations.

In contrast to the HII, the OI is a *reactive* ICIC tool, essentially indicating, at three levels (low/medium/high), the uplink interference experienced by a cell on its different resource blocks. A neighboring eNodeB receiving the OI could then change its scheduling behavior to improve the interference situation for the eNodeB issuing the OI.

For the downlink, *the relative narrowband transmit power* (RNTP) was defined to support ICIC operation (see Figure 13.5). The RNTP is similar to the HII in the sense that it provides information, for each resource block, whether or not the relative transmit power of that resource block is to exceed a certain level. Similar to the HII, a neighboring cell can use the information provided by the received RNTP when scheduling its own devices, especially devices on the cell edge that are more likely to be interfered by the neighboring cell.

13.2 MULTI-POINT COORDINATION/TRANSMISSION

During the work on LTE release 10, the possibility for more dynamic coordination between network points was discussed under the term *Coordinated Multi Point* (CoMP) transmission/reception. Although initially discussed as part of the 3GPP activities on LTE release 10, the main features related to CoMP were introduced into the LTE specifications as part of release 11 and enhanced in later releases.

A main difference between the LTE release 8 ICIC activities described previously and the release 10/11 CoMP activities is that the latter focused on radio-interface features and device functionality to assist different coordination means. At the same time, there were no discussions on specific inter-eNodeB signaling to support CoMP. Rather, there was an assumption that low-latency backhaul was available for the coordination, in practice limiting release 11 CoMP features to either sectors of the same site or network points connected by direct low-latency links. There was also an implicit assumption that the different network points involved in the coordination were tightly synchronized and time aligned with each other. Extensions to relaxed backhaul scenarios with noncentralized baseband processing were introduced in release 12. These enhancements mainly consisted of defining new X2 messages for exchanging information about so-called *CoMP hypotheses*, essentially a potential resource allocation, and the associated gain/cost. In the same way as for ICIC, the eNodeBs can use this information for scheduling coordination.

The different approaches to CoMP considered for the LTE downlink can be divided into two main groups:

- Schemes where transmission is carried out from a specific transmission point but where the scheduling and link adaptation may be coordinated between transmission points. We refer to this as *multi-point coordination*.
- Schemes where transmission to a device may be carried out from different transmission points (*multi-point transmission*). The transmission can then either switch dynamically between the different transmission points or be carried out jointly from multiple points.

A similar distinction can be made for the uplink transmission direction in which case one would distinguish between (uplink) multi-point coordination, where the uplink scheduling is coordinated between different reception points, and *multi-point reception* where reception may be carried out at multiple points. It should be noted that, at least from a radio-interface point of view, uplink multi-point coordination/reception is very much a network implementation issue with very little impact on the device and very little visibility in the radio-interface specifications. The discussions in Sections 13.2.1 and 13.2.2 focus on coordination in the downlink transmission direction. Section 13.2.3 briefly discusses some aspects of uplink multi-point coordination/reception.

13.2.1 MULTI-POINT COORDINATION

As described earlier, multi-point coordination implies that transmission is carried out from a specific transmission point but functions such as link adaptation and/or scheduling are coordinated between multiple points.

13.2.1.1 Coordinated Link Adaptation

Link adaptation—the dynamic selection of data rate based on estimates/predictions of the instantaneous channel conditions to be experienced by a transmission—is one of the basic mechanisms for good system performance in LTE. Good link adaptation relies on the availability of good predictions of the interference level to be experienced by the transmission. However, in case of highly dynamic traffic conditions, the traffic activity of neighbor transmission points may vary rapidly. As a consequence the interference level may also vary rapidly and in an (apparently) unpredictable way.

Coordinated link adaptation is about using information related to transmission decisions of neighboring transmission points in the link-adaptation process, that is, in the decision with what data rate to transmit on a given resource. Note that this implies a multi-step process in the scheduling and link adaptation at transmission points:

1. For a given subframe, transmission points carry out transmission decisions. In the simplest case this may be decisions on whether or not to transmit data on a certain set of time–frequency resources, that is, a certain set of resource blocks within the subframe. In a more general case it may also include, for example, decisions on transmission power and/or beam-forming decisions for the given set of resources.
2. Information about the transmission decisions is shared between neighboring transmission points.
3. Transmission points use the information about transmission decisions of neighboring transmission points as input to the link-adaption decision for the transmission(s) to take place in the given subframe.

In LTE, link adaptation is carried out at the network side. However, as described in Chapter 9, the network typically bases the link-adaptation decisions on CSI reports provided by the devices. To enable coordinated link adaptation, that is, to allow for the network to take information about the transmission decisions made by neighboring transmissions into account in the rate selection, the device should provide multiple CSI reports corresponding to different *hypothesis* regarding the transmission decisions of neighboring transmission points. These CSI reports can then be used together with information about the actual transmission decisions of neighboring transmission points in the link adaptation.

In order for a device to be able to provide CSI reports corresponding to different hypothesis regarding the transmission decisions of neighboring transmission points, it should be configured with *multiple CSI processes*. As described in Chapter 9, each such process would correspond to a set of CSI-RS, one for each antenna port, and one CSI-IM resource for interference estimation. In order to support coordinated link adaptation, the set of CSI-RS should be the same for all processes and reflect the channel of the different antenna port(s) for the transmission point from which transmission is to be carried out. In contrast, the CSI-IM resources of the different CSI processes should be different and configured in such a way that they reflect the interference to be expected for different hypothesis regarding the transmission decisions of neighboring transmission points.

As an example, Figure 13.6 illustrates the case of coordinated link adaptation between two transmission points. The figure also illustrates three different CSI-RS resources on which there is either transmission, corresponding to ordinary (nonzero-power) CSI-RS, or no transmission, corresponding to zero-power CSI-RS, for the two transmission points.

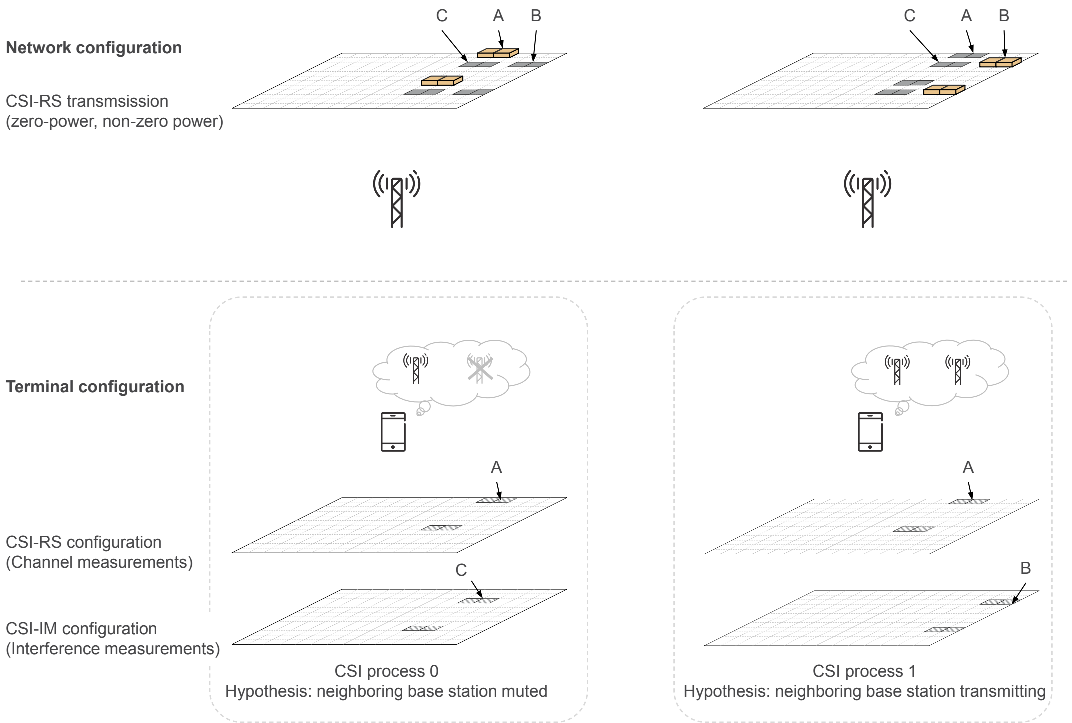


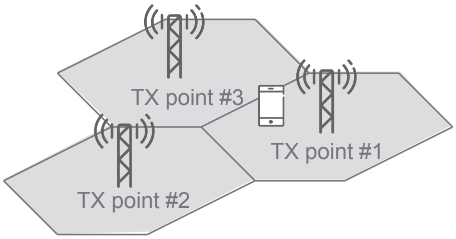
FIGURE 13.6

Example of using multiple CSI processes.

For a device associated with the left side transmission point, two CSI processes are configured:

- Process 0 with CSI-RS corresponding to resource A and CSI-IM corresponding to resource C (configured as zero-power CSI-RS at the neighboring transmission point). CSI-reporting by this CSI process will thus reflect the channel state under the hypothesis that there is no transmission from the neighboring transmission point.
- Process 1 with CSI-RS corresponding to resource A (same as for process 0) and CSI-IM corresponding to resource B (configured as nonzero-power CSI-RS at the neighboring transmission point). CSI reported by this process will thus reflect the channel state under the hypothesis that there is transmission from the neighboring transmission point.

The CSI reports delivered by the device for the different CSI processes would thus correspond to the different hypotheses regarding the transmission decision of the neighboring transmission point. Based on information regarding the expected transmission from the neighboring transmission point, the network can select the appropriate CSI report and use that in the link-adaptation decision.



Resource	TX point #1	TX point #2	TX point #3
A	ZP CSI-RS	ZP CSI-RS	ZP CSI-RS
B	ZP CSI-RS	ZP CSI-RS	CSI-RS
C	ZP CSI-RS	CSI-RS	ZP CSI-RS
D	ZP CSI-RS	CSI-RS	CSI-RS
E	CSI-RS	ZP CSI-RS	ZP CSI-RS
F	CSI-RS	ZP CSI-RS	CSI-RS
G	CSI-RS	CSI-RS	ZP CSI-RS

FIGURE 13.7

CSI-RS/IM structure to support coordinated link adaption between three transmission points.

Coordinated link adaptation can also be carried out between more than two transmission points. As an example, consider a case where one would like to carry out coordinated link adaptation between three different transmission points (Figure 13.7). In this case there is a need for a total of seven CSI-RS resources, labeled A to G, configured as nonzero-power and zero-power CSI-RS at the different transmission points according to Figure 13.7.

A device associated with transmission point 1 should, in this case, be configured with four CSI processes, the CSI-IM resources of which would correspond to resources A to D in Figure 13.7. Measurements on these four CSI-IM resources would provide interference predictions that would correspond to different hypotheses regarding the transmission decisions of neighboring points. More specifically:

- Measurements on the CSI-IM resource corresponding to resource A would provide an interference prediction corresponding to the hypothesis that there is transmission from neither transmission point 2 nor transmission point 3 at the time of transmission.
- Measurements on the CSI-IM resource corresponding to resource B would provide an interference prediction corresponding to the hypothesis that there is transmission from transmission point 2 but not from transmission point 3.
- Measurements on the CSI-IM resource corresponding to resource C would provide an interference prediction corresponding to the hypothesis that there is transmission from transmission point 3 but not from transmission point 2.
- Finally, measurements on the CSI-IM resource corresponding to resource D would provide an interference prediction corresponding to the hypothesis that there is transmission from both transmission point 2 and transmission point 3.

Similarly, a device associated with transmission point 2 would be configured with CSI processes, the CSI-IM of which would correspond to resource A, B, E, and F in Figure 13.7. In this case, as an example, measurements on the CSI-IM resource corresponding to resource E would provide an interference prediction corresponding to the hypothesis that there is transmission from transmission point 1 but not from transmission point 3.

Likewise, a device associated with transmission point 3 would be configured with CSI processes, the CSI-IM of which would correspond to resources A, C, E, and G in Figure 13.7.

The support of multiple CSI processes greatly enhanced the support for CoMP and various beamforming schemes. However, one drawback with the current CSI process approach is the lack of scalability. If coordination across a large number of nodes is desirable or a large number of potential beam-forming candidates are to be evaluated, there is an exponential increase in the number of CSI processes with a corresponding increase in the CSI-RS overhead. Therefore, alternative way of reporting CSI for multiple transmission hypotheses may be needed in future LTE releases. Since the device can measure the signal strength from all points in the coordination set, one possibility could be to let the device compute and report the CSI under different hypotheses with the interference level computed from the signal strength measurements.

13.2.1.2 Coordinated Scheduling

Dynamic link adaption as described in the preceding paragraphs is about using information related to the transmission decisions made by neighboring transmission points in the link-adaptation decision, that is, in the selection of transmission rate to be used by a transmission point. Dynamic link adaptation is applicable and useful regardless of whether or not the actual transmission decisions are coordinated between the transmission points.

Coordinated scheduling is about coordinating the actual transmission decision(s) between transmission points. Thus, while coordinated link adaptation is about sharing of information between transmission points for better predictions of the interference levels, coordinated scheduling is about sharing of information and coordination between transmission points to reduce and control the actual interference levels.

In its most simple case, coordinated scheduling is about dynamically preventing transmission at certain time–frequency resource in order to reduce the interference to be experienced by a device served by a neighboring transmission point. In the LTE CoMP discussions, this has been referred to as *dynamic point blanking*. In the more general case it can also involve dynamically adjusting the transmit power (*coordinated power control*) or dynamically adjusting the transmission direction (*coordinated beam-forming*) for a specific set of resources. The enhancements part of FD-MIMO—see Chapter 10—can also be used for even better coordination gains.

In order to enable dynamic point blanking the network should be able to estimate/predict the impact to a device in terms of expected channel quality of transmissions from a neighboring transmission points and also be able to predict how much the channel quality would improve if transmissions from the neighboring transmission point would not take place. To enable this, multiple CSI processes configured in the same way as for coordinated link adaptation, discussed earlier, may be used. The different CSI processes provide different CSI reports reflecting different hypotheses regarding the transmission at the neighboring transmission points. By comparing these CSI reports, the network can estimate how much would be gained from blanking relevant time–frequency resources at a neighboring transmission point.

As an example, consider a device associated with transmission point 1 in the example scenario of Figure 13.7. If there were a large difference in the CQI, that is, the recommended data rate, of the CSI reports corresponding to resource B and D, this would be an indication that the device would be severely interfered by transmissions from transmission point 2 and it would be relevant to consider blanking of relevant time–frequency resources at that transmission point to improve the experienced channel quality and, as a consequence, the data rate that can be supported, for the device associated with transmission point 1.

On the other hand, if there were a very small difference in the CQI of the CSI reports corresponding to resource B and D, this would be an indication that the device is not severely interfered by transmissions from transmission point 2 and, at least in terms of channel quality for this specific device, it is not beneficial to apply blanking to transmission point 2.

13.2.2 MULTI-POINT TRANSMISSION

Multi-point coordination as described previously implies that transmissions carried out from neighboring transmission points are coordinated in terms of scheduling (if/when to transmit) and/or link adaption (with what rate to transmit). However, the transmission to a given device is still assumed to be carried out from one specific transmission point. In contrast, in case of *multi-point transmission*, the transmission to a given device can be carried out from different transmission points, either so that the point of transmission can change dynamically, referred to as *dynamic point selection*, or so that the transmission can be carried out jointly from multiple transmission points, referred to as *joint transmission*.

13.2.2.1 Dynamic Point Selection

As mentioned earlier, dynamic point selection implies transmission from a single transmission point but where the point of transmission can be changed dynamically as illustrated in Figure 13.8.

In the LTE context, dynamic point selection, and actually all CoMP schemes, are assumed to be based on the use of transmission mode 10. Thus, in case of dynamic point selection PDSCH transmission relies on DM-RS for channel estimation. As a consequence, the device does not need to be aware of the change of transmission point. What the device will see is simply a PDSCH transmission, the instantaneous channel of which may change abruptly as

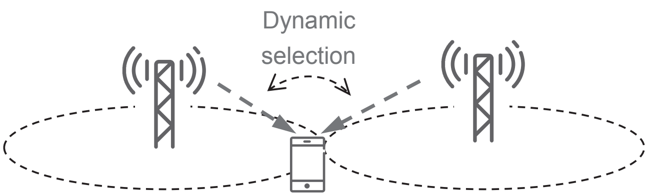


FIGURE 13.8

Dynamic point selection between two transmission points.

the point of transmission is changed. In essence, from a device point of view, the situation would be identical to that of beam-forming based on non-codebook-based precoding.[3]

To assist in the dynamic selection of transmission point, a device should provide CSI reports corresponding to multiple transmission points. Similar to coordinated link adaptation and coordinated scheduling this may be achieved by configuring the device with multiple CSI processes.

As just described, in the case of coordinated link adaptation and coordinated scheduling the different CSI processes should correspond to the same transmission point, that is, the set of CSI-RS should be the same for the different processes. At the same time, the CSI-IM resources should be different for the different processes, allowing for the interference measurements and thus also the CSI reports to reflect different hypothesis regarding the transmission decisions of the neighboring transmission points.

In contrast, to support dynamic point selection the different CSI processes should provide CSI reports corresponding to different transmission points. Thus, the set of CSI-RS of the different processes should be different and correspond to CSI-RS transmitted by the different transmission points between which the dynamic point selection is carried out.

In addition to CSI reporting, the other main specification impact of dynamic point selection relates to PDSCH mapping and what a device can assume in terms of quasi-colocation relation between different reference signals.

In the normal case, PDSCH mapping to the resource blocks assigned for transmission avoids the resource elements used for CRS transmission within the serving cell of the device. However, in case of dynamic point selection the PDSCH transmission to a device may be carried out from a transmission point associated with a different cell than the serving cell. If this cell has a different CRS structure, in terms of number of CRS and/or CRS frequency shift, and the PDSCH mapping remained according to the CRS structure of the serving cell, CRS transmissions from the actual point of transmission would be severely interfered by the PDSCH transmission. Rather, in case of dynamic point selection, one would like the PDSCH mapping to dynamically match the CRS structure of the actual point of transmission.

A similar situation may arise for L1/L2 control signaling. The size of the control region, and thus the starting point for PDSCH transmission, of a certain cell may vary dynamically with information about the size of the control region provided to the device by means of the PCFICH (see Section 6.4). However, in case of dynamic point selection, if the size of the control region of the actual point of transmission differs from that of the serving cell and the PDSCH mapping remained according to the PCFICH of the serving cell, the L1/L2 control signaling of the actual point of transmission would run the risk of being severely interfered by the PDSCH transmission. Thus, similar to the case of CRS one would like the PDSCH mapping to dynamically match the size of the control region of the actual point of transmission.

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[3] There would be a difference in what the device can assume in terms of quasi-colocation, as further discussed subsequently.

Furthermore, as described in Chapter 6, a device may be configured with a set of zero-power CSI-RS resources. From a device point of view the zero-power CSI-RS simply defines a set of resource elements to which PDSCH is not mapped, typically because these resources elements are used for other purposes, for example, as CSI-RS for other devices or as CSI-IM resources. However, if the PDSCH transmission is carried out from a different point one would typically like the PDSCH mapping to avoid a different set of resource elements as this transmission point would typically use different resource elements for CSI-RS and CSI-IM.

To handle these related problems in a unified way, transmission mode 10 allows for the dynamic reconfiguration of the PDSCH mapping by means of a *PDSCH-mapping-and-quasi-colocation indicator* provided as part of the downlink scheduling assignment, more specifically as part of DCI format 2D as described in Section 6.4.

A device can be provided with up to four different *PDSCH mapping and quasi-colocation configurations*.[4] Each such configuration specifies:

- a specific CRS configuration in terms of number of CRS and CRS frequency shift,
- a specific PDSCH starting point,
- a specific MBSFN subframe configuration,[5]
- a specific zero-power CSI-RS configuration.

The *PDSCH-mapping-and-quasi-colocation* indicator provided in the scheduling assignment then explicitly indicates which one of the up to four different configurations the device should assume for the PDSCH mapping for the corresponding subframe.

It should be noted that the PDSCH starting point indicator does not guarantee perfect match with the size of the control region of the actual point of transmission as the size of the control region can vary dynamically. The PDSCH starting point indication should be set to a sufficiently large value to guarantee that the PDSCH transmission does not overlap with the control region. As the size of the control region never exceeds three OFDM symbols (corresponding to control signaling in OFDM symbol 0, 1, and 2), the most straightforward way of achieving this would be to set the PDSCH starting point to three.[6] However, lower values can be used, allowing for a larger PDSCH payload, if one knows that, in a certain cell, the control region will always be limited to a lower value.

As the name suggests, the *PDSCH-mapping-and-quasi-colocation* configurations and the corresponding indicator in the scheduling assignment also provide information about what the device can assume in terms of quasi-colocation relation between antenna ports. As discussed in Chapter 6, for transmission mode 1 to 9, a device can assume that the antenna ports

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[4]Note the different between the *PDSCH-mapping-and-quasi-colocation configuration* provided by means of higher layer signaling and the *PDSCH-mapping-and-quasi-colocation indicator* provided by the scheduling assignment.

[5]The MBSFN subframe configuration is related to the CRS configuration as it impacts the presence of CRS reference symbols in the data part of the subframe.

[6]In case of the smallest LTE cell bandwidths, the size of the control region could be up to four OFDM symbols.

corresponding to CRS of the serving cell, DM-RS, and the CSI-RS configured for the device are all jointly quasi-colocated. However, in case of dynamic point selection, a device may be configured with different sets of CSI-RS by means of different CSI processes. In practice these sets of CSI-RS correspond to different transmission points. Eventually, the PDSCH together with its corresponding DM-RS will be transmitted from one of these transmission points. The antenna ports used for the PDSCH transmission will then, in practice, be quasi-colocated with the set of CSI-RS corresponding to that specific transmission point. To provide this information to the device, which is not explicitly aware of from what transmission point the PDSCH transmission takes place, each *PDSCH mapping and quasi-colocation* configuration also indicates a specific set of CSI-RS for which the device can assume quasi-colocation with the DM-RS for the specific subframe.

13.2.2.2 Joint Transmission

While dynamic point selection implies transmission from a single transmission point but where the point of transmission can be changed dynamically, joint transmission implies the possibility for simultaneous transmission from multiple transmission points to the same device (Figure 13.9).

In case of joint transmission one can distinguish between two cases:

- Coherent joint transmission.
- Noncoherent joint transmission.

In case of coherent joint transmission it is assumed that the network has knowledge about the detailed channels to the device from the two or more points involved in the joint transmission and selects transmission weights accordingly, for example, to focus the energy at the position of the device. Thus, coherent joint transmission can be seen as a kind of beam-forming for which the antennas taking part in the beam-forming are not colocated but correspond to different transmission points.

There is currently no support in the LTE specifications for the device to report this kind of detailed channel knowledge for multiple transmission points and thus currently no explicit support for coherent joint transmission.

In contrast, for *noncoherent* joint transmission it is assumed that the network does not make use of any such detailed channel knowledge in the joint transmission. Thus, the only gain of noncoherent joint transmission is that the power of multiple transmission points is used for transmission to the same device, that is, in practice, a power gain. The benefit of this depends on whether or not the power of the second transmission point can be of better use for the transmission to other devices and also to what extent the extra transmission will cause

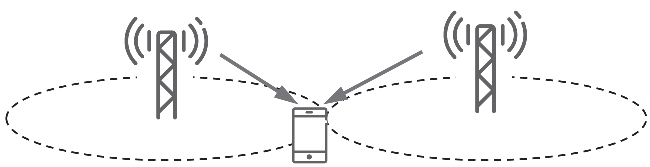

FIGURE 13.9

Joint transmission from two transmission points to the same device.

harmful interference to other transmissions. In practice, noncoherent joint transmission is only beneficial at low-load situations,

- where there is no other device available for which the second transmission point can be used,
- where the additional interference from the second transmission does not really cause any harm.

It should be noted that, in case of joint transmission, PDSCH may be jointly transmitted from points corresponding to two cells with, for example, different CRS configurations or different MBSFN configurations. In such a case one would like for the PDSCH mapping to match the configurations of both cells. However, currently each *PDSCH-mapping-and-quasi-colocation* configuration only corresponds to a single CRS configuration.

13.2.3 UPLINK MULTI-POINT COORDINATION/RECEPTION

The previous sections, Sections 13.2.1 and 13.2.2, focused on *downlink* multi-point coordination/transmission. However, as already mentioned, the same basic principles are also applicable for transmissions in the uplink direction (*uplink CoMP*). More specifically:

- Dynamic coordination of uplink transmissions in order to control uplink interference and achieve improved uplink system performance (uplink multi-point *coordination*).
- Reception of uplink transmissions at multiple points (uplink multi-point *reception* or uplink *joint reception*).

However, in contrast to downlink multi-point coordination/transmission, uplink multi-point coordination/reception has very little impact on the radio-interface specifications. Especially, any channel-state information needed for uplink scheduling coordination would be directly derived at the network (reception) side and would not require any specific device feedback.

Also, a device does not need to be aware at what point its uplink transmission is received as long as any downlink transmission corresponding to the uplink transmission, such as Hybrid ARQ feedback) is, for the device, transmitted in an expected way. In practice this means that even if the uplink is received at a point different from the transmission point associated with the serving cell, feedback such as Hybrid ARQ acknowledgments must still be transmitted from the transmission point of the serving cells. This would require the availability of low-latency connectivity between the reception and transmission points to ensure, for example, that the Hybrid-ARQ timing relations are retained. As already mentioned, the 3GPP release 10/11 CoMP discussions focused on the situation of low-latency connectivity between transmission/reception points.

Some aspects of the radio-interface design have taken the possibility for multi-point reception into account. For example, uplink multi-point reception was the main reason for introducing support for device-specific assignment of uplink reference-signal sequences as described in Section 7.2.