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Operating the USCH in Soft Hand-off

1 Introduction

In some scenario's system performance and uplink capacity can be enhanced by providing the capability to operate the USCH in soft hand-off. Motivations for providing the capability to operate the USCH in SHO include [1,2,3,4,5]:

1. Range extension
2. Capacity gain due to selection diversity
3. Softer handoff comes for free (at least in terms of required land-line capacity)

In this paper the protocol implications of operating the USCH in soft hand-off are discussed.

2 Contents

3 Modification of the USCH model for support of SHO

One of the main features of the uplink shared channel as it has been described to date is that in each cell there is a timebase associated with the USCH which is fixed and could for example be tied to the ACCH. In order to keep this model as it stands then when the USCH is operated in soft hand-off it would be necessary for the base site framing to be synchronised.

Since the base site framing will not always be synchronised then the model of the USCH would have to be changed in the following way: The USCH would basically represent a shared uplink power resource which can be re-allocated rapidly on a frame by frame basis by MAC. For each UE operated in SHO one BS (and more specifically, one BS's ACCH) would have to be chosen to which the UE would synchronise its transmissions (we will call this the Synch-BS). The scheduler would have to take into account framing offsets between UE transmissions in the scheduling process. Figure 1 shows the scenario described. The aggregate usage of the shared power resource allocated to the USCH in BS #1 is shown as a function of time at the bottom of the diagram.

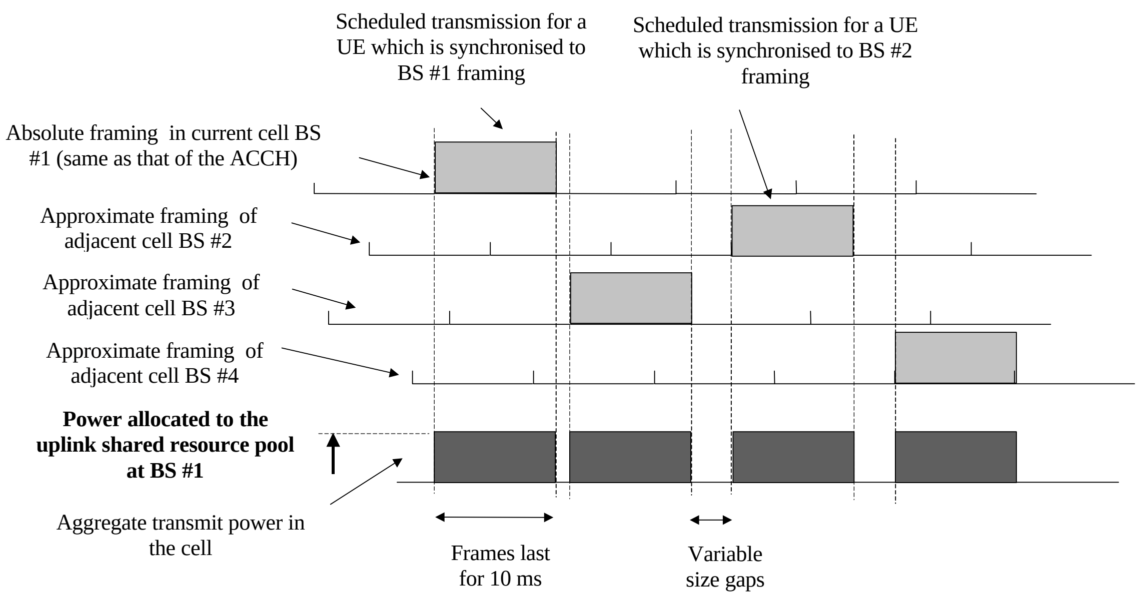

Figure 1) Diagram which shows the USCH as simply a shared power resource

4 Different SHO scenario's

There are a number of different scenario's under which it proves useful to assess the operation of the USCH in SHO. These scenario's are identified in this section and more detailed discussion of each scenario is provided in subsequent sections. In order to identify the scenario's of interest let's consider the situation where the UE is only using a packet data service.

From the network perspective there are two cases to consider:

Case A: Single RNC

The packet data UE is in SHO to cells which are all controlled by a single RNC.

Case B: Multiple RNC

The packet data UE is in SHO to cells, some of which are controlled by one RNC and some of which are controlled by another RNC.

From a PHY layer point of view there are then also two options:

PHY Case I: Hybrid DCH+USCH

At the start of a packet call, bi-directional low rate DCH's are set up from each BS in the active set. These DCH's are maintained for the entire duration of the packet call (and for some period afterwards). These DCH's would only be used to carry L1 and L2 signalling information. In this way link maintenance between packet bursts would be achieved. If the UE requires more resource than that available on the DCH then it must obtain it from the USCH, this additional resource would be allocated by the MAC_sh entity in the CRNC. This approach can be considered as a hybrid of the dedicated channel and the shared channel.

PHY Case II: Pure USCH

In this case there is no dedicated resource allocation. Bi-directional link maintenance between packet bursts is not (generally) maintained. We believe that this PHY option is valuable because the overhead cost of link maintenance channels increases linearly as the number of packet data UE's increases. There are then performance benefits to be exploited when the number of packet data users is high. This can be considered as pure USCH.

Let's now consider each possible combination of PHY and network options in turn:

5 Scenario (i): Single RNC involved, hybrid of DCH plus USCH (Case A + Case I)

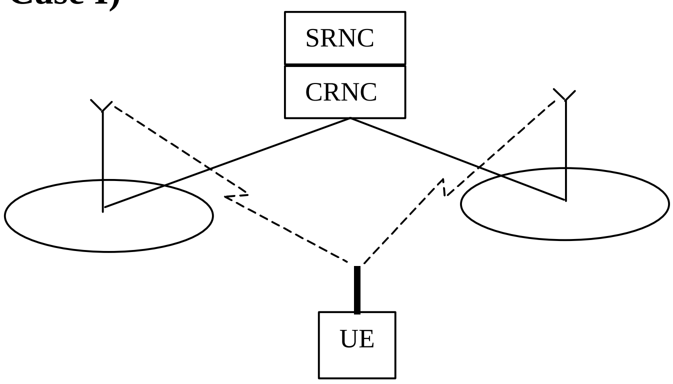

Figure 2) Diagram showing the network nodes involved in the scheduling and signalling for Scenario's (i) and (ii)

In this scenario low rate bi-directional channels are set up at the beginning of the packet call. This resource is dedicated. However, if the UE has some data to transmit during the packet call then it must be requested from the MAC_sh entity in the CRNC which can allocate capacity from the shared resource pool. This solution could therefore be considered to be a hybrid of both a dedicated channel and a shared channel.

The key differences with respect to the current DCH are that:

- Uplink scheduling is performed frame by frame by the MAC_sh entity in the CRNC (this means that the UE must indicate its requirements to the network).

- Framing synchronisation is always with respect to the ACCH of one of the BS's in the active set. To date this option has not been proposed for the DCH though it would clearly be possible to achieve on a DCH as well. By maintaining synchronisation to one of the base sites the SHO scheduling process and scheduling control will be simplified.

With this scenario, the scheduling process can take into account any inter-cellular interference impacts. In addition power control will be maintained to all BS's in the active set. Signalling of requests and allocations from/to CRNC/MAC could be conveyed on the low rate bi-directional DCH.

5.1 Protocol Impacts

In Figure 3 the protocol termination points are shown. There is a MAC_sh entity in the CRNC which performs the scheduling of access to the shared uplink resource.

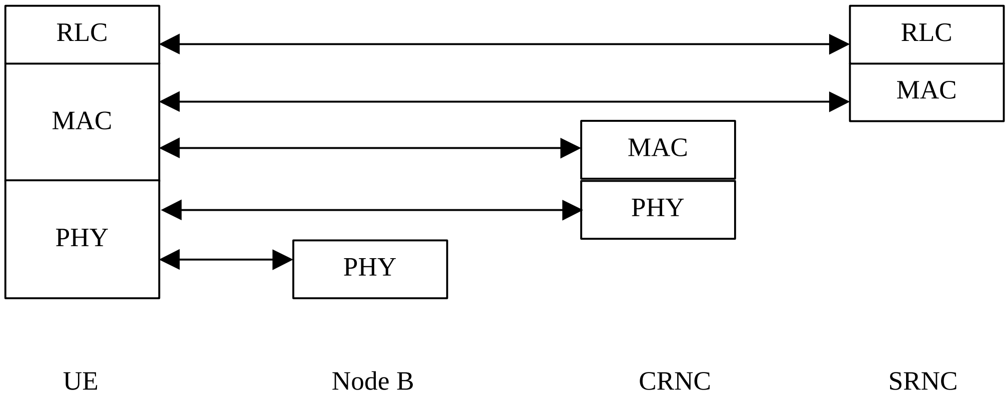

Figure 3) Protocol termination points for both 'Pure USCH' and 'hybrid DCH+USCH'

Figure 4 shows a MAC model for the process at the UE side. Measurements of the status of uplink packet queues are made and resource request messages are generated as appropriate. These are then multiplexed onto the low rate DCH (during a packet call) or onto a RACH at the beginning of a packet call.

On the downlink the UE receives the messages containing the uplink resource allocations. This information is used in the UE uplink MAC multiplexer.

Figure 5 shows the corresponding diagram for the network side. It can be seen that the MAC_sh entity in the CRNC is involved in managing the access to the shared uplink resource pool (see the box in the diagram with the heavy outline). The uplink resource allocations could be conveyed on a number of different channels:

At the start of the packet call, the allocations could be conveyed on either the FACH or ACCH. A UE would initiate a packet call using the RACH which will contain both RRC and MAC information. The response to the RRC message would be on the FACH, therefore any MAC_sh allocations of uplink resource could also be multiplexed onto this FACH. Thereafter uplink resource allocations would be carried on the low rate DCH.

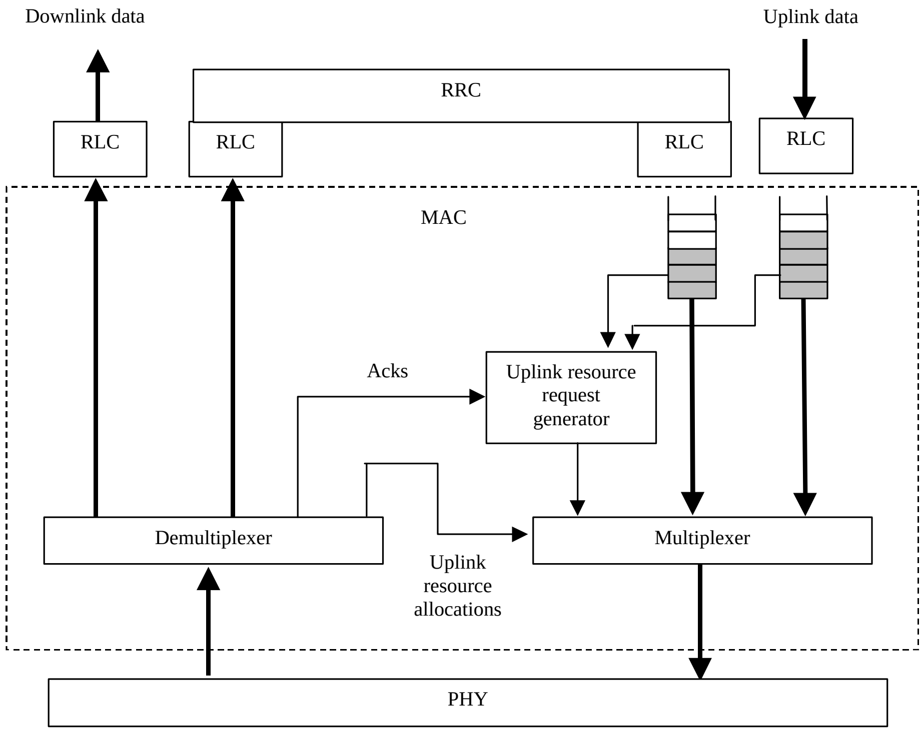

Figure 4) MAC process for accessing the shared uplink resource, UE side

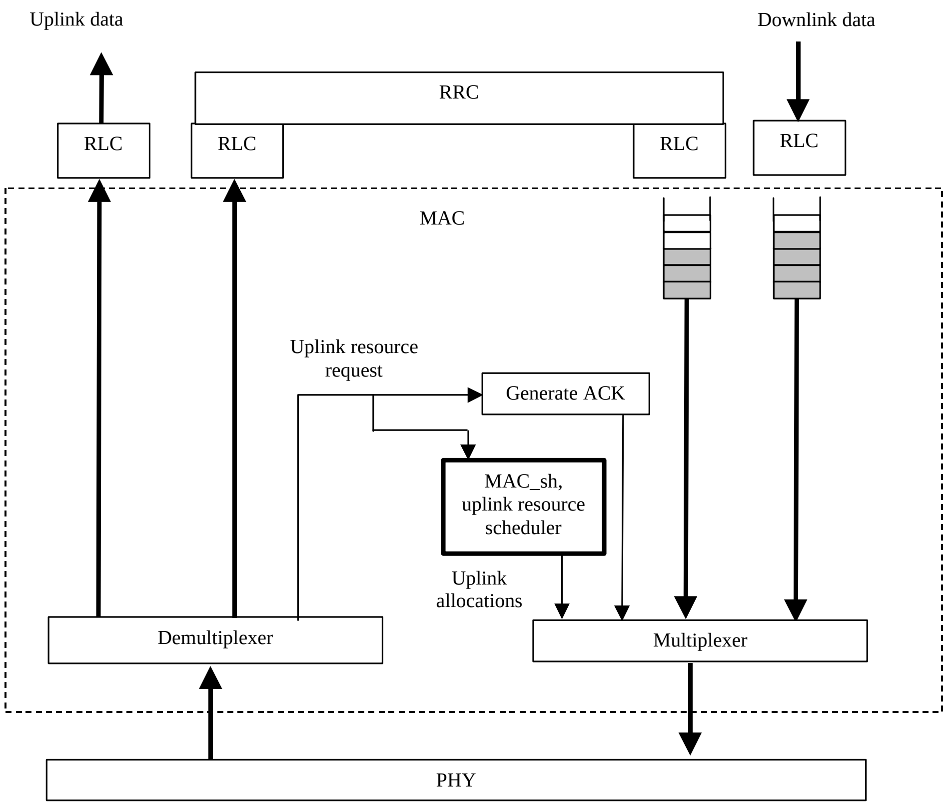

Figure 5) Diagram showing operation of MAC in the RNC

5.1.1 Acknowledgement of resource requests and allocations

Figure 4 and Figure 5 show the use of acknowledgements generated by the network MAC layer in response to uplink resource request messages. It is worth making a few comments on the requirements for sending messages in acknowledged mode.

Firstly, consider messages allocating uplink resource (which are sent on the downlink). If the UE does not get the message (or receives it in error) then the result is that the UE will not use his allocation. This would mean that, occasionally resource would be wasted, however, the advantages would be that fast scheduling onto a fat pipe would be possible without any danger that other users on the system would be detrimentally affected (by the failure of the message to get through). Since resource allocations are made in every frame, any failure of a message to get through will not have any lasting impact. When the CRNC MAC layer detects that the uplink resource was not used then it can re-schedule the resource allocation again for a later time.

When it comes to conveying resource request messages on the uplink there is a different problem. How does the UE know that the CRNC MAC_sh entity got its uplink capacity resource request?

There are a number of ways in which this could be handled:

1. The resource requests could be acknowledged by the CRNC MAC_sh entity (as shown in Figure 4 and Figure 5).

2. The UE could send status reports regularly (every X frames) so that failure of any one message to get through won't generally result in too much additional delay.

Note that there is a precedent for performing ACK's on the MAC layer. The provision of MAC layer acknowledgements for the RACH has been discussed for quite a few meetings now, we do not see the proposal described above to provide MAC layer ACK's for uplink resource requests as any different. Even so, although in the diagrams acknowledgement of uplink resource request messages is shown this would not have to be used (option (2) above could be applied instead).

5.1.2 TFC Selection

With regards to TFC selection, there are basically two options which have been identified, either the CRNC/MAC_sh decides which TFC the UE will use or else the CRNC/MAC_sh entity just allocates the spreading factor (SF). We would advocate the latter approach since the allocation message would be smaller when only the SF is indicated. When this approach is adopted there would then be two alternatives available in the network:

1. If there is a one to one mapping between SF and TFCI, then the BS will know what PHY layer processing to perform as soon as the data starts arriving (no buffering of PHY samples in the network would be required).

2. Alternatively, the Node B would have to buffer the whole frame before the TFCI is determined and only after this is done can the PHY layer processing be performed. This option provides more flexibility, since the UE can schedule the highest priority data (queue information available at the CRNC will never be as fresh as the information available at the UE). The downside is a greater Node B memory requirement.

5.1.3 Scheduling information requirements

In order for the CRNC/MAC_sh to perform the scheduling it will require the following information:

1. The transport format combination set for each UE which makes use of the uplink shared resource pool. This is needed in order for the scheduler to know which SF's can be assigned. This knowledge is always available at the RNC in any case.

2. UE transmit power limitations (and mean propagation loss information). This information is necessary in order to ensure that the SF assigned does not require a UE transmit power beyond that which is possible. The transmit power could be obtained using the RRC measurement report procedure. The mean propagation loss information will be available from measurements made for handover purposes.

3. In order to schedule the transmissions in SHO the MAC_sh entity must clearly be informed of the active set for UE's accessing the USCH.

4. Frame synchronisation offsets of each UE requesting access to the USCH. Again this information will often already be available in the RNC. If base sites are synchronised then this framing information is not required/implicit.

5. Quantity and priority of queued packets within the UE's

6 Scenario (ii): Single RNC involved, pure USCH (Case A + Case II)

With this scenario, bi-directional DPCCH's[1] are only provided when the uplink transmission actually occurs (and for a one frame precursor interval prior to the packet transmission[2] [8]). There is consequently no associated dedicated channel and hence Scenario (ii) can be considered as the pure USCH (not a dedicated/shared hybrid as in Scenario (i)).

6.1 Protocol impacts

6.1.1 Resource request and allocation between packet transmissions

Since with Scenario (ii) there is no low rate DCH available, then in the intervals between packet transmissions the UE must listen to a common downlink channel (the ACCH) to determine when it has been allocated capacity.

Between packet transmissions the UE would only have to listen to one ACCH, the ACCH of the Synch-BS. The power of the ACCH would be chosen so that a reasonable signal would be obtained by the most distant UE in the cell. Since the information transmitted on the ACCH in each cell would be different and since the framing of each ACCH in each cell could be different it would not be possible to coherently combine the D/L signals in the UE RAKE receiver. The gain from listening to two ACCH's without use of coherent combining in the UE would probably not be worthwhile.

The protocol termination points for the ACCH are shown in Figure 6. The possibility of carrying the ACCH over the FACH is still under discussion.

[1] Note, downlink power control bits from the Synch-BS would be conveyed on the ACCH
[2] This precursor interval enables the power control loops to converge and accurate channel estimates to be obtained prior to the packet transmission.

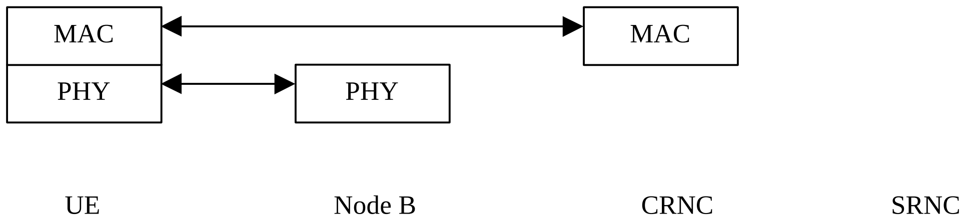

Figure 6) Protocol termination points for ACCH

The only option open for transmitting uplink resource requests between packet transmissions is to use the RACH. There should be no real protocol termination point implications, since for the RACH channel there is already a MAC_sh entity in the CRNC (required to read RNTI and thereby enable routing to appropriate MAC_d entity).

6.1.2 Resource request and resource allocation during packet transmissions

When a packet transmission is actually occurring on either the uplink or downlink, resource requests and allocation messages could be piggy-backed onto the allocated channels.

6.1.3 Protocol modeling - Provision of power control bits in the downlink

There are essentially two methods by which power control bits can be conveyed in the downlink from each of the base sites in the active set. In this section the effect on the protocol modelling of both of these options is discussed. The options are that either:

1. The UE receives power control bits on the ACCH associated with each BS in its active set.

2. The UE receives power control bits on individual DPCCH's transmitted from each BS in the active set.

If the ACCH were to be used then in the event that BS's are not synchronised, one of the implications would be that the slot framing would be different from each BS and this would have some impact on the fading rate which could be tracked. However, in the event that an operator chooses to synchronise the framing at his base sites then this problem would disappear.

Let's now consider the option of using individual DPCCH's. Where base site framing is not synchronised and link maintenance is not maintained between the packet bursts of a packet call then neither the existing dedicated or shared channel models work well. The bi-directional DPCCH's would only exist whilst the packet is being transmitted and whilst this is a dedicated resource, it is only dedicated for the duration of the burst. Allocation of the resource would have to be performed by the MAC_sh entity not by RRC. Hence, the downlink DPCCH could not be considered as a dedicated channel. Instead it would have to be considered as a resource allocation taken from the downlink shared channel. The downlink shared channel would still be described as a shared power and code resource but with the difference that the framing associated with transmissions on the DSCH would not always be aligned.

One option which is available to the operator is to synchronise the framing of his base sites. If this option is provided then, as mentioned in Section 3, the existing model for the USCH and DSCH as described in previous meetings would still be valid (ie. all USCH and DCSH transmissions would be frame aligned).

An example of how the USCH and the DSCH could be operated together, shown here for the case in which the operator chooses to synchronise base sites is shown in Figure 7. During an uplink packet transmission on the USCH, downlink power control commands could be provided by DPCCH's on the

DSCH of the cells in the UE active set (and vice-versa for the case of a downlink transmission on the DSCH). Note that any downlink packet transmissions on the DSCH could still just be transmitted from one base site only.

In the example shown in Figure 7 the USCH is operated in SHO to two base sites (Synch-BS and BS#2. There are three packet transmissions shown.

With the first uplink packet transmission which is shown downlink power control commands are provided from the Synch-BS on the ACCH and from BS#2 on a DSCH DPCCH. A one frame pre-cursor is used prior to the transmission of the packet.

The second packet transmission shown is on the DSCH, again a precursor is transmitted on the uplink and downlink DPCCH's prior to the packet transmission in order to converge power control loops and to achieve acceptable channel estimates.

Toward the right hand side of the diagram, a situation is shown in which the UE begins by transmitting an uplink packet and whilst transmitting in the uplink a packet is also transmitted on the downlink. When the downlink transmission begins the UE stops receiving power control commands supplied on the Synch-BS ACCH and the power control fields used on the ACCH are released. The UE instead starts to receive power control commands and other PHY control data on the DSCH-DPCCH of the Synch-BS.

We are currently under-taking work to decide which of the options (1) or (2) above should be recommended.

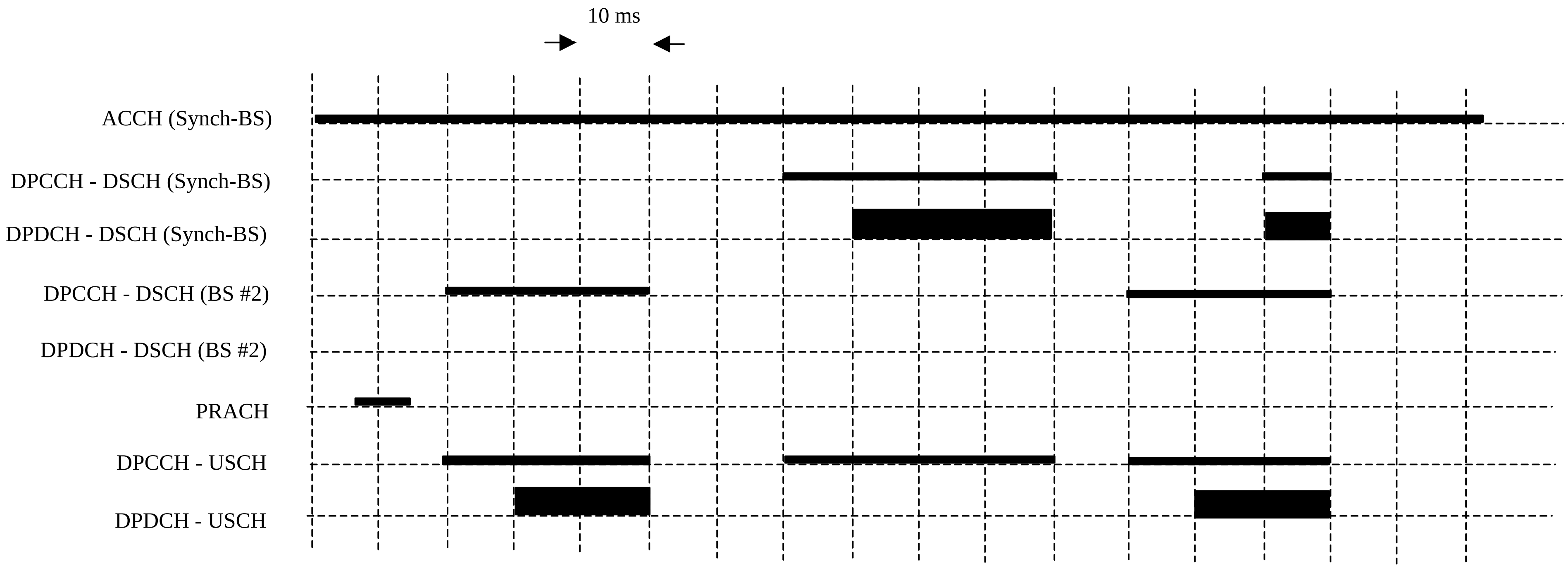

Figure 7) Diagram showing how management of the USCH and DSCH could be organised if BS's are synchronised

7 Scenario (iii): Multiple RNC's involved, hybrid of DCH plus USCH (Case B + Case I)

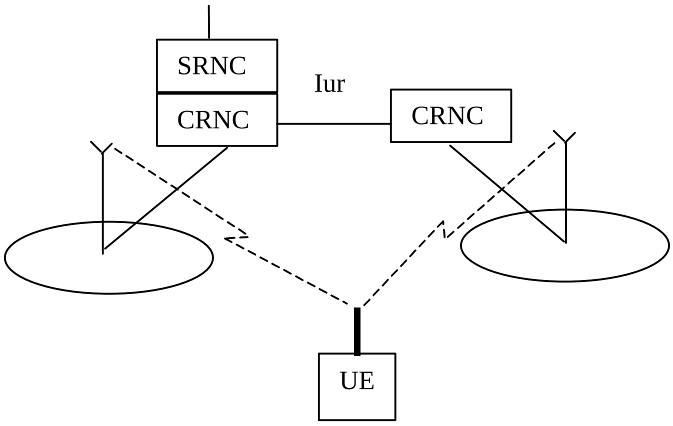

Figure 8) Diagram showing the network nodes involved in the scheduling and signalling for Scenario's (iii) and (iv)

In a companion paper [6] some reasons were provided for why dynamic scheduling between users should be performed in the CRNC/MAC. It is assumed that each UE selects one MAC_sh entity (in either the SRNC or the DRNC) as being its 'scheduling controller'. A very light-weight signalling exchange across the Iur may be used between CRNC MAC_sh scheduling entities to improve the efficiency of the SHO scheduling. In this section we further discuss the protocol impacts of such a model.

7.1 Protocol impacts

Some more discussion is required with respect to the signalling mechanisms for the situation under discussion in which a low rate DCH is available (Scenario (iii)).

7.1.1 Signalling of uplink resource requests

When the UE requests uplink resource the message is destined for just one CRNC. There are essentially two options by which it can be conveyed:

1. The message can be sent in SHO but is read at just one CRNC (ie. not all uplink SHO legs are combined) before the message is read.

2. The message is sent in SHO but this time the different SHO legs are always combined before the MAC message is read.

The advantage of (1) is that scheduling delay is minimised but the probability that the message gets through will be reduced, and vice-versa for (2).

In order for option (1) to be as efficient as possible there would have to be the possibility of combining at least the SHO legs under the CRNC associated with the Synch-BS.

7.1.2 Signalling on the downlink of uplink resource allocations

Downlink signalling could be conveyed on either the ACCH or on a PHY field of the DPCCH (as per the Nokia proposal for the DSCH [7]). Alternatively the allocation could be sent back across the Iur for transmission in SHO, though this would mean more delay.

7.1.3 Signalling recommendation

Delay in transmitting the downlink allocation information would seem to be of more concern, since it would mean that it would be necessary to perform the scheduling onto the USCH a few frames in advance of the actual transmission. Delay in obtaining the queue status of a UE is not of such importance since it only affects the UE concerned. In other words by combining all SHO legs before reading the MAC resource request has the effect that the absolute delay experienced by the UE concerned may be increased but efficient operation of the fat pipe would still be possible and delay experienced by other UE's operating on the USCH (which might be in HHO) would not be affected.

We would recommend using the ACCH for signalling the downlink allocation messages. Since the power of the ACCH will be adequate to cover the entire cell, therefore the message should be received with an acceptable error rate which will not necessarily be the case with PHY signalling on just one branch of the DCH. In the uplink the option should be provided for the MAC_sh entity of a single CRNC to open the MAC message even if all SHO legs have not been combined. Whilst the error rate in reception of the MAC message will increase, the use of MAC layer acknowledgements, or regularly sent uplink resource requests will mean that the system will be sent the MAC message again later. However, the majority of resource requests will not experience delay.

8 Scenario (iv): Multiple RNC's involved, Pure USCH (Case B + Case II)

The solution here would be essentially the same as that for Scenario (ii). However, this time the ACCH would be used for signalling in the downlink both between and during packet transmissions. Between packet transmissions in the uplink, the RACH would be used (as with Scenario (ii)). During uplink packet transmissions both of the options discussed with respect to Scenario (iii) exist. In other words it should be possible to read the uplink MAC resource request message either at one CRNC only (without combining all SHO legs) or else after soft combining of all SHO legs.

9 Proposals

- The MAC models in S2.21 be updated to show the functionality associated with CRNC/MAC_sh layer scheduling as specified in Figure 4 and Figure 5.

- The protocol termination for the 'Pure USCH' and hybrid 'USCH+DCH' shown in Figure 3 should be incorporated into S2.01.

- Reference in all specifications to the 'DSCH control channel' to be changed to the 'Access Control CHannel' and comment to be added to S2.02 to explain that the ACCH may contain resource allocation messages for both the USCH and the DSCH.

- USCH to be modelled as a shared power resource, access to which is managed by CRNC/MAC_sh.

- Users on the USCH and DSCH should synchronise their framing to one base site in their active set, this BS to be known as the Synch-BS.

10 References

[1] F. Ling, B. Love and M. Wang, " Behavior and Performance of Power Controlled IS-95 Reverse Link under SHO", VTC-97.

[2] M. Chopra , K. Rohani and D. Reed, "Analysis of CDMA Range Extension due to Soft-Handoff," VTC-1995.

[3] A. Ghosh and K. Rohani, "Effect of Mobile Power Control Saturation in DS-CDMA", ICUPC-96

[4] A.J. Viterbi et.al, "Soft Handoff Extends CDMA Cell Coverage and Increases Reverse Link Capacity", International Zurich Seminar, pp.541-551, March 1994.

[5] A.J. Viterbi, "Principles of Spread Spectrum Multiple Access Communications", 1995.

[6] Motorola, “Comparison of RRC and MAC based methods of dynamic scheduling between users on the uplink”, Tdoc 3GPP RAN WG2 /99

[7] Nokia, “Comparison of alternative DSCH structures”, 3GPP RAN WG2 042/99

[8] Motorola, 'Operation of the USCH without link maintenance', 3GPP RAN WG2 TSGR2#2(99) 129, March8-11, 1999