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1. INTRODUCTION

In RAN #7 a work item on High Speed Downlink Packet Access (HSDPA) was proposed by Motorola with support from Nokia, BT/Cellnet, T-Mobil and NTT DoCoMo [1]. It was agreed in principle and consequently a feasibility study will be done during year 2000. The study results will be collected into a technical report which is to be approved in RAN #10 in December, 2000.

In the previous RAN WG1 and WG2 meetings possible technical improvements for downlink packet access were presented and discussed [3, 4, 5]. In this contribution further discussion on these technical solutions is presented. Some characteristics presented herein are proposed to be incorporated into the document under preparation.

2. TECHNICAL CONSIDERATIONS OF HSDPA

In [3, 4, 5], various technical aspects of the HSPDA have been considered. More specifically, the technical proposals presented so far describe the so-called Enhanced DSCH (E-DSCH). The following sections present further discussion on the subject.

2.1 Adaptive Modulation and Coding Schemes (AMCS)

Adaptive Modulation and Coding (AMC) has been proposed as one form of link adaptation to deliver good performance in changing channel conditions. Areas to be considered with AMCS include:

- Modulation and coding formats
- Adaptation rate
- Control of AMC
- Interaction between AMCS and HARQ

Modulation and coding formats proposed so far include 4-PSK (QPSK), 8-PSK, 16-QAM and 64 QAM, and coding rates of ½ and ¾ [2, 3, 4]. One decision criteria when selecting the modulation and coding formats is the maximum achievable bit rate for one radio link. No requirements have been set so far but in minimum the maximum bit rate should be around 10 Mbits/s.

Different combinations of modulation order and code rate give a wide set of bit rates (at L1-L2 interface, including CRC bits) that can be supported. The maximum bit rate for a single user is affected also by other factors. If we don't guarantee that total bit rate for N users can be the same as for a single user (that is we neglect the code shortage problem at higher spreading factors), we get for e.g. SF=32 the maximum single user bit rates as shown in Table 1. Note that with no coding option even 16-QAM would give almost 15 Mbits/s maximum bit rate.

Table 1. Maximum single user bit rates at L1-L2 interface for SF=32. CRC bits are included in the figures.

	Max. single user bit rate (kbps)			
Code rate	**4-PSK**	**8-PSK**	**16-QAM**	**64-QAM**
1/3	2474	3714	4954	7428
1/2	3711	5571	7431	11141
3/4	5566	8356	11146	16712
1	7440	11160	14880	22320

As also pointed out in [4], the use of 64-QAM may not be feasible in cellular environment. Before adopting it (or even 16-QAM) careful analysis of the implementation aspects (both receiver and transmitter) must be conducted preferably in RAN WG4.

One point to consider is the AMCS adaptation rate. Intuitively, as fast adaptation rate as possible would be performancewise good. In practice there are, however, many factors that will affect the performance. They include needed measurements and their accuracy, needed feedback from UE to UTRAN and related signaling errors and uplink overhead, and interaction with other possible techniques like HARQ.

For best link level performance the selection of the AMCS should be based on the quality of the signal received by the UE. We could define AMCS specific measurements to be performed by the UE but it would be much better to use the existing ones. In fact we could use e.g. CPICH E_c/I_o that gives information of the channel conditions. Yet, it should be noted that currently the accuracy of the measurement as defined in RAN WG4 (*TS25.133 v3.1.0)* is ± 3 dB which could be sufficient for this purpose. The needed measurement time for this accuracy is on the order of 100-200 ms which suggests that very fast and reliable measurements for AMCS control purposes may not be possible.

In general, the control of the AMCS should reside somewhere on UTRAN side as there are other aspects than just the performance of one radio link when deciding on the AMCS to be used. Therefore, any measurements done by the UE should be reported to the UTRAN. Overhead in uplink will naturally depend on the reporting rate. As more frequent reporting will mean increased uplink overhead it is desirable to try to minimize the reporting rate.

Instead of using AMCS for fast link level adaptation we could use, as also pointed out in [3], fast HARQ for adapting to instantaneous channel conditions. Depending on the details of the HARQ it may not be suitable to change the AMCS very frequently. For example, changing the code rate between retransmissions should not be done as it interferes with the combining process.

Given all the above mentioned considerations, it seems that AMCS could be used for relatively slow link adaptation where the adaptation rate is on the order of a few hundred milliseconds. Faster adaptation could then be handled by a fast HARQ. Detailed modulation orders and coding rates require clearly further studies.

2.2 Fast hybrid ARQ

Another way of adapting to changing channel conditions is to use Automatic-Repeat-Request (ARQ) methods. In [2, 3] a fast Hybrid ARQ (HARQ) method based on dual-channel stop-and-wait principle is proposed. It seems to be technically a very promising way of enhancing the downlink packet access. One big advantage of the fast HARQ is that buffering requirements at receiver side are close to same as with the existing RLC level ARQ having no combining function. Thus, from implementation perspective this possible improvement should be carefully considered also in the context of RLC level HARQ work.

Regarding the fast HARQ there are issues needing further considerations including:

- Protocol termination point
- Feedback signaling in uplink

In order to make fast ARQ operation possible the round-trip delays between the transmitting and receiving entities must be short. As proposed in [2], one way of ensuring this is to change the ARQ protocol termination point in the network by relocating some of the functions to Node B. The RLC level of the protocol is split to two, RLC_{top} and RLC_{bottom} that are located in SRNC and Node B, respectively. As the RLC_{bottom} is taking care of the ARQ control the I_{ub} delays are avoided making the fast operation even at RLC level possible. From protocol operation point of view this does not mean big changes. Therefore, we consider this as a very potential solution for providing the fast HARQ operation.

The dual channel stop-and-wait requires very fast feedback signaling in uplink. According to [3] uplink DCH is used for signaling. It is not completely clear how this kind of solution can facilitate fast enough signaling as the DCH is a transport channel and will therefore be interleaved over the radio frame.

2.3 Fast Cell Site Selection (FCSS)

FCSS has been proposed as yet another technique to boost the performance of downlink packet access. The concept is in a way similar to SSDT power control at least from site selection point of view. In [4] it was pointed out that you could have two slightly different kind of solutions. You could either be allowed to perform the cell selection between all the active set Node B’s or only between the sectors of one active set Node B. Which way to go must be carefully evaluated as it will have impacts to implementation and possibly also on performance.

2.4 Frame length

It has been proposed that shorter than 10 ms granularity of the radio frame could be used for E-DSCH [3, 4]. As going down to radio frame lengths of few slots (or few milliseconds in time) will also put more stringent requirements on uplink signaling delay its performance benefits when compared to the use of current radio frame length of 10 ms should be carefully analyzed.

2.5 Code structure

Use of fixed or flexible spreading factor on E-DSCH and code multiplexing of different users has also been discussed in [2, 3, 4]. Basically, the idea of using a fixed spreading factor on E-DSCH sounds good as it simplifies the concept. So far different spreading factors ranging between 4 and 32 have been proposed. Based on some initial consideration it may be that the SF should be in minimum 16 due to implementation and detection performance reasons in case of higher order QAM modulation. Therefore, either 16 or 32 could be a good solution. As one further possibility we could consider how “fixed” the spreading factor should be, though. One option is that the SF will be fixed per transport channel configuration but in different configurations the SF can be varied based on the network decisions.

In [4] it was also considered if the code multiplexing of the users should be adopted for E-DSCH or not. Simplified signaling and easier implementation of interference cancellation were mentioned as one motivation not to allow for code multiplexing among users. Code multiplexing will, however, allow for more flexibility in scheduling of E-DSCH. Especially, when FCSS and distributed scheduling is used code multiplexing may be an important feature. Thus, code multiplexing should be possible also on E-DSCH.

2.6 Interaction of different techniques

The three basic techniques, AMC, fast HARQ and FCSS, can be applied independently or jointly. It is partly performance but also implementation complexity issue what kind of concept should eventually be selected. When using the techniques simultaneously there are several aspects that should be taken into account.

As already mentioned there are certain design aspects that must be taken into account when using AMCS and fast HARQ together. The soft combining process of HARQ will be disturbed if the code rate is changed. Even if relatively simple type I HARQ with soft combining having fixed code rate is to be applied, changing only the modulation order is not a straightforward procedure. Changes in the modulation order may affect the code block segmentation causing problems in soft combining. Therefore, it seems that the AMCS should be allowed to change only when a transport block(s) is (are) transmitted for the first time.

If only AMCS and FCSS are applied together there seems to be quite little interaction between them. Naturally, if UE is doing AMCS related measurements it should know which Node B is transmitting. When the transmitting Node B is changed then also the AMCS can be changed although the most recent measurement information at UE may be missing.

As already pointed out in [4], use of fast HARQ and FCSS together needs some careful consideration. Due to feedback signaling errors in uplink the different active set Node Bs may not have the same understanding of the ARQ state, i.e. what is the next transport block to be transmitted. Thus, as proposed in [3], one solution is to send the sequence number of the last received RLC PDU to the new Node B. Even so, it is possible that some packets will be lost and some packets may be transmitted more than once (not counting the retransmissions). The existing RLC level ARQ protocol can basically handle this kind of situations. Yet, if the corresponding protocol at RLC level is absent at transmitter side some changes to the ARQ operation may be needed. One possible option could be to run the existing RLC level ARQ on top of the fast ARQ. This kind of hierarchical solution could take care of the erroneous situations without a need for frequent retransmissions from the application layer.

When all the three techniques are applied together there is at least one more issue that should be taken into account. When the transmitting cell site is changed the new Node B should know also the AMCS information used by the old Node B. One obvious solution, as proposed in [3], is to send the needed information from the UE to the new Node B before it starts its transmission.

3. CONCLUSIONS

Some further technical considerations of open questions related to high speed downlink packet access have been presented in this contribution. Clearly, the advantages and disadvantages of the proposed solutions must be carefully analyzed with the help of simulations before any conclusions can be drawn.

4. PROPOSAL

Based on the discussion and motivation presented in this paper, we propose to include into the new technical report under preparation in RAN WG2 the following text entries:

5.1 Architectural issues

In order to make fast ARQ operation possible (needed for n-channel stop-and-wait schemes) the round-trip delays between the transmitting and receiving entities must be short. One way of ensuring this is to change the ARQ protocol termination point in the network by relocating some of the functions to Node B. If ARQ control is handled by Node B in RLC the I_{ub} and I_{ur} delays are avoided making the fast operation even at RLC level possible. Another approach to consider is to add a new level of fast ARQ on the physical layer in Node B.

5.3 Basic physical structure

A physical frame length shorter than 10 ms granularity of the radio frame has been proposed. As going down to radio frame lengths of few slots (or few milliseconds in time) will also put more stringent requirements on uplink signaling delay its performance benefits when compared to the use of current radio frame length of 10 ms should be carefully analyzed.

On fixed or flexible spreading factors on E-DSCH the initial assumption is that SF will be fixed per transport channel configuration but in different configurations the SF can be varied based on network decisions.

Spreading factors ranging between 4 and 32 have been proposed. Different combinations of modulation order and code rate give a wide set of bit rates (at L1-L2 interface, including CRC bits) that can be supported. The maximum bit rate for a single user is affected also by other factors. If we don't guarantee that total bit rate for N users can be the same as for a single user (that is we neglect the code shortage problem at higher spreading factors), we get for e.g.

SF=32 the maximum single user bit rates as shown in Table 1. Note that with no coding option even 16-QAM would give almost 15 Mbits/s maximum bit rate.

Table 2. Maximum single user bit rates at L1-L2 interface for SF=32. CRC bits are included in the figures.

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Code multiplexing of users should be possible also on E-DSCH. Code multiplexing allows more flexibility in scheduling of E-DSCH. Especially, when FCSS and distributed scheduling is used code multiplexing may be an important feature.

6.1 Adaptive Modulation and Coding Schemes

Adaptive Modulation and Coding (AMC) is used for link adaptation. Areas of study include:

- Modulation and coding formats
- Adaptation rate
- Control of AMC
- Interaction between AMCS and HARQ

Proposed modulation rates are:

- 4-PSK (QPSK)
- 8-PSK
- 16-QAM (FFS, performance benefit and increased complexity to be verified)
- 64 QAM (FFS, performance benefit and increased complexity to be verified)

Proposed coding rates are:

- ½
- 1/3

Factors affecting AMCS adaptation rate are e.g.:

- Measurements and their accuracy
- Feedback from UE to UTRAN
- Related signaling errors

- Uplink overhead
- Interaction with other possible techniques like HARQ.

To achieve best link performance the selection of the AMCS should be based on the quality of the signal received by the UE. From the existing measurements e.g. CPICH E_c/N_o can be utilized. Currently the accuracy of the measurement as defined in RAN WG4 is ± 3 dB which could be sufficient for this purpose. The needed measurement time for this accuracy is on the order of 100-200 ms which suggests that very fast and reliable measurements for AMCS control purposes may not be possible.

Depending on the selected HARQ method it may not be suitable to change the AMCS very frequently, as changing the code rate between retransmissions interferes with the combining process.

6.x (new section) Interaction of considered technologies

The three basic techniques, AMCS, fast HARQ and FCSS, can be applied independently or jointly. It is partly performance but also implementation complexity issue what kind of concept should eventually be selected. When using the techniques simultaneously there are several aspects that should be taken into account.

When using AMCS and fast HARQ together, the soft combining process of HARQ will be disturbed if the code rate is changed. Even if relatively simple type I HARQ with soft combining having fixed code rate is to be applied, changing only the modulation order is not a straightforward procedure. Changes in the modulation order may affect the code block segmentation causing problems in soft combining. Thus, if possible, AMCS should be allowed to change only when a transport block(s) is (are) transmitted for the first time.

If only AMCS and FCSS are applied together little interaction is observed between them. Naturally, if UE is doing AMCS related measurements it should know which Node B is transmitting. When the transmitting Node B is changed then also the AMCS can be changed although the most recent measurement information at UE may be missing.

Use of fast HARQ and FCSS together needs careful consideration. Due to feedback signaling errors in uplink the different active set Node Bs may not have the same understanding of the ARQ state, i.e. what is the next transport block to be transmitted. One solution is to send the sequence number of the last received RLC PDU to the new Node B. Even so, it is possible that some packets will be lost and some packets may be transmitted more than once (not counting the retransmissions). The existing RLC level ARQ protocol can basically handle this kind of situations. Yet, if the corresponding protocol at RLC level is absent at transmitter side some changes to the ARQ operation may be needed. One possible option could be to run the existing RLC level ARQ on top of the fast ARQ. This kind of hierarchical solution could take care of the erroneous situations without a need for frequent retransmissions from the application layer.

When all the three techniques are applied together it should additionally be taken into account that when the transmitting cell site is changed the new Node B should know also the AMCS information used by the old Node B. One solution is to send the needed information from the UE to the new Node B before starting transmission.

7.3 Evaluation of different AMCS

Decision criteria for selecting applicable AMCS:

- maximum achievable bit rate for one radio link (target value 10 Mbits/s)

8.1 Hybrid ARQ / Technical details:

The dual channel stop-and-wait requires very fast feedback signaling in uplink. New transport methods may need to be considered as e.g. the DCH is interleaved over a complete radio frame.

8.4 Hybrid ARQ / Evaluation of different schemes

Subjects needing further consideration include:

- Protocol termination point (round-trip delay, effect on buffering)
- Feedback signaling in uplink
- Terminal buffering requirement

10.3 Fast Cell Site Selection / Evaluation of different schemes

FCSS has been proposed as either:

- allow to perform the cell selection between all the active set Node B's
- only between the sectors of one active set Node B

Selected method must be carefully evaluated as it will have impacts to implementation and possibly also on performance.

REFERENCES

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