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1 Introduction

This document addresses the issue of multiplexing packet users in the uplink direction. Several contributions have already been discussed around the USCH concept, and the need for an efficient multiplexing scheme for packet services has been recognised.

In this document, several possible multiplexing options have been analysed, and a refined USCH concept is proposed to overcome potential drawbacks of each option. The performances of these options have then been compared in terms of packet transmission delay and cell throughput, including radio aspects. Results prove the interest of implementing the proposed concept in order to improve quality of service for packet users.

Some specific proposals are then presented for UTRAN specifications.

2 Analysis of multiplexing options

According to the current available specifications and proposals, two main options are possible for the multiplexing of packet users in the uplink direction. Packet users may be assigned independent DCH transport channels that are controlled by RRC procedures, or may be multiplexed on the USCH common channel. Both options are briefly analysed hereafter.

2.1 DCH multiplexing

DCH transport channels may be used to support packet services. In this case, they are established at each activity period with a given TFCS chosen by the RRC in the RNC, which corresponds to a given maximum transmission bit rate. The TFCS may then be further controlled through RRC procedures (TFCS Limitation, TFCS Reconfigure) in order to adapt the transmission bit rate to the network load conditions.

This kind of control is however rather slow because it requires RRC signalling on the Uu, and should typically be at least of 100 to 200 ms. It seems therefore difficult to change the allocated bit rate to all UEs each time a new UE starts to transmit data. This leads therefore to allocate a rather low maximum bit rate to all users, which means large transmission times for users. On the other hand, the interference generated by such users should vary slowly and thus not disturb too much other types of services.

2.2 USCH multiplexing

In the USCH concept, users are allocated some specific DCH transport channels, whose transmission bit rate may be controlled at each frame through the downlink ACCH channel. Packet users may be multiplexed in time and/or code domain on a frame basis, allowing then to quickly adapt the transmission bit rate to the number of active users. This permits to allocate a high transmission rate when the number of active users is low, and should therefore lead to lower transmission times for users.

However, the USCH requires a fast downlink signalling channel (ACCH) which may affect the downlink performance in order to improve the uplink one. Since it is expected to have larger traffic in downlink than in uplink, we should be careful in not overloading the downlink direction with this signalling channel and reduce it to the minimum required for a proper control of packet users.

Also it is believed that a code multiplexing option will provide the best performance on the radio interface due to the better potential for the statistical averaging of interference, whereas a pure time multiplexing option will probably degrade overall performances in a cellular network, especially with high bit rate transmission.

Regarding pros and cons of both options, it leads us to think about a slightly different approach of the USCH concept, for which a fast downlink signalling channel is still being used, but with limited contents. One way to limit the contents of this channel is to provide common information for all packet users, and to control the network load with these common parameters. As described below, this refined USCH concept has almost the same potential as the original USCH concept, since it permits to react very quickly to the actual traffic conditions, the only limitation being that it does not permit to implement a pure time multiplexing option. This option is however not being considered as a viable one for UMTS, due to the CDMA properties. This solution will require only a limited signalling overhead on downlink, which can probably easily be added on the ACCH transport channel.

In the following the refined USCH concept is proposed together with a 'dynamic packet admission control'. Then its performances are compared to a DCH multiplexing scheme, and proposals for additions in the UTRAN specifications are presented.

3 The refined USCH concept with a 'Dynamic packet admission control' procedure

The procedure consists in broadcasting regularly to all uplink packet users some information allowing them to independently select the appropriate transmission format. This permits to achieve a decentralized multiplexing of packet users with a limited signaling overhead while keeping a good control of the network load.

It is proposed that at each frame, the UTRAN broadcast to all packet users the following information:

- Some parameters need to be given to all UEs at the first access and then updated through broadcast procedures from time to time (on a multi-frame basis for example):
    - Transmission time validity $T_{validity}$, which indicates the time duration for which an access for transmission of data is granted. It may be set by the UTRAN in relation with the activity statistics of real time services, in order to maintain priority for those users.
    - T_{retry}, which indicates, in case the resource has not been granted, the time duration before retrying to access the resource. It may be set by the UTRAN in relation with the activity statistics of real time services, in order to maintain priority for those users.
    - T_{out}, which indicates the maximum silent period duration before releasing the resource.
- Some parameters need to be broadcast at each frame:
    - Transmission probability p_{tr}, which indicates the probability for a mobile to be allowed to transmit. It may be computed according to the actual network load (evaluated from the averaged uplink interference level), and should be regularly updated (every frame or every few frames).
    - Maximum transmission user bit rate, which indicates the maximum user bit rate allowed in that frame. It may be set according to the actual number of active users and to the total bit rate allocated to packet users. It should then be updated according to the rate of transmission activity among all users. The maximum transmission bit rate may be expressed by a minimum allowed spreading factor SF_{min}. The UE has then to select a suitable Transport Format Combination TFC in order not to use a lower spreading factor.

Part or all of these parameters may be user class dependent. In particular, the maximum allowed transmission bit rate might vary with user class. Some parameters may be updated at each frame in order to control the network load, and in particular to avoid that the uplink interference level received by each Node B exceeds a predefined threshold (which would lead to network instability). Examples of parameters are presented below.

On the UE (User Equipment) side, when data has to be transmitted on uplink, due to source activity, the UE makes a DCH allocation request on RACH. Once the DCH has been allocated together with a Transport Format Combination Set TFCS, the UE listens to the packet information broadcast to get recent updates of parameters, as described in Figure 1and Figure 2. The UE selects TFC according to the minimum allowed spreading factor SF_{min} and to its capabilities and needs. The user bit rate may indeed be limited by transmitter power or the UE may only have a small amount of data to transmit, thus not requiring the maximum allowed bit rate. It determines the probability threshold p_{own}, according to p_{tr} and to its own SF (see examples equations in
Lastly, a single-cell model has been used with fast closed loop power control. The interference is modeled as follows:

Iototal = Iointern + Ioextern

Where Iointern stands for the interference level at the Node B, generated by all the UE within this cell.
Ioextern stands for the global interference level at the Node B generated by the neighboring cells.
Ioextern = 0.6 * Iointern

It is pointed out that results might be slightly different in a multicell model due to the decorrelation between intra cell and inter cell interference. It is intended to compare the above options in a multicell context in the near future.

4.2.2 Parameters). Then the UE picks a random number between 0 and 1, and decides to transmit if this number is below p_{own}. If transmission is allowed, transmission of data is granted for $T_{validity}$, but the UE shall continuously monitor the UTRAN information at each frame, in order to adapt its bit rate according to the minimum allowed spreading factor at each frame. If transmission has not been granted, the UE will try again after a period of T_{retry}. When no more data has to be sent, the UE keeps its DPCCH (Dedicated Physical Control Channel) for a given period T_{out}, and then releases the DCH if no activity has occurred during this period.

Soft handover on the uplink DCH may be used with such a concept, but the UE needs to listen to broadcast packet information only from the ‘primary’ cell, i.e. the one with the lowest pathloss. A scheme similar to Site Selection Diversity SSDT might be used in order to identify the ‘primary’ cell, but the information would additionally need to be forwarded to the CRNC which control the relevant ACCH. The UE reports the identity of the primary cell as for SSDT, and all cells involved in the active set should continue to listen to the UE. The UE should react to TPC commands sent by all cells. For the evaluation of the packet information (determination of SF_{min} and p_{tr}), the UE should be counted only in the primary cell.

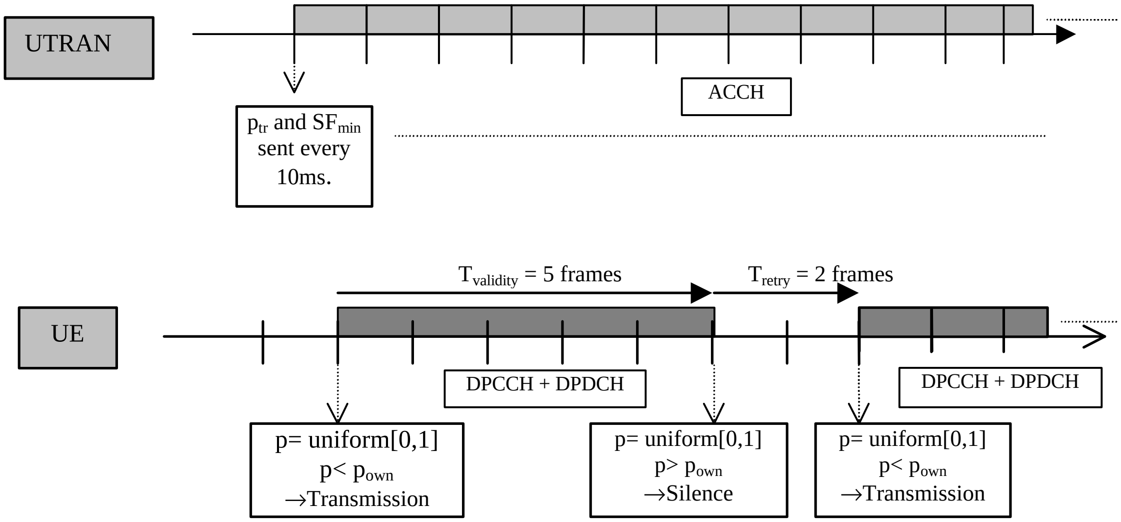

Figure 1: typical DPAC sequence

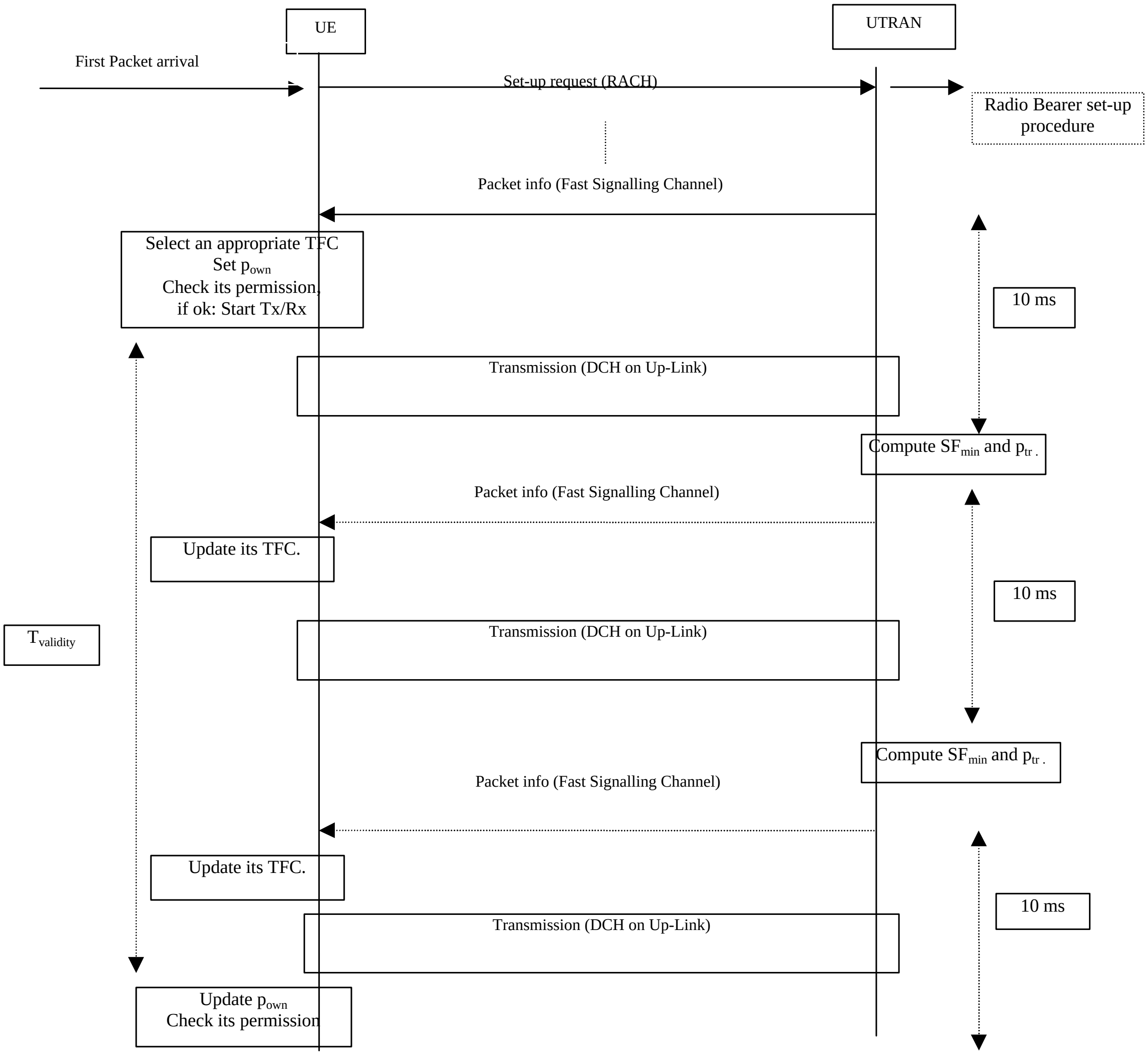

Figure 2**:** Flow Diagram between UTRAN and UE

4 Performance evaluation and comparison with DCH multiplexing

This section describes the models used in simulations to evaluate the performances of the different multiplexing options and presents simulations results showing advantages and drawbacks of each one. It is however pointed out that an optimal USCH multiplexing has not been simulated.

4.1 Simulations models

4.1.1 RRC multiplexing

In such a procedure, users request resources via a classical set-up procedure using RACH, which is not simulated here, and are allocated a DCH with a given SF which takes into account the current number of active packet users within the cell. Then they can start to transmit. A UE is said active when it transmits traffic. Otherwise, if it has nothing to send, it keeps on transmitting DPCCH. If silence is detected over more than T_{out} frames, then the DCH is released. In case a UE wishes to re-access the resource after a short silent period (i.e. with DCH still active), it only has to send a preamble access message on the RACH in order to notify to the Node-B which code to listen in the next

DPDCH frames. The allocated bit rate, in terms of spreading factor, SF_{min} (which stands for the minimum allowed spreading factor within the cell) is then updated according to the number of active packet users, through a TFCS reconfiguration located in the RRC sub-layer. Such a reconfiguration is expected to take at least 200 ms. It means each time a UE becomes non-active or becomes active again, the allocated resource will be updated at least 200 ms later. Such a scheme is represented in Figure 3. Mobile j stands for a continuously active packet user, which updates its SF after a T_{update} long delay.

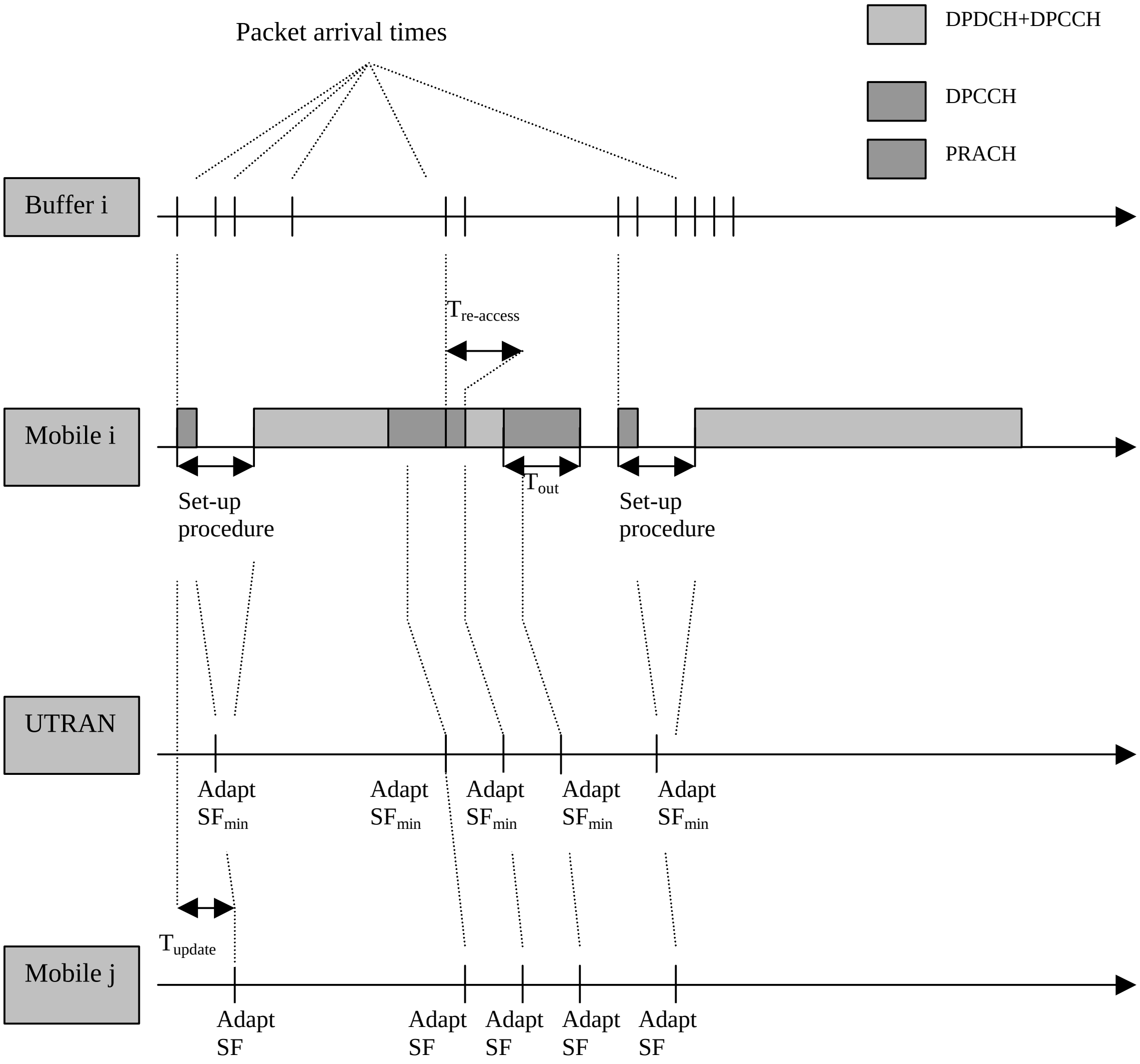

Figure 3: Typical delays for packet-switched type transmissions managed via RRC procedure.

The first option will result in a sub-optimal usage of radio resources and in extra delay at each transmission. In fact, RRC could assign a high bit rate on DCH but resource is likely to be wasted. Moreover, a high bit rate user could generate an unacceptable interference level that could only be reduced by the RRC at least 200 ms later. Collisions can not be avoided and this may lead to a large retransmission overhead. This scheme will probably prevent packet users from transmitting at high bit rate. Lastly, as the resource is controlled on a very slow basis (round trip delay between UE and UTRAN around 200 ms), the resource may be wasted whilst set-up and release procedure.

4.1.2 Code-multiplexing scheme in MAC.

The code-multiplexing procedure, as simulated here, is not so far from the previous procedure but the resource is here dynamically managed within the MAC layer. It means the system could react much faster to changes of the number of active packet users and of the current interference level at Node-B. The allocated SF_{min} may be changed every 10 ms through the ACCH, but based on interference measurements made 50 ms before (due to Node B – RNC signalling).

This procedure reduces delays in the resource management and therefore could help solving most of the problems, which arise in the first solution. In comparison with the DPAC procedure, there is no control for the access to resources, and therefore there are more active users on average. The transmission delay is thus higher than with the DPAC procedure, as shown in the following results.

4.1.3 DPAC procedure

The procedure described in The refined USCH concept with a 'Dynamic packet admission control' procedure has been simulated according to the following diagrams.

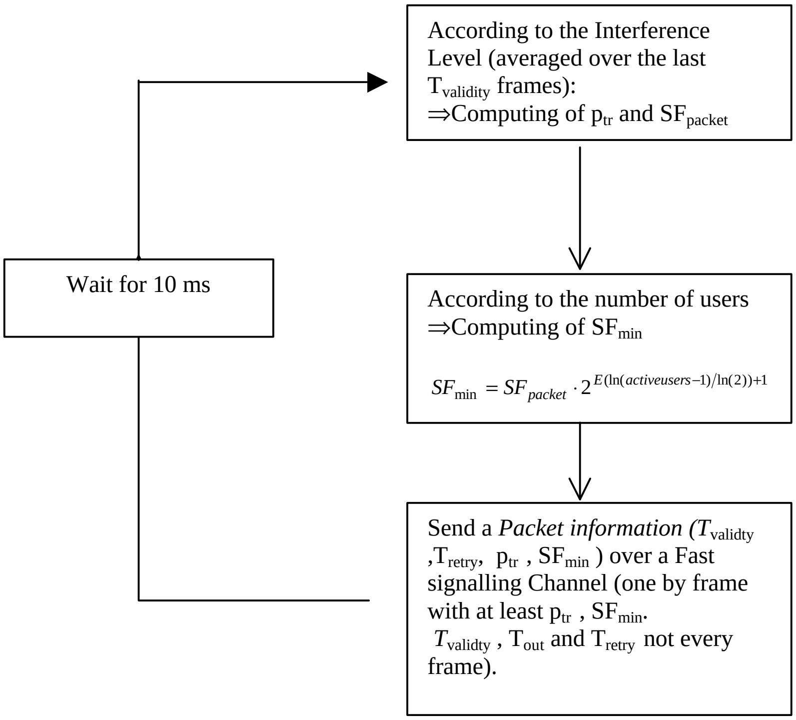

Figure 4: Flow diagram form UTRAN side

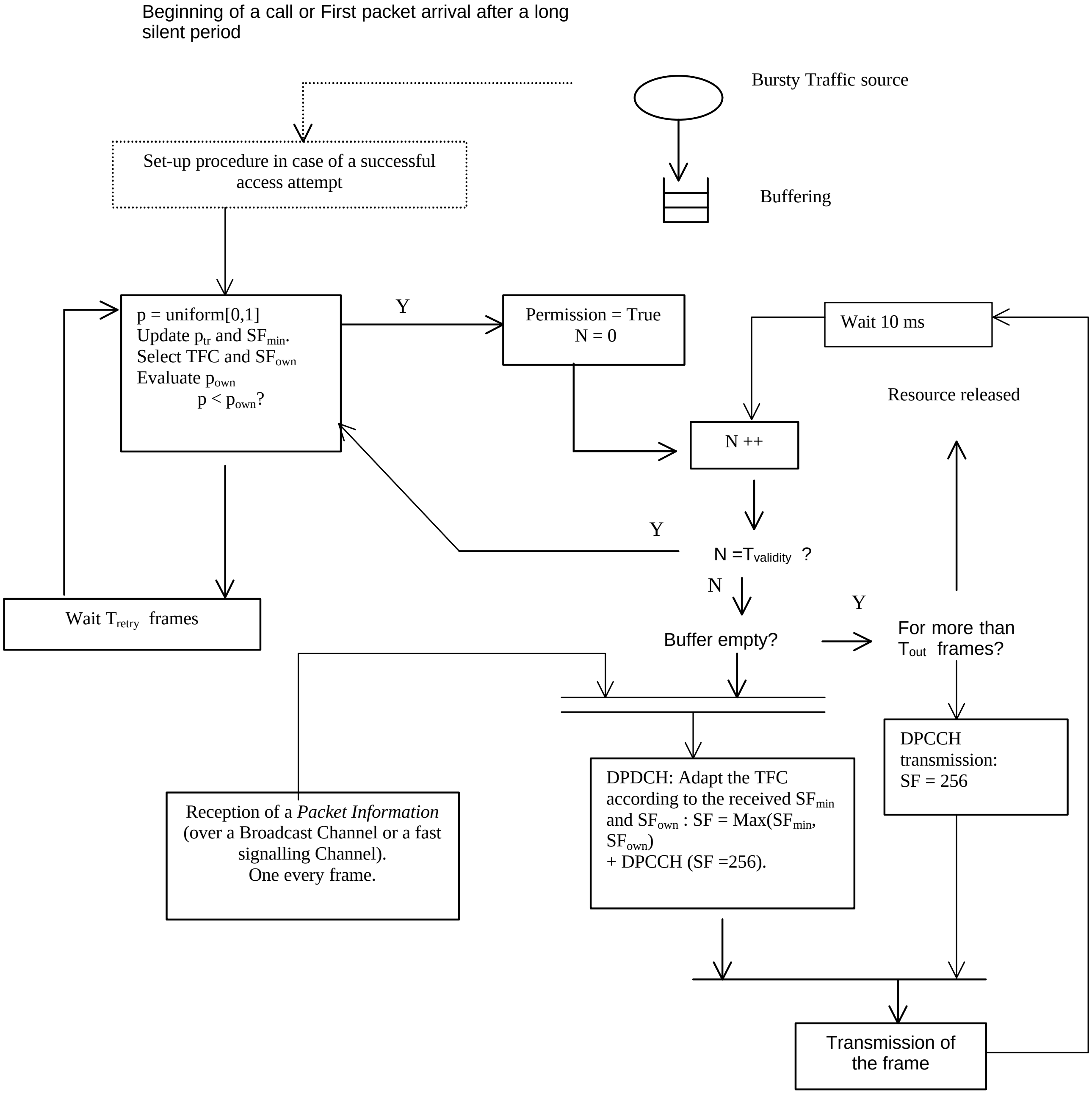

Figure 5: Flow diagram from UE side

4.2 Simulations parameters

4.2.1 Traffic Model

Figure 6 illustrates a typical packet service session as described in UMTS 30.03, Selection procedure for the choice of radio transmission technologies of the UMTS', version 3.2.0, April 98.. A packet service session contains one or several packet calls. The number of packet call is geometrically distributed with a mean of 5. The reading time between two consecutive packet calls is exponentially distributed with a mean of 4 seconds. Each packet call constitutes of a bursty sequence of packet. The number of packet by packet call is geometrically distributed with a mean of 25. The inter-arrival time between two consecutive packets within a packet call is exponentially distributed with a mean value, which depends on the data rate at the traffic source. In these simulations, a source rate of 144 kbps has been chosen, which means a mean inter-arrival time of 27.7 ms. Packet size is exponentially distributed with a mean of 480 bytes.

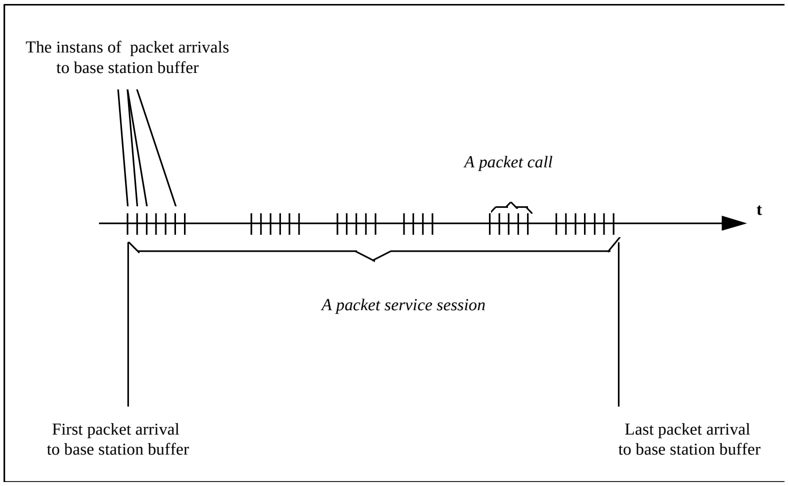

Figure 6: typical WWW browsing session

Lastly, a single-cell model has been used with fast closed loop power control. The interference is modeled as follows:

$$Io_{total} = Io_{intern} + Io_{extern}$$

Where Io_{intern} stands for the interference level at the Node B, generated by all the UE within this cell.

Io_{extern} stands for the global interference level at the Node B generated by the neighboring cells.

$Io_{extern} = 0.6 * Io_{intern}$

It is pointed out that results might be slightly different in a multicell model due to the decorrelation between intra cell and inter cell interference. It is intended to compare the above options in a multicell context in the near future.

4.2.2 Parameters

Figure 7 gives the relation between the Transmission probability p_{tr} and the uplink total received power level (equivalent to the interference level) Io, given two thresholds L1 and L2 and two corresponding transmission probability P1 and P2. This has been derived from [1].

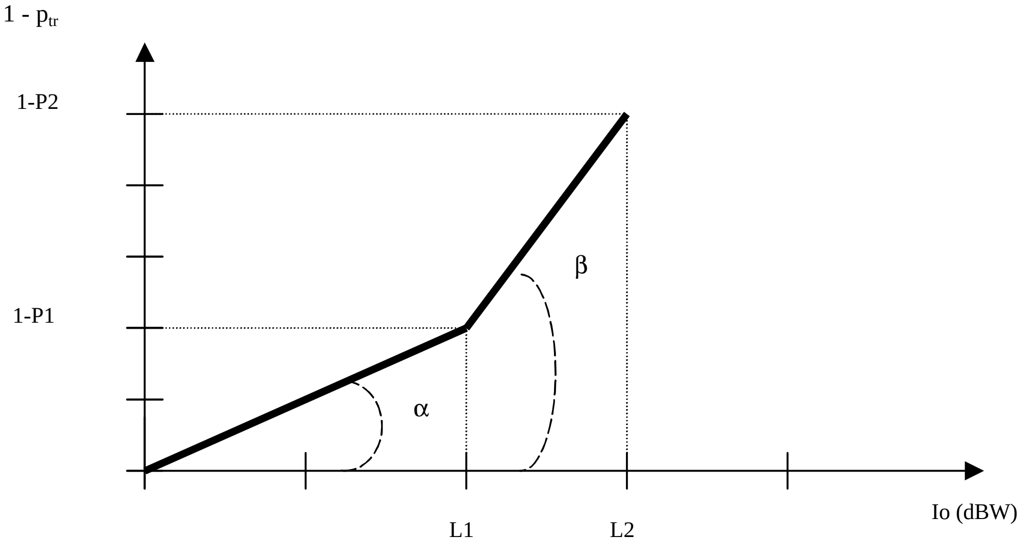

Figure 7 Transmission probability VS interference level

The UE probability p_{own} may be evaluated as: $P_{own} = P_{tr}^{SF_{\min}/SF}$ where SF = Max(SF_{min}, SF_{own})
The minimum allowed spreading factor SF_{min} may be set according to the number of active users and an assumed minimum spreading factor (or maximum bit rate) allocated to packet users SF_{packet}. This implies that bit rate is equally shared among all users, irrespective of their position in the cell.

SF_{min} is obtained as: $SF_{\min} = SF_{packet} \cdot 2^{E(\ln(activeusers-1)/\ln(2))+1}$ for activeusers > 1

$SF_{min} = SF_{packet}$ for activeusers >=1

A slightly more complex formula could be used in case the minimum spreading factor is user class dependent.

Table 1 gives the set of values that have been chosen for the parameters of the algorithm. Values for L assume a noise level of –102 dBm.
Simulations have consisted in optimizing transmissions delays in each of the four simulations, providing the following criteria: Pb (Eb/No < 4 dB) < 0.1. It is assumed that packets are lost where the Eb/No is below 4dB, but the retransmission protocol is not modelled in the simulations.

The following parameters have been used.

	L1	L2	P1	P2	SF_{packet} / SF_{own}	T_{access}	T_{update} (s)	$T_{reaccess}$ (s)	$T_{validity}$ (s)	T_{retry} (s)	T_{out} (s)
DCH allocations in RRC	NA	NA	1	1	8 / 64 8 / 32	0.5	0.2	0.01	NA	NA	0.5
DCH allocations in MAC	NA	NA	1	1	8 / 32 4 / 32	0.5	0.05	0.05	NA	NA	0.5
DPAC	N0+5	No+9	0.3	0	1 / 8	0.5	0.05	0.01	0.1	0.1	0.5

Table 1: Parameters Values example

T_{access} refers to the needed time to access the resource at the first access.

$T_{reaccess}$ refers to the delay before re-accessing the resource after a silent period providing the resource has not been released yet (period shorter than T_{out}). In case 1 and 3, UE simply notifies to the UTRAN (through RACH) which code to listen in the next frame. In case 2, UE needs an explicit permission and needs to be allocated the appropriate data rate.

T_{update} refers to the delay the CRNC needs to adapt to changes (round-trip delay between UE and CRNC). In case resource is managed by RRC, it takes around 200 ms to reconfigure allocated data rate, whereas it only takes around 50 ms in case 2 and 3 (MAC procedure located in CRNC).

4.3 Simulations results

Reader could refer to Figure 12, Figure 13 and Figure 14 (at the end of this document) in order to check transmissions quality in terms of Eb/No. On these curves, a ramp may be observed around 4 dB, which is the minimum acceptable transmission quality in all the simulations. This ramp is due to the closed-loop power control, which ensures that Eb/No remains close to 4 dB.

	Mean Tx delays by packet (s)	Pb (Eb/No <4)	Mean Tx delays by packet (s) (with retransmission)	Mean Throughput (kbps/cell)	Max throughput for 90% outage probability (kbps/cell)
DCH allocations in RRC	1.4	7.2%	1.5	121	250 (1)
DCH allocations in MAC	1.16 0.9	6.2% 11.5%	1.23 1	120 133	190 (2) (3)
DPAC	0.47	7.3%	0.5	160	250 (4)

Table 2: comparisons between code-multiplexing schemes and refined USCH in terms of Delays and Throughput.

As described in Table 2, a DPAC procedure allows to transmit twice as fast as in a code-multiplexing scheme in MAC and three times as fast as in a RRC multiplexing, with the same acceptable transmission quality. These differences could be observed as well on the mean throughput. It means the DPAC procedure, by combining statistical time-multiplexing and code-multiplexing schemes, permits to provide fat pipe to a limited number of simultaneous active users.

This analysis is confirmed by the Figure 8. In case DPAC is used, as delays area is shorter, resource is not used 70 % of the time, in comparison with 40 % of the time in case 1 and 2. When the resource is busy, it is fully used in case 4. Moreover, the maximum number of simultaneous active users decreases with DPAC procedure, allowing high data rate transmissions and acceptable interference level at the same time.

This compromise between the allocated data rate and the number of simultaneous active users could be observed on Figure 9, Figure 10 and Figure 11, where throughput stands for the global data rate during active periods. With code-multiplexing scheme, relatively low global data rate (below 120 kbps) is allocated for up to 50% of the active period's duration, whereas it only represents less than 10% with DPAC.

As stated above, the simulations have been carried in a single cell simulator, and results might be slightly different in a multicell scenario. In particular interference statistics might be different when using high bit rates. It is however believed that these results have shown the interest of having a fast downlink signalling channel in order to optimise the usage of radio resources.

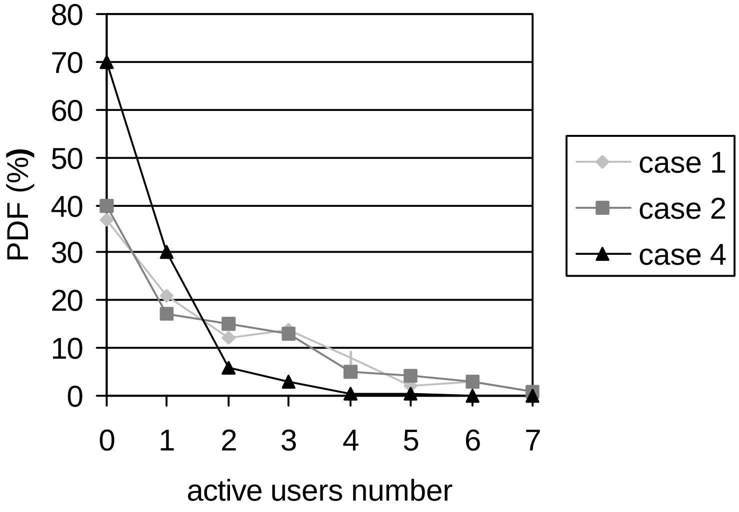

Figure 8: PDF (active users number) in case 1,2 and 4

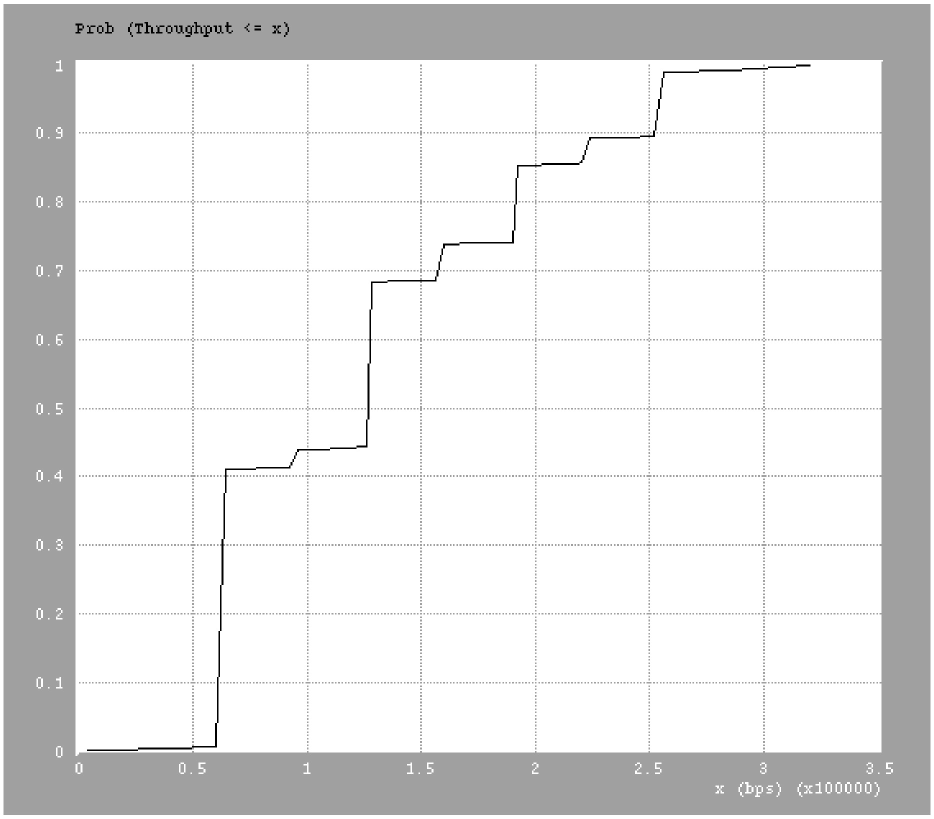

Figure 9: CDF (Throughput) in case 1

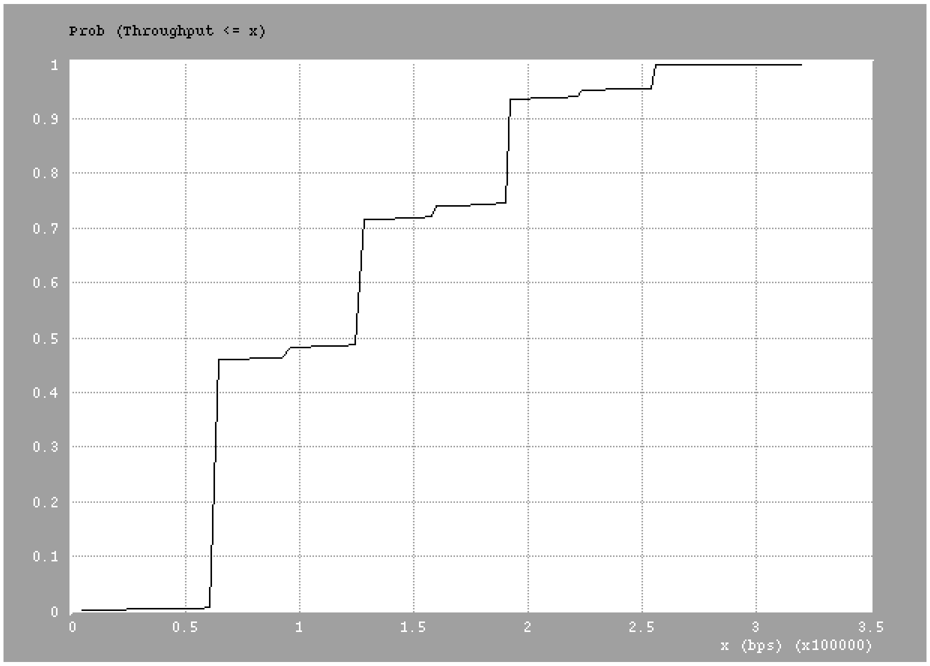

Figure 10: CDF (Throughput) in case 2

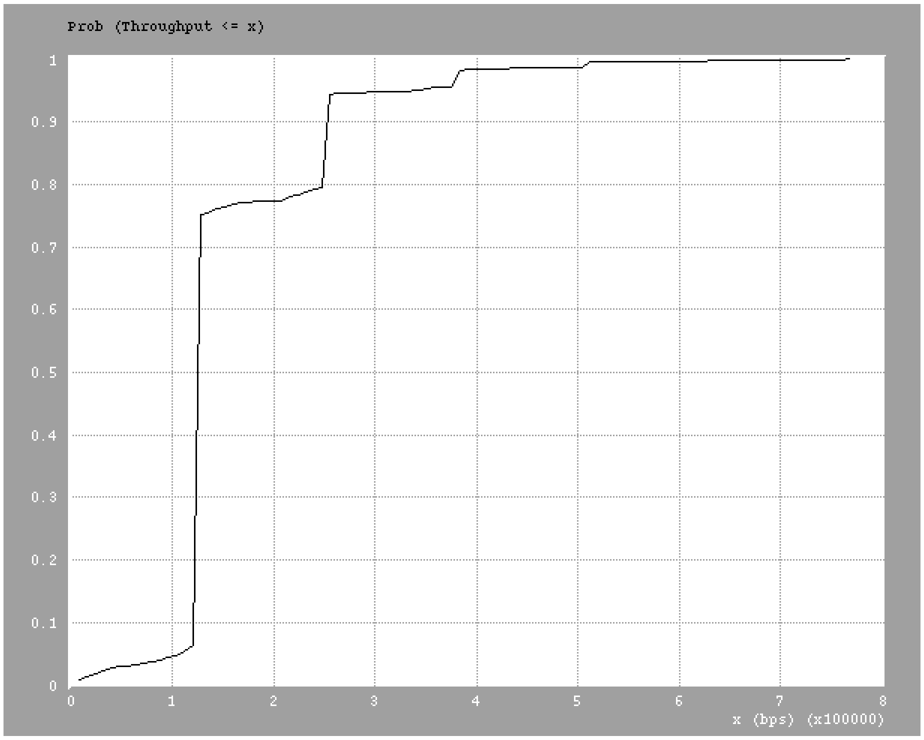

Figure 11: CDF (Throughput) in case 4

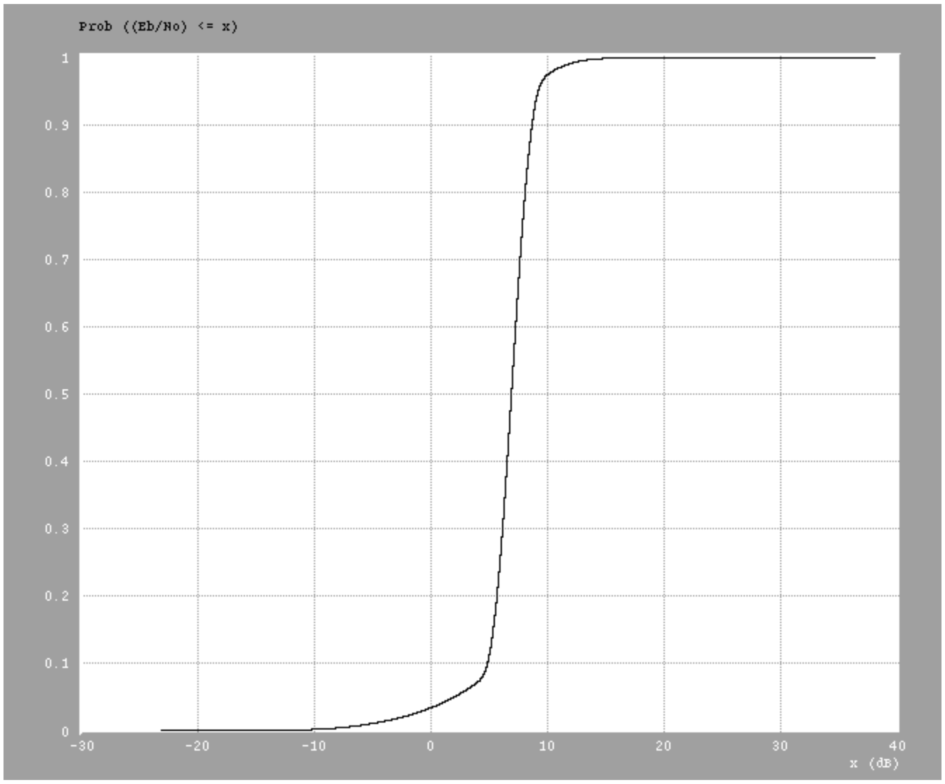

Figure 12: CDF (Eb/No) in case 1

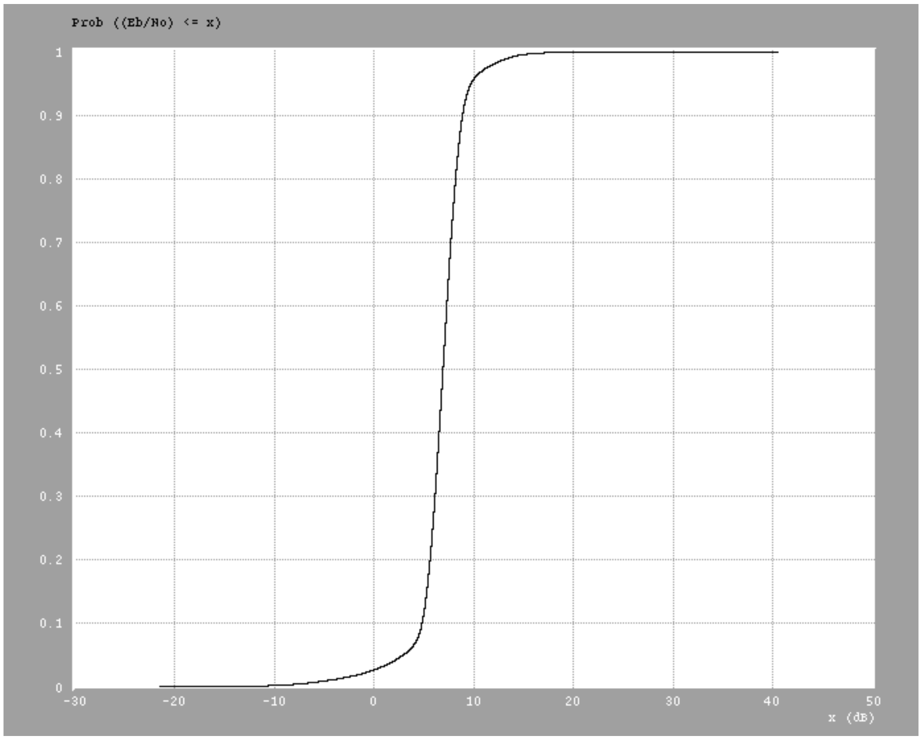

Figure 13: CDF (Eb/No) in case 2

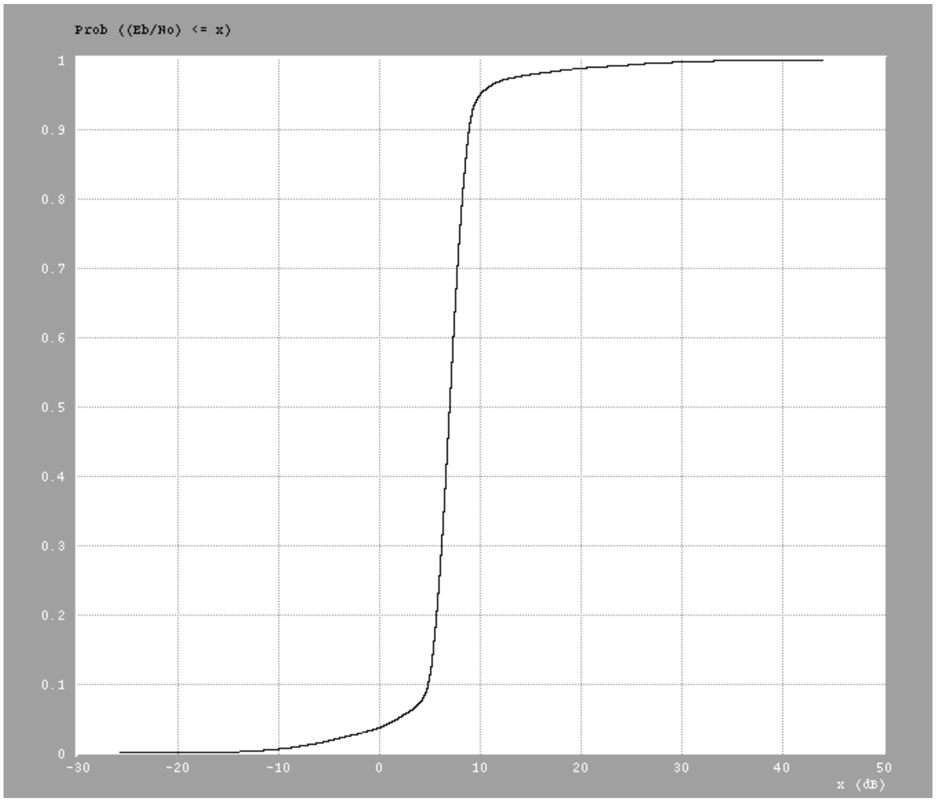

Figure 14: CDF (Eb/No) in case 4

5 Proposed changes to UTRAN specifications

In order to implement the dynamic packet admission control procedure, it is required to support a fast downlink signalling channel for packet information broadcast and a specific uplink DCH for packet users that support the procedure.

For the downlink signalling scheme, it is proposed to add the required uplink packet information fields in the already proposed ACCH transport channel. This downlink control channel is already used for DSCH signalling and TPC bits needed for uplink power control. The update of the packet information may be done in the MAC-sh (located in CRNC or maybe in Node B), according to actual network load measurements. The required signalling overhead may be evaluated as follows : 4 bits for the transmission probability and 3 bits for the minimum spreading factor, which need to be updated at each frame (7 bits per frame). If several user classes are supported, with different priorities, there will be one set of parameters per user class. The other parameters need to be updated and broadcast on a slower rate, and might be broadcast on the BCCH on a multiframe basis. They only need to be decoded at DCH allocation, and could even be given in-band during the DCH allocation procedure. In the original USCH, each active UE should be allocated a SF at each frame, which means 3 bits for SF and probably 4 for UE Id, per UE on the ACCH at each frame. According to this short analysis, it is clear that the refined USCH concept will permit to save a lot of signalling overhead on the downlink ACCH. This saving might be used to increase the protection of the packet information bits in order to avoid too many errors.

As far as the specific DCH transport channel is concerned, the main change with respect to a standard DCH is that the UE has to listen to the downlink signalling channel, and to transmit according to the proposed dynamic admission control procedure. This procedure may be considered as a MAC-sh procedure. The specific DCH might be called USCH.

For packet only services, it seems appropriate to allocate a USCH / DSCH + ACCH configuration, where the ACCH would contain signalling information for both USCH and DSCH. The UE would need to receive two codes in downlink.

For speech + packet services, the configuration could be DCH (speech) + USCH (packet) / DSCH (packet) + DCH (speech) + ACCH, which is slightly more complex. On uplink, both DCH could be multiplexed on a single code physical channel, whereas on downlink, the UE would need to receive 3 different codes. An alternative would be to provide the packet information directly on the downlink DCH, together with the DSCH signalling and TPC bits. In this case, a more explicit multiplexing scheme could be supported, as proposed in the original USCH concept. The configuration would then be DCH + USCH / DSCH + DCH. The impact of soft handover on such a configuration would need deeper study. The trade-off between receiver complexity and signalling overhead would need to be better assessed in order to select one option.

Proposed modifications related to USCH have already been identified in [4], and are mostly valid with the refined proposal. A few additional changes are proposed :

The USCH is characterised by :

- Existence in uplink only
- Associated with the Access Control Channel (ACCH) which supports TPC info and MAC multiplexing information
- Capability of using fast power control
- In-band identification of UE’s is not necessary
- Used for packet services in conjunction with a MAC multiplexing procedure

The ACCH is characterised by :

- Existence in downlink only
- Provision of power control fields for associated USCH channels
- Capacity for conveyance of MAC ~~assignment~~ multiplexing information provided in every frame
- Lack of fast power control
- Requirement for in-band identification of users

6 Conclusion

In this contribution, the multiplexing of packet users on uplink has been studied, and it has been shown that a fast downlink signalling channel is required in order to implement an efficient multiplexing scheme. This has already been identified in the USCH concept, and a slightly different approach is proposed, in order to reduce the signalling overhead.

It is proposed that WG2 adopts the USCH concept as refined in this document.

7 References

[1] ‘Performance of a joint CDMA/PRMA protocol for mixed voice/data transmission for third generation mobile communication’, A.E. Brand, A.H. Aghvami, IEEE Journal on selected areas in communications, vol.14, No9, December 1996.

[2] ‘Benefits of the uplink shared channel USCH’, Tdoc SMG2 UMTS L23 47/99, Motorola

[3] ‘Change requests related to the Uplink Shared Channel (USCH)’, Motorola, Tdoc RAN WG2 48/99

[4] UMTS 30.03, Selection procedure for the choice of radio transmission technologies of the UMTS’, version 3.2.0, April 98.

[5] ‘UMTS S2.03, description of UE states and procedures in connected mode’, version 0.0.1, Tdoc RAN WG2 40/99.

[6] ‘UMTS S2.01, Radio Interface Protocol Architecture’, version 0.0.1, Tdoc RAN WG2 30/99.