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Agenda item: **4.8**
Source: **Motorola**
Title: **UE Capability**
Document for: **Discussion**

1. Introduction

In a previous contribution [1], the parameterization of specific UE capabilities for LTE was discussed, including peak data rate support and HARQ memory buffer sizing. This contribution further refines the observations of [1] in light of recent discussions of stage 1 rate matching, HARQ timing, and further discussion in RAN4 on initial bandwidth mode support in LTE.

2. Discussion

2.1. Prior Proposals

Contribution [1] proposed the set of UE capabilities for downlink DL-SCH operation listed in Table 1.

Category	Max. # MIMO Streams	Max. # RB's	H-ARQ Soft Buffer Size (*kilo* Locations)[1] With (Without) Stage 1 RM	Peak Data Rate (Mbps)
1	2	10	100.8 (302.4)	12.6
2	2	25	252 (756)	31.5
3	2	50	504 (1512)	63
4	2	100	1008 (3024)	126
5	4	100	1900.8 (5702.4)	237.6
6	4	200	3801.6 (11404.8)	475.2

Table 1 – DL-SCH related UE capability categories from [1].

Since that initial proposal, RAN4 have clarified [3] the initial set of supported bandwidths for LTE deployments according to Table 2. Here, it can be observed that – although all UE's will of course support 20MHz signalling bandwidth in both downlink and uplink in any frequency band supporting 20MHz operation – there is a fairly direct mapping between the UE capability of Table 1 and the maximum number of resource blocks (RB's) allocable per subframe according to each bandwidth mode.

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[1] *1 K locations equal 1000 soft memory locations. The word length of each location is implementation specific. For dimensioning purposes, N=6 equal size HARQ channels and minimum memory first stage RM are assumed.*

Some refinement could still be made, however, of the categories defined in Table 1. In particular, Category 1 of Table 1 could be adjusted to support the maximum allocable number of RB's for the 3/3.2MHz case (i.e. 15/16 RB's) and so simultaneously support the maximum allocable number of RB's for both 1.4MHz and 3/3.2MHz modes. However another alternative is to further distinguish Category 1 and Category 2 devices by reducing Category 1 support to the minimum required for effective low-rate service (e.g. VoIP) operation, while remaining consistent with the minimum 1.4MHz bandwidth mode – i.e. to provide support for only 6 RB's for the very lowest tier of UE capability.

Operating system bandwidth [MHz]	1.4*	1.6**	[3] or [3.2]	5	10	15	20
Number of resource blocks	6	7	[15] or [16]	25	50	75	100
Note*: This system bandwidth is used only for FDD band Note**: This system bandwidth is used only for TDD band							

Table 2 – Initial set of LTE support bandwidth modes [3].

A companion contribution [2] further discusses the minimum HARQ-related 1-way delay and the related minimum number N_{ARQ} of HARQ processes. [2] concludes that support for $N_{ARQ} = 8$ is required for at least some network deployment scenarios (i.e. large cell radii), although $N_{ARQ} = 7$ would typically apply and could be supported if two values of N_{ARQ} were allowed. This revised maximum value of N_{ARQ} increases the total HARQ soft memory size over that outlined in [1], which assumed 6 HARQ processes.

Recent discussions have also highlighted the potential benefits of avoiding "stage 1" rate matching in order to simplify rate matching specification and testing. Nevertheless, the complete elimination of stage 1 rate matching, or more correctly, the elimination of any mechanism to lower-bound (at a rate above the mother code rate of 1/3) the achievable code rate applicable to a transport block after HARQ combining, would unduly burden the UE with unnecessary cost and complexity, and merits further discussion.

2.2. Revised Proposals – UE Downlink Capability

A revised set (over [1]) of categories applicable to DL-SCH operation appears in Table 3 assuming 8 HARQ processes. Note that the limitation of the maximum number of RB's allocable per subframe could be equivalently expressed in terms of the maximum total number of transport channel bits in each TTI (subframe) to permit further refinement when additional transport channels (BCH, MCH) are considered, but the RB notation is intentionally retained for now to better illustrate the linkage to Table 2.

As can be observed from Table 3, support of a minimum of 2 stream SU-MIMO operation for all UE categories is retained from [1] (consistent with the current draft TS 36.803 [3]). The specified peak rate is computed assuming 1 OFDM symbol is allocated to the PDCCH and accounting for reference symbol allocations but neglecting SCH, BCH etc. overhead. A maximum code rate of 0.75 for one transmission was also assumed when computing soft buffer sizes, although larger values are clearly applicable. Note finally that two 4-stream capable categories are established as Categories 5 and 6.

When determining whether stage 1 rate matching is required, it is useful – as in [1] – to compare the soft buffer memory requirements of Table 3 with that specified for HSDPA-capable UE's. This is illustrated in Figure 1, where HARQ memory sizes with and without stage 1 rate matching are illustrated.

Category	Max. # MIMO Streams	Max. # RB's	H-ARQ Soft Buffer Size (*kilo* Locations)[2] With (Without) Stage 1 RM	Peak Data Rate (Mbps)
1	2	6	80.6 (181.4)	7.6
2	2	25	336.0 (756.0)	31.5
3	2	50	672.0 (1512.0)	63.0
4	2	100	1344.0 (3024)	126.0
5	4	100	2534.4 (5702.4)	237.6
6	4	200	5068.8 (11404.8)	475.2

Table 3 – Revised UE capabilities for DL-SCH.

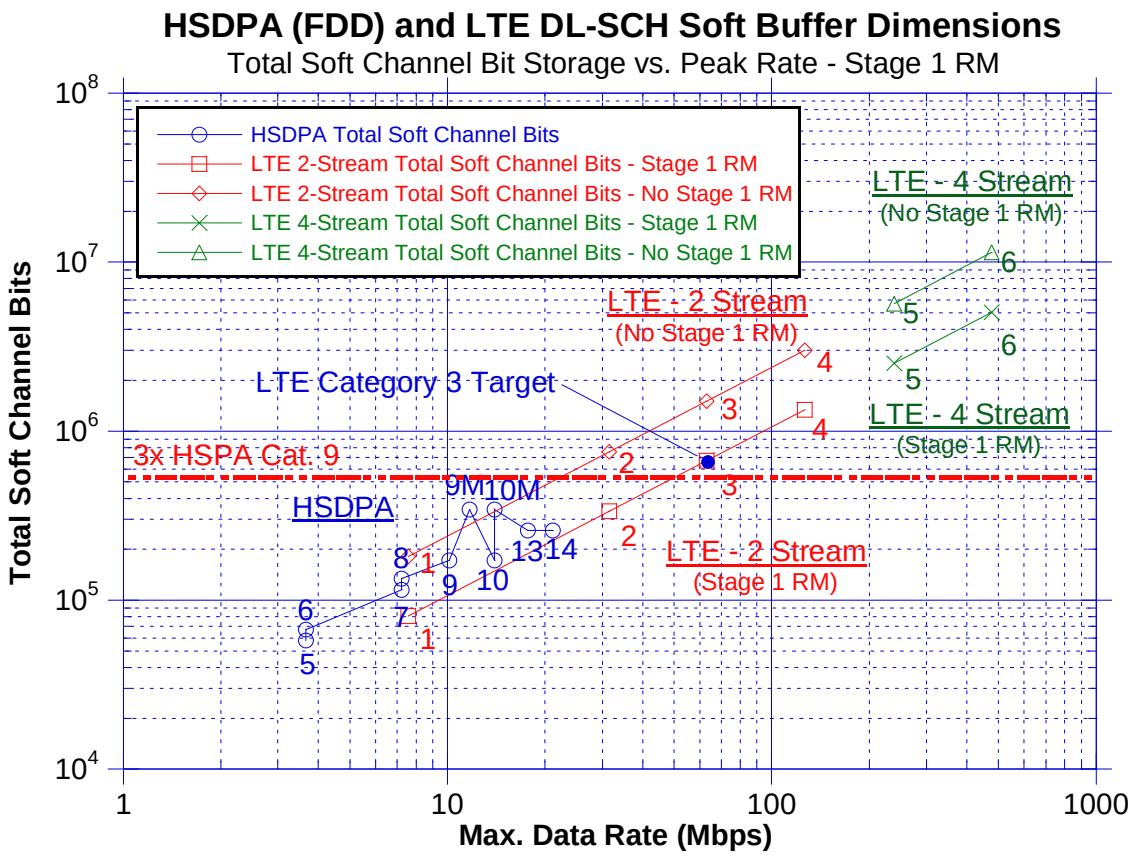

Figure 1 – HSPA and DL-SCH capabilities from Table 3.

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[2] *1 K locations equal 1000 soft memory locations. The word length of each location is implementation specific. For dimensioning purposes, N=8 equal size HARQ channels and minimum memory first stage RM are assumed, which means the effective mother code rate is 3/4 after first stage RM.*

In establishing a practical bound on the total HARQ soft memory for LTE that is consistent with the evolution of UE implementation technology, one crude "*rule of thumb*" is to require that the ratio of the total soft memory size to the peak supported data rate should be approximately constant. That is, each UE capability represented in Figure 1 should be located approximately on a line with unit gradient in the log domain. This is of course a natural consequence of the method of computing the soft memory size implicit in Table 3, and is consistent with the pattern of HSDPA capabilities which also appear in Figure 1. The key issue then is the vertical offset applicable to UE capabilities in Figure 1, which shows the offsets (i.e. upper and lower bounds on UE soft memory size) applicable with and without stage 1 rate matching.

In order to further establish an appropriate offset in Figure 1, a further approximate guide is to require that the total HARQ soft memory storage for an LTE UE capable of 50Mbps should be no greater than 3 times that of a corresponding HSDPA Category 9 (10.1Mbps) device. This places an upper limit of approximately 520k soft locations on a 50Mbps LTE UE, which can be extrapolated to approximately 650k soft locations for the Category 3 device in Table 3. This suggests that a stage 1 rate matching function, or at least a means of limiting the effective mother code rate applicable to a transport block, is required for the LTE downlink. This can be readily achieved using the adopted circular buffer rate matching methodology, as discussed in [5].

Concerning the requirement for uplink stage 1 rate matching, [4] suggests that the increased soft memory resource available at the eNB receiver compared to the UE receiver renders uplink stage 1 rate matching unnecessary. However, if stage 1 rate matching is defined for the LTE downlink, making it available for the uplink appears possible with minimal effort.

2.3. Soft Memory Partitioning

Contribution [4] indicates that UE soft memory should be equi-partitioned on a static basis between HARQ processes. At present, there appears to be little evidence of a compelling hardware complexity benefit in restricting HARQ memory to be equally partitioned between HARQ processes. At the same time, equi-partitioning of soft memory causes a resulting loss of network flexibility in allocating H-ARQ memory to specific processes according to e.g. differing QoS requirements. Accordingly, it is proposed that UE soft memory be partitionable between HARQ processes in a manner similar to that of HSDPA.

3. Impact of UE Capability on Network Performance

Further insight into the required set of UE capabilities can be obtained by studying the variation in sector and cell edge throughout as a function of UE capability. Figure 2 and Figure 3 illustrate the relative change in those metrics for the full buffer traffic model for deployment Cases 1 and 3 respectively, in conformance with [6], where 10 UE's per sector are deployed. It can be seen that there is only minimal difference in sector and cell edge throughout as a function of UE capability. More importantly, it can be observed that the higher UE categories permit increased service rates to such UE's, but the mix of UE categories does not reduce the overall sector throughput and cell edge throughput.

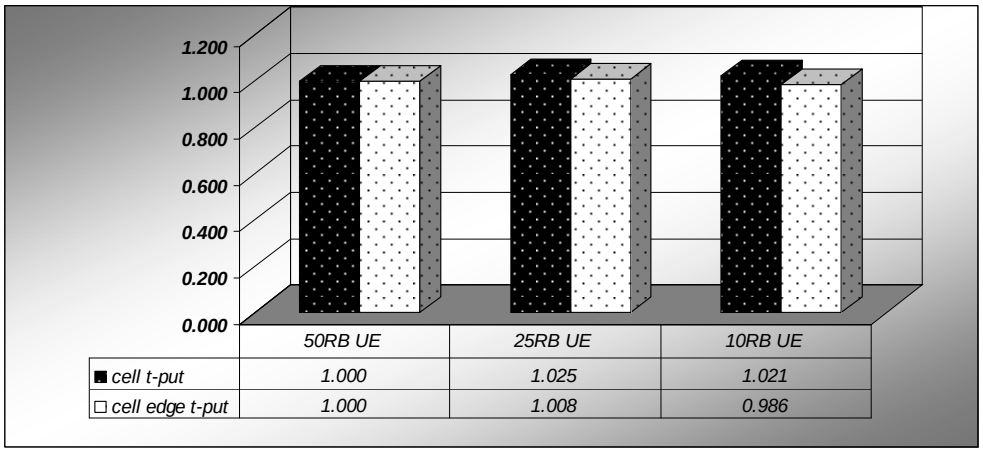

Figure 2 – Case 1 sector and cell-edge throughout vs. UE capability.

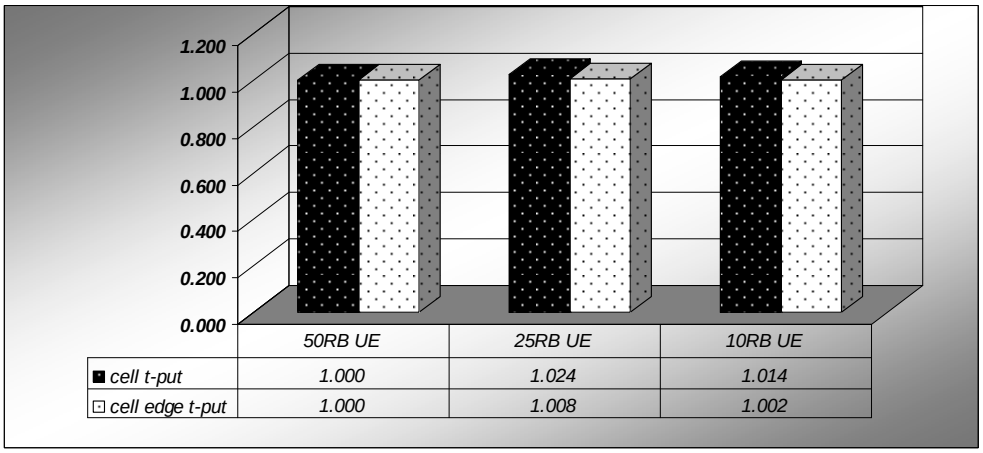

Figure 3 – Case 3 sector and cell-edge throughout vs. UE capability.

4. Conclusions

This contribution continues the discussion of [1] on UE capabilities, with emphasis on DL-SCH capabilities. Specifically, the contribution proposes:

a) four 2-stream UE categories for DL-SCH operation in LTE, and two 4-stream capable UE categories;

b) to implement stage 1 rate matching functionality for at least the LTE downlink, and observes that while not essential for uplink operation, if stage 1 rate matching is available for the downlink making it available to the uplink appears supportable with minimum effort. Stage 1 rate matching is available for each UE category.

c) that UE soft memory need not be allocated on a static basis to each HARQ process, but should rather be flexibly allocable between HARQ processes, in a fashion similar to that supported by HSDPA today.

Finally, the contribution notes that simulations indicate that the current PDCCH and PDSCH designs support efficient allocation of radio resources regardless of UE capability, and that an initial set of four UE capabilities aligned with those of Table 3 may provide a sufficiently flexible approach to UE configuration without negatively impacting sector throughput.

5. References

[1] R2-072080, Motorola, “UE Capabilities”, RAN2#48, Kobe, Japan, 7-11 May 2007

[2] R1-073366, Motorola, “HARQ Timing”, RAN1#50, Athens, Greece, 20-24 August 2007

[3] 3GPP TS 36.803v0.4.0, “User Equipment (UE) Radio Transmission and Reception”

[4] R1-073027, Ericsson, “On the number of hybrid ARQ processes in LTE”, RAN1#49bis, Orlando, USA, 25-29 June 2007

[5] R1-073359, Motorola, “On supporting 1st stage turbo code rate matching”, RAN1#50, Athens, Greece, 20-24 August 2007

[6] R1-070674, Orange et al., “LTE physical layer framework for performance verification”, RAN1#48, St. Louis, USA, 12-16 February, 2007