3G Evolution

Chapter: **19**

LTE Transmission Procedures

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Outline

- RLC and hybrid-ARQ in operation
  - Hybrid-ARQ with soft combining
  - Radio-link control (RLC)
- Scheduling and rate adaption
  - Downlink/downlink scheduling
  - Semi-persistent scheduling
  - Scheduling for half-duplex FDD
  - Channel-status reporting
- Uplink power control
  - Power control for PUCCH, PUSCH and SRS
- Discontinuous reception (DRX)
- Uplink timing alignment
- UE categories

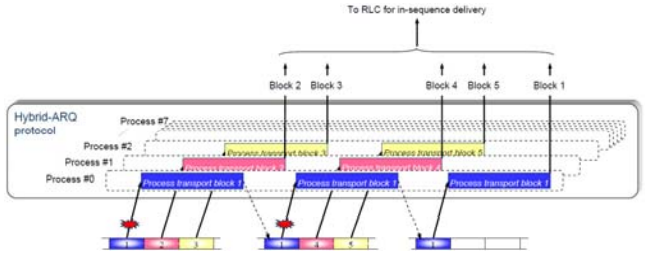
RLC and hybrid-ARQ in operation

– Hybrid-ARQ with soft combining

– Radio-link control (RLC)

19.1 Hybrid-ARQ with soft combining

- HARQ with soft combining (see Ch7 for details)
  - Original and retransmitted data softly combined at receiver
  - Retransmission may contain:
    - New code bit of same data (Incremental Redundancy) ⇦ Used in LTE
    - Same code bits (Chase combining)
- Several HARQ processes exist in parallel
- One bit "new-data indicator" on PDCCH indicate that the soft buffer should be cleared for a HARQ process



19.1 Hybrid-ARQ with soft combining

- HARQ may be
  - Synchronous vs. Asynchronous
    - Time domain
    - Retransmission occur at fixed time after transmission if synchronous. Benefit: reduced control signaling.
  - Adaptive vs. Non-adaptive
    - Frequency domain, transmission format
    - For non-adaptive, same freq. resources and format is used
- In LTE
  - Downlink : Asynchronous adaptive HARQ
  - Uplink: Synchronous non-adaptive (adaptive) HARQ
- Flexibility in downlink in order to avoid collisions with system information, MBSFN subframes etc.
- No HARQ for broadcast traffic.

19.1 Hybrid-ARQ with soft combining

- **Uplink HARQ:**
  - Synchronous non-adaptive (adaptive) HARQ
  - Retransmission occur 8 sub-frames after previous submission (for the given process) in case of FDD
  - NAC on PHICH triggers retransmission
  - Possible to explicitly schedule retransmission using PDCCH; override the PHICH and enabled adaptive retransmission

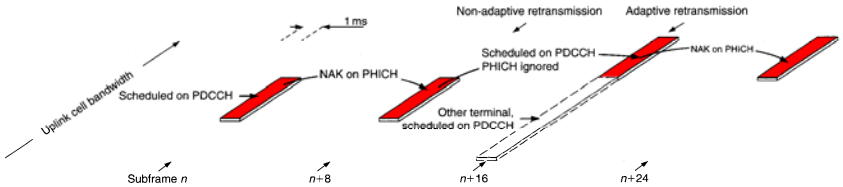


Figure 19.2 *Non-adaptive and adaptive hybrid-ARQ operation.*

19.1 Hybrid-ARQ with soft combining

- **HARQ timing (synchronous):**
  - Position (in time) of retransmission gives process number
  - In LTE: 8 parallel HARQ processes in FDD, therefore retransmission in subframe n+8
  - ACK submitted in n+4
  - Terminal has ~2.3ms to perform HARQ (worst case 100km from BS)

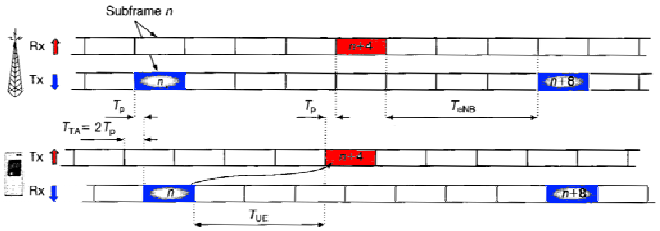


Figure 19.3 *Timing relation between downlink data in subframe n and uplink hybrid-ARQ acknowledgment in subframe n + 4 for FDD.*

The book seem to confuse uplink and downlink in 19.1.1.3. Assume synchronous both ways…?

19.1 Hybrid-ARQ with soft combining

For TDD: Resubmissions in subframe n+k, where k dependent on configuration!

Table 19.1 *Number of hybrid-ARQ processes and uplink acknowledgment timing k for different TDD configurations.*

Configuration	DL:UL allocation	Processes: Uplink	Processes: Downlink	Value of k upon reception of data in subframe: 0	1	2	3	4	5	6	7	8	9
0	2:3	7	4	4	6	–	–	–	4	6	–	–	–
1	3:2	4	7	7	6	–	–	4	7	6	–	–	4
2	4:1	2	10	7	6	–	4	8	7	6	–	4	8
3	7:3	3	9	4	11	–	–	–	7	6	6	5	5
4	8:2	2	12	12	11	–	–	8	7	7	6	5	4
5	9:1	1	15	12	11	–	9	8	7	6	5	4	13
6	5:5	6	6	7	7	–	–	–	7	7	–	–	5

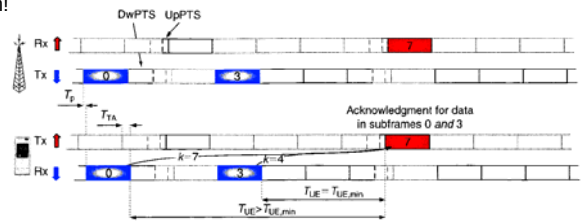


Figure 19.4 *Example of timing relation between downlink data and uplink hybrid-ARQ acknowledgment for TDD (configuration 2).*

19.1 Radio-link control (RLC)

- **The RLC protocol is responsible for:**
  - Segmentation, concatenation and reassembly of RLC SDUs (received from PDCP)
  - In sequence delivery for corresponding logical channel
  - RLC retransmission

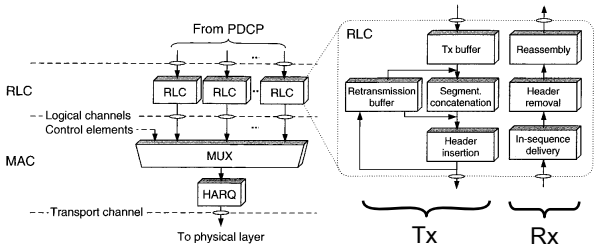


Figure 19.5 *MAC and RLC structure (single-terminal view).*

19.1 Radio-link control (RLC)

- **Segmentation, concatenation and reassembly of RLC SDUs**
  - Goal is to deliver appropriately sized PDUs given the delivered SDUs
  - In LTE, flexible PDU sizes
    - Avoid too big overhead and padding

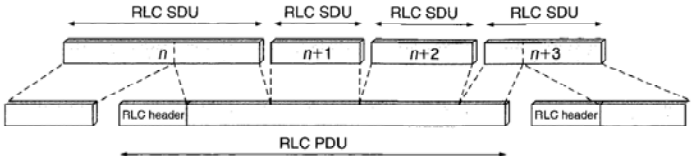


Figure 19.6 *Generation of RLC PDUs from RLC SDUs.*

19.1 Radio-link control (RLC)

- **RLC retransmission**
  - Main functionality of RLC
  - Request retransmission of missing PDUs
    - On request via a status report (from Tx RLC)
    - Automatically if lost package when timer expired (or if lost package as reported from HARQ)

RLC and HARQ complement each other for retransmission.

In LTE, both are located in the eNodeB and can thus cooperate!

- **In sequence delivery**
  - Make sure SDUs are delivered in order
  - Due to the HARQ the PDUs may turn up in the wrong order

- RLC can work in three modes:

Transparent mode	Unacknowledged mode	Acknowledged mode
RLC does nothing… Used for broadcast channel mainly.	Support segmentation/reassembly and in-sequence delivery. Used e.g. for multicast services and VoIP.	All RLC functionality enabled. Main mode for TCP/IP data transmissions.

19.1 Radio-link control (RLC)

- **Example:**
  - Tx/Rx window contains all PDUs eligible for transmission/reception.

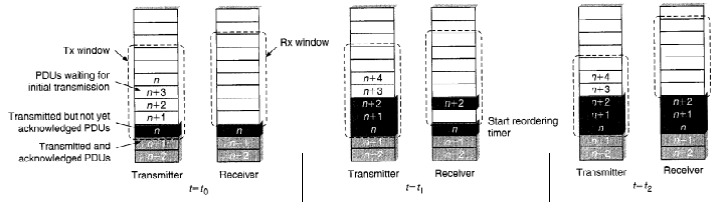


Figure 19.7 *In-sequence delivery.*

t_0:

PDU n transmitted

PDU n+1, n+2, n+3 waiting to be transmitted

t_1:

PDU n+1 missing at Rx

Reordering timer started; when timed out retransmission requested

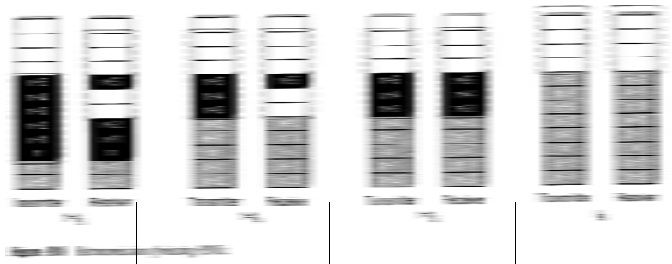
t_2:

PDU n+1 show up before timer expire

PDU n, n+1, n+2 waiting to be acknowledged

19.1 Radio-link control (RLC)

- Example 2: Retransmission



t_3:

PDUs n to n+5 transmitted

PDU n+3, n+4 missing at Rx, timers set

t_4:

Timer expire.

Control PDU with status report transmitted from Rx

(with higher priority than data)

t_5:

Retransmission succeeded

Rx send status report requested in last data PDU

t_6:

All data transmitted and acknowledged

Scheduling and rate adaption

- Downlink scheduling
- Uplink scheduling
- Semi-persistent scheduling
- Scheduling for half-duplex FDD
- Channel-status reporting

19.2 Scheduling and rate adaption

- **Scheduling overview:**
  - Located in the eNodeB
  - Decide how and by whom the time/freq. resources are used
  - Can communicate with other nodes over the X2 interface
  - High impact on overall system performance
  - Scheduling strategy implementation-specific (not in specs.)

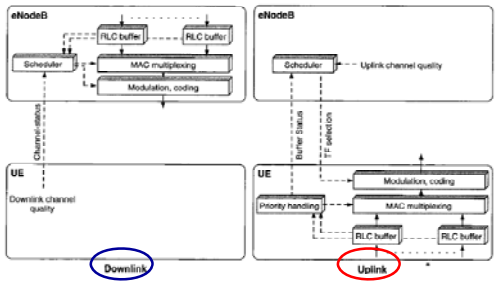


Figure 19.9 *Transport format selection in downlink (left) and uplink (right).*

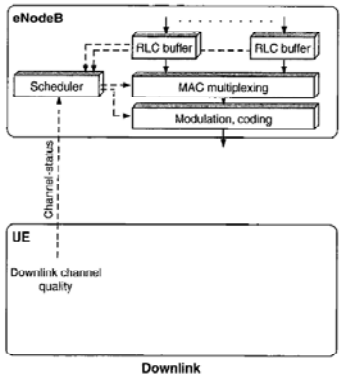
19.2 Scheduling and rate adaption

- **Downlink scheduling**
  - Dynamically decide which users to transmit to and on which resources.
  - In control of several layers
    - RLC:

      Need for concatenation/segmentation depending on data rate.
    - MAC:

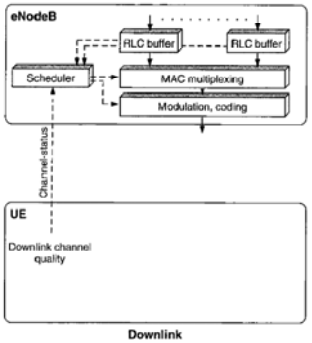
      Multiplexing of streams is priority dependent. Has to be considered.
    - L1:

      Selection of coding, modulation and layers (MIMO).
  - Scheduling decisions transmitted on PDCCH to the users



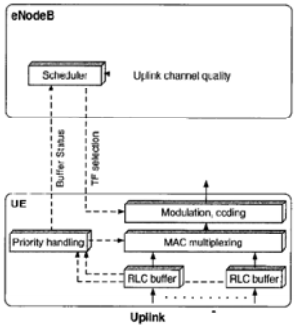
19.2 Scheduling and rate adaption

- **Downlink scheduling (cont.)**
  - May require information about
    - Channel conditions at terminal:
      - obtained through channel-status reports (and any other means)
      - for decisions on power control, modulation and coding
    - Buffer status and priorities of data flows
      - so that empty buffers are not scheduled
      - so that the most important data is handled first by the MAC
    - Interference situation in neighboring cells
      - if inter-cell interference cooperation is implemented



19.2 Scheduling and rate adaption

- **Uplink scheduling**
  - eNodeB in full control
  - eNodeB deliver **scheduling grants** which
    - provide info about the resources and transport format (block size, modulation etc.)
    - are valid for one subframe
    - needed for a terminal to be allowed to transmit
    - are transmitted on downlink PDCCH
  - Priority handling performed by MAC at terminal, given a set of rules
  - Scheduler may use buffer, channel and interference information.



19.2 Scheduling and rate adaption

- **Uplink scheduling: Scheduling requests**
  - Terminal make a **scheduling request (SR)** if it wants to transmit
  - One bit SR is transmitted on a dedicated PUCCH schedule request resource
  - Initially, buffer situation at terminal unknown:
    Possibly, scheduler give small resource and then ask for buffer status (etc.) transmitted via a specific MAC control header.
  - Terminal without SR resource has to rely on random access mechanism (see ch18)

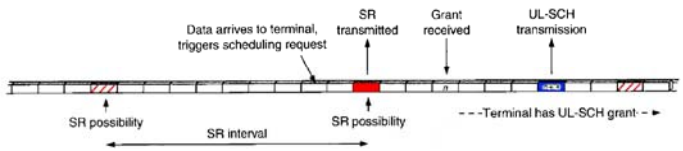


Figure 19.12 *Scheduling request transmission.*

19.2 Scheduling and rate adaption

- **Uplink scheduling: Inter-cell interference coordination**
  - Uplink interference coordination used to improve for cell edge users
  - Neighboring cells exchange indicators via X2 interface:
    - High interference indicator
      Specify on which resources cell edge users will be scheduled
    - Interference indicator
      Gives interference situation in each resource block:
      low, medium, high

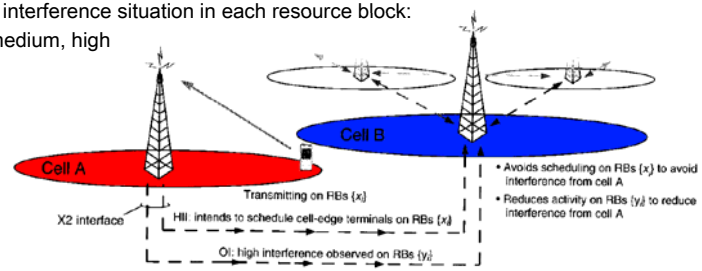


Figure 19.14 *Example of uplink inter-cell interference coordination.*

19.2 Scheduling and rate adaption

- Semi-persistent scheduling
  - Possible to schedule recourses to be used until further notice (on every n:th subframe)
  - Help reduce control signaling
  - Used for e.g. VoIP

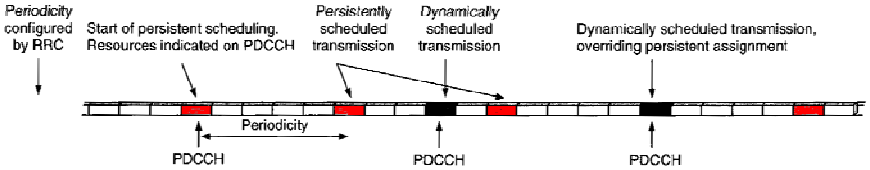


Figure 19.15 *Example of semi-persistent scheduling.*

19.2 Scheduling and rate adaption

- Scheduling for half-duplex FDD
  - Impose constraints on the scheduling
  - Terminal cant transmit Uplink/downlink simultaneously.

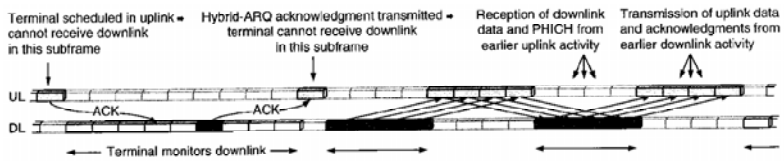


Figure 19.16 *Example of half-duplex FDD terminal operation.*

19.2 Scheduling and rate adaption

- Channel-status reporting
  - **Channel-status reports** provided by the terminal

    Contains recommendations on what signaling format the BS should use for downlink

    Contain one or several of:

Rank indication (Number of layers)	Precoder matrix indication	Channel quality indication (Proposed coding & modulation schemes)

  - Reports may be
    - periodic or a-periodic/trigger based
    - wideband or per-subband reports

Uplink power control

- Power control for PUCCH
- Power control for PUSCH
- (Power control for SRS)

19.3 Uplink power control

- Power control for PUCCH
  - Decide at what power the terminals transmit
    - Facilitate a good SINR (interference important!)
    - Take into account that different control signals have different requirements
  - Terminal get a power control command every time it is scheduled
  - The power control is expressed as

$$P_T = \min\{P_{max}, P_0 + PL_{DL} + \Delta_{format} + \delta\}$$

where

P_{max}	- the maximul transmit power
P_0	- may be seen an the desired received power (broadcasted)
PL_{DL}	- the pathloss
Δ_{format}	- a format dependent offset
δ	- an accumulative command; **Main tool** (few dB adjustmens).

19.3 Uplink power control

- Power control for PUCCH (cont.)
  - The accumulative command δ
    - This is the main control tool
    - Can be increased by: $[-1\text{dB}, 0\text{dB}, +1\text{dB and } +3\text{dB}]$
    - Is transmitted every time the terminal is scheduled (via PDCCH)
    - (also possible to control several terminals using DCI format 3/3A)
  - P_0 is broadcasted together with the system information and may be changed depending on system load.

    The terminal generally don't access this information while connected.

19.3 Uplink power control

- Power control for PUSCH
  - Similar to, but independent from, PUCCH power control
  - The power control is expressed as

$$P_T = \min\{P_{max}, P_0 + \alpha \cdot PL_{DL} + 10 \cdot \log_{10}(M) + \Delta_{MCS} + \delta\}$$

where

P_{max}	- the maximum transmit power
P_0	- may be seen an the desired received power (broadcasted)
PL_{DL}	- the path-loss
α	- the partial path-loss compensation factor
Δ_{MCS}	- a modulation & coding scheme dependent offset
M	- number of resource blocks. (More BW more power)
δ	- an accumulative command

19.3 Uplink power control

- Power control for PUSCH (cont.)
  - A few words about the partial path-loss compensation ($\alpha \neq 0$)
    - It will reduce the power close to the cell boarder, which will reduce the inter-cell interference.
    - Terminal is thus forced to signal at a lower rate

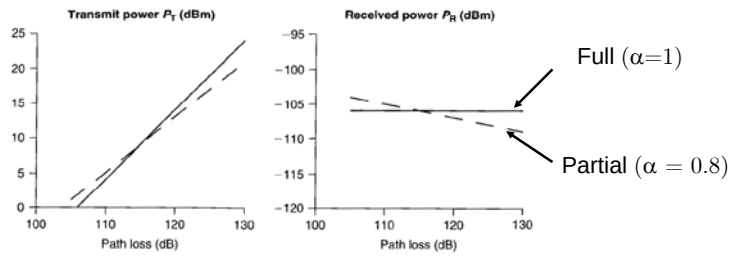


Figure 19.17 *Full vs. partial path-loss compensation. Solid curve. Full compensation ($\alpha = 1$); Dashed curve: Partial compensation ($\alpha = 0.8$).*

- Discontinous reception (DRX)
- Uplink timing alignment
- UE categories

19.4 Discontinous reception (DRX)

- Packet data transmissions are generally bursty, transmissions may occur anytime.
- If terminal is always awake ➜ high power consumption
- To save power, terminal may listen only on specified subframes, and sleep in-between.
- Two DRX cycles possible:
  - Long cycle: Sufficient in most cases. Terminal assumed to stay awake a while after being scheduled.
  - Short cycle: A shorter cycle may be needed for e.g. VoIP

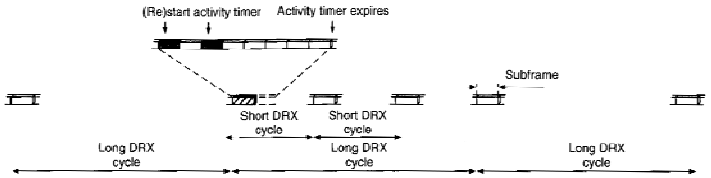


Figure 19.18 *Illustration of DRX operation.*

19.5 Uplink timing alignment

- For DFTS-OFDM-multiple access in the uplink, the different terminal transmissions has to be time aligned
  - To keep orthogonality transmissions should arrive within the CP
- This is solved using **timing advance**
  - which is a terminal specific negative timing offset
  - Command usually transmitted a few times per second
- Transmitted as a MAC control element on DL-SCH
- Same same but different for TDD…

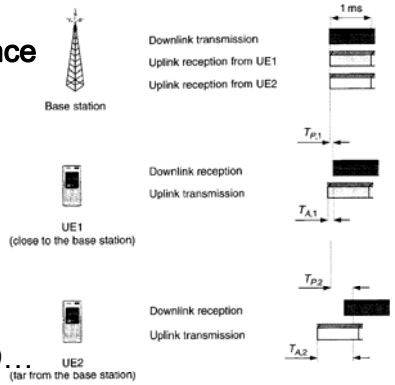


Figure 19.19 *Uplink timing advance.*

19.6 UE categories

- UE are grouped into different categories depending on the specific physical layer implementation
- Five different categories from low-end to high-end products

Table 19.3 *UE categories.*

Category	1	2	3	4	5
Downlink peak rate (Mbit/s)	10	50	100	150	300
Uplink peak rate (Mbit/s)	5	25	50	50	75
Soft buffer size (Msoft bit)	0.25	1.2	1.2	1.8	3.7
Maximum downlink modulation		64QAM			
Maximum uplink modulation		16QAM			64QAM
Max layers for spatial multiplexing	1		2		4

Chapter summary

- The hybrid-ARQ with soft combining in action
  - Retransmission process
- The Radio Link Control (RLC)
  - Segmentation, retransmission etc.
- Scheduling in LTE
  - eNodeB in full control of freq./time resources; use info on buffers, channels and interference
  - Scheduling strategy implementation-specific (not in specs.)
- Power control
  - Terminal power adjusted to get good SINR
- Uplink timing alignment
  - To get inter-user orthogonality at BS for DFTS-OFDM