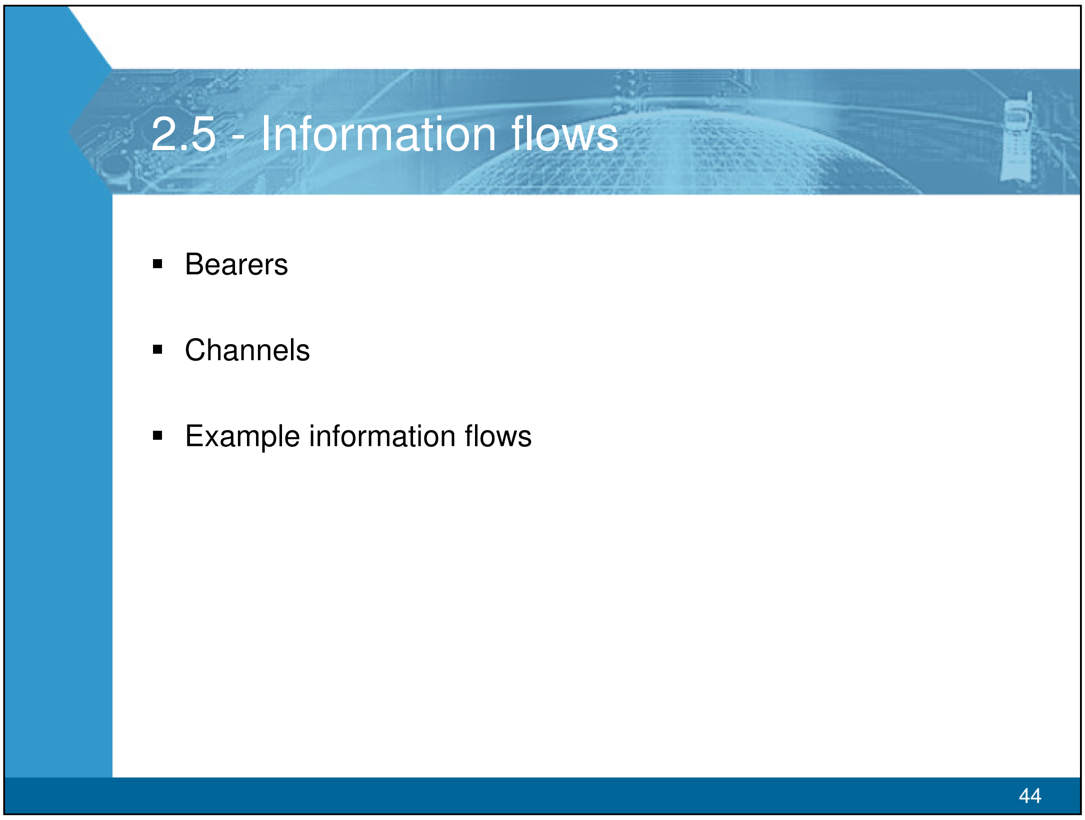
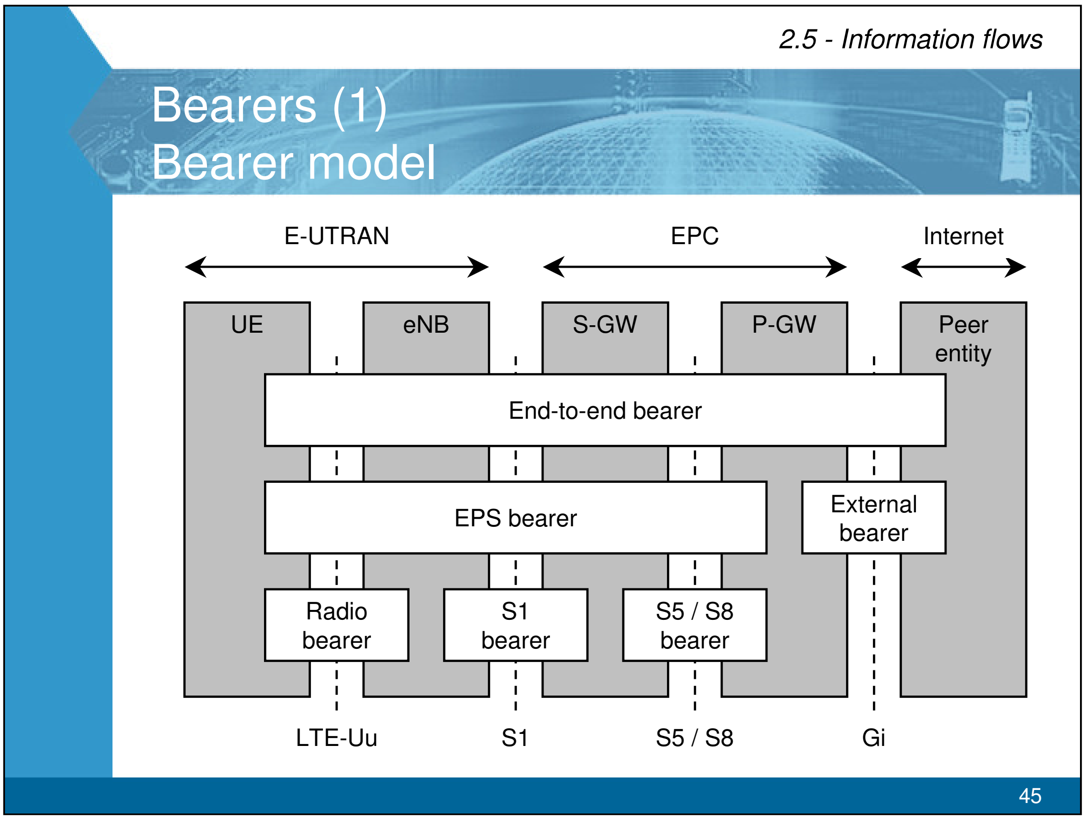


2.5 - Information flows

In this section, we will describe two important types of data stream in the evolved packet system:

- *Bearers*, which carry information from one part of the system to another, with a particular quality of service.
- *Channels*, which carry information between different levels of the air interface protocol stack.

We will also look at some example information flows over the air interface, to see how the protocol stacks, bearers and channels interact with each other.



Bearers (1) - Bearer model TS 36.300 § 13.1

A *bearer* carries data from one network element to another. It is associated with a particular *quality of service*, which describes parameters such as the data rate, error rate and delay.

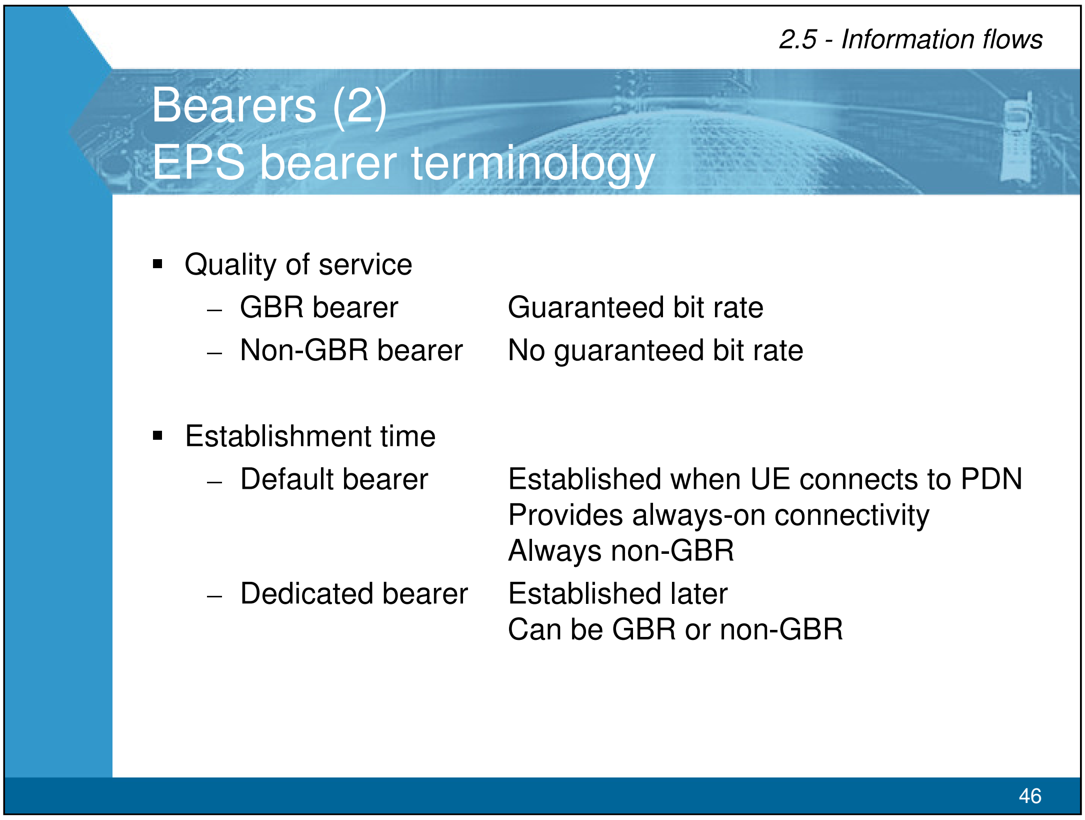
The most important bearer is an *EPS bearer*, which carries data between the UE and the PDN gateway (P-GW). When the network sets up a data stream, the data are carried by an EPS bearer, and are associated with a particular quality of service.

It's impossible to implement an EPS bearer directly, because it spans several interfaces that use different transport protocols. The EPS bearer is therefore broken down into three lower-level bearers:

- The *radio bearer* carries data between the UE and the E-UTRAN Node B (eNB).
- The *S1 bearer* carries data over the S1 interface, between the eNB and the serving gateway (S-GW).
- The *S5/S8 bearer* carries data over the S5 or S8 interface, between the S-GW and the P-GW. (If these network elements are co-located, then this bearer is absent.)

The network can implement each of these bearers using the transport protocols that are appropriate for the corresponding interfaces. In particular, the radio bearer is implemented using the air interface protocols that we saw earlier, and the channels that we'll consider in a few slides time.

Of course the EPS bearer doesn't carry the full end-to-end service, because there is also an external bearer which carries the data in the external network. This bearer lies outside the scope of the system, and we won't consider it further.



Bearers (2) - EPS bearer terminology

TS 36.300 § 13
TS 23.401 § 4.7.2

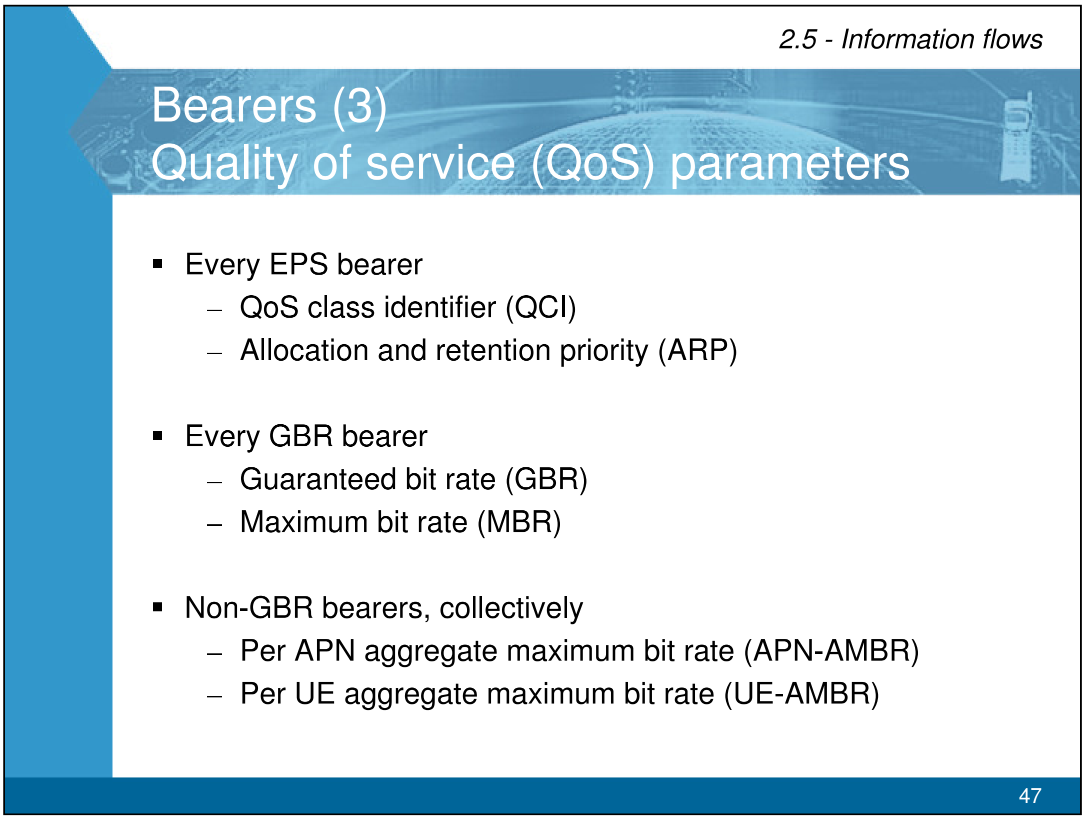
There are a few different types of EPS bearer. One classification refers to quality of service:

- A *GBR bearer* has a guaranteed bit rate (GBR) amongst its quality-of-service parameters. A GBR bearer would be suitable for a conversational service, such as a voice call.
- A non-GBR bearer does not have a guaranteed bit rate. A non-GBR bearer would be suitable for a background service, such as EMail.

Another classification refers to the time when the bearer is established:

- One EPS bearer is established when the UE connects to a packet data network. This is known as a *default bearer*. It provides the user with an always-on IP connection to that network. A default bearer is always a non-GBR bearer.
- Any additional EPS bearers for the same packet data network are known as *dedicated bearers*. Dedicated bearers can be either GBR or non-GBR bearers.

In addition, every EPS bearer is associated with two *traffic flow templates* (TFTs), one for the uplink and one for the downlink. The TFT is a set of packet filters, which the UE and network use to map incoming packets to the correct EPS bearer.



Bearers (3) - Quality of service (QoS) parameters TS 36.300 § 13.2

TS 23.401 § 4.7.3

Every EPS bearer is associated with the following QoS parameters:

- *QoS class identifier* (QCI): This is a number which describes the error rate and delay that are associated with the service. More details are given on the next slide.
- *Allocation and retention priority* (ARP): This determines whether a bearer can be dropped if the network gets congested, or whether it can cause other bearers to be dropped. Emergency calls might be associated with a high ARP, for example.

Every GBR bearer is also associated with the following parameters:

- *Guaranteed bit rate* (GBR): This is the long-term average bit rate that the user can expect to receive.
- *Maximum bit rate* (MBR): This is the maximum instantaneous bit rate that the network will ever provide. In release 8, the maximum bit rate equals the guaranteed bit rate, but this may be relaxed in future releases.

Non-GBR bearers are collectively associated with the following parameters:

- *Per APN aggregate maximum bit rate* (APN-AMBR): This limits the total bit rate of the non-GBR bearers that a UE is exchanging with a particular access point name.
- *Per UE aggregate maximum bit rate* (UE-AMBR): This limits the total bit rate of all of the non-GBR bearers for a particular UE.

(GBR bearers are excluded from these last two parameters.)

2.5 - Information flows

Bearers (4)
QoS class identifier (QCI)

QCI	Bearer	Priority	Delay	PELR	Examples
1	GBR	2	100 ms	10^{-2}	Conversational voice
2		4	150 ms	10^{-3}	Conversational video
3		3	50 ms	10^{-3}	Real-time games
4		5	300 ms	10^{-6}	Streaming video
5	Non-GBR	1	100 ms	10^{-6}	IMS signalling
6		6	300 ms	10^{-6}	Streaming video, web, EMail
7		7	100 ms	10^{-3}	Voice, video, games
8		8	300 ms	10^{-6}	Streaming video, web, EMail
9		9			

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Bearers (4) - QoS class identifier (QCI) TS 23.203 § 6.1.7

Every EPS bearer is associated with a number called the *QoS class identifier* (QCI). Network nodes use the QCI as a reference, so as to look up the parameters that control the way in which packets from that data stream are forwarded. Example parameters include scheduling weights and queue management thresholds.

Some QCI values have been standardised, and are associated with quality-of-service parameters that are listed in the table above. The parameters are as follows:

- QCI: Standardised QoS class identifier. Other values can be defined by the network operator.
- Bearer: Whether or not the bearer has a guaranteed bit rate.
- Priority: This affects the scheduling at the network nodes. 1 is the highest priority.
- Delay: Upper bound (with 98% confidence) for the delay that a packet can experience between the UE and the P-GW.
- Packet error loss rate (PELR): Upper bound for the proportion of packets that are lost. (Non-GBR services can experience additional packet loss due to congestion.)

The QoS parameters are not mandatory: instead, they are guidelines that network operators can use to work out the node-specific parameters noted above. The intention is that applications mapped to a particular QCI should receive roughly the same quality of service, whichever network they're in.

2.5 - Information flows

Bearers (5)
Signalling radio bearers (SRBs)

Bearer	Function	Configured by
SRB 0	Sets up RRC signalling	System information
SRB 1	Carries other RRC messages & piggybacked NAS messages Sets up NAS signalling	Messages on SRB 0
SRB 2	Carries other NAS messages	Messages on SRB 1

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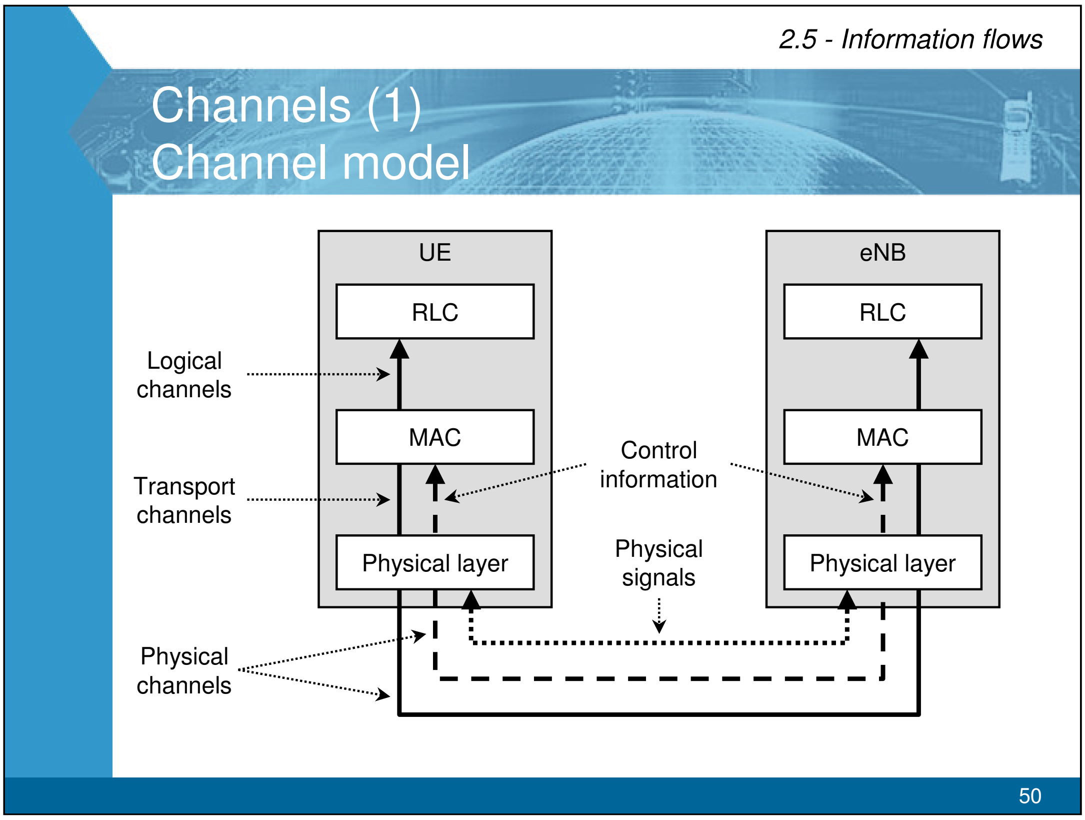
Bearers (5) - Signalling radio bearers (SRBs) TS 36.331 § 4.2.2

Three special radio bearers are used to transfer signalling messages between the UE and the network. They are known as *signalling radio bearers* (SRBs):

- *SRB 0*: This sets up signalling communications between the UE and the E-UTRAN. The network advertises the configuration of SRB 0 using the system information that it broadcasts over the whole of the cell, which ensures that every mobile can transmit and receive it.
- *SRB 1*: This is used for two things:
    - SRB 1 is used for all subsequent RRC messages. A few of these messages can also contain piggybacked NAS messages, so as to reduce the signalling latency between the UE and the network.
    - SRB 1 is also used to set up NAS signalling communications between the UE and the EPC.

  SRB 1 is configured when the UE sets up signalling communications with the E-UTRAN, using messages that are exchanged on SRB 0.
- *SRB 2*: This is used for all other NAS messages. It is configured by the E-UTRAN, after the security procedures have been run, using messages that are exchanged on SRB 1.

We can see that the signalling radio bearers are similar to those in UTRAN, but there are fewer of them, and they are used in slightly different ways.



Channels (1) - Channel model

A *channel* carries information between different levels of the air interface's protocol stack. As in the UTRAN, there are three types of channel:

- *Logical channels* flow between the radio link control (RLC) and medium access control (MAC) protocols.
- *Transport channels* flow between the MAC protocol and the physical layer.
- *Physical channels* flow out of the bottom of the physical layer.

The specifications also define two types of low-level signalling information:

- *Control information* appears at the same level as the transport channels. It is composed by the transmitter's MAC protocol; it is then transported using the physical channels, and travels as far as the receiver's MAC protocol. It is completely invisible to higher layers.
- *Physical signals* appear at the same level as the physical channels. They are composed by the transmitter's physical layer, and travel as far as the receiver's physical layer. They are completely invisible to higher layers.

2.5 - Information flows

Channels (2)
Logical channels

		Name	Use
UL+DL	**DTCH**	**Dedicated traffic channel**	**Data**
	DCCH	**Dedicated control channel**	**Signalling on SRB 1/2**
	CCCH	Common control channel	Signalling on SRB 0
DL only	MTCH	Multicast traffic channel	MBMS data
	MCCH	Multicast control channel	MBMS signalling
	PCCH	Paging control channel	Paging messages
	BCCH	Broadcast control channel	System information

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Channels (2) - Logical channels TS 36.300 § 6.1.2

Logical channels flow between the radio link control and medium access control protocols. They are distinguished by the type of information that is being exchanged between the E-UTRAN and the UE.

Three logical channels are used in both the uplink and downlink:

- *Dedicated traffic channel* (DTCH): This carries user-plane data to or from a single UE.
- *Dedicated control channel* (DCCH): This carries control-plane signalling messages to or from a single UE, on SRB 1 or 2. It is used by UEs that already have a signalling connection with the E-UTRAN.
- *Common control channel* (CCCH): This carries signalling radio bearer 0. It is used to set up a signalling connection between the UE and the E-UTRAN.

The DTCH and DCCH are the most important ones, so have been highlighted above.

The other four are only used in the downlink:

- *Multicast traffic channel* (MTCH): This is a point-to-multipoint channel. It carries the *multimedia broadcast / multicast service* (MBMS) from the network to a group of UEs, for applications such as mobile TV.
- *Multicast control channel* (MCCH): This is a point-to-multipoint channel. It carries signalling messages that are related to MBMS.
- *Paging control channel* (PCCH): This transfers paging messages from the network to the UE, if the network doesn't know which cell the UE is in. (If the network does know which cell the UE is in, then it can transfer the paging message on the DCCH, like any other type of signalling.)
- *Broadcast control channel* (BCCH): This carries system information, which is broadcast over the whole of the cell to tell the UEs how the cell is configured.

2.5 - Information flows

Channels (3)
Transport channels

		Name	Use
UL	**UL-SCH**	**UL shared channel**	**UL data & signalling**
	RACH	Random access channel	Signalling connection request
DL	**DL-SCH**	**DL shared channel**	**DL data & signalling**
	MCH	Multicast channel	MBMS when using MBSFN
	PCH	Paging channel	Paging messages
	BCH	Broadcast channel	Important system information

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Channels (3) - Transport channels TS 36.300 § 5.3

Transport channels flow between the MAC protocol and the physical layer. They are distinguished by the way in which the information is transported.

The uplink uses two transport channels:

- *Uplink shared channel* (UL-SCH): This carries all the UE's data and signalling on the uplink. It supports hybrid ARQ.
- *Random access channel* (RACH): This is used to request the establishment of a signalling connection between the UE and the network, and to re-establish timing synchronisation between them. (Unlike in UTRAN, it doesn't actually carry any signalling or data: such information is always carried on the UL-SCH.)

The downlink uses four:

- *Downlink shared channel* (DL-SCH): This carries all the UE's data and signalling on the downlink, except for the specific cases listed below. It supports hybrid ARQ.
- *Multicast channel* (MCH): This carries data and signalling for the multimedia broadcast / multicast service (MBMS). It supports transmission using multimedia broadcast on a single frequency network (MBSFN). (If we are not using MBSFN, then the information can be transmitted on the DL-SCH.)
- *Paging channel* (PCH): This carries paging messages that have been transmitted on the PCCH. It supports discontinuous reception (DRX).
- *Broadcast channel* (BCH): This carries the most important system broadcast information from the BCCH. (Other system broadcast information can be transported on the DL-SCH.)

2.5 - Information flows

Channels (4)
Control information

		Name	Use
UL	UCI	UL control information	Channel quality information Hybrid ARQ acknowledgements UL scheduling requests
DL	DCI	DL control information	UL scheduling information DL scheduling information Power control commands
	HI	Hybrid ARQ indicator	Hybrid ARQ acknowledgements
	CFI	Control format indicator	How to read the PDCCH

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Channels (4) - Control information TS 36.212 § 4

Control information is composed by the transmitter's medium access control protocol. It is transported using the physical channels, and travels as far as the MAC protocol in the receiver. It is completely invisible to higher layers.

The uplink uses one set of control information:

- *Uplink control information* (UCI): This carries the following:
  - Information about the downlink channel quality
  - The hybrid ARQ algorithm's acknowledgements of data that the UE has received on the downlink
  - Requests for uplink scheduling

The downlink uses three:

- *Downlink control information* (DCI): This carries the following:
  - Scheduling information for the uplink
  - Scheduling information for the downlink
  - Power control commands for the mobile transmitter
- *Hybrid ARQ indicator* (HI): This carries the hybrid ARQ algorithm's acknowledgements of data that the eNB has received on the uplink.
- *Control format indicator* (CFI): This describes the physical channel resources that are being used by the physical downlink control channel (PDCCH), which we will see in a moment.

2.5 - Information flows

Channels (5)
Physical channels

		Name	Use
UL	**PUSCH**	**Physical UL shared channel**	**UL-SCH, UCI**
	PUCCH	Physical UL control channel	UCI
	PRACH	Physical random access channel	RACH
DL	**PDSCH**	**Physical DL shared channel**	**DL-SCH, PCH**
	PMCH	Physical multicast channel	MCH
	PBCH	Physical broadcast channel	BCH
	PCFICH	Physical control format indicator channel	CFI
	PDCCH	Physical DL control channel	DCI
	PHICH	Physical hybrid ARQ indicator channel	HI

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Channels (5) - Physical channels TS 36.300 § 5

The physical channels flow out of the bottom of the physical layer. They have a relationship with the transport channels which is very nearly one-to-one.

The uplink uses three physical channels:

- *Physical uplink shared channel* (PUSCH): This carries the uplink shared channel. It can also carry the uplink control information, if a mobile needs to transmit data and control information at the same time.
- *Physical uplink control channel* (PUCCH): This carries the uplink control information, if the mobile does not need to transmit data at the same time.
- *Physical random access channel* (PRACH): This carries the random access channel.

The downlink uses six:

- *Physical downlink shared channel* (PDSCH): This carries the downlink shared channel and the paging channel.
- *Physical multicast channel* (PMCH): This carries the multicast channel.
- *Physical broadcast channel* (PBCH): This carries the broadcast channel.
- *Physical control format indicator channel* (PCFICH): This carries the control format indicators.
- *Physical downlink control channel* (PDCCH): This carries the downlink control information.
- *Physical hybrid ARQ indicator channel* (PHICH): This carries the hybrid ARQ indicators.

2.5 - Information flows

Channels (6)
Physical signals

	Name	Use
UL	Demodulation reference signal	Pilot signal for demodulation
	Sounding reference signal (SRS)	Pilot signal for scheduling
DL	Cell-specific reference signal	Pilot signal for any UE
	UE-specific reference signal	Pilot signal for a specific UE
	MBSFN reference signal	Pilot signal for the PMCH
	Primary synchronisation signal	Acquisition
	Secondary synchronisation signal	Acquisition

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Channels (6) - Physical signals TS 36.211 § 5.5, 6.10, 6.11

Physical signals are composed in the physical layer of the transmitter, and travel as far as the physical layer of the receiver. They are completely invisible to higher layers. (They are analogous to the UTRAN physical channels that don’t carry transport channels, such as the SCH and CPICH.)

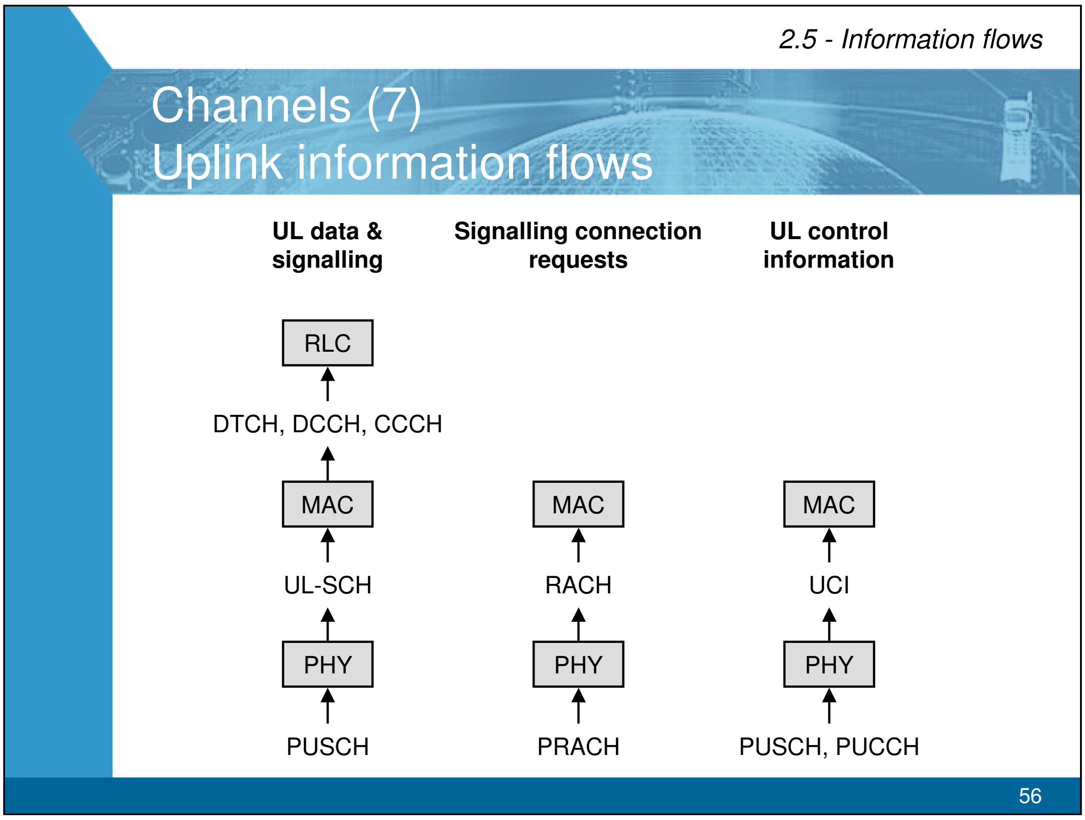
Most of the physical signals are *reference signals*, also commonly known as pilot signals. They provide the receiver with amplitude and phase references, which have various different uses. The uplink uses two reference signals:

- *Demodulation reference signal*: This helps the eNB to demodulate the information that the UE is transmitting on the PUSCH and PUCCH.
- *Sounding reference signal* (SRS): This helps the eNB to decide which carrier frequencies it should assign to the UE for transmission. The idea is to choose carrier frequencies that are being strongly received, and to avoid carrier frequencies that are currently undergoing fades.

The downlink uses three reference signals, which are all used for demodulation:

- *Cell-specific reference signal*: This is a pilot signal for the antenna beams that the cell transmits towards any UE.
- *UE-specific reference signal*: This is a pilot signal for antenna beams that are directed towards individual UEs.
- *MBSFN reference signal*: This is a pilot signal for the PMCH.

Synchronisation signals help the UE during acquisition. The downlink uses two, the *primary synchronisation signal* and the *secondary synchronisation signal*. Together, they allow the UE to establish timing synchronisation with the cell, and to find its identity.



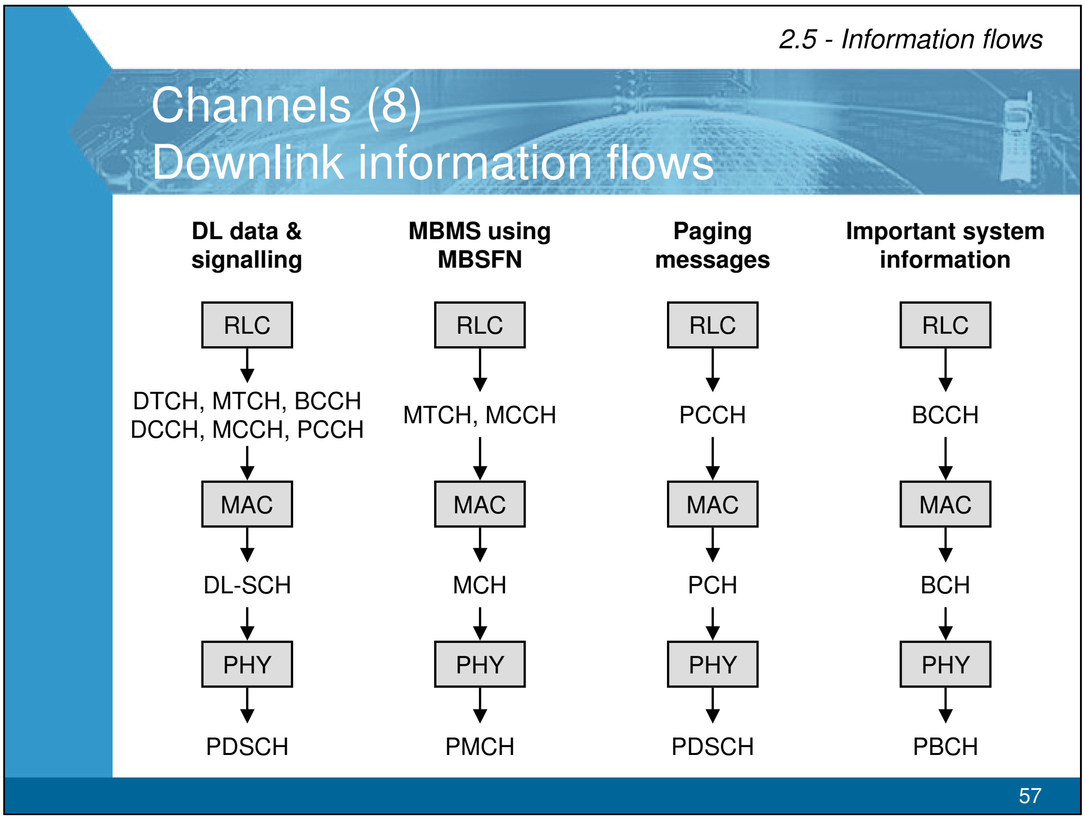
Channels (7) - Uplink information flows TS 36.300 § 5.3.1, 6.1.3

TS 36.302 § 6.1

There are far too many channels to remember easily. However they group together into a limited number of information flows, which are best considered by looking at the transport channels and transport-level control information.

This slide shows the information flows on the uplink. The arrows are drawn from the viewpoint of the eNB receiver, so that upwards-pointing arrows correspond to uplink channels. There are three cases to consider:

- Uplink data and signalling messages are transmitted on the UL-SCH and the PUSCH.
- Requests for a signalling connection or for timing synchronisation are transmitted on the RACH and PRACH. (The RACH is composed in the UE's MAC protocol and terminates in the eNB's MAC protocol, so it should probably have been called a set of control information.)
- Uplink control information is transmitted on the PUSCH (if the UE also has data to transmit), or on the PUCCH (if it doesn't).

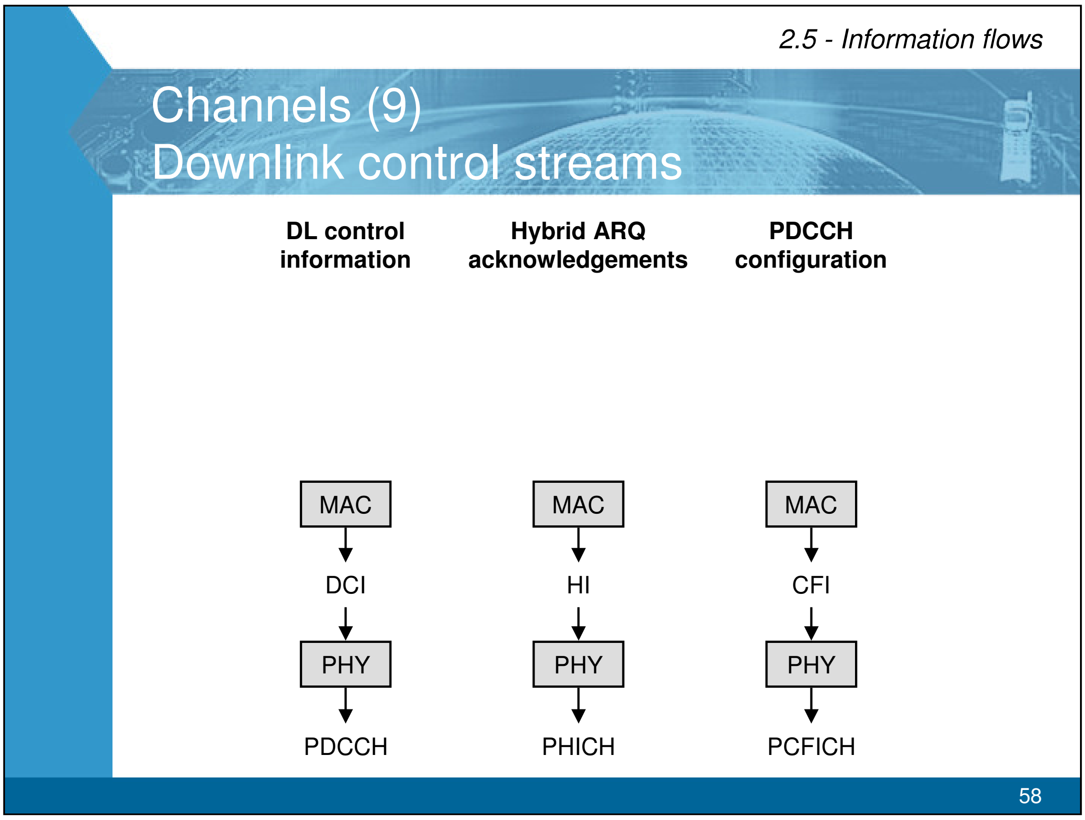


Channels (8) - Downlink information flows TS 36.300 § 5.3.1, 6.1.3

TS 36.302 § 6.2

The next two slides show the corresponding situation on the downlink. First we will look at the downlink transport channels. There are four cases to consider:

- Most of the downlink data and signalling messages are transmitted on the DL-SCH and PDSCH.
- The multimedia broadcast / multicast service (MBMS) is transmitted on the MCH and PMCH, if the network is using multimedia broadcast on a single frequency network (MBSFN). (Otherwise, the service can be transmitted on the DL-SCH and PDSCH.)
- Paging messages are transmitted on the PCCH, PCH and PDSCH, if the network doesn't know which cell the UE is in. (Otherwise, the messages can be transmitted on the DCCH, DL-SCH and PDSCH.)
- Important system information is transmitted on the BCCH, BCH and PBCH.



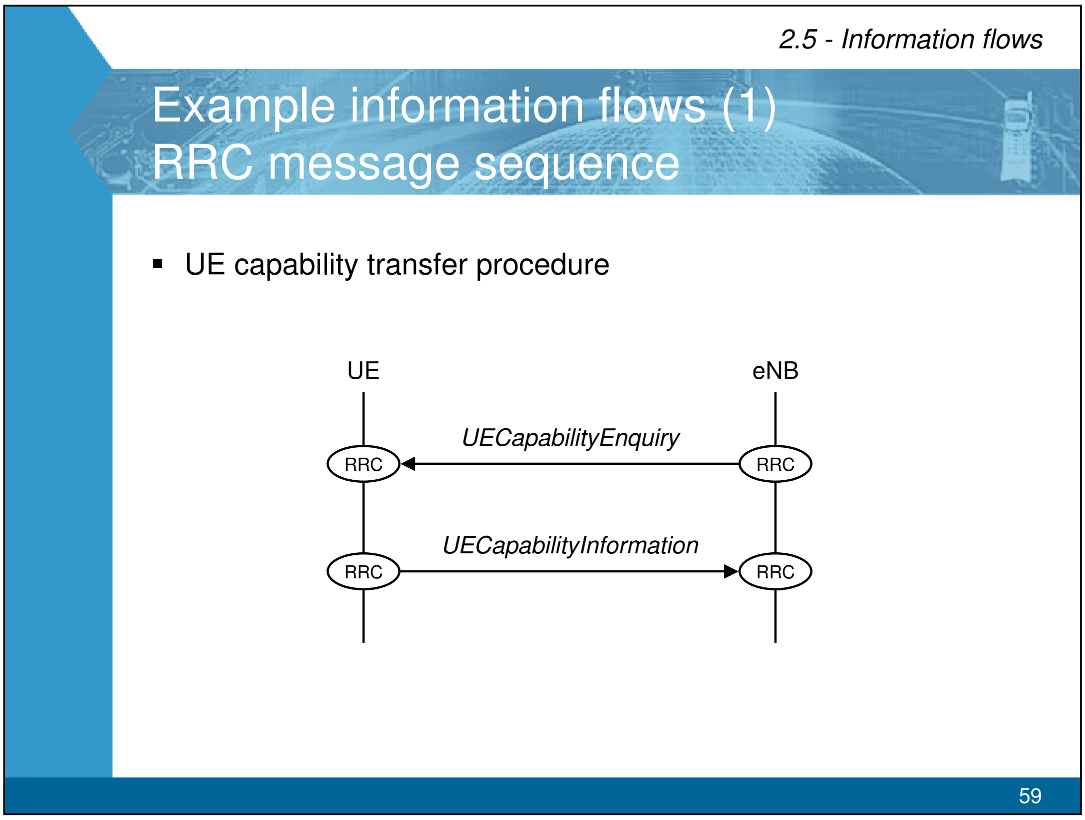
Channels (9) - Downlink control streams TS 36.300 § 5.3.1, 6.1.3

TS 36.302 § 6.2

There are three flows of control information in the downlink:

- Downlink control information is transmitted on the PDCCH.
- Hybrid ARQ acknowledgements are transmitted on the PHICH.
- Information describing the PDCCH is transmitted on the PCFICH.

Clearly there are many interactions between these different information flows. If, for example, the network wants to send a UE data or signalling on the PDSCH, then it must first send it scheduling information on the PDCCH. After receiving the information, the UE will reply with a hybrid ARQ acknowledgement on the PUCCH or PUSCH. For those who are studying the details of the physical layer, we will consider these interactions later in the course, when we discuss procedures.



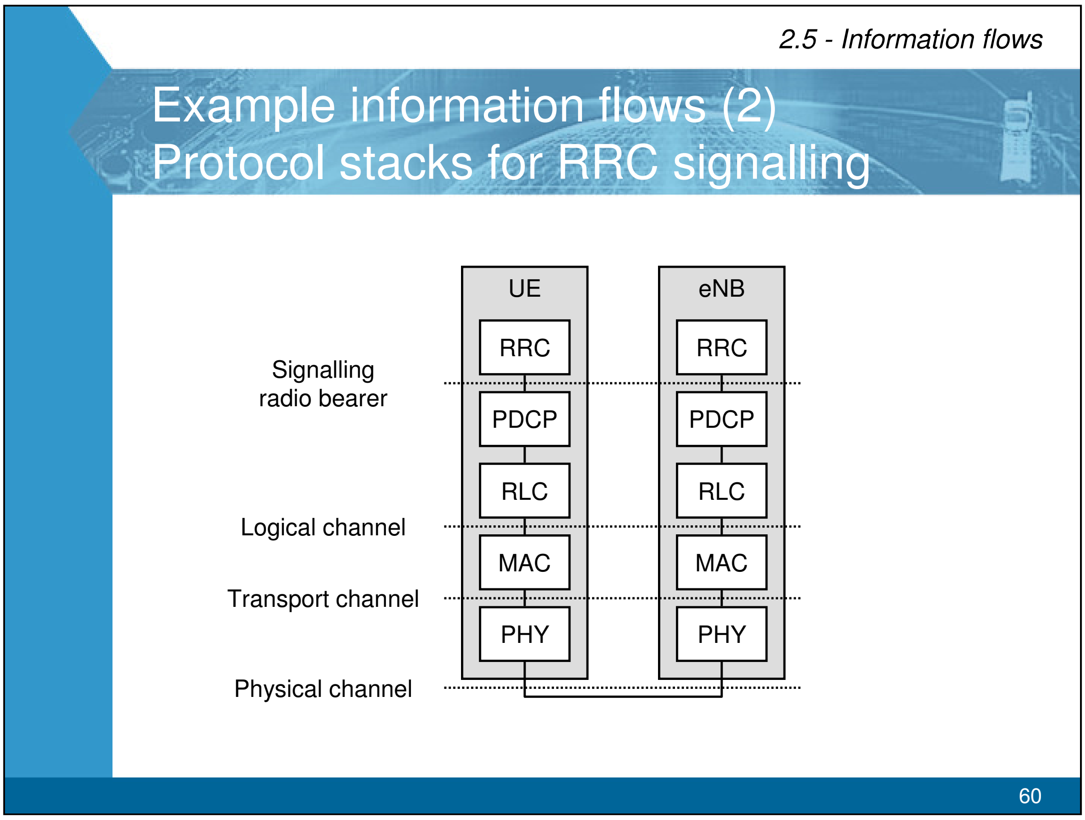
Example information flows (1) - RRC message sequence TS 36.331 § 5.6.3, 6.2.2

To close this section, we will look at some example information flows between the UE and the network.

This slide shows the message sequence chart for a simple RRC procedure, the *UE capability transfer*. If the eNB wishes to find out a UE's radio access capabilities, then it sends the UE an RRC message called *UECapabilityEnquiry*. The message is transmitted on signalling radio bearer 1 (SRB 1), using the DCCH, DL-SCH and PDSCH.

The UE responds using an RRC message called *UECapabilityInformation*, in which it lists the radio access capabilities that we noted earlier. The message is transmitted on SRB 1, using the DCCH, UL-SCH and PUSCH.

(A few RRC messages are transmitted on SRB 0. These use the CCCH logical channel, but the transport and physical channels are unchanged.)



Example information flows (2) - Protocol stacks for RRC signalling

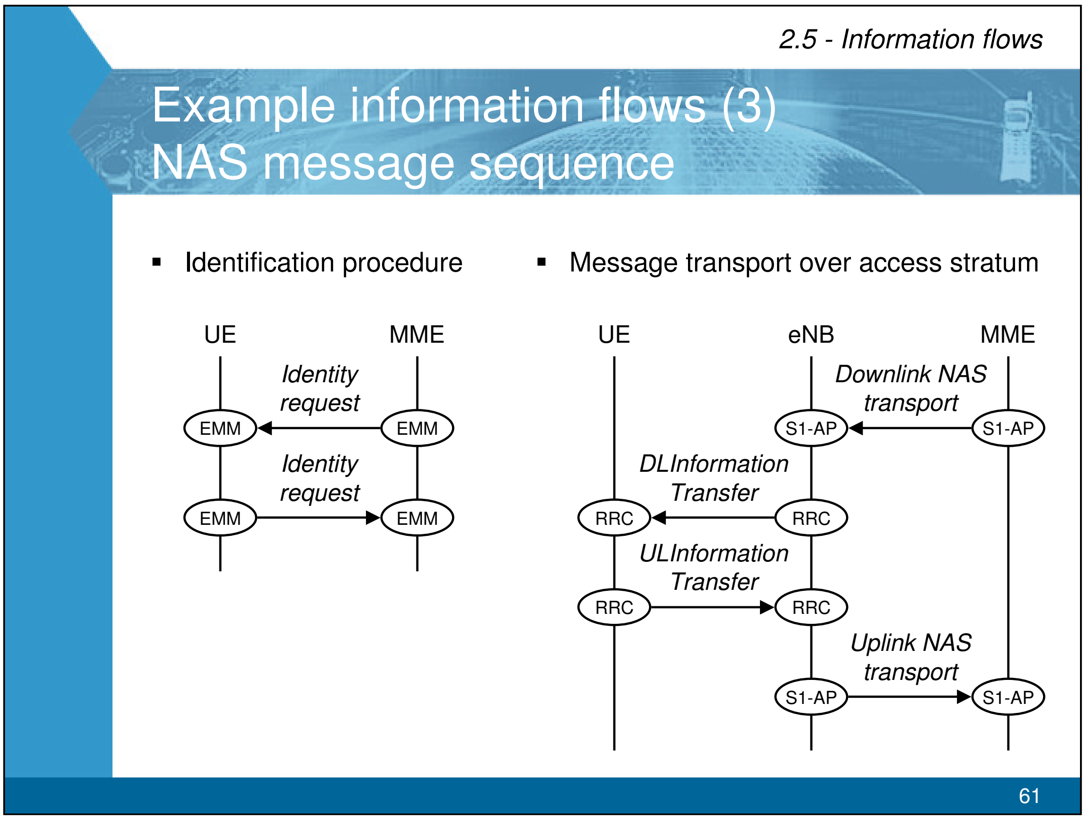
TS 36.300 § 4.3.2

This slide shows the protocol stacks that are used to transmit the messages from the previous slide.

In the eNB, the message is composed in the RRC protocol, and then passes through the following:

- The PDCP carries out encryption and integrity protection, and buffers the message in case of a handover.
- The RLC protocol buffers the message again, in case it needs to be re-transmitted from layer 2.
- The MAC protocol prioritises the message and schedules it for transmission.
- The physical layer transmits the message to the UE.

The UE receives the message, and reverses the process for its reply.



Example information flows (3) - NAS message sequence TS 24.301 § 5.4.4

TS 36.331 § 5.6.1, 5.6.2

TS 36.413 § 8.6

The exchange of non-access stratum messages, between the UE and the EPC, is more complicated.

The message sequence chart on the left shows a simple NAS procedure, the *Identification procedure*. If the MME wishes to confirm a mobile's identity, then it sends the mobile an EMM message called *Identity request*. The mobile replies with an EMM message called *Identity response*, which contains the requested identity.

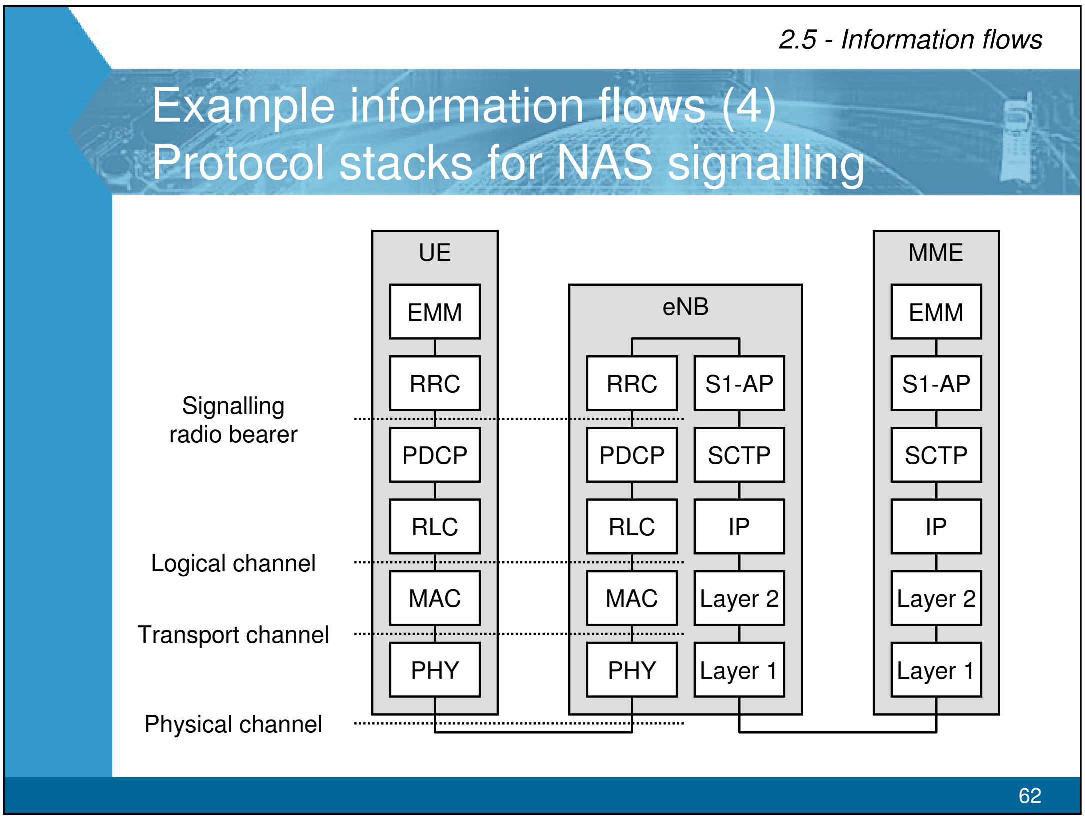
The chart on the right shows the implementation of this procedure in the access stratum:

- On the S1-MME interface, the NAS messages are transmitted by embedding them in messages written using the S1 application protocol: *Downlink NAS transport* in the downlink, and *Uplink NAS transport* in the uplink.
- On the air interface, the NAS messages are transmitted by embedding them in messages written using the RRC protocol: *DLInformationTransfer* in the downlink, and *ULInformationTransfer* in the uplink. These messages are usually transmitted using SRB 2.

(These access stratum messages are the equivalent of direct transfers in UTRAN.)

Two cases are slightly different, and will be considered later:

- If the UE wishes to establish a signalling connection with the EPC, then its NAS message is transported by an S1-AP message called *Initial UE message*.
- In some cases (including the establishment of an EPC signalling connection), NAS messages can be transported on the air interface by piggybacking them onto other RRC messages. This reduces the signalling delays.



Example information flows (4) - Protocol stacks for NAS signalling

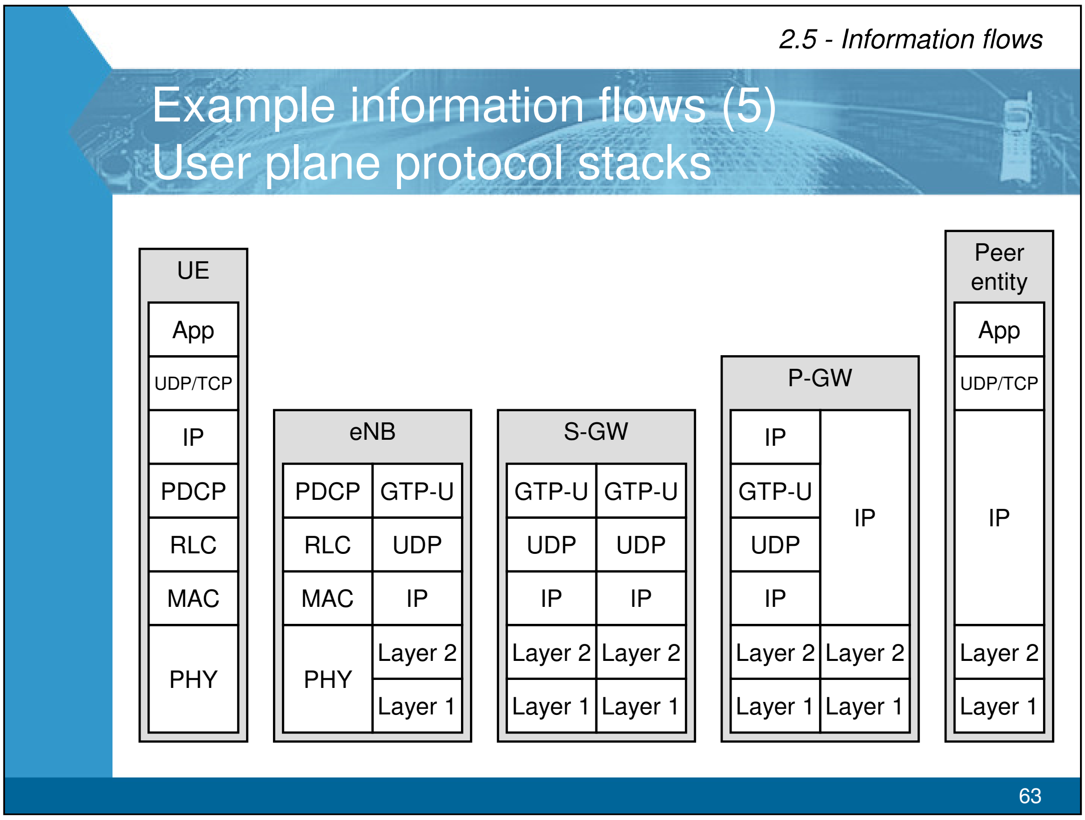
TS 36.300 § 4.3.2

TS 36.410 § 6

This slide shows the protocol stacks that are used to transport the NAS messages shown earlier.

On the air interface, the messages are transported by embedding them into RRC information transfers, in the same way as for the RRC messages considered earlier.

On the S1 interface, the messages are transported by embedding them into S1 NAS transport messages. The protocol stack is the same one used for other S1 signalling messages.



Example information flows (5) - User plane protocol stacks TS 23.401 § 5.1.2

This slide shows the protocol stacks that are used to exchange data between the UE and a server in the outside world.

The protocol stacks are less complex than they probably look. On the air interface, data are transported using the PDCP, RLC, MAC and physical layer. On both the S1 and S5 interfaces, they are transported using the GPRS tunnelling protocol user part, UDP and IP.

2.5 - Information flows

Summary

- Bearers
  - Default EPS bearer provides always-on connectivity
  - Dedicated EPS bearer can provide a guaranteed bit rate
- Three signalling radio bearers
  - SRB 0 sets up RRC signalling
  - SRB 1 carries RRC messages and sets up NAS signalling
  - SRB 2 carries NAS messages
- Channels
  - Logical, transport & physical channels as before
  - Control information and physical signals are new

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