1xEV-DO Revision A + B
White Paper

1xEvolution – Data Optimized (1xEV-DO) is a 3GPP2 “cdma2000® High Rate Packet Data Air Interface” specification.
Since its introduction (Release 0), Revisions A and B have brought improvements in the data throughput in both directions and in the overall network capacity.

This white paper presents the Revision A and B concepts for 1xEV-DO and explains key features.

ROHDE&SCHWARZ

White Paper

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1 Introduction

With the implementation of 1xEV-DO Release 0, 3GPP2 has developed the first mobile radio technology that is based completely on data traffic (packet-switched data, full IP). Channel widths (1.25 MHz), spectral characteristics and basic concepts were taken from CDMA2000 1X . The protocol is completely new and the forward link uses time-division multiplexing (TDM).

Release 0 permits data rates of up to 2.4 Mbps in the forward link. In the reverse link data rates of 153 kbps were possible. Release 0 was optimized for asymmetrical data transfers that are tolerant of delays, such as web browsing or data downloads. Delay-sensitive applications such as VoIP were not covered by Release 0.

Revision A

1xEV-DO Revision A was developed to enhance the forward and reverse data rates. A large number of changes were made in this transition.

Early termination procedures were added to both the forward and reverse links, so that the receiving side could acknowledge that a packet had been completely received prior to the end of the transmission of the packet. This allowed the link to benefit from rapidly changing channel conditions.

Other changes were made to improve the amount of time that it took to re-establish a data connection.

More users were supported. Additional packet encoding formats, both smaller and larger were added. The data rates on both the forward and reverse links improved as did the end to end latency.

1xEV-DO Revision A supports a maximum theoretical data rate of 3.1 Mbps in the forward link and 1.8 Mbps in the reverse link.

The architecture of Revision A permits new services, including video telephony, voice over IP (VoIP) and Push to Talk over Cellular (PoC).

With Revision A different physical layer subtypes are defined. They are called Subtype 0,1 and 2 (see section 2.2 for a detailed description).

Revision B

In Revision B, data rates were further increased with the introduction of a higher mode of modulation in the forward link, as well as by aggregating multiple carriers (multicarrier mode).

1xEV-DO Revision B supports multi-carrier operation where a number (up to 15) of 1.25 MHz carriers may be used to create proportionally faster transmission speeds. In the real world, most implementations of 1xEV-DO Rev B, use 2 or 3 carriers. Additional packet encoding formats were defined to increase the maximum, per carrier, data rates to 4.9 Mbps on the forward link.

With the addition of the new forward data rates and the multi-carrier operation, very high speed data rates could be supported. Essentially, the forward link data rate could be 'n' x 4.9 Mbps, with 'n' as the number of carriers. In the reverse link 'n' x 1.84 Mbps are possible.

With Revision B a new physical layer subtype 3 is defined (see section 3.2 for a detailed description).

This white paper provides an overview of the essential characteristics of the technology behind 1xEV-DO Revisions A and B. 1xEV-DO Release 0 is described in more detail where needed to better explain the optimizations or further developments in Revisions A and B. This white paper assumes a basic understanding of 1xEV-DO Release 0.

2 Revision A

2.1 Overview of key features in Rev A

Release 0 was designed for asymmetrical usage; for example, web surfing, file downloads and so on – tasks that primarily involve transferring data from the base station to the end user (forward link) and that therefore are not overly impacted by delays.

The main intent of Rev A was to reduce the latency for applications such as voice (VoIP), PTT or gaming. The focus was also on increasing the data rate (e.g. for applications like video telephony or video data transmission) both in the forward and the reverse link.

Revision A is fully backward compatible with Release 0. To ensure this, the physical layer of Release 0 was implemented in Revision A as subtype 0. The communication in the system always starts with the physical layer of Release 0 (or subtype 0).

Based on the requirements described above, improvements and adaptations were made in the physical layer that were then combined into subtype 2. A detailed description of the physical layer follows in 2.2.

Improvements in the forward link

Early termination

When implementing packet-switched transmission the possibility of early termination by the base station during the transmission of data packets from the access terminal is desirable. This would take place as soon as the data packet has been received completely and without errors. Before the data was transmitted, the MAC layer of the AT determined the class of transmission rate. The AN then choose, within this class, the data rate and repetition rate for the data packet to be transmitted, while taking the RF conditions between the AN and the AT into consideration. However, it is possible for the conditions to improve during the data transmission, which would make the originally selected higher repetition rate unnecessary. Allowing the receiver to terminate unneeded packet repetitions allows the next packet to be sent sooner.

This is why an automatic retransmission request (ARQ) was implemented in the forward link, with the option of early termination.

Data rates / packet sizes

Additional packet sizes were defined along with additional data rates. For delay-sensitive services such as voice transmission (VoIP), small packet sizes were introduced that reduce the latency. This does not increase the data rate. On the other hand, the introduction of large packet sizes allow higher data rates (up to 3.072 Mbps).

Multi-user packets

Multi-user packets were defined for the forward link. Multi-user packets can carry data for multiple ATs. The AT is able to distinguish between a single-user packet and a multi-user packet via the protocol.

Improvements in the reverse link

Subpackets

Subpackets and subframes were newly defined in order to support hybrid-ARQ mode on the reverse link.

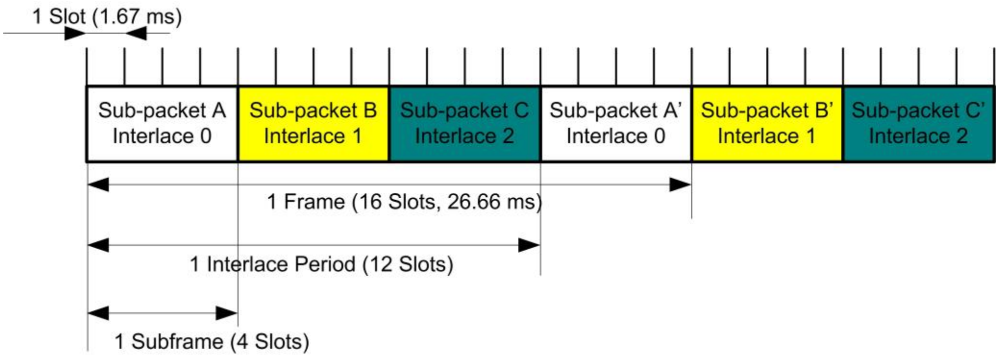


Fig. 1: Subpackets in reverse link subtype 2. A total of 26.66 ms is required to transmit a frame.

In subtype 2, the reverse traffic channel uses an interleaved transmission. The AT sends these data packets split into up to four subpackets, which in turn are always transmitted in four contiguous slots in interlaced mode.

The subpackets are separated by two subframes that transmit data from other packets. This interlaced operation uses time-delayed transmission of contiguous data packets to create time for responses from the base station.

Data rates / modulation

New packet sizes were defined that provide effective data rates from 4.8 kbps to 1843.2 kbps. Higher modulation modes are also used (QPSK and 8-PSK).

Soft handoff

Release 0 provided a soft handoff between cells. Although switching between cells interrupted the data transfer, it did not significantly affect applications such as web surfing or downloads. In Release 0 the Soft handoff is controlled via the DRC channel (see 2.2.1.2).

To support delay-sensitive applications, a new channel was introduced (DSC; see 2.2.3.2), which transmits the same information as the DRC, but is updated more often.

Protocol changes

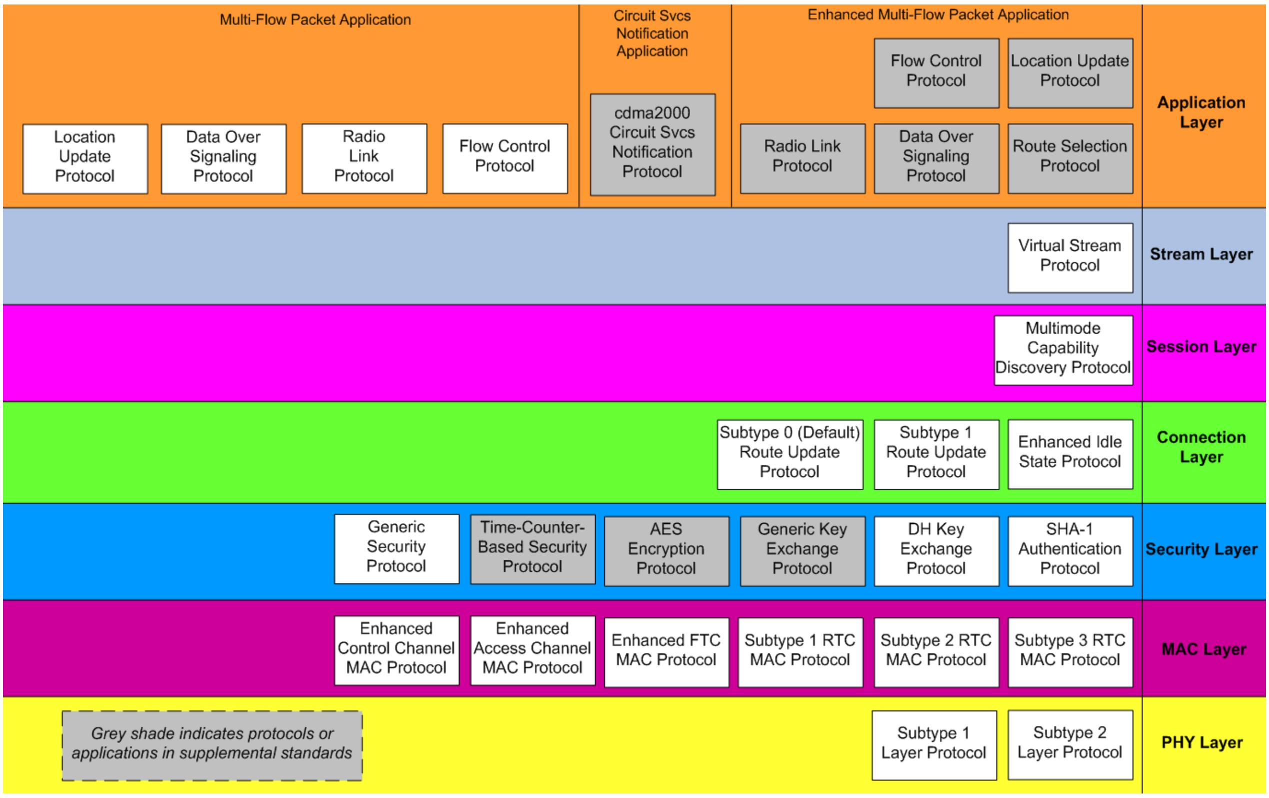


Fig. 2: Overview of the protocol stack in Revision A.

Rev A introduced the multiflow packet application in the application layer. This was an important step to ensure that different applications (VoIP, gaming, etc.) can be active at the same time.

Special applications were additionally defined in [2] to support testing of the physical layer. This ensures well defined parameter sets for repeatable testing. The forward test applications allow testing of the AT's receiver. The reverse test applications are for AT's transmitter testing. For Revision A, these are

- Forward test application (FTAP): (Defined in Release 0)
  - Supports Subtype 0/1: DRCIndices 0 to 12: 0 bps to 2457.6 kbps (see Fig. 6)
- Reverse test application (RTAP): (Defined in Release 0)
  - Supports Subtype 0/1: Data rate indices 0 to 5: 0 bps to 153.6 kbps
- Forward enhanced test application (FETAP): (Defined in Rev A)
  - Supports Subtype 2: Packet type 1 to 37: 4.8 kbps to 3072.0 kbps (see Fig. 14 to Fig. 17)
- Reverse enhanced test application (RETAP): (Defined in Rev A)
  - Supports Subtype 2: Data rate indices 0 to 12: 0 bps to 1843.2 kbps

Hybrid mode / Cooperation with CDMA2000

To support voice and data services, an AT with hybrid mode can operate in both 1xEV-DO and CDMA2000 networks and monitor the control channels of each network. For this it has to switch between both networks (if only one RF chain is assumed). Once an active connection is needed, the AT must switch to that network. Unless the AT is able to periodically tune away from the active network, there was no way to be active on both networks at the same time.

With Revision A a new protocol was defined, that allows CDMA messages to be sent through 1xEV-DO to enable calls, SMS and other network operations.

2.2 Physical layer in Rev A

Rev A specifies three different physical layer subtypes:

- Subtype 0: Corresponds to the physical layer from Rel 0 and ensures full backward compatibility
- Subtype 1: Incorporates small changes in the reverse link and *no* changes in the forward link
- Subtype 2: Incorporates changes in both the forward and the reverse link, and is therefore the most important subtype in Rev A

2.2.1 Subtype 0

Physical layer subtype 0 corresponds to the physical layer in Release 0. As a result, Revision A is fully backward compatible with Release 0.

2.2.1.1 Forward link

Fig. 3 provides an overview of the channels in the forward link.

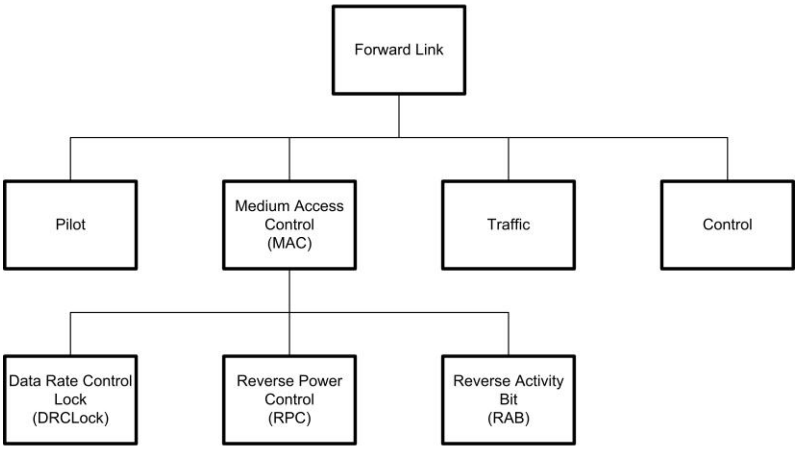


Fig. 3: Forward link channel structure (subtype 0).

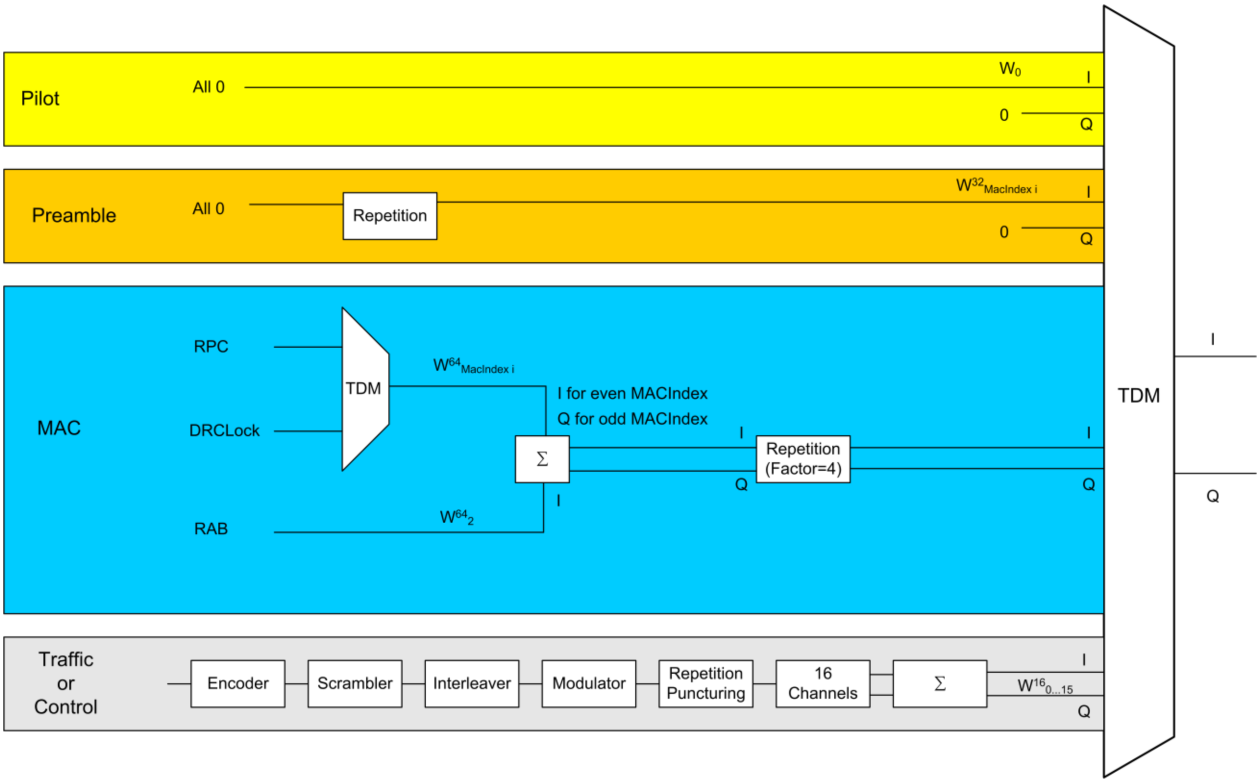


Fig. 4: Overview of the channel structure in the forward link (subtype 0). All channels are time multiplexed and provided with different Walsh covers. The MAC channel uses CDM using the MACindex to select active AT's.

All channels in the forward link are transmitted by the use of time-division multiplexing (TDM).Code-division multiplexing (CDM) is only used in the MAC. A frame is 26.67 ms long and consists of 16 slots. A slot is therefore 1.67 ms long and is further split into two half slots, each with a duration of 833.3 µs.

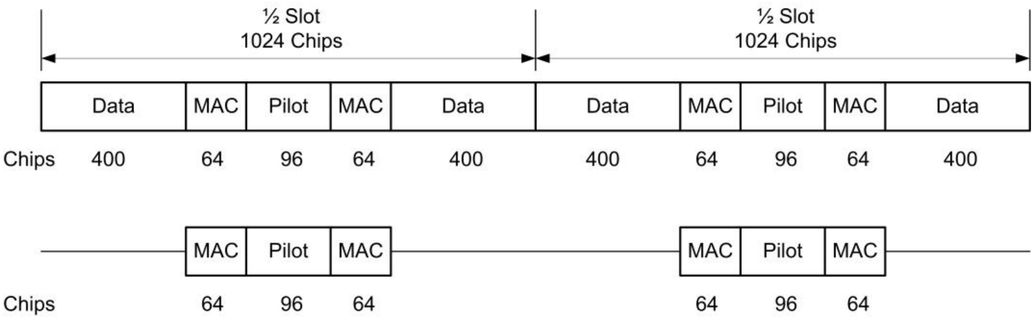


Fig. 5: Slot structure in the forward link. In principle, every half slot always transmits the MAC and the pilot (idle slot). If data is also to be transmitted (active slot), then two data packets are transmitted in every half slot.

Pilot channel

The access network continually broadcasts the pilot channel in every half slot at full power. This provides a reference signal for coherent demodulation of the data and

MAC channels. It is also used to synchronize all access terminals in the sector. The access terminals detect the available pilot signals from various sectors and select the strongest. The pilot signal is not modulated (All 0) and is transmitted only using the I component.

MAC channels

The MAC channels consist of three subchannels that are divided by means of code-division multiplexing (CDM). For this purpose, they each use one of 64 Walsh codes (0 to 63). Even Walsh codes (known as MACIndices) are sent on the I component and odd Walsh codes on the Q component. Only 1 bit is transmitted using BPSK modulation.

MAC subchannel: Reverse activity (RA)

The access network uses the RA bit (RAB) to inform access terminals that it should decrease its data rate in the reverse link. This is done to reduce the load of the base station in times of heavy reverse link activity. The RAB channel uses MACIndex (Walsh code) 4 and is transmitted on the I component. The update rate is adjustable between 8 and 64 slots. All AT's with an active connection must monitor this bit. When the bit becomes active the AT will pseudo-randomly decide if they should lower their reverse link data rate. When the bit is inactive, the AT's will run at their ideal data rate.

MAC subchannel: Reverse power control (RPC)

When a traffic channel is active, the closed loop power control system is used in conjunction with the open loop power control that all AT's, active or not, use.

For closed loop power control, the RPC channel is used to send power control bits to each AT that has an active connection, i.e. that they have a MACIndex assigned. The AN uses the RPC channel to control the amount of power within the ATs reverse pilot channel. The power level of the other channels on the reverse link of the AT are controlled via signaling parameters relative to the pilot channel.

Individual active ATs are addressed via their MACIndex (5 to 63). One bit is transmitted per slot, which results in an update rate of 600 Hz. The AT increases its transmit power whenever the RPC bit has a value of 0 (up). Similarly, the AT reduces its transmit power whenever the RPC bit has a value of 1 (down). The RPC subchannel alternates with the DRCLock subchannel using TDM. Mapping is to either I or Q, depending on the MACIndex.

Data rate control (DRC)Lock subchannel

The DRCLock informs the AT that the AN cannot receive the DRC channel correctly from the AT. A value of DRCLock = 0 indicates to the AT that none of the data specified by the DRC is being received by the AN. This provides the AT with information about the reliability of the reverse link to the AN, allowing it to find the best connection possible.

Traffic channel

The traffic channel transports data packets to the access terminal. In Release 0 (or subtype 0), only one user in the sector can receive data at any given time via the single-user protocol (SUP).

A data packet consists of 1024 to 4096 bits and can use 1 to 16 slots. The packet starts with a preamble. The preamble assigns the data to a specific AT via the MACIndex (5 to 63). The length of the preamble is dependent on the data rate and it is transmitted only on the I component.

The data rate varies between 38.4 kbps and 2457.6 kbps. Packets are encoded with multiple levels of processing:

- Turbo coding
- Interleaving / bit repetition / puncturing
- Walsh covering: 16 subchannels
- QPSK / 8-PSK / 16 QAM modulation

Fig. 6 provides an overview of the packets, data rates, coding, modulation and slots used.

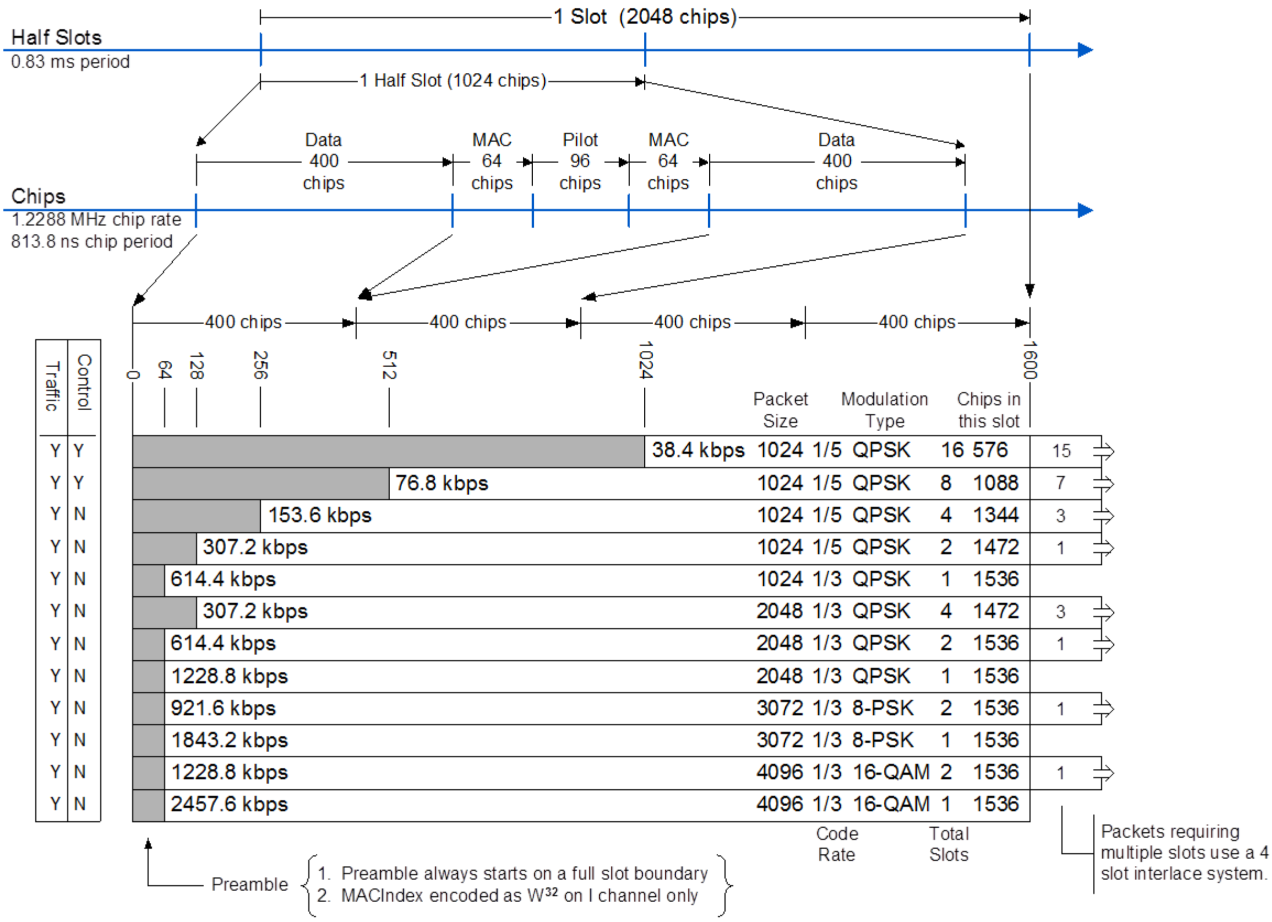


Fig. 6: Overview of data packets in the forward link in subtype 0.

Control channel

The control channel is used to deliver broadcast messages or dedicated messages to access terminals. Walsh indices in the preamble are used to differentiate between control or traffic channels. The packets are 1024 bits in size and are transmitted with QPSK modulation on 8 or 16 slots (see the first two rows in Fig. 6). MACIndex 2 (38.4 kbps) or 3 (76.8 kbps) is used.

2.2.1.2 Reverse link

The reverse link has a similar structure as the forward link. The frame is 26.67 ms long and consists of 16 slots, 1.67 ms each. The reverse link supports two types of channels. Multiple channels of each type can be supported:

- Access channel
- Traffic channel

Fig. 7 provides an overview of the channels for subtype 0 (or Release 0). All channels in the reverse link are BPSK-modulated.

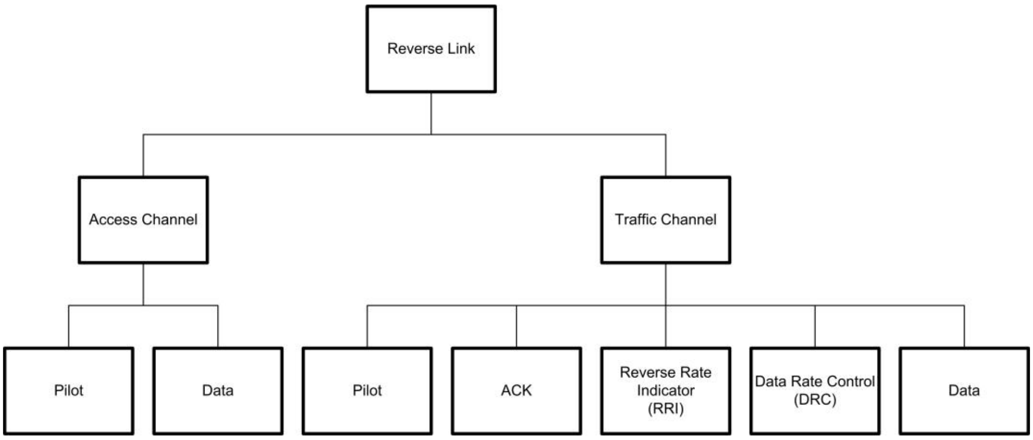


Fig. 7: Reverse link channel structure (subtype 0 or Release 0).

Access channel

The AT will use an access channel when it does not have an traffic channel assigned. Typically it is used when:

- the AT wants to register with the network
- the AT wants to start a session
- smaller amount of data has to be sent without setting up a traffic channel

The access channel will transmit a series of pilot only slots, known as the preamble. It stays at a constant power level. Following the preamble, data and pilot are transmitted together at the same nominal power level as the preamble only section. Thus, the power level of the pilot is reduced by 3 dB while data is being transmitted. This can be seen in Fig. 8.

In subtype 0 (and Release 0), the data is always 9.6 kbps using a 256 bit packet. The number of preamble slots is set by values in the control channel messaging. A minimum of 16 slots are used to transmit the data. The pilot sends All 0 on the I component with Walsh cover W^{16}_{0}. The data channel uses the Q component with W^{4}_{2}

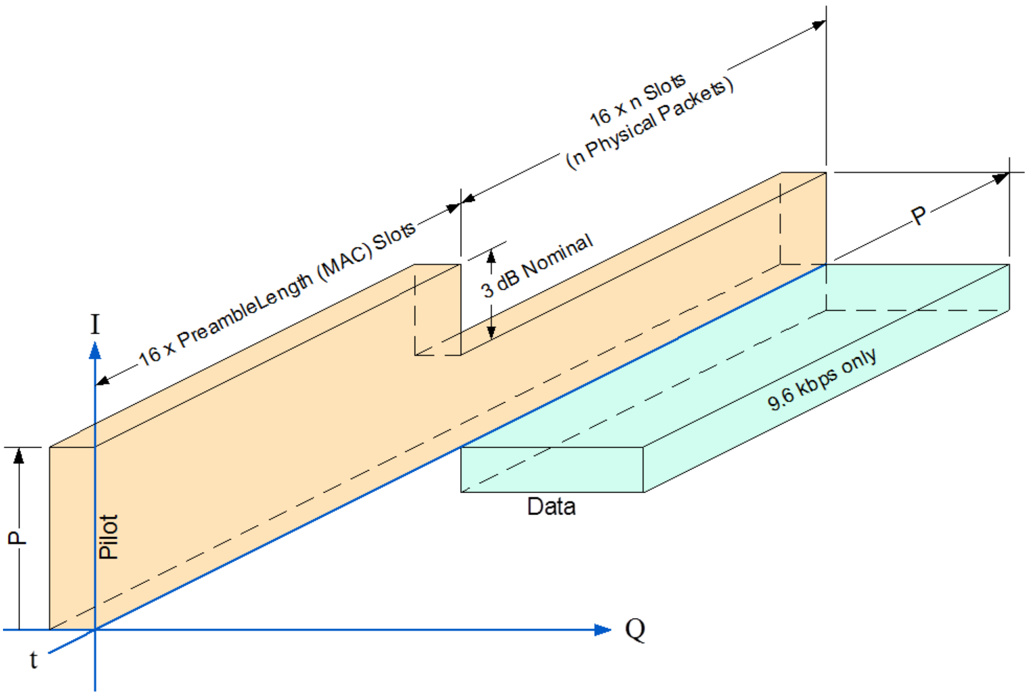


Fig. 8: Reverse link access channel (subtype 0).

Traffic channel

The reverse traffic channel is made up of five subchannels (pilot, data, RRI, DRC, ACK).

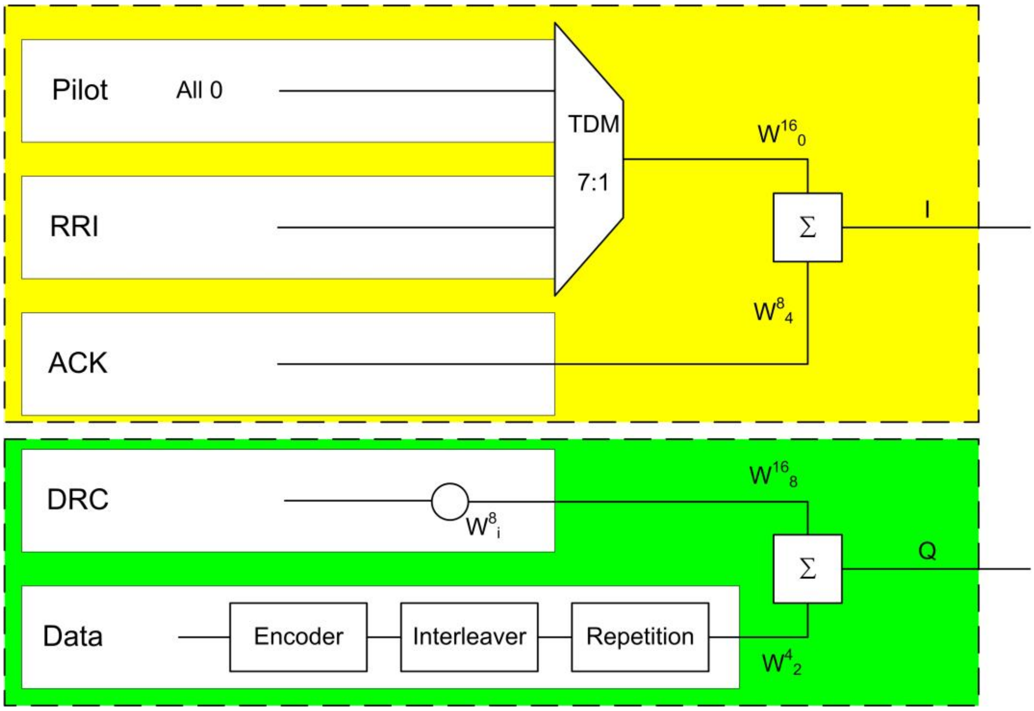


Fig. 9: Overview of the channel structure (traffic channel) in the reverse link (subtype 0). RRI replaces the pilot in 1/8th of a slot. A complex multiplication (quadrature spreading) of I and Q is then performed with a separate short PN sequence and a user long code (not shown here).

The data channel is present when there is user data to be transmitted. The ACK is present only for the first half slot if data is being received on the forward link. A packet is always 16 slots in length. For the pilot, the power is controlled directly as a closed loop via the forward link subchannel RPC (see above). Messaging is used to specify the level of the other subchannels in the reverse link relatively to the pilot as well as specifying the magnitude of the power control steps. Individual ATs are identified by means of code division using long code masks.

Pilot

The pilot channel provides a training signal to aid the receiver in the AN in demodulating the AT reverse link. The pilot signal is a series of All 0 bits covered by W^{16}_0 and placed on the I component.

Reverse rate indicator (RRI)

The RRI channel reports the reverse link data rate to the AN. It is coded with 3 bits and sent in every slot of a packet. Available rates are:

- No data
- 9.6 kbps
- 19.2 kbps
- 38.4 kbps
- 76.8 kbps
- 153.6 kbps

The RRI channel replaces the pilot in the first 1/8th of each slot. It is covered with W^{16}_{0} and is placed on the I component, just like the pilot.

Data rate control (DRC)

The DRC channel is used to communicate two pieces of information to the AN:

- It specifies which data rate is to be used on the forward link under the current channel conditions. This information is coded in 4 bits.
- It selects which AN (sector) should serve data to the AT. This information is coded using one of eight possible Walsh covers over the 4 bits for the data rate (see above). This allows the AT to assist in the selection of serving AN's when the channel conditions are changing.

The DRC is transmitted over an entire slot, but it is offset by half a slot. It uses W^{16}_{8} on the Q component.

ACK

The ACK channel uses ACK/NACK to inform the AN about the successful receipt of packets in the forward link. This requires a single bit that is sent in the first half of the slot. ACK is sent only if data is present in the forward link. It uses W^{8}_{4} on the I component.

Data

Data is transmitted in packet lengths of 256 to 4096 bytes at data rates of 9.6 kbps to 153.6 kbps. One packet is always 16 slots. It uses W^4_2 on the Q component.

The I/Q diagram in Fig. 10 shows the traffic channel over time.

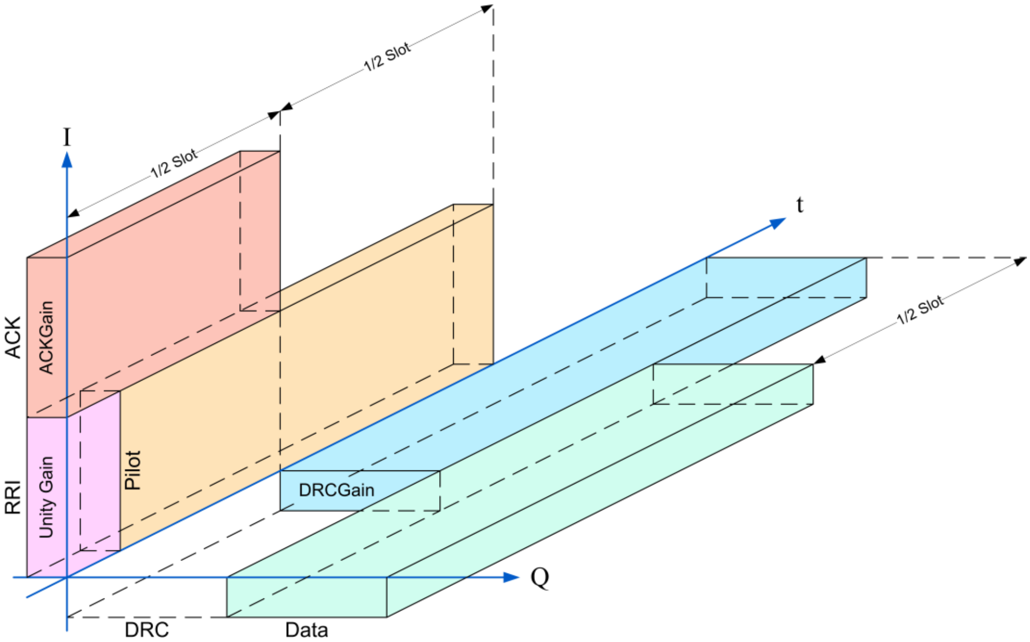


Fig. 10: Reverse link traffic channel (subtype 0).

2.2.2 Subtype 1

The forward link is identical to subtype 0.

Reverse link

Changes in the reverse link affect only the **access** channel. It provides the following two data rates in addition to the previous data rate of 9.6 kbps:

- 19.2 kbps (packet length 512 bits)
- 38.4 kbps (packet length 1 024 bits)

The higher data rates are achieved by decreasing the interleaved symbol repetition interval. When using the access channel with these higher data rates, the power of the combined pilot and data section can be higher than the power of the pilot only section (see also 2.2.1.2: Access channel).

In addition, the duration of the preamble can be shortened to maximize the capacity of the access channel.

2.2.3 Subtype 2

The majority of improvements in the physical layer for Revision A are contained in subtype 2. To support these improvements, the existing channel structure from Release 0 (subtype 0) has been modified and expanded.

2.2.3.1 Forward link

Fig. 11 provides an overview of the channel structure in the forward link for subtype 2. The ARQ subchannel has been added to the MAC channel. The traffic and control channels were modified from subtype 0.

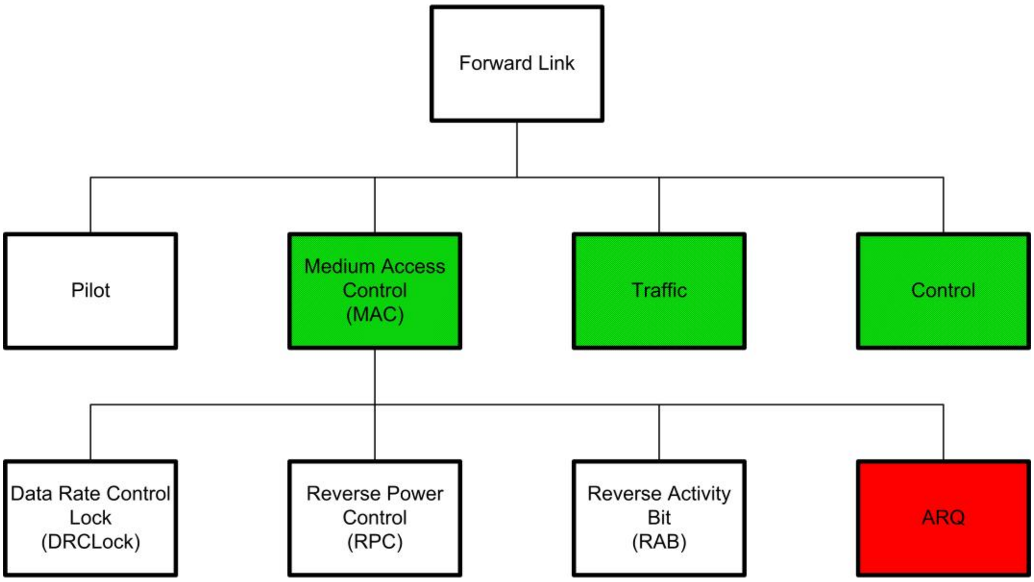


Fig. 11: Forward link channel structure (subtype 2). The new ARQ channel is highlighted in red. Green channels have undergone significant changes.

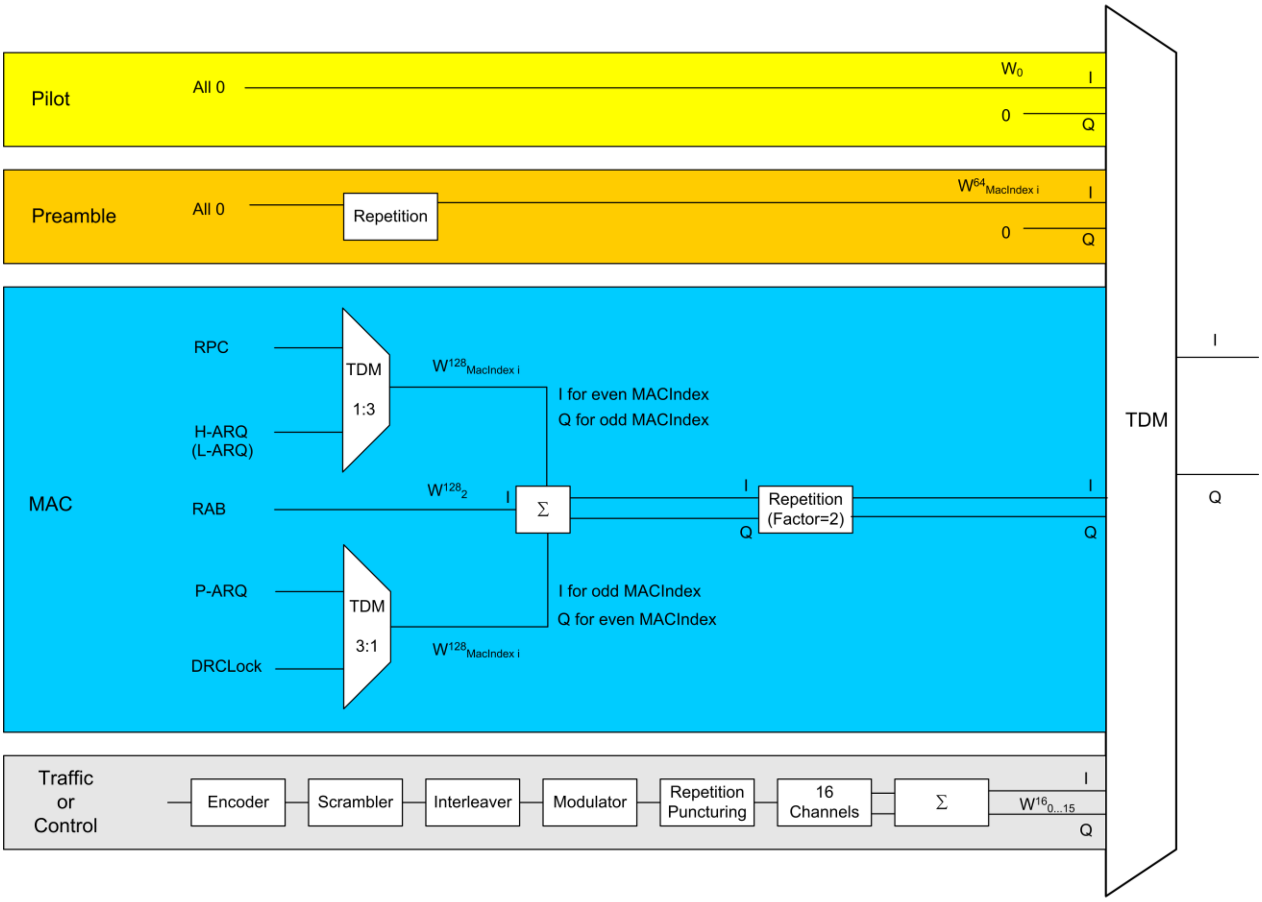


Fig. 12: Overview of the channel structure in the forward link (subtype 2). All channels are time multiplexed and provided with different Walsh covers. The MAC channel uses CDM using the MACindex to select active AT's.

MAC channels

General changes

128 MACIndices are now available (Release 0: 64). 128 Walsh cover codes are used for the MACIndex.

The time domain multiplexing was modified (see also Fig. 12):

- RPC and H-ARQ/L-ARQ is transmitted on one component (I or Q, based on the MACIndex).
- RPC is transmitted in the first of 4 slots and ARQ in the other three slots. The effectively reduces the RPC data rate to 150 kbps.
- DRCLock and P-ARQ is transmitted on one component (Q or I, based on the MACIndex, opposite to RPC / H-/L-ARQ).
- RAB is transmitted on the I component and the update rate is 1 bit per slot.

MACIndex 66 to 70 are reserved for multi-user packets.

ARQ channel

This new channel supports reverse hybrid-ARQ mode. It transmits a positive ACKnowledgment or a Negative ACKnowledgment (NACK) for the data packets in the reverse link.

Three different messages (bits) are used to implement hybrid ARQ:

- Hybrid-ARQ bit (H-ARQ)
  - Transmitted after each of the first three reverse subpackets (see 2.1) are received
  - Selectable coding:
    ON-OFF keying (OOK) (+1 -> ACK, 0 -> NAK)
    Bipolar keying (+1 -> ACK, -1 -> NAK)

- Last-ARQ (L-ARQ) bit
  - Sent after the last reverse subpacket is received
  - Uses ON-OFF keying

- Packet-ARQ (P-ARQ) bit
  - Sent 48 slots after the reverse subpackets are started
  - Uses ON-OFF keying

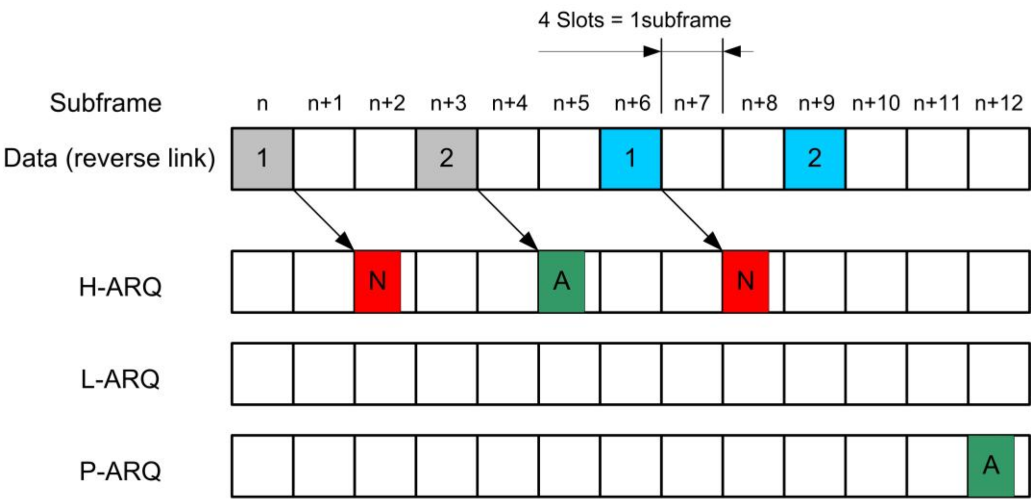


Fig. 13: Example of the HARQ mechanism: early termination (physical packet #1 in grey; packet #2 in blue).

The AT starts to transmit data in the reverse link with subpacket 1. The AN answers two subframe later on the H-ARQ channel. This happens for the first three subpackets (in the example the second subpacket is ACKed, the ARQ process can be early terminated; the AT continues with the next physical packet). As in this example only two subpackets were sent, there will be no message on the L-ARQ channel. The P-ARQ channels indicates successful reception vie ACK in subframe n+12.

Traffic channel

Significant changes were made in the traffic channel. Several new packet sizes were introduced. Shorter packet lengths permit reduced latency times, while larger packets increase the data rate. The following new packet sizes were defined:

- 128 bits
- 256 bits
- 512 bits
- 5120 bits

The CRC was expanded from 16 bits to 24 bits for all packet sizes. Both the channel interleaver and the turbo-coder were modified.

The data is allocated to a specific AT via the MACIndex (5 to 128). The length of the preamble is dependent on the data rate and it is transmitted only on the I component. 64 bi-orthogonal Walsh codes are used for the preamble. AT's supporting Release 0 only can use Walsh code up to 64. To ensure backwards compatibly walsh codes smaller than 64 are assigned to them.

Fig. 14 through Fig. 17 show the data packets.

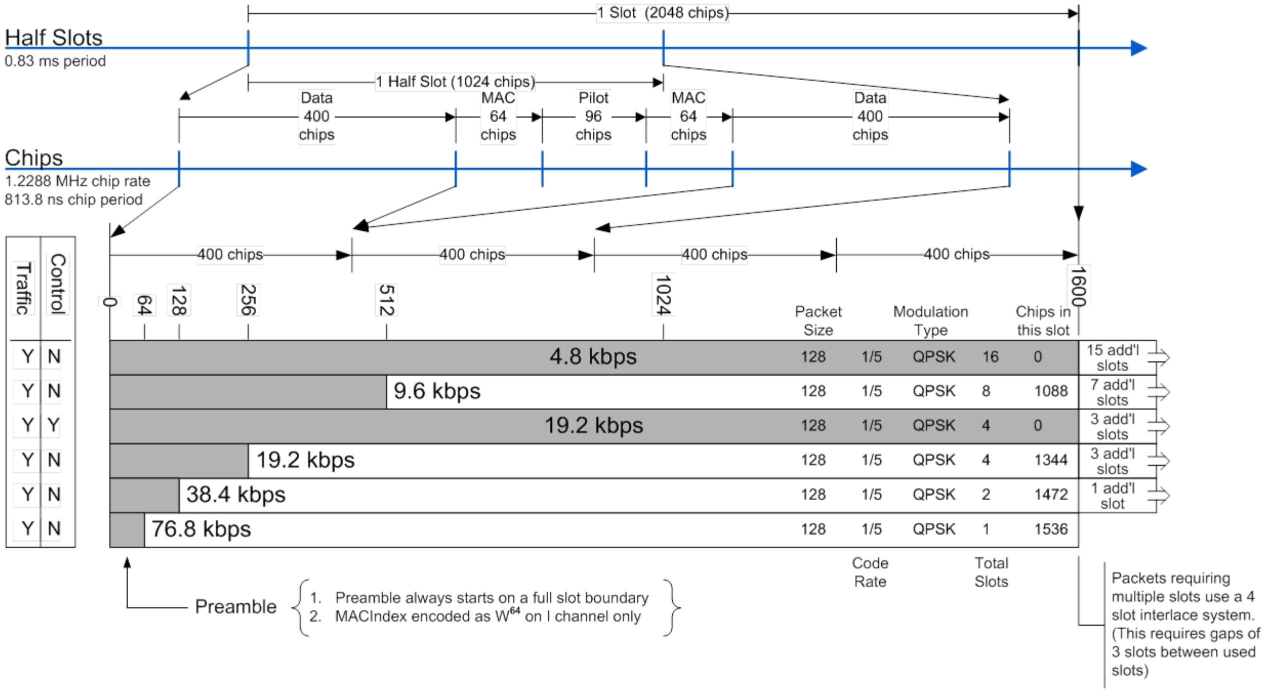


Fig. 14: Overview of data packets in the forward link using subtype 2 for packets of 128 bits (new packet size).

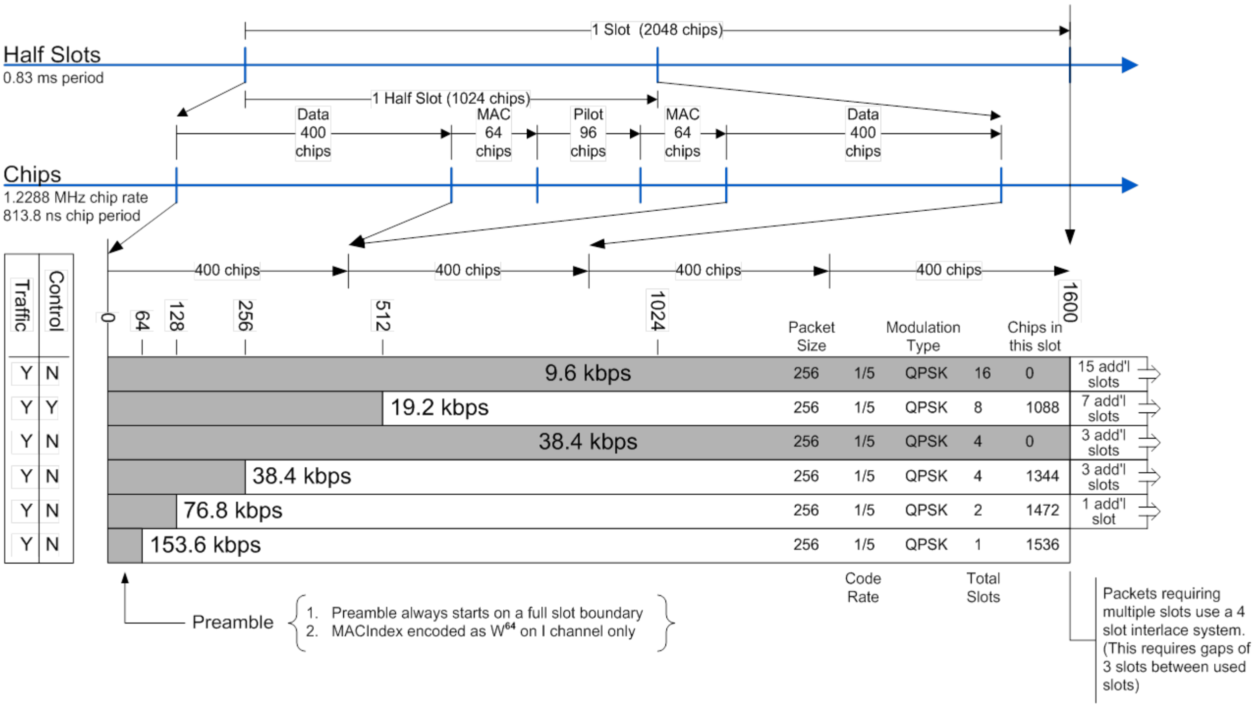


Fig. 15: Overview of data packets in the forward link using subtype 2 for packets of 256 bits (new packet size).

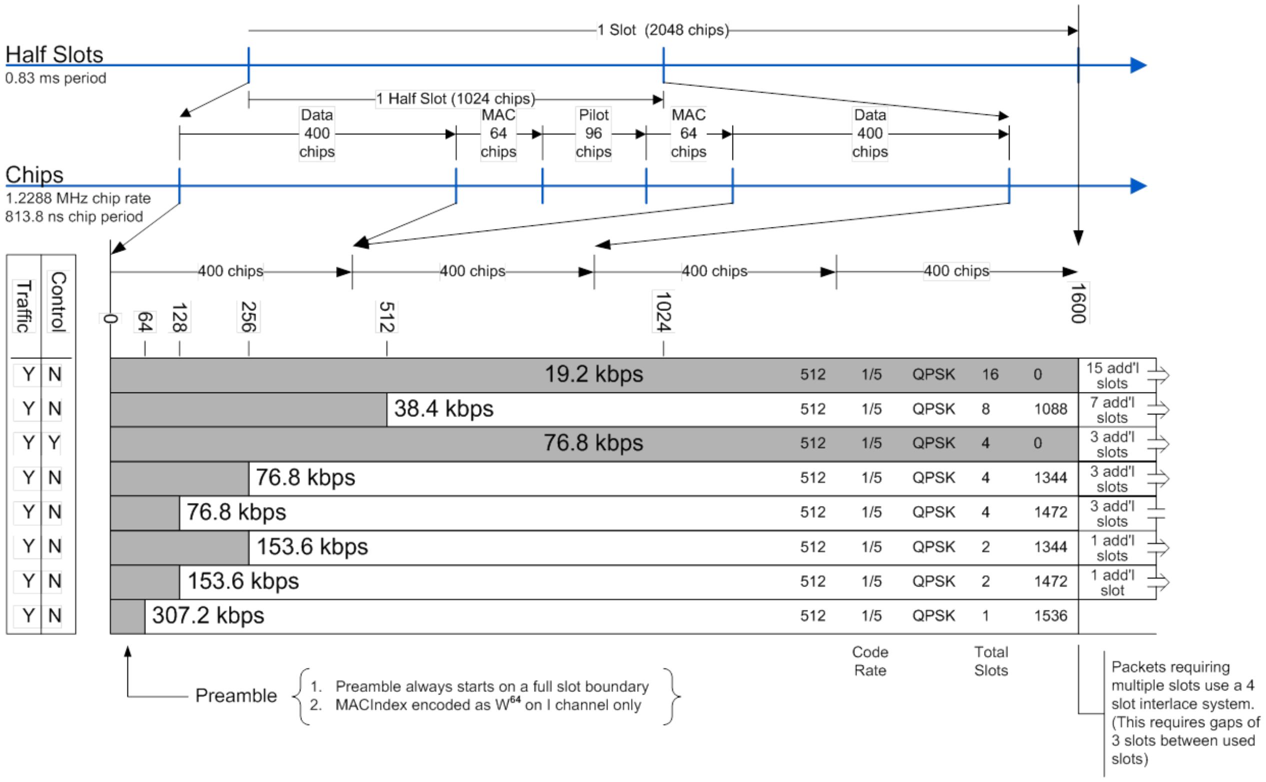
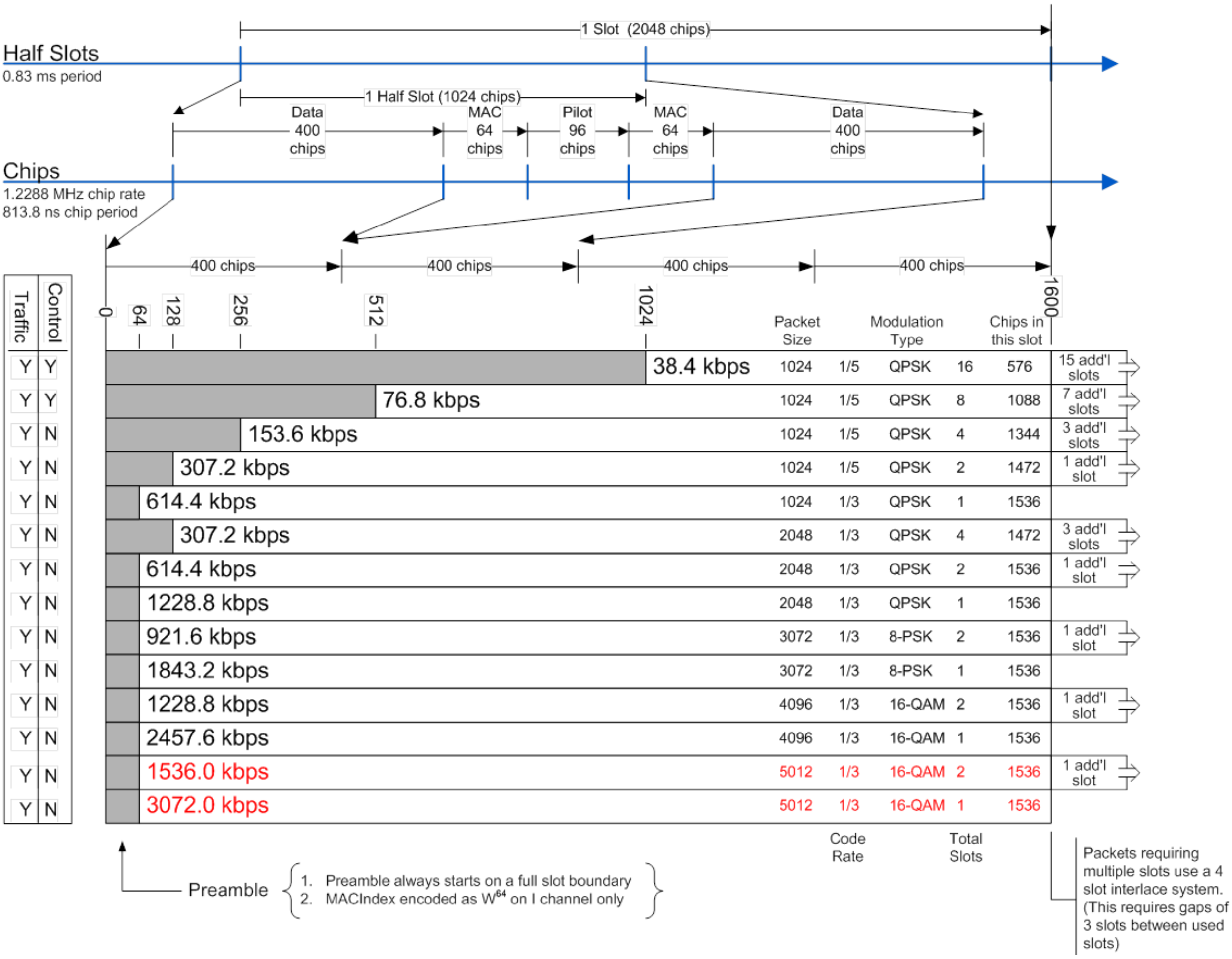


Fig. 16: Overview of data packets in the forward link using subtype 2 for packets of 512 bits (new packet size).



Traffic	Control	Rate	Packet Size	Code Rate	Modulation Type	Total Slots	Chips in this slot	
Y	Y	38.4 kbps	1024	1/5	QPSK	16	576	15 add'l slots
Y	Y	76.8 kbps	1024	1/5	QPSK	8	1088	7 add'l slots
Y	N	153.6 kbps	1024	1/5	QPSK	4	1344	3 add'l slots
Y	N	307.2 kbps	1024	1/5	QPSK	2	1472	1 add'l slot
Y	N	614.4 kbps	1024	1/3	QPSK	1	1536	
Y	N	307.2 kbps	2048	1/3	QPSK	4	1472	3 add'l slots
Y	N	614.4 kbps	2048	1/3	QPSK	2	1536	1 add'l slot
Y	N	1228.8 kbps	2048	1/3	QPSK	1	1536	
Y	N	921.6 kbps	3072	1/3	8-PSK	2	1536	1 add'l slot
Y	N	1843.2 kbps	3072	1/3	8-PSK	1	1536	
Y	N	1228.8 kbps	4096	1/3	16-QAM	2	1536	1 add'l slot
Y	N	2457.6 kbps	4096	1/3	16-QAM	1	1536	
Y	N	1536.0 kbps	5012	1/3	16-QAM	2	1536	1 add'l slot
Y	N	3072.0 kbps	5012	1/3	16-QAM	1	1536	

Fig. 17: Overview of data packets in the forward link using subtype 2 for packets of 1 024 bits or greater (new packet size marked in red).

With the (reverse) DRC channel (see also 2.2.1.2), the AT tells the AN, which data rate can be used by the AN. The DRC just uses an index to a table with predefined canonical transmit formats (rate sets). The AN then chooses the appropriate rate from this group set, see following table.

Transmission formats according to DRC, subtype 2				
DRC index	**Rate metric** (kbps)	**slots**	**TX format** (packet, slots, preamble)	**Data rate** (kbps)
0x0	0	16	128, 16, 1024 256, 16, 1024 512, 16, 1024 **1024, 16, 1024**	4.8 9.6 19.2 **38.4**
0x1	38.4	16	128, 16, 1024 256, 16, 1024 512, 16, 1024 **1024, 16, 1024**	4.8 9.6 19.2 **38.4**
0x2	76.8	16	128, 8, 512 256, 8, 512 512, 8, 512 **1024, 8, 512**	9.6 19.2 38.4 **76.8**
0x3	153.6	4	128, 4, 256 256, 4, 256 512, 4, 256 **1024, 4, 256**	19.2 38.4 76.8 **153.6**
0x4	307.2	2	128, 2, 128 256, 2, 128 512, 2, 128 **1024, 2**, 128	38.4 76.8 153.6 **307.2**
0x5	307.2	4	512, 4, 128 1024, 4, 128 **2048, 4**, 128	76.8 153.6 **307.2**
0x6	614.4	1	128, 1, 64 256, 1, 64 512, 1, 64 **1024, 1, 64**	76.8 153.6 307.2 **614.4**
0x7	614.4	2	512, 2, 64 1024, 2, 64 **2048, 2, 64**	153.6 307.2 **614.4**
0x8	921.6	2	1024, 2, 64 **3072, 2, 64**	307.2 **921.6**
0x9	1228.8	1	512, 1, 64 1024, 1, 64 **2048, 1, 64**	307.2 307.2 **1228.8**
0xa	1228.8	2	**4096, 2, 64**	**1228.8**

Transmission formats according to DRC, subtype 2				
DRC index	**Rate metric** (kbps)	**slots**	**TX format** (packet, slots, preamble)	**Data rate** (kbps)
0xb	1843.2	1	1024, 1, 64 **3072, 1, 64**	614.4 **1843.2**
0xc	2457.6	1	**4096, 1, 64**	**2457.6**
0xd	1536	2	**5120, 2, 64**	**1536**
0xe	3072	1	**5120, 1, 64**	**3072**

Fig. 18: Canonical transmission formats for subtype 2

Control channel

Like in Release 0, the control channel has the same structure as the traffic channel. As a result, the new packet sizes for the traffic channel are also supported:

- 128 bits
- 256 bits
- 512 bits

The new data rates use a MACIndex 71 preamble, to identify them as subtype 2 control packets.

2.2.3.2 Reverse link

Fig. 19 provides an overview of the new channel structure. An auxiliary pilot channel and the data resource control (DSC) channel are new. Additional changes were made in the data channel, to enhance throughput.

In subtype 2, the access channel is identical to the access channel in subtype 1.

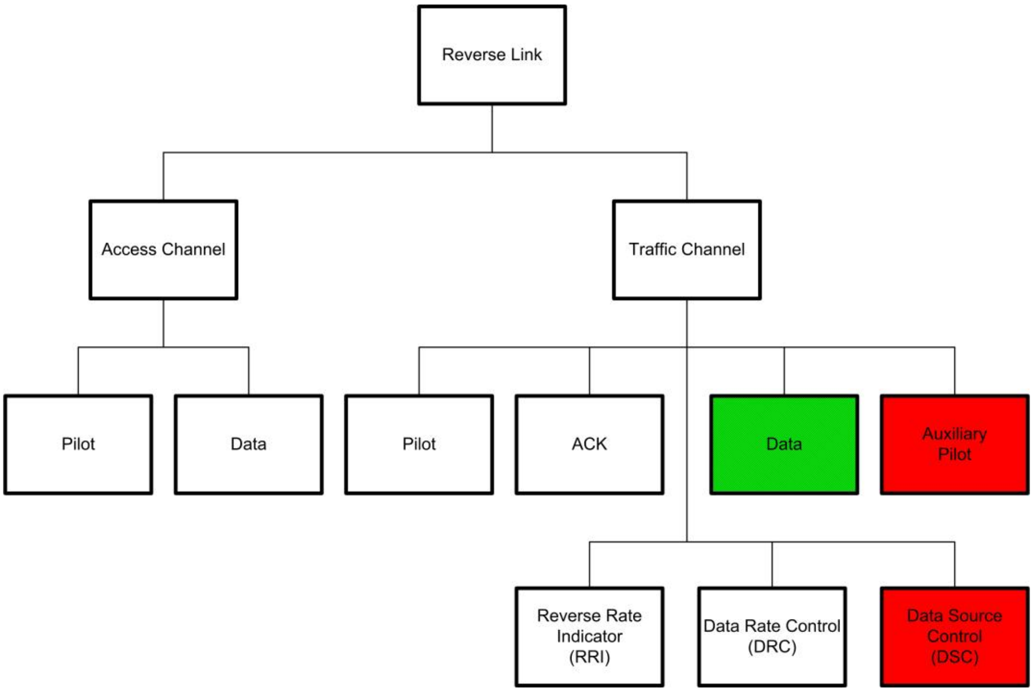


Fig. 19: Reverse link channel structure (subtype 2). The new channels are highlighted in red. Green channels have undergone significant changes.

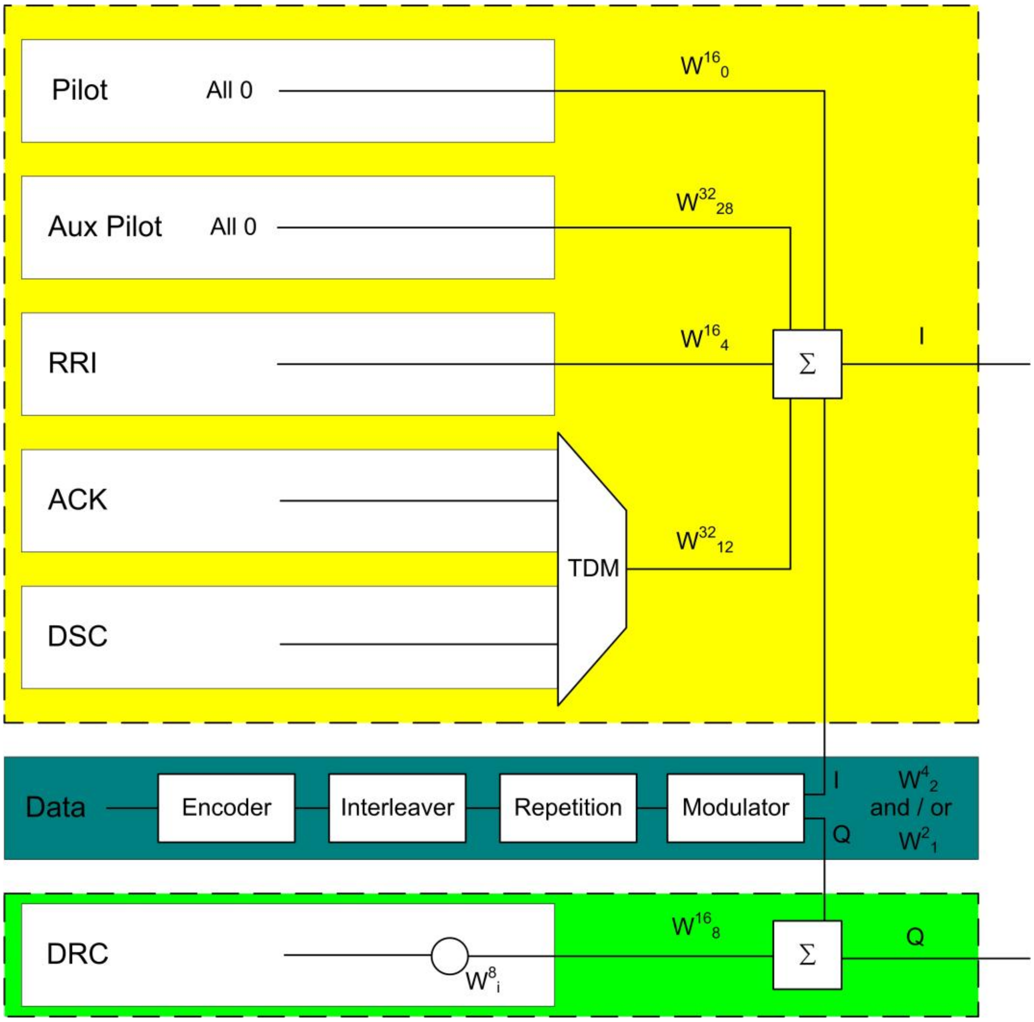


Fig. 20: Overview of the channel structure in the reverse link (subtype 2). ACK and DSC are time-multiplexed and then, together with both pilots and RRI, provided with different Walsh covers and transmitted on the I component. DRC is located in the Q component. Data undergoes a hybrid modulation (see below) and is transmitted via I and Q.

Pilot channel

The pilot is the same like in subtype 0, but is not longer time multiplexed with the RRI.

Auxiliary pilot channel

The auxiliary pilot supports the AN with the demodulation during transmission of higher data rates. It is transmitted one half slot before and after the data packet and uses W^{32}_{28} on the I component.

Reverse rate indicator (RRI)

The RRI channel reports the reverse link data rate to the AN. In subtype 2 it is coded with 6 bits and sent in every slot of a packet. It is not time multiplexed with the pilot channel anymore and now covered with W^{16}_{4}.

Data source control channel (DSC)

The AT uses the DSC channel to select which sector has to serve data to the AT. The DSC is transmitted only during the second half slot and goes into effect one slot after its transmission has ended. This allows the serving sector to be changed without interruption.

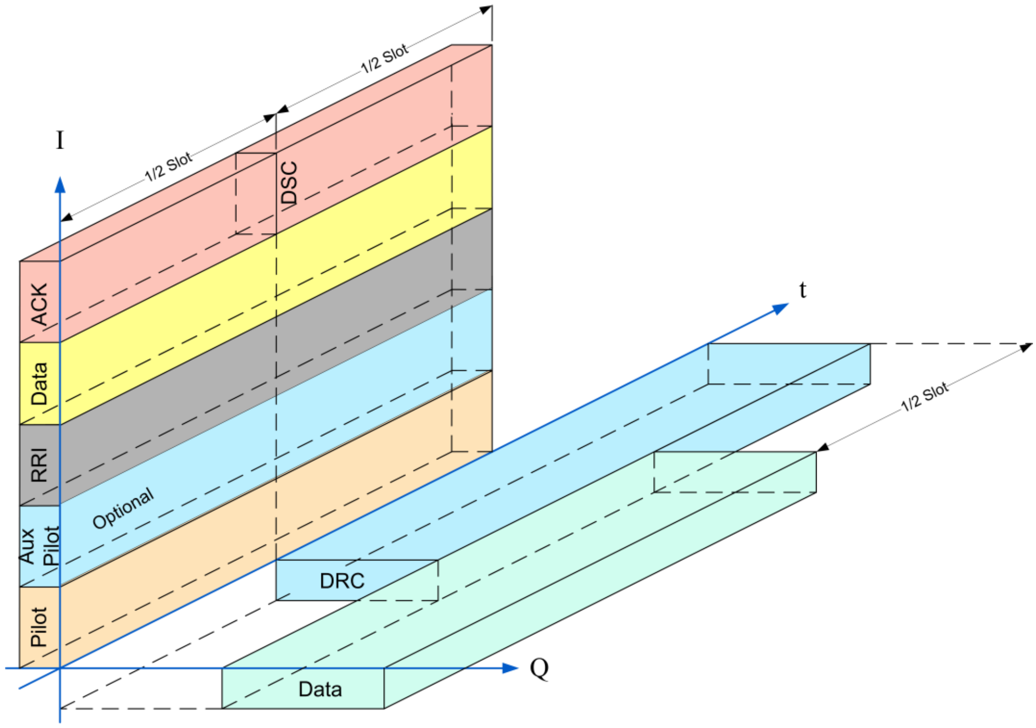
Data channel

The data rate in the reverse link has been increased by the addition of two modulation types, QPSK und 8-PSK (BPSK modulation was used in Release 0 and subtype 0). In addition, the channel is spread orthogonally across I and Q components using another layer of Walsh covering ("multicoding").

This results in the following modulation formats:

Data channel modulation parameters, subtype 2				
Modulation format	**Modulator**	**Walsh code**	**Component**	**Payload sizes**
B4	BPSK	W^4_2	Q	128 256 512 768 1024
Q4	QPSK	W^4_2	I + Q	1536 2048
Q2	QPSK	W^2_1	I + Q	3072 4096
Q4Q2	QPSK	$W^4_2 + W^2_1$	I + Q	6144 8192
E4E2	8PSK	$W^4_2 + W^2_1$	I + Q	12288

The I/Q diagram in Fig. 21 shows the structure in time of the reverse link.



Note: Diagram doesn't indicate channel gains

Fig. 21: Reverse link traffic channel (subtype 2).

3 Revision B

3.1 Overview of key features in Rev B

Just as the development of Rev A focused on basic improvements, e.g. a reduction in the latency for applications such as voice (VoIP), PTT or gaming, Rev B efforts are centered on further increasing the data rate. This is being achieved primarily through the bundling of multiple carriers ("carrier aggregation").

Revision A is fully backward compatible with Revision A and Release 0. This was ensured by supporting the physical layer with subtype 0 to 2. The communication in the system always starts with the physical layer of Release 0 (or subtype 0).

The improvements and modifications to the physical layer were combined into a subtype 3 and are described in detail in section 3.2.

The features can be characterized as either basic features (mandatory, implemented via software upgrade) or enhanced features (optional, requires additional hardware).

Basic features

Basic features	
Feature	**Remark**
Up to 3 carriers aggregated	Symmetrical carrier deployment
Forward link peak data rate **n** x Rev A carrier	Max. 3 x 3.1 Mbps = 9.3 Mbps
Reverse link peak data rate **n** x Rev A carrier	Max. 3 x 1.84 Mbps = 5.5 Mbps

Table 1: Basic features for Rev B

Carrier aggregation

As a basic feature, two or three carriers from Rev A (subtype 2) can be aggregated. Aggregating three adjacent carriers of 1.23 MHz each covers a 5 MHz spectrum. However, the carriers can also be distributed over the frequency band. Please note that the carriers are not required to be contiguous. The distribution is symmetrical in the uplink and downlink, i.e. the number of forward links must equal the number of reverse links. The forward link has a maximum data rate of 9.3 Mbps and the reverse link 5.5 Mbps.

Enhanced features

In addition to the basic features, other features were added, that require a hardware (chipset) upgrade in both AT and AN.

Enhanced features	
Feature	**Remark**
Up to 15 carriers aggregated	Symmetrical and asymmetrical carrier deployment
Larger packet sizes	
64-QAM modulation on the forward link	
Forward link peak data rate **n** x Rev B carrier	3 x 4.9 Mbps = 14.7 Mbps max. 15 x 4.9 Mbps = 73.5 Mbps
Reverse link peak data rate **n** x Rev A carrier	Max. 15 x 1.84 Mbps = 27.6 Mbps
Discontinuous transmission / reception at AT	DTX / DRX

Table 2: Enhanced features for Rev B

Carrier aggregation

The specification allows up to 15 carriers to be aggregated as an enhanced feature. The carriers need not be adjacent to one another. Aggregating 15 carriers of 1.23 MHz each covers 20 MHz spectrum. Distribution can be either symmetrical or asymmetrical, i.e. the number of forward links does not have to equal the number of reverse links. Again, the carriers need not to be adjacent to each other. The forward link has a maximum data rate of 73.5 Mbps and the reverse link 27.6 Mbps.

Packet size / modulation

Larger packet sizes were defined that, together with the newly introduced 64-QAM modulation in the forward link, allow data rates of up to 4.9 Mbps per carrier.

Discontinuous transmission / reception at AT (DTX, DRX)

DTX allows the AT to switch off the transmitter temporarily for short bursted signals (e.g. VoIP). This serves also to increase the system capacity for applications with lower data rates, by reducing the background noise within the system.

DRX allows the AT to switch off the receiver if it knows beforehand about idle slots from the AN.

Both features were added to improve the battery life.

Protocol changes

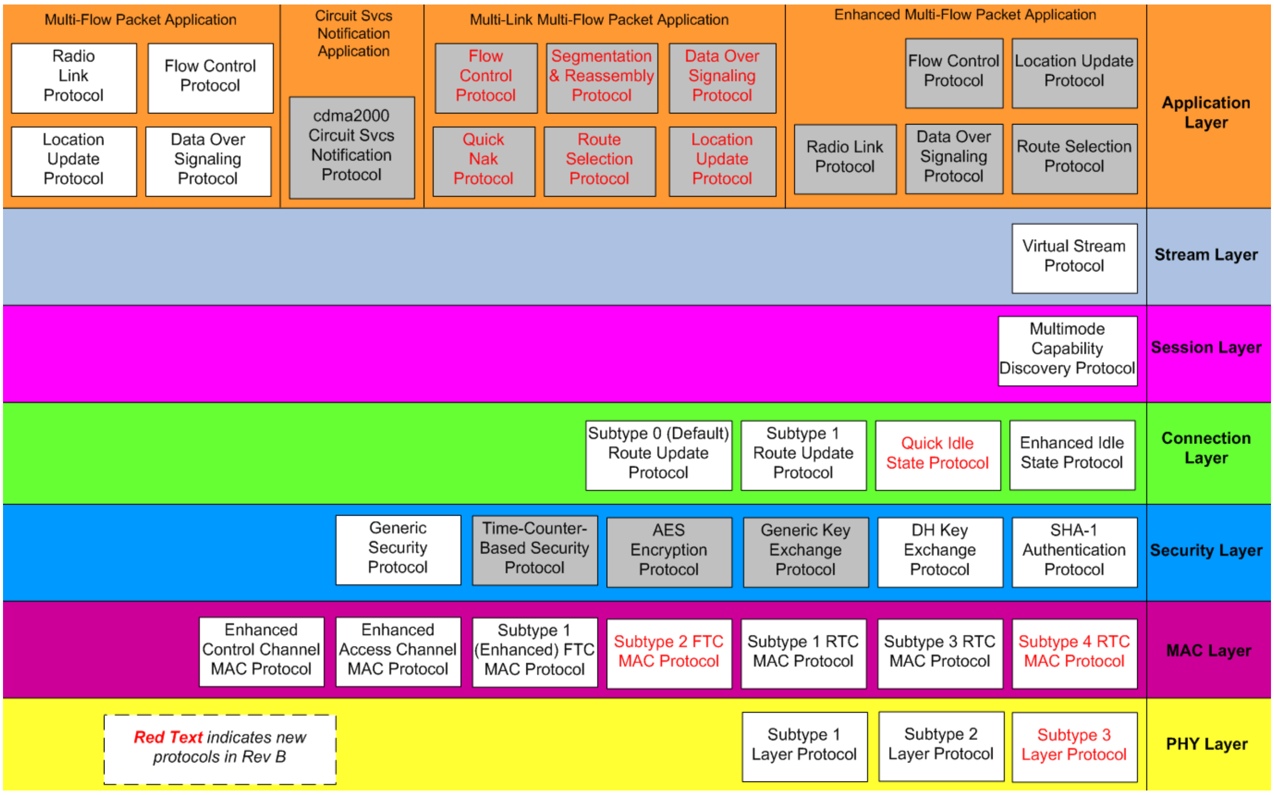


Fig. 22: Overview of the protocol stack in Revision B.

Rev B introduced the multi-link multi-flow packet application (MMPA) in the application layer. It expands the enhanced multiflow application from Rev A to include the multicarrier options, and it supports quality of service for the various applications in the different flows.

Subtype 3 was added to the physical layer (see 3.2). (Subtypes 0 to 2 ensure backward compatibility to Release 0 and Revision A).

Special applications were additionally defined in [2] for tests. For Rev B, the following are added beyond those already available in Rev A:

- Forward multicarrier test application (FMCTAP): Subtype 3
  - Subtype 3: Packet type 1 to 37 from subtype 2, plus 14 optional packet types: 4.8 kbps to 4 915.2 kbps

- Reverse multicarrier test application (RMCTAP): Subtype 3
  - Subtype 3: Data rate indices (from subtype 2) 0 to 12: 0 bps to 1 843.2 kbps

3.2 Physical layer in Rev B: Subtype 3

Rev B adds subtype 3 to the three different subtypes 0 to 2 available in the physical layer in Rev A.

All features can be classified as:

- Basic features: Mandatory for all ANs and ATs
- Enhanced features: **Optional** features

3.2.1 Multicarrier concept

The introduction of multicarrier mode brought additional requirements for the feedback channels. In the case of the mandatory (basic) features, the carriers are distributed symmetrically (number of forward links = number of reverse links) and every pair of carriers behaves the same as in single-carrier mode. However, if the distribution is asymmetrical (number of forward links ≠ number of reverse links), the feedback channels must be multiplexed to ensure proper operation of the system.

No Feedback multiplexing (symmetric system)

For a symmetric system, every forward/reverse pair of carriers functions the same as in single-carrier mode. This means that every reverse link transmits the feedback information (DRC, ACK, DSC) separately. This is known as NoFeedback multiplexing mode. Each pair does its own power control like in a single link.

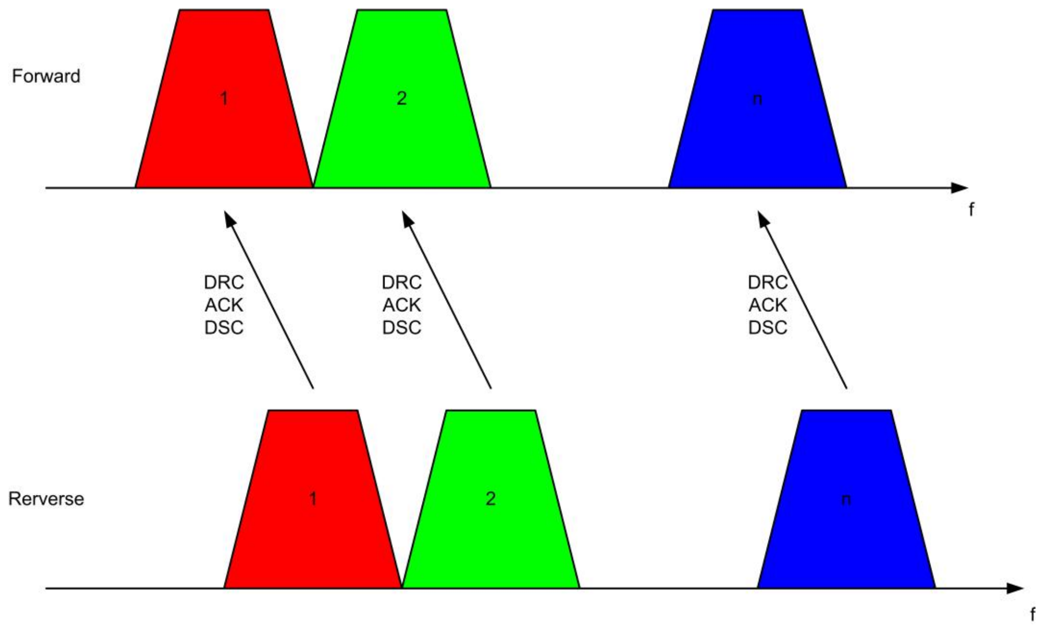


Fig. 23: Symmetrical division of the multicarrier. Every reverse link serves a forward link.

Reverse feedback multiplexing

This is used when there are fewer reverse link channels than there are forward link channels. In **BasicFeedBack multiplexing** (optional), so the feedback from multiple (n) forward channels must use one or more reverse links. In this case, the individual feedback channels (DRC, ACK, DSC, “reverse overhead channels”) are transmitted on a single carrier, separated by **n** long code masks.

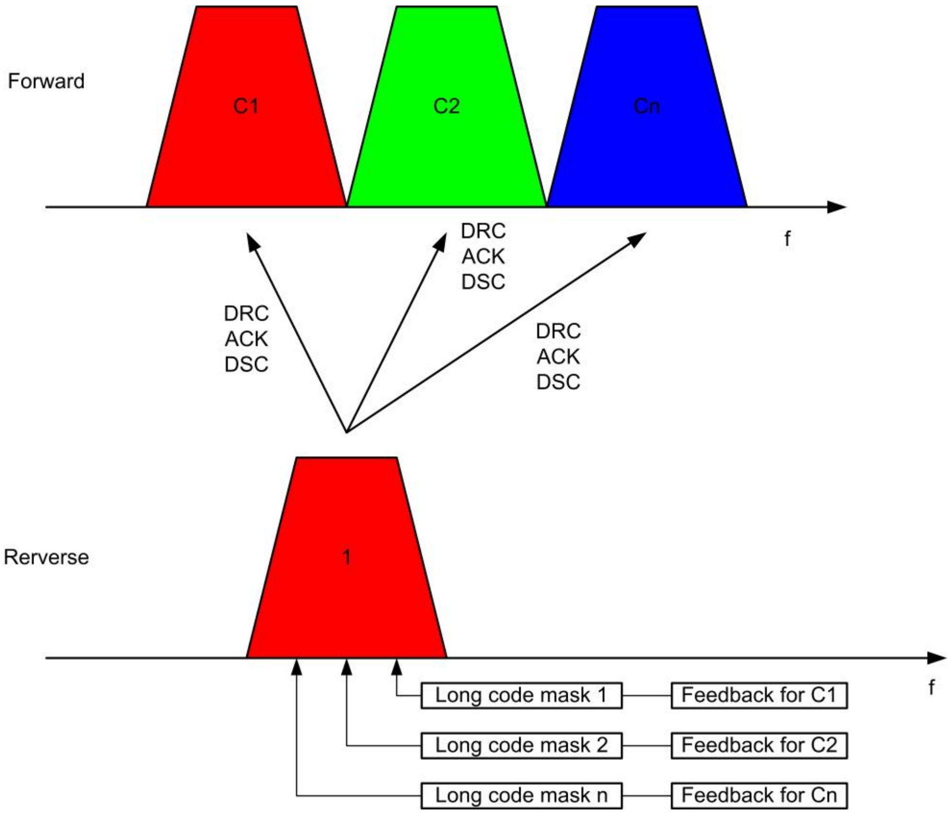


Fig. 24: Reverse BasicFeedBack multiplexing. The feedback is transmitted together via one reverse link, separated by various long code masks.

EnhancedFeedback multiplexing allows the feedback from up to four forward links to be transmitted on a single reverse link. To do this, the feedback channels (DRC, ACK, DSC, “reverse overhead channels”) are separated both using time (TDM) and code (CDM) and then transmitted with one long code mask.

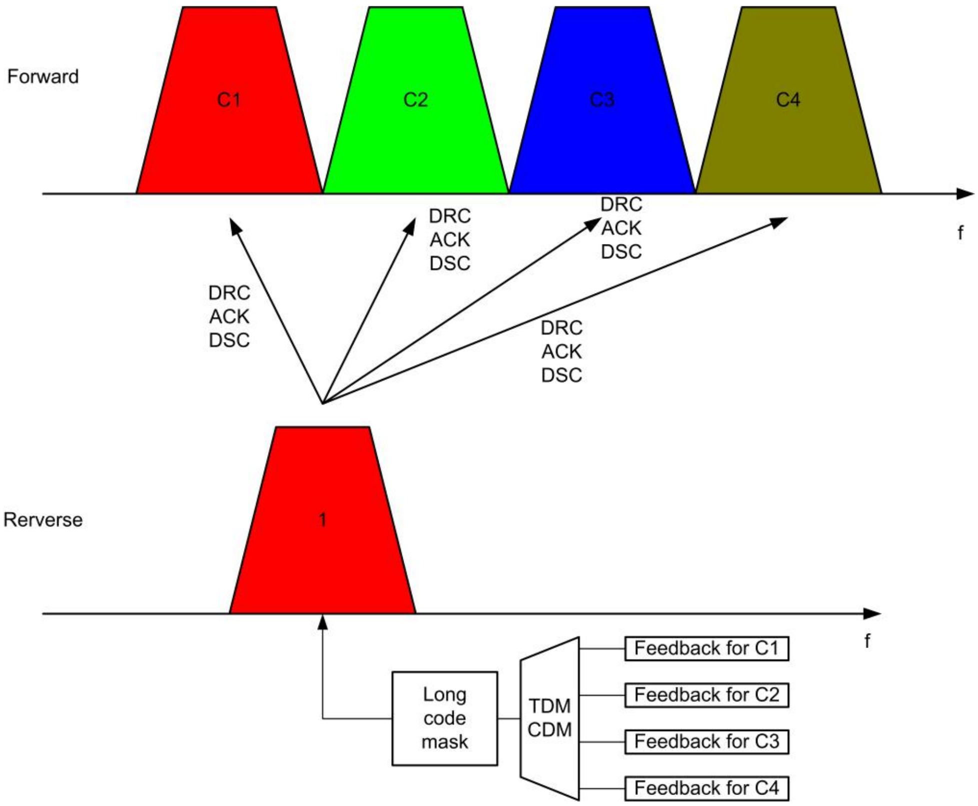


Fig. 25: Reverse EnhancedFeedBack multiplexing. The feedback for up to four carriers is separated by means of TDM and CDM and then combined in one reverse link.

Forward feedback multiplexing

When there are more reverse links than forward links, then the forward link feedback (subchannels RPC, RAB) must serve multiple reverse links. This is done using several different MACIndices to cover the feedback subchannels:

- Reverse link MACIndex: Multiplexing RPC, DRCLock, ARQ
- RABMACIndex: Multiplexing RAB

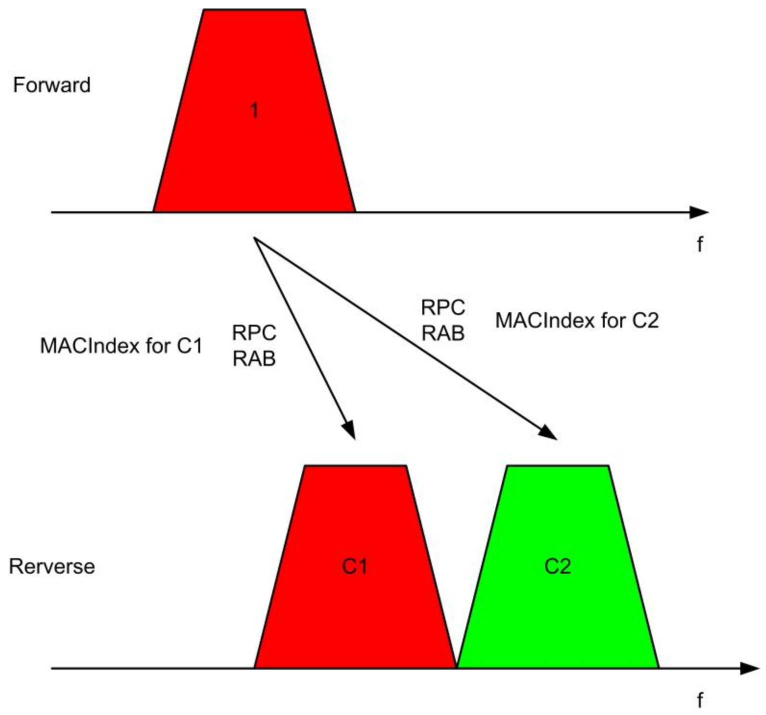


Fig. 26: A forward link serving two reverse links. The separation is carried out using different MACIndices.

3.2.2 Forward link

Subtype 3 was derived from subtype 2 maintaining the same channels and timing. A number of changes were made to support asymmetric link configurations and some new data rates. Some changes are handled as optional features.

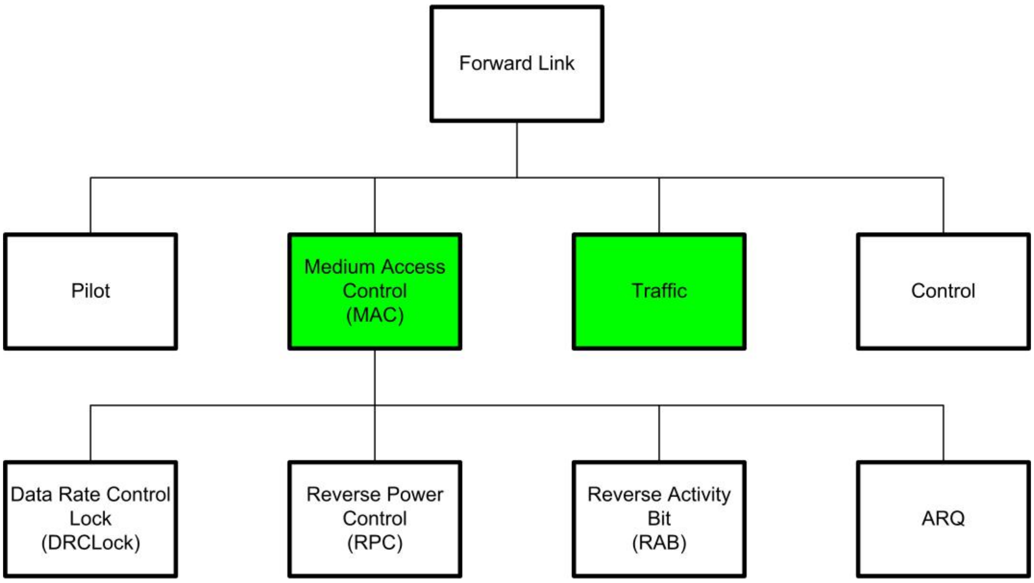


Fig. 27: Forward link channel structure (subtype 3). Green channels have undergone significant changes.

To support new, higher, data rates, new packet sizes were added, as well as the addition of 64 QAM as a modulation type. Due to the need to support asymmetric link configurations, changes were made in the Walsh codes used to cover elements of the MAC channel. This increased the number of available MACindices to support feedback operations to multiple reverse link channels from a single forward link

Changes were made in the packet sizes and in the modulation in the traffic channel, as well as in the Walsh code in the MAC channel. The preamble was additionally mapped to the I/Q components differently, based on the MACIndex.

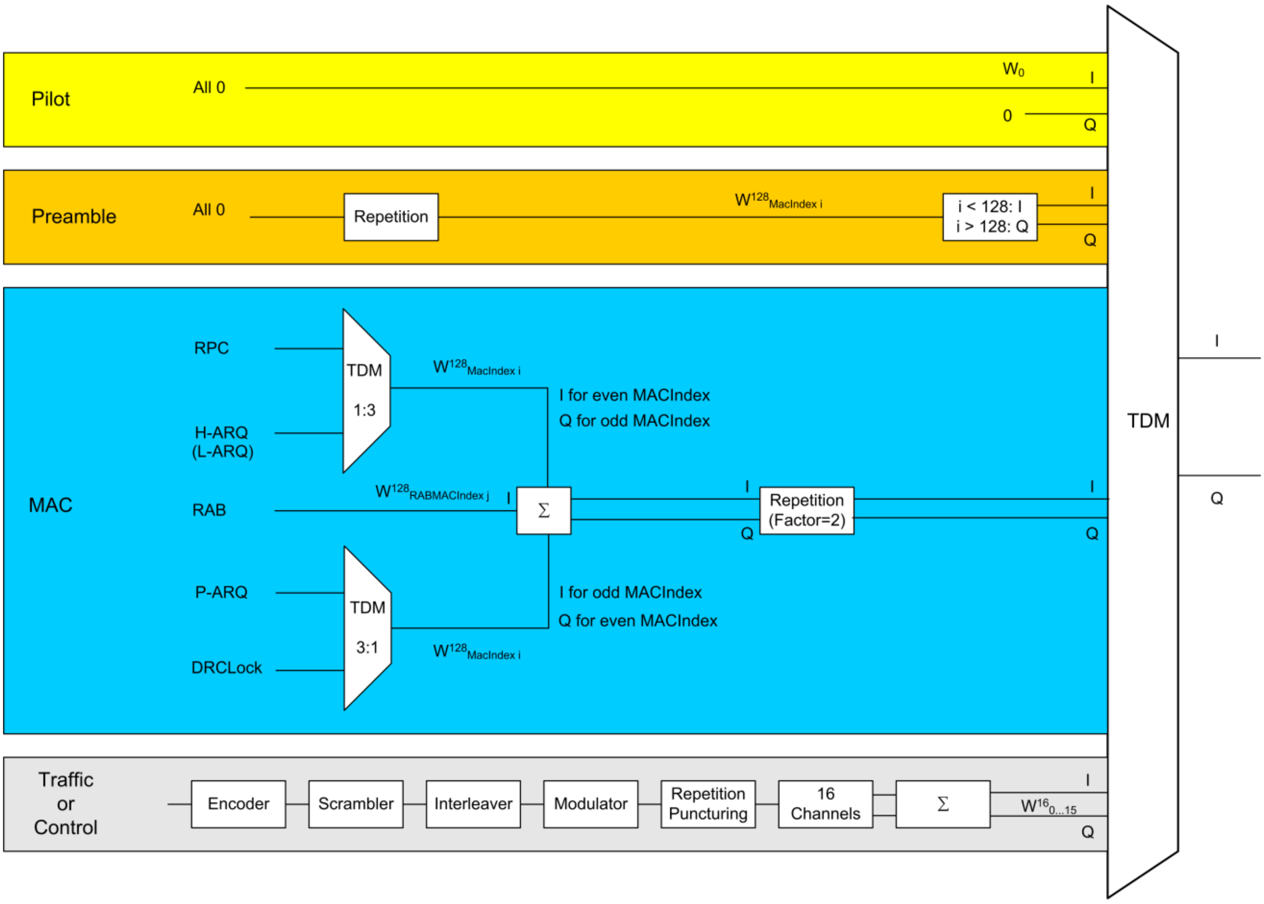


Fig. 28: Overview of the channel structure in the forward link (subtype 3). All channels are time multiplexed and provided with different Walsh covers. The MAC channel uses CDM using the MACindex to select active AT's.

MAC channels

383 MACIndices are now available (Revision A: 128). The number of Walsh cover codes remains at 128.

The Walsh code is determined based on MACIndex 0 to 383 in accordance with Table 12.4.1.3.2.2-1 from [1]. For example, even MACIndices up to 62 use Walsh code $W^{128}_{i/2}$.

The MACIndices are typically available for use in the MAC channels as shown in Fig. 29. There are several MACIndices to identify. Because a forward link might have to transmit MAC channel information for several reverse links, these can be multiplexed using different MACIndices:

- RAB uses the RABMACIndex from ranges 4 to 63 and 66 to 127
- RPC, DRCLock and ARQ use the ReverseLinkMACIndex from ranges 4 to 63, 66 to 127, 130 to 191, 194 to 255, 258 to 319, 322 to 383

These are different from the ForwardTrafficMACIndex, which is used in the preamble to address data packets to specific ATs (see the section titled "Traffic channel").

MACIndex	
MACIndex	**MAC channel use**
0 and 1	Not used
2	Not used
3	Not used
4 to 63 66 to 127	Available for RPC channel, DRCLock channel, ARQ channel and RA channel
64 to 65 128 to 129 192 to 193 256 to 257 320 to 321 384 to 512	Not used
130 to 191 194 to 255 258 to 319 322 to 383	Available for RPC channel, DRCLock channel, ARQ channel

Fig. 29: Use of the MACIndices in the MAC channels.

Traffic channel

Packet size / transmission formats

New packet sizes were introduced in the traffic channel, along with the new 64-QAM modulation. The packet sizes and transmission formats from subtype 2 must still be supported. Three new packet sizes have been defined to allow the data rate to be increased to a maximum of 4915.2 Mbps:

- 6144 bits
- 7168 bits
- 8192 bits

With the (reverse) DRC channel (see also 2.2.1.2 and 2.2.3.1), the AT tells the AN, which data rate can be used by the AN. The DRC just uses an index to a table with predefined canonical transmit formats (rate sets). The AN then chooses the appropriate rate from this group set, see following table. New DRCindices are added to the existing ones (0x0…0xe; see Fig. 18)

Transmission formats according to DRC, subtype 3				
DRC index	**Rate metric** (kbps)	**TX format** (packet, slots, preamble)	**Termination Target** (slots)	**Maximum span** (slots)
0x10	460.8	1024, 4, 64 2048, 4, 64 **3072, 4, 64**	4	8
0x11	614.4	1024, 4, 64 2048, 4, 64 **4096, 4, 64**	4	8
0x12	768.0	1024, 4, 64 2048, 4, 64 **5120, 4, 64**	4	8
0x13	921.6	2048, 4, 64 **6144, 4, 64**	4	8
0x14	1075.2	1024, 4, 64 **7168, 4, 64**	4	8
0x15	1228.8	8192, 4, 64	4	4
0x16	1843.2	2048, 2, 64 **6144, 2, 64**	2	4
0x17	2150.4	1024, 2, 64 **7168, 2, 64**	2	4
0x18	2457.6	**8192, 2, 64**	2	4
0x19	3686.4	2048, 1, 64 **6144, 1, 64**	1	4
0x1a	4300.8	1024, 1, 64 **7168, 1, 64**	1	4
0x1b	4915.2	**8192, 1, 64**	1	4

Fig. 30: New, optional canonical transmission formats in the forward link, subtype 3. See Fig. 18 for existing suptype 2 formats.

Preamble

128 bi-orthogonal Walsh codes are used for the preamble. Even indices with $W^{128}_{i/2}$ are mapped to the I component and odd indices with $W^{128}_{(i-1)/2}$ are mapped to the Q component as a bitwise complement. Using this new mapping for the Forward Traffic MACIndex permits the addressing of up to 255 unique AT's.

3.2.3 Reverse link

The reverse link remains essentially unchanged from Rev A or subtype 2 with respect to logical (channels) and timing structure. However, the introduction of the multicarrier concepts (see 3.2.1) means that the feedback channels DRC, ACK and DSC will require multiplexing to support multiple forward links. When multiplexing is needed, this is done by the use of additional Walsh cover codes.

NoFeedback multiplexing

In symmetrical mode, every reverse link has its own forward link, so, just as in single carrier mode, all feedback channels are transmitted with every reverse link.

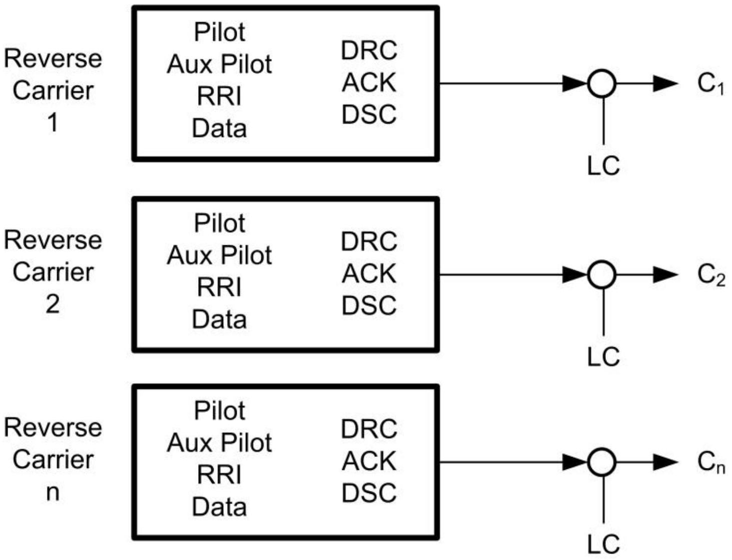


Fig. 31: Reverse link in symmetrical NoFeedback mode. Every carrier transmits all channels. U_I and U_Q are User Long-Code (LC) PN Sequences for I or Q channels

BasicFeedBack multiplexing

In this mode, both the reverse channels (pilot, data, RRI, AuxPilot) and the reverse overhead channels (DRC, ACK, DSC) are transmitted over **one** reverse link for **all** forward links. The individual feedback channels may be distinguished by the use of different long code masks.

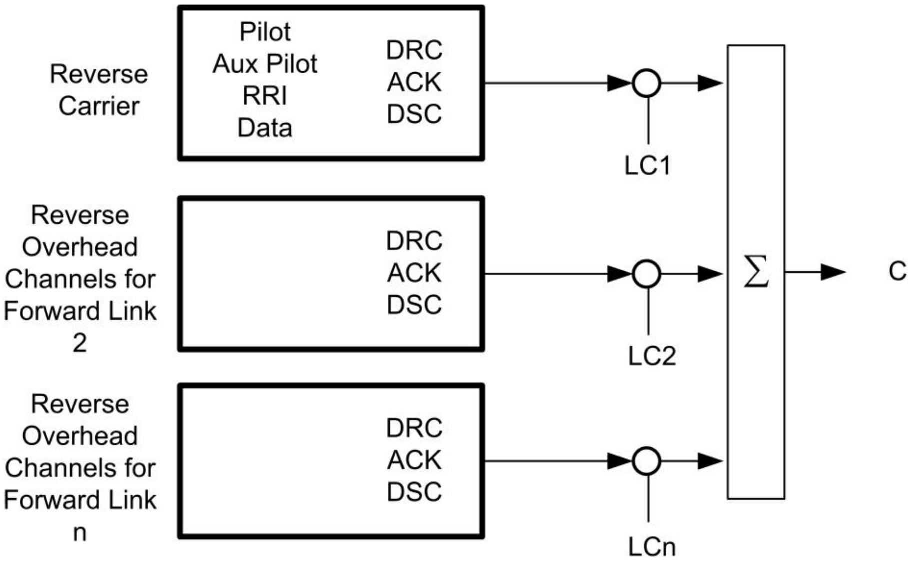


Fig. 32: BasicFeedback multiplexing: All reverse overhead channels are transmitted over one single reverse link. They are differentiated by the different long code (LC) masks.

EnhancedFeedback multiplexing

In this case, the reverse overhead channels are transmitted over a single reverse link for up to four forward links. That means four reverse links are needed to support the maximum possible 15 forward links. To do this, the reverse overhead channels (ACK, DSC and DRC) are multiplexed in TDM and CDM. To support more links, the basic structure from subtype 2 is extended to use both I and Q components. Additional Walsh codes are used to codemultiplex them, e.g. to transmit two reverse subchannels for different forward links are at the same time and on the same component.

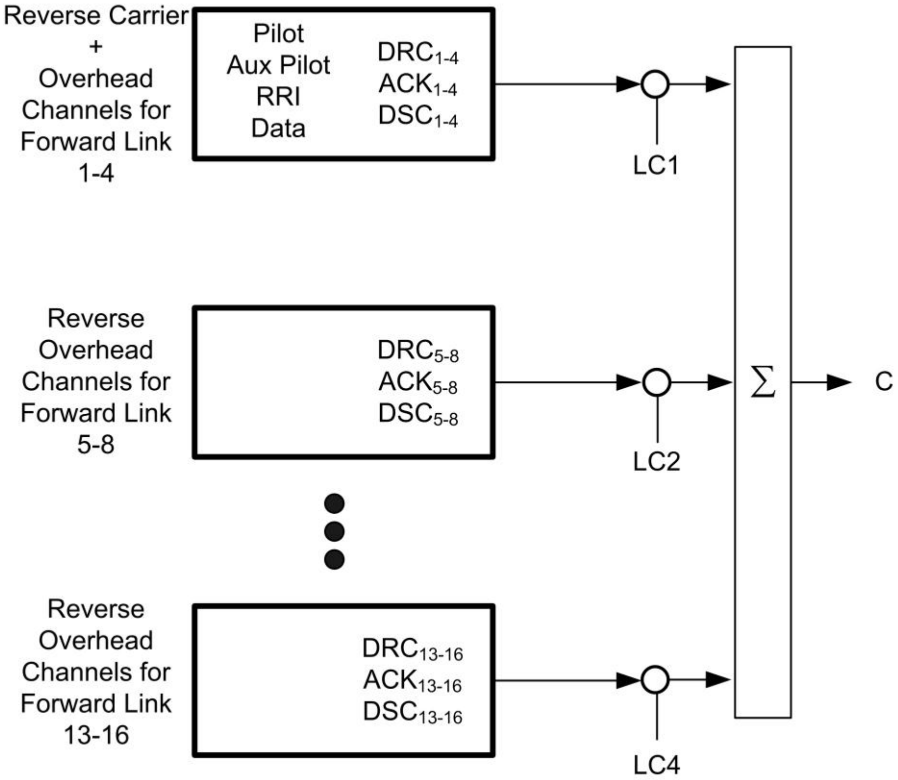


Fig. 33: EnhancedFeedback multiplexing: One reverse channel and up to four reverse overhead channels are combined in a single carrier. This means that at most, four reverse links (with different long code (LC) masks are needed in order to use all possible forward links.

As a recall from NoFeedback Multiplexing, the DSC channel is time multiplexed with the ACK channel every half slot using a common Walsh code (W^{32}_{12}) and mapped to the I component. The DRC is mapped to the Q component with an offset of one half slot.

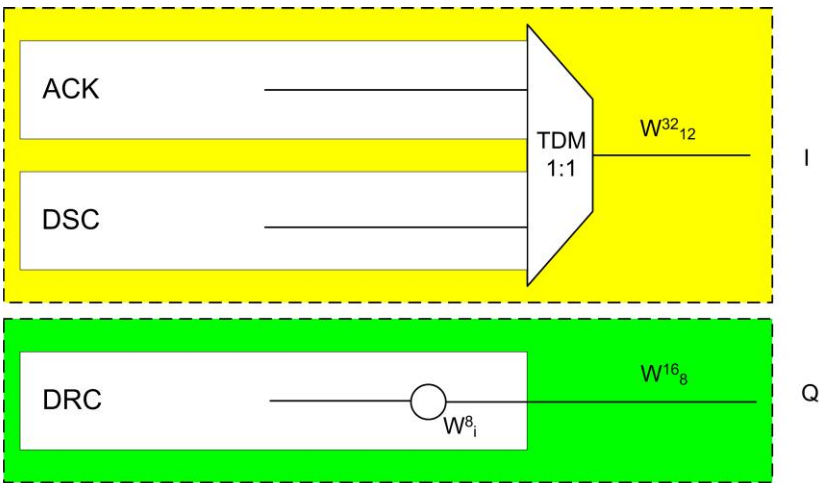


Fig. 34: Channel structure of reverse overhead channels supporting one forward carrier

Two Forward Links

To support two forward links, the additional channels ACK2, DSC2 and DRC2 use the same structure like the channels for Carrier 1, but are mapped on the opposite component. That means, ACK2 and DSC2 are time multiplexed every half slot using a common Walsh code (W^{32}_{12}) and mapped to the Q component. The DRC2 is mapped to the I component with an offset of one half slot.

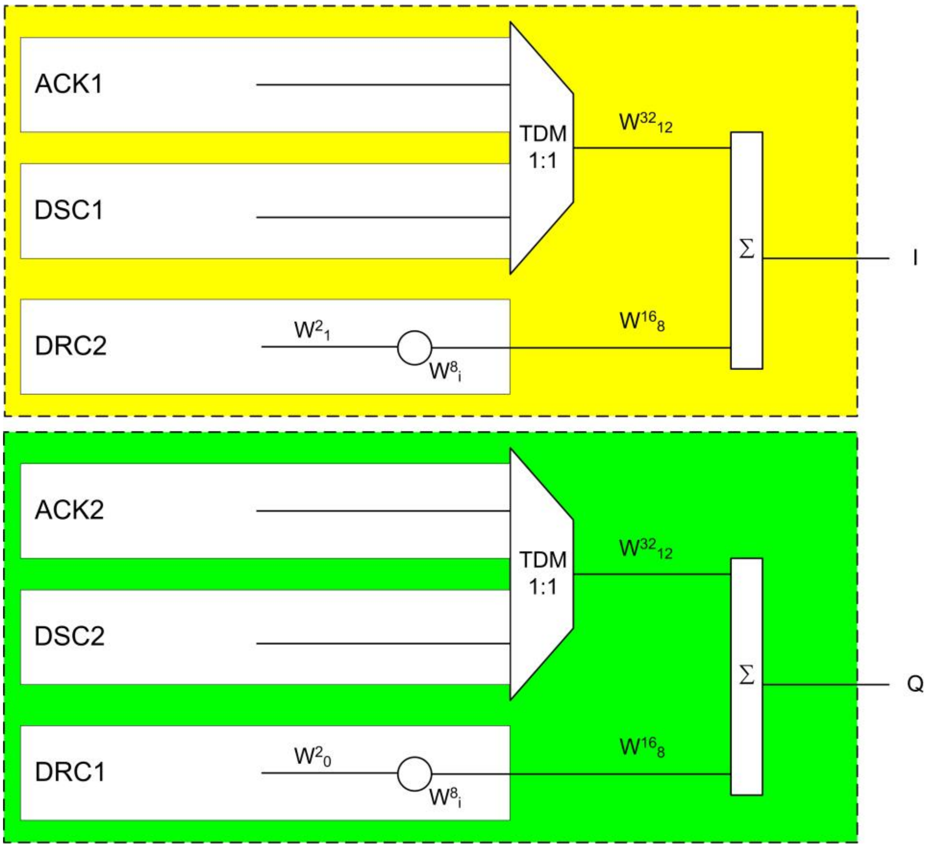


Fig. 35: Channel structure of reverse overhead channels supporting two forward carriers in Enhanced Feedback multiplexing

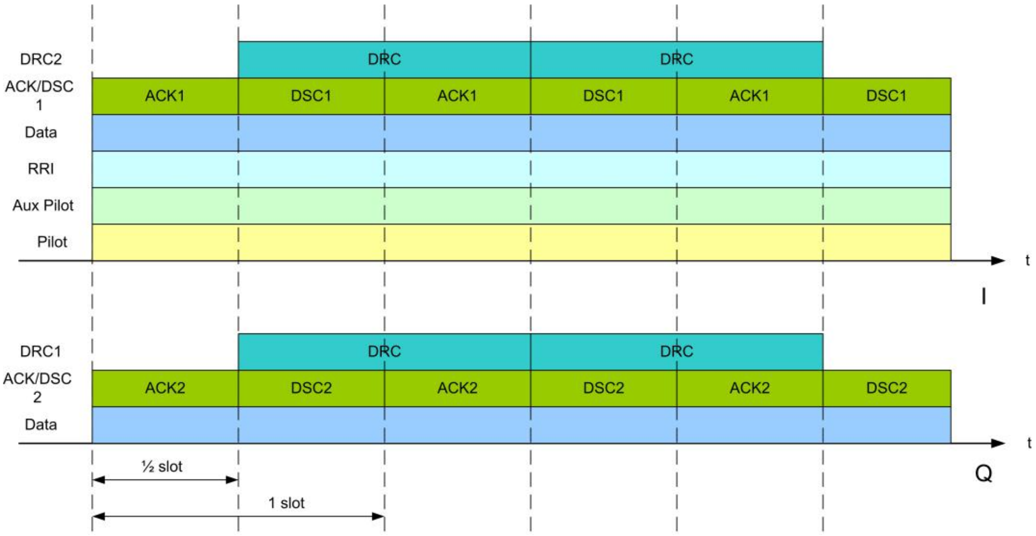


Fig. 36: Timing structure of one reverse traffic channel subtype 3 in EnhancedFeedback multiplexing for 2 forward carriers

Four Forward Links

To support four forward links, ACK1/2 and DSC1/3 are time multiplexed every half slot using a common Walsh code (W^{32}_{12}) and mapped to the I component. DSC1 and DSC3 are alternating every second half slot. The DRC3 and DRC4 are mapped to the I component with an offset of one half slot. To distinguish between ACK1 and ACK2 and DRC3 and DRC4 additional Walsh codes are used. All remaining channels (ACK3/4, DSC2/4 and DRC1/2) are mapped on the same way to the Q component.

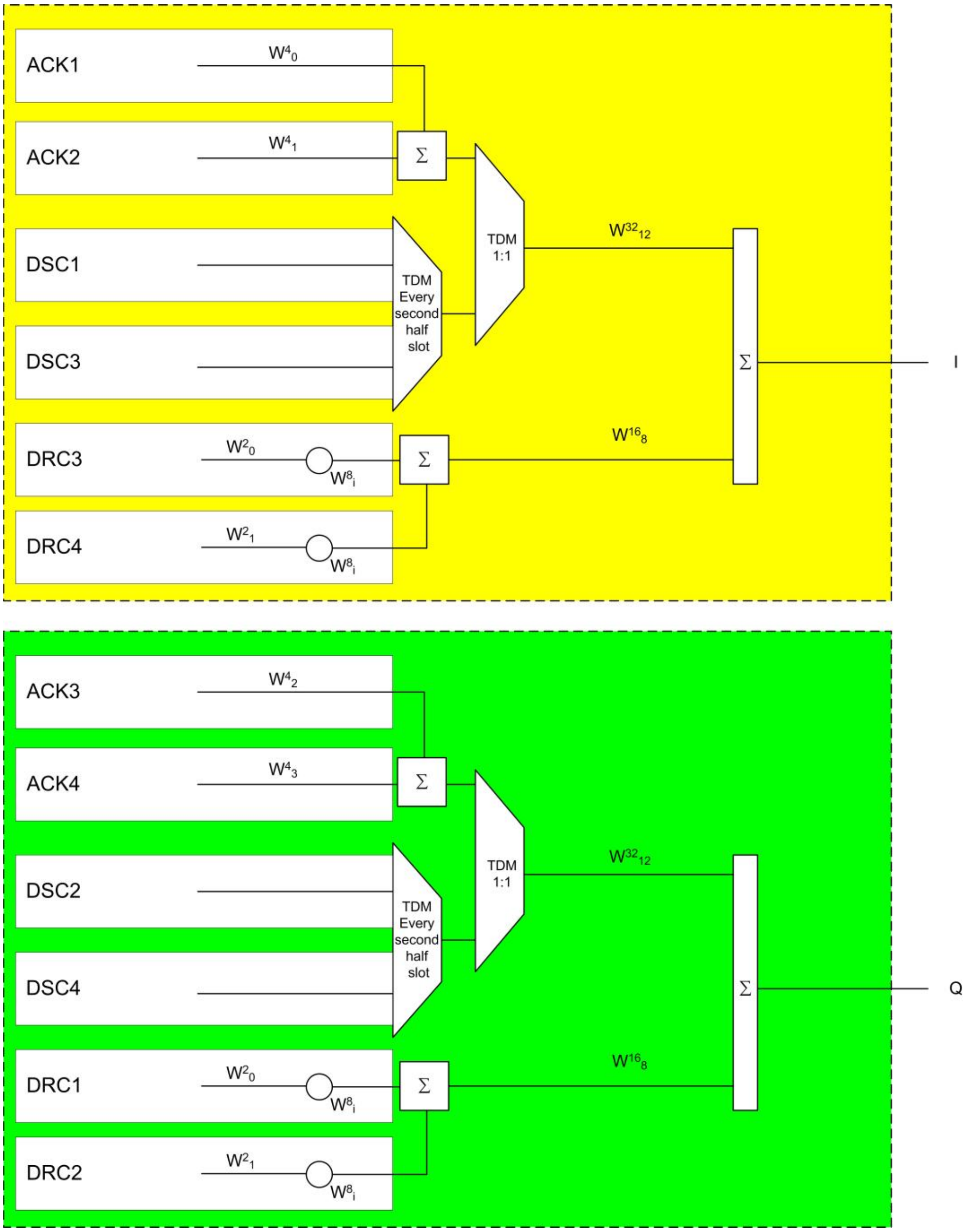


Fig. 37: Channel structure of reverse overhead channels supporting four forward carriers in Enhanced Feedback multiplexing

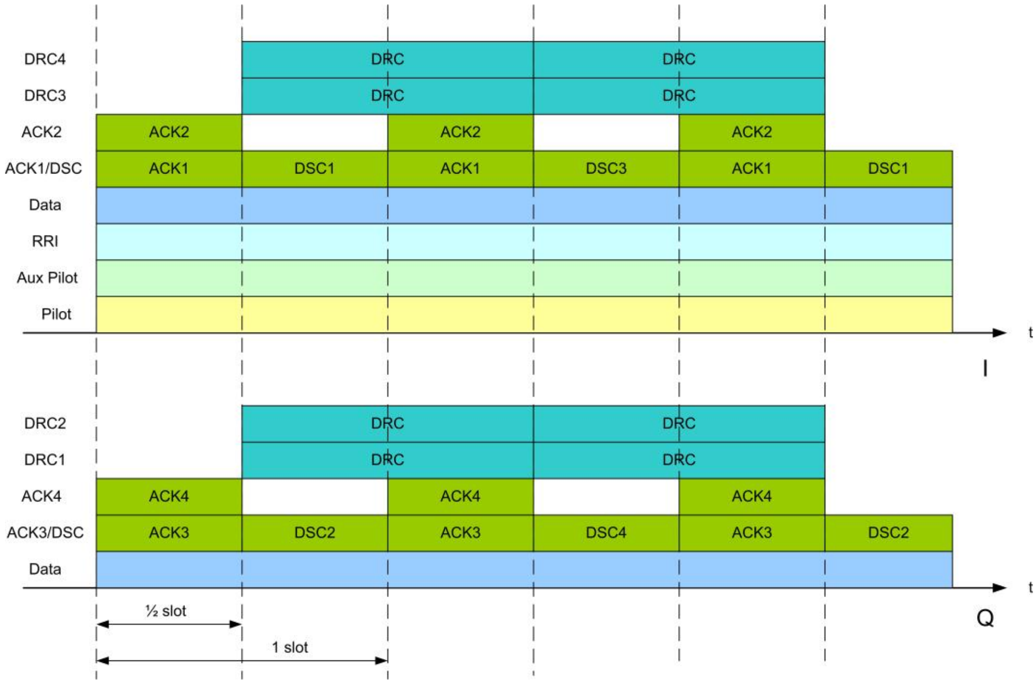


Fig. 38: Timing structure of one reverse traffic channel subtype 3 in EnhancedFeedback multiplexing for 4 forward carriers

4 Appendix

4.1 1xEV-DO states

Following figure gives an overview about the states and transitions:

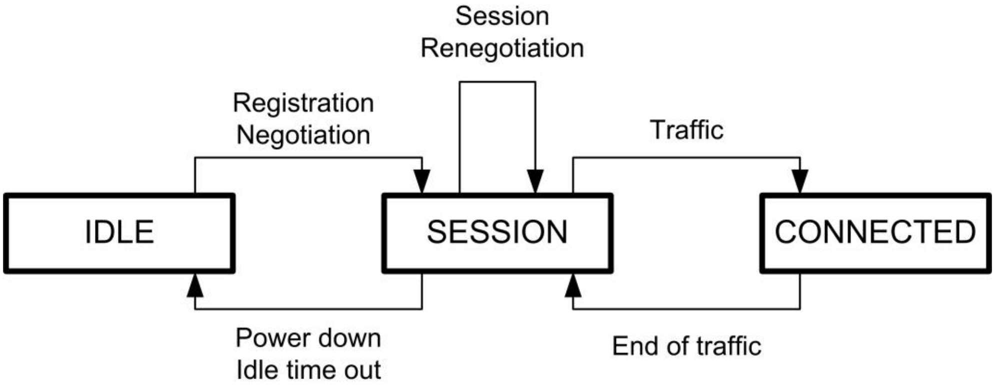


Fig. 39: 1xEV-DO states

4.2 Abbreviations

1xEV-DO	1xEvolution-Data Optimized
3GPP	Third Generation Partnership Project
3GPP2	Third Generation Partnership Project 2
ACK	Acknowledgment
AN	Access Network
ARQ	Automatic Retransmission Request
AT	Access Terminal
bps	Bits per Second
BPSK	Binary Phase Shift Keying
CDG	CDMA Development Group
CDM	Code Division Multiplex
CDMA	Code Division Multiple Access
CRC	Cyclic Redundancy Check
dB	Decibel
DO	Data Optimized
DRC	Data Rate Control
EV	Evolution
FCS	Frame Check Sequence
FL	Forward Link
FTC	Forward Traffic Channel
GHz	Gigahertz
GPS	Global Positioning System

HDR	High Data Rate
HPSK	Hybrid Quadrature Phase Shift Keying
HRPD	High Rate Packet Data
Hz	Hertz
I	In-Phase Component
IMT	International Mobile Telecommunication
ITU	International Telecommunications Union
kbps	Kilobits per Second
kHz	Kilohertz
LCM	Long Code Mask
LSB	Least Signification Bit
MAC	Medium Access Control
Mbps	Megabits per Second
MHz	Megahertz
ms	Milliseconds
NAK	Negative Acknowledgement
ns	Nanoseconds
PER	Packet Error Rate
PN	Pseudo-Noise
PPS	Pulse per Second
PSK	Phase Shift Keying
Q	Quadrature Phase Component
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RA	Reverse Activity
RAB	Reverse Activity Bit
RAN	Radio Access Network
RF	Radio Frequency
RL	Reverse Link
RPC	Reverse Power Control
RRI	Reverse Rate Indicator
RTC	Reverse Traffic Channel
Rx	Receive
TIA	Telecommunications Industry Association
TDM	Time Division Multiplex
Tx	Transmit
UTC	Universal Coordinated Time
VoIP	Voice over Internet Protocol
µs	Microsecond

4.3 References

[1] 3GPP2 C.S0024; **cdma2000 High Rate Packet Data Air Interface Specification**; Version C.S0024-B v3.0; June 2012 *{Revision B}*

[2] 3GPP2 C.S0029; **Test Application Specification (TAS) for High Rate Packet Data Air Interface**; Version C.S0029-B v1.0; March 2008 *{Revision B}*

4.4 Additional Information

Please send your comments and suggestions regarding this white paper to

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About Rohde & Schwarz

Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established more than 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

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