



LTE evolution

source: E. Dahlman: 4G, LTE-Advanced Pro and The Road to 5G

winter semester 2025/2026

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|                          | Release 10                                                                                 | Release 11                                                                                                                        | Release 12                                                                                                                                                                              | Release 13                                                                                |
|--------------------------|--------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| new scenarios            |                                                                                            |                                                                                                                                   | <ul style="list-style-type: none"> <li>• DTD</li> <li>• MTC</li> </ul>                                                                                                                  | <ul style="list-style-type: none"> <li>• eDTD</li> <li>• eMTC</li> <li>• NBIoT</li> </ul> |
| device enhancement       |                                                                                            | <ul style="list-style-type: none"> <li>• Performance requirements for Interference rejection receivers</li> </ul>                 | <ul style="list-style-type: none"> <li>• Network-assisted interference cancellation</li> <li>• SIC, IRC for SUMIMO</li> </ul>                                                           |                                                                                           |
| densification            | <ul style="list-style-type: none"> <li>• HetNet</li> <li>• Relaying</li> </ul>             | <ul style="list-style-type: none"> <li>• HetNet deployments</li> </ul>                                                            | <ul style="list-style-type: none"> <li>• dual connectivity</li> <li>• small cell ON/OFF</li> <li>• dynamic TDD</li> <li>• Mobility enhancements in heterogeneous deployments</li> </ul> | <ul style="list-style-type: none"> <li>• dual connectivity</li> <li>• LAA</li> </ul>      |
| multi-antenna techniques | <ul style="list-style-type: none"> <li>• DL 8 x 8 MIMO</li> <li>• UL 4 x 4 MIMO</li> </ul> | <ul style="list-style-type: none"> <li>• CoMP with low-latency backhaul</li> <li>• Enhanced control-channel structures</li> </ul> | <ul style="list-style-type: none"> <li>• CoMP with nonideal backhaul</li> </ul>                                                                                                         | <ul style="list-style-type: none"> <li>• FD-MIMO</li> </ul>                               |
| Spectrum flexibility     | <ul style="list-style-type: none"> <li>• CA</li> </ul>                                     | <ul style="list-style-type: none"> <li>• Carrier aggregation across different TDD configurations</li> </ul>                       | <ul style="list-style-type: none"> <li>• CA: FDD + TDD</li> </ul>                                                                                                                       | <ul style="list-style-type: none"> <li>• CA up to 32 carriers</li> <li>• LAA</li> </ul>   |
| miscellaneous            |                                                                                            |                                                                                                                                   | <ul style="list-style-type: none"> <li>• smart congestion mitigation</li> </ul>                                                                                                         | <ul style="list-style-type: none"> <li>• SC-PTM</li> </ul>                                |

### main milestones of LTE evolution

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| UE DL category | Max. data rate in Mbps | CC | MIMO            | Modulation     | Comment                                                 |
|----------------|------------------------|----|-----------------|----------------|---------------------------------------------------------|
| 11/12          | ~ 600                  | 2  | 4/4             | 64QAM          | 256QAM added in 3GPP Release 12                         |
|                |                        |    | 2/4             | 256QAM         |                                                         |
|                |                        | 3  | 2/2/4           | 64QAM          |                                                         |
|                |                        |    | 2/2/2           | 256QAM         |                                                         |
|                |                        | 4  | 2/2/2/2         | 64QAM          |                                                         |
| 13             | ~ 400                  | 1  | 4               | 256QAM         | Carrier aggregation beyond 5CC added in 3GPP Release 13 |
|                |                        | 2  | 2               |                |                                                         |
| 14             | ~ 4000                 | 5  | 8               | 256QAM         |                                                         |
| 15             | ~ 750 - 800            | 2  | 4/4             | 256QAM         |                                                         |
|                |                        | 3  | 4/4/2           | 2*64QAM/256QAM |                                                         |
|                |                        | 4  | 2/2/2/2         | 256QAM         |                                                         |
| 16             | ~ 1000                 | 3  | 2/4/4           | 256QAM         |                                                         |
|                |                        | 3  | 4/4/4           | 2*64QAM/256QAM |                                                         |
|                |                        | 4  | 2/2/2/4         | 256QAM         |                                                         |
|                |                        | 5  | 2/2/2/2/2       | 256QAM         |                                                         |
| 17             | ~ 25000                | 32 | 8               | 256QAM         |                                                         |
| 18             | ~ 1200                 | 6  | 2/2/2/2/2/2     | 256QAM         |                                                         |
|                |                        | 4  | 4/4/4/4         | 64QAM          |                                                         |
|                |                        | 3  | 4/4/4           | 256QAM         |                                                         |
|                |                        | 2  | 4/8             | 256QAM         |                                                         |
| 19             | ~ 1600                 | 8  | 2/2/2/2/2/2/2/2 | 256QAM         |                                                         |
|                |                        | 6  | 2/2/2/2/4/4     | 256QAM         |                                                         |
|                |                        | 4  | 4/4/4/4         | 256QAM         |                                                         |
|                |                        | 2  | 8/8             | 256QAM         |                                                         |
| 20             | ~ 2000                 | 8  | 2/2/2/2/2/2/4/4 | 256QAM         |                                                         |
|                |                        | 5  | 4/4/4/4/4       | 256QAM         |                                                         |
|                |                        | 4  | 4/4/4/8         | 256QAM         |                                                         |
|                |                        | 3  | 4/8/8           | 256QAM         |                                                         |

DL UE categories

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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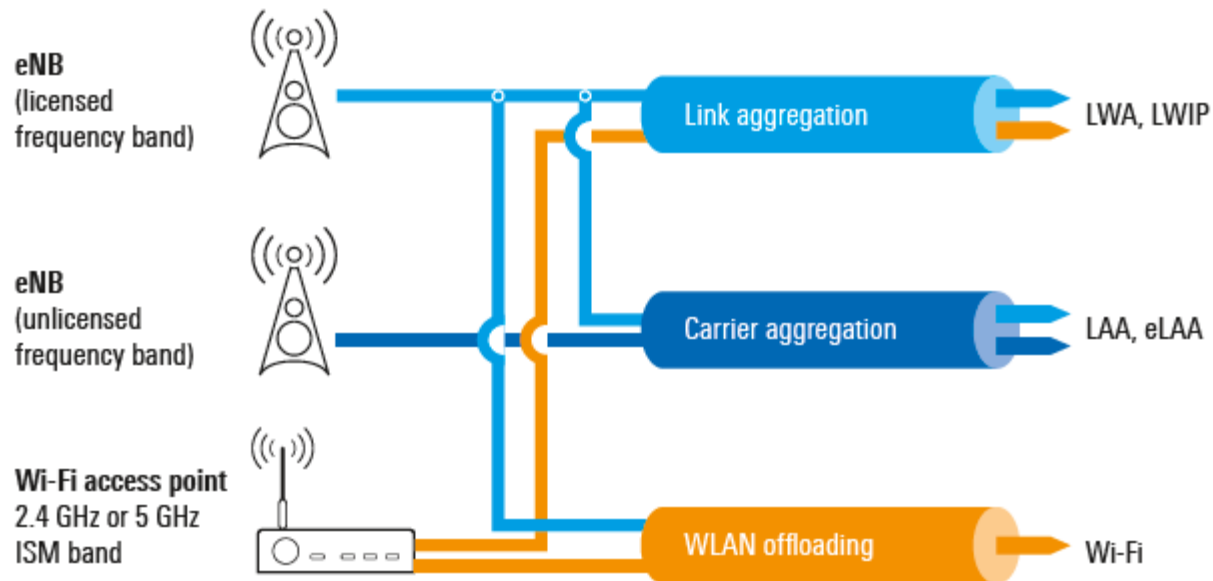
| UE UL category | Max. data rate in Mbps | CC | MIMO | Modulation | Comment                         |
|----------------|------------------------|----|------|------------|---------------------------------|
| 13             | ~ 150                  | 2  | 1    | 64QAM      | 256QAM added in 3GPP Release 14 |
| 14             | ~ 9600                 | 32 | 2    | 64QAM      |                                 |
| 15             | ~ 225                  | 3  | 1    | 64QAM      |                                 |
| 16             | ~ 105                  | 1  | 1    | 256QAM     |                                 |
| 17             | ~ 2100                 | 5  | 4    | 256QAM     |                                 |
| 18             | ~ 210                  | 2  | 1    | 256QAM     |                                 |
| 19             | ~ 13500                | 16 | 4    | 256QAM     |                                 |
| 20             | ~ 315                  | 3  | 1    | 256QAM     |                                 |
| 21             | ~ 300                  | 4  | 1    | 64QAM      |                                 |

### UL UE categories

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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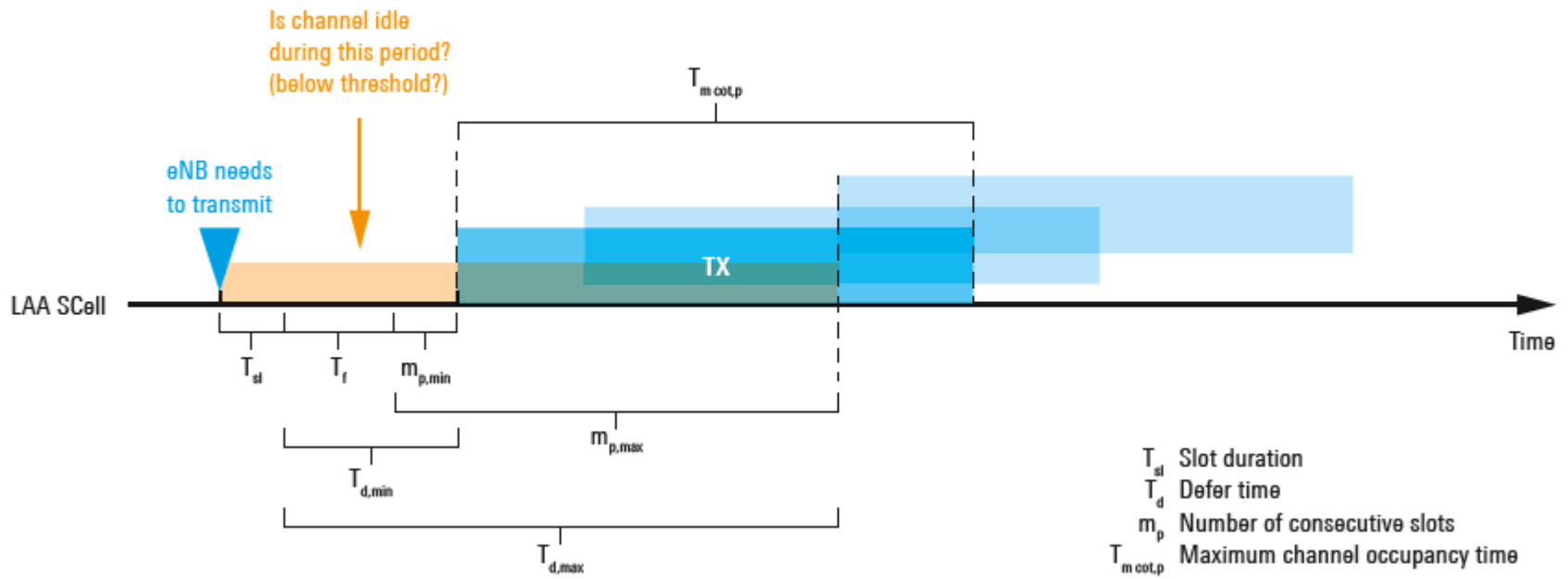
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3 ways to use free bandwidth in 3GPP

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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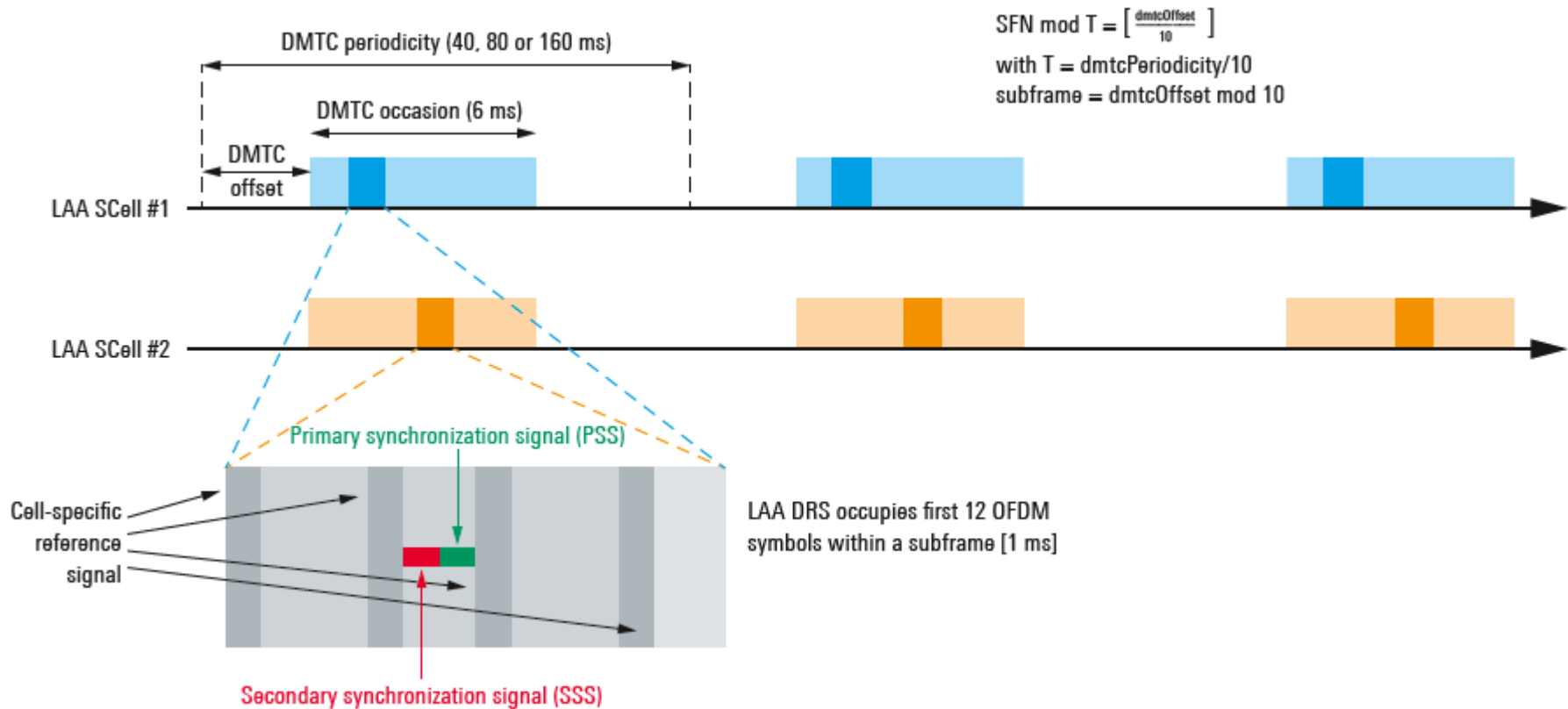
LAA LBT DL procedure

| Channel access priority class (p) | $m_p$ | $CW_{min,p}$ | $CW_{max,p}$ | $T_{mcot,p}$ | allowed $CW_p$ sizes        |
|-----------------------------------|-------|--------------|--------------|--------------|-----------------------------|
| 1                                 | 1     | 3            | 7            | 2 ms         | {3,7}                       |
| 2                                 | 1     | 7            | 15           | 3 ms         | {7,15}                      |
| 3                                 | 3     | 15           | 63           | 8 or 10 ms   | {15,31,63}                  |
| 4                                 | 7     | 15           | 1023         | 8 or 10 ms   | {15,31,63,127,255,511,1023} |

priorities for channel access

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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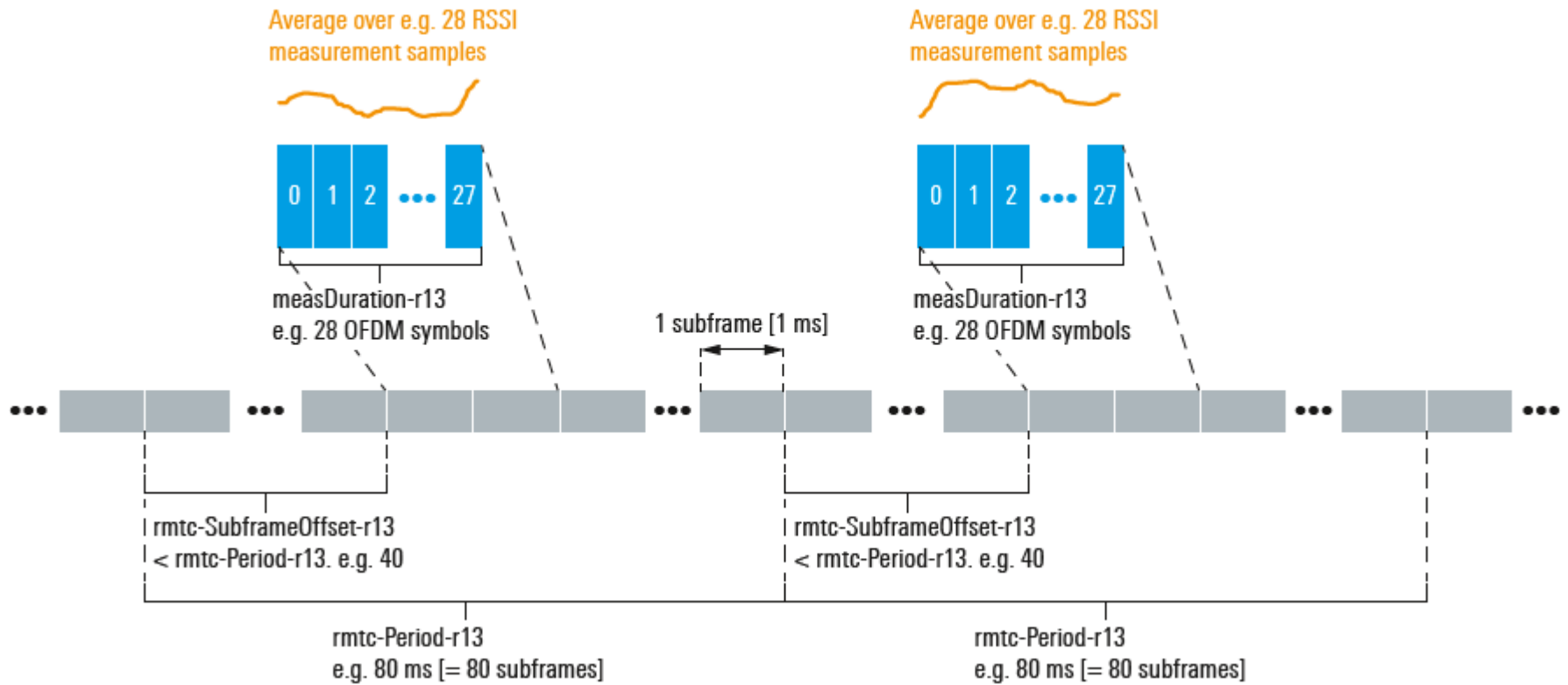


DRS in LAA

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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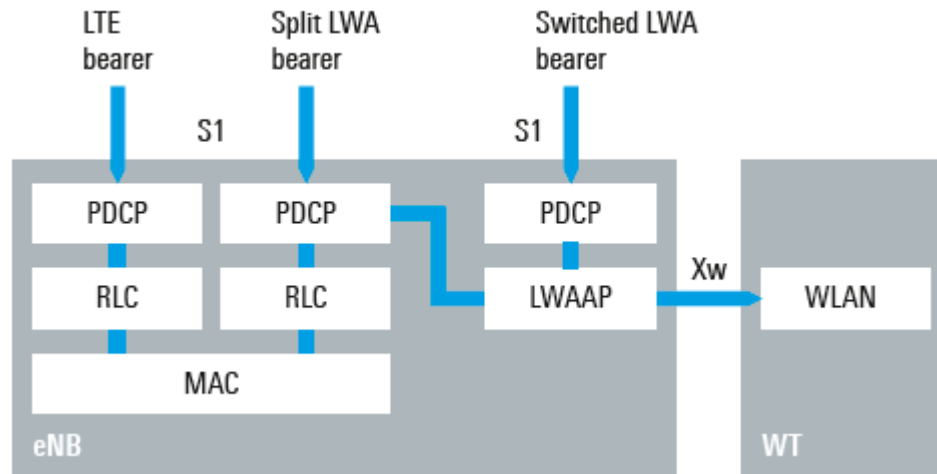


example of RSSI based channel time utilization measurement

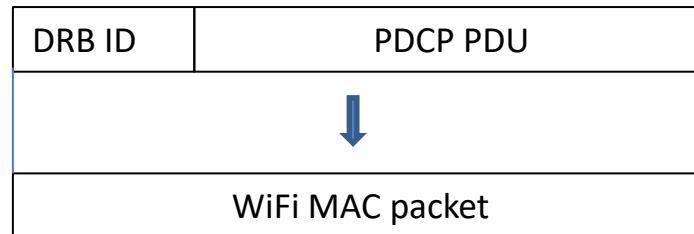
source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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radio protocol architecture for eNB and WT

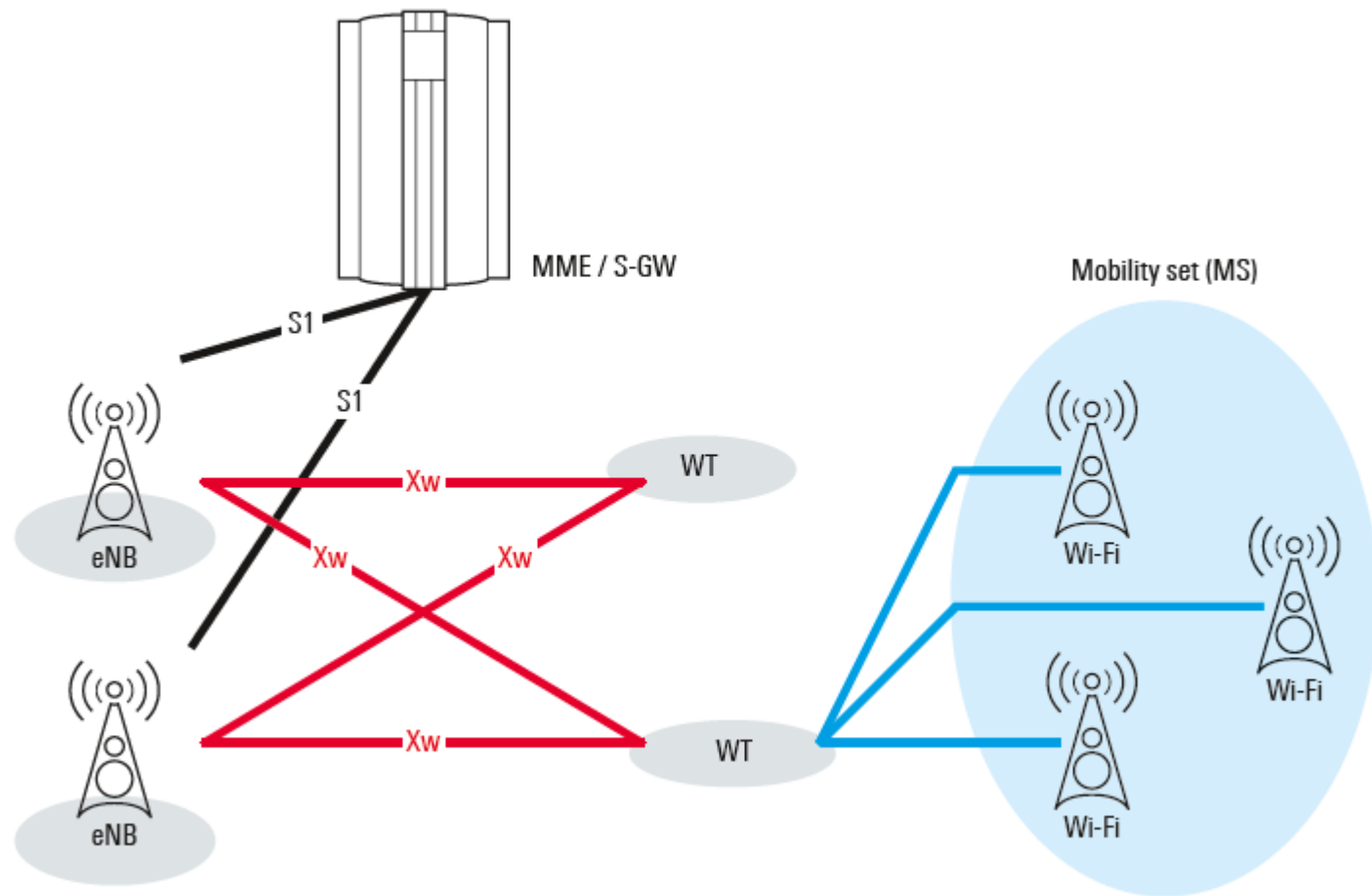


encapsulation of LW PDU into WiFi MAC packet

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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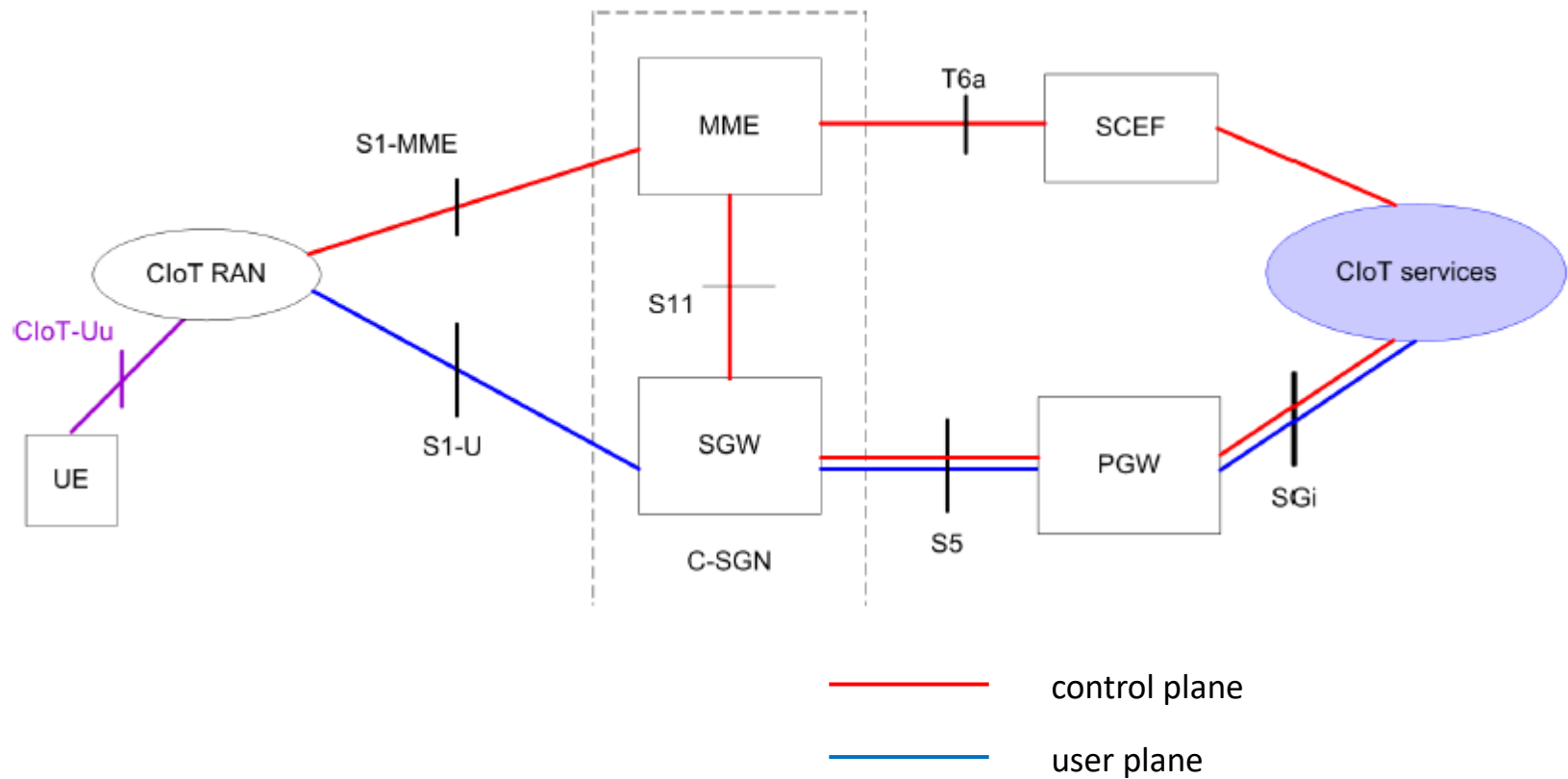


overall architecture of LWA

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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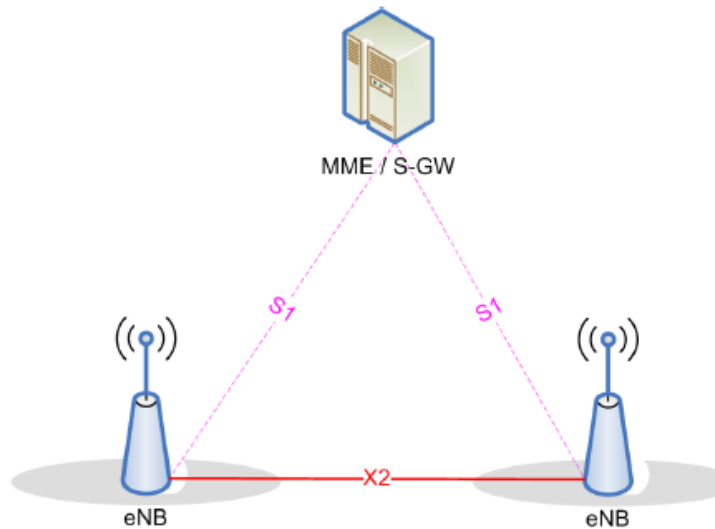


Network architecture for NB-IoT

source: Rhode & Schwarz: NB-IoT White paper

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network architecture towards  
towards the radio interface

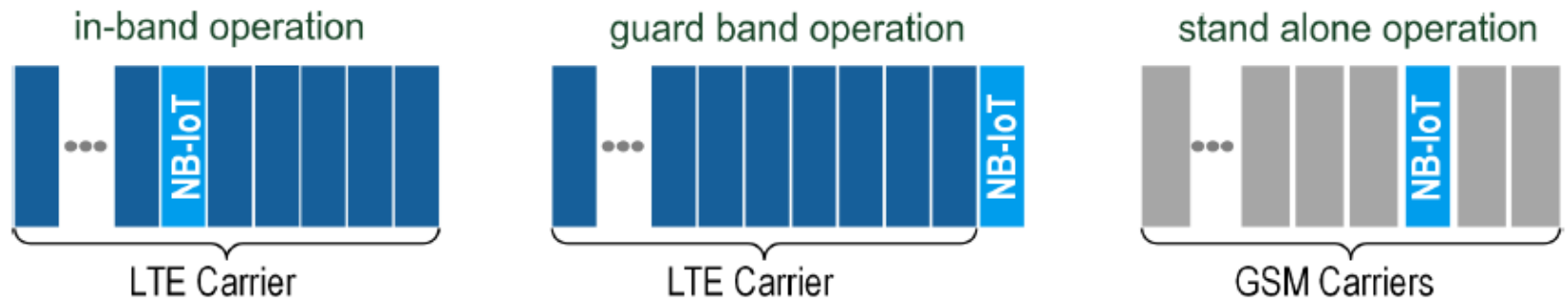
| Band Number | Uplink frequency range / MHz | Downlink frequency range / MHz |
|-------------|------------------------------|--------------------------------|
| 1           | 1920 - 1980                  | 2110 - 2170                    |
| 2           | 1850 - 1910                  | 1930 - 1990                    |
| 3           | 1710 - 1785                  | 1805 - 1880                    |
| 5           | 824 - 849                    | 869 - 894                      |
| 8           | 880 - 915                    | 925 - 960                      |
| 12          | 699 - 716                    | 729 - 746                      |
| 13          | 777 - 787                    | 746 - 756                      |
| 17          | 704 - 716                    | 734 - 746                      |
| 18          | 815 - 830                    | 860 - 875                      |
| 19          | 830 - 845                    | 875 - 890                      |
| 20          | 832 - 862                    | 791 - 821                      |
| 26          | 814 - 849                    | 859 - 894                      |
| 28          | 703 - 748                    | 758 - 803                      |
| 66          | 1710 - 1780                  | 2110 - 2200                    |

frequency bands for NB-IoT

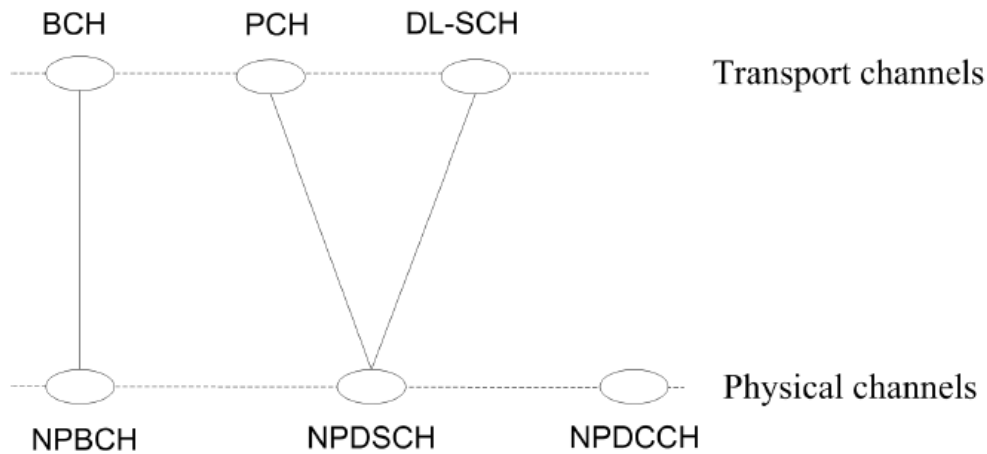
source: Rhode & Schwarz: NB-IoT White paper

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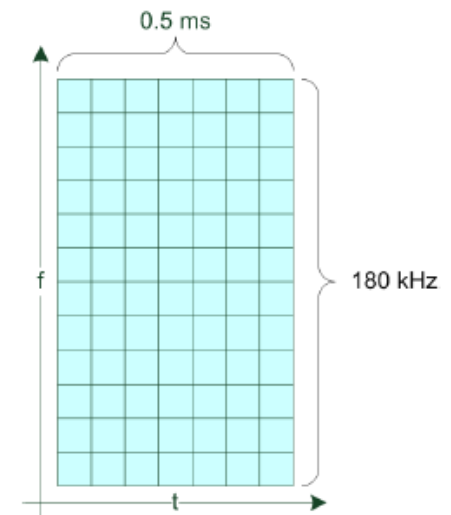
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NB-IoT operating modes



new DL PHY channels in NB-IoT



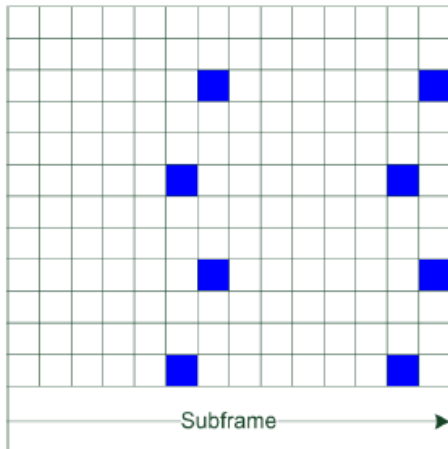
1 slot

source: Rhode & Schwarz: NB-IoT White paper

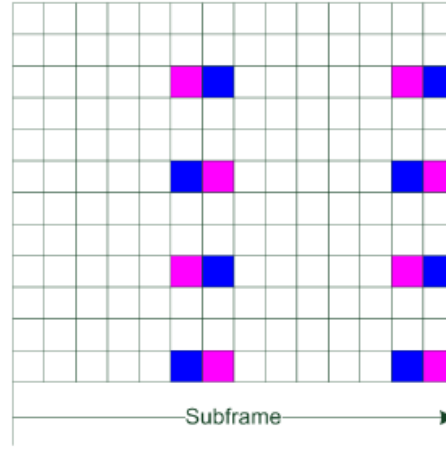
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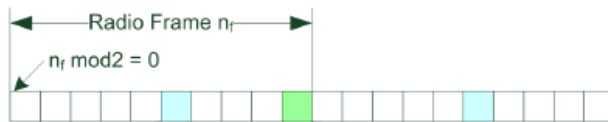
One Antenna Port



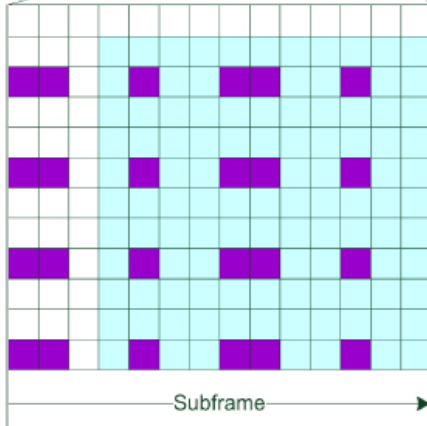
Two Antenna Ports



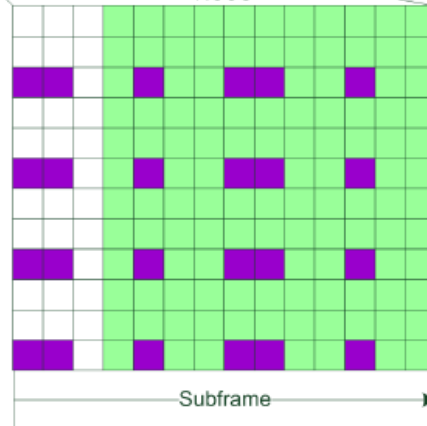
NB-IoT NRS



NPSS



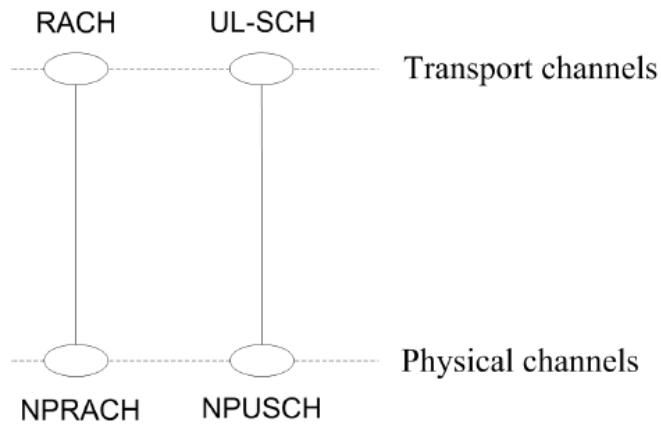
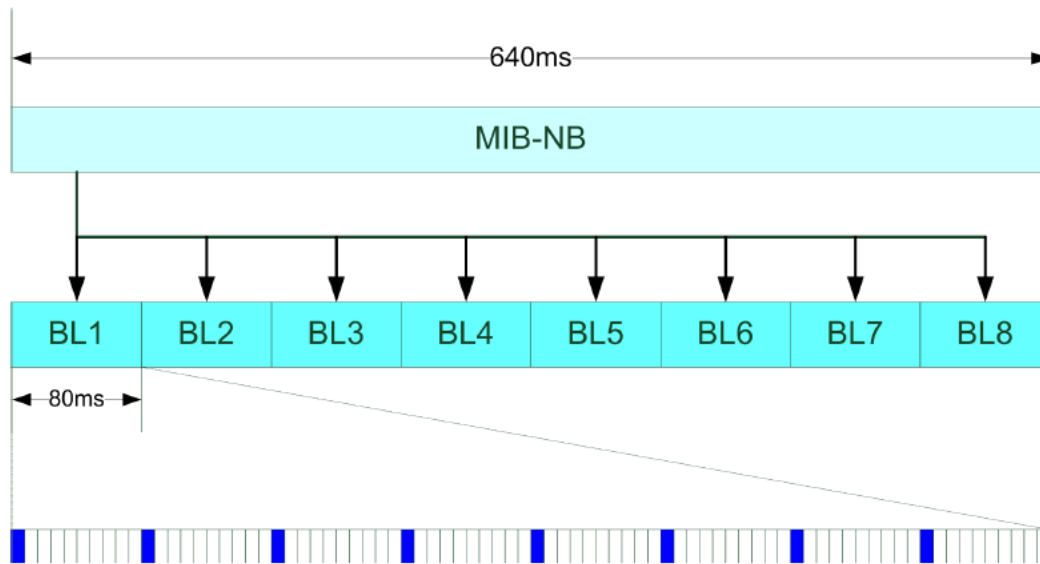
NSSS



NB-IoT NPSS and NSSS

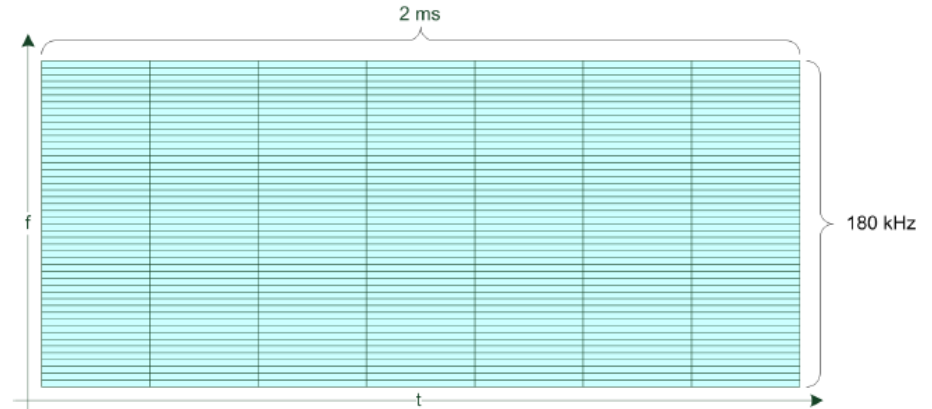
source: Rhode & Schwarz: NB-IoT White paper

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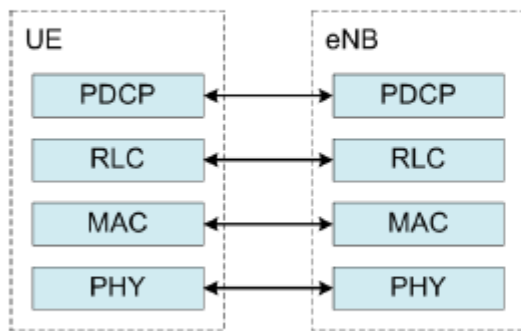


new UL PHY channels in NB-IoT

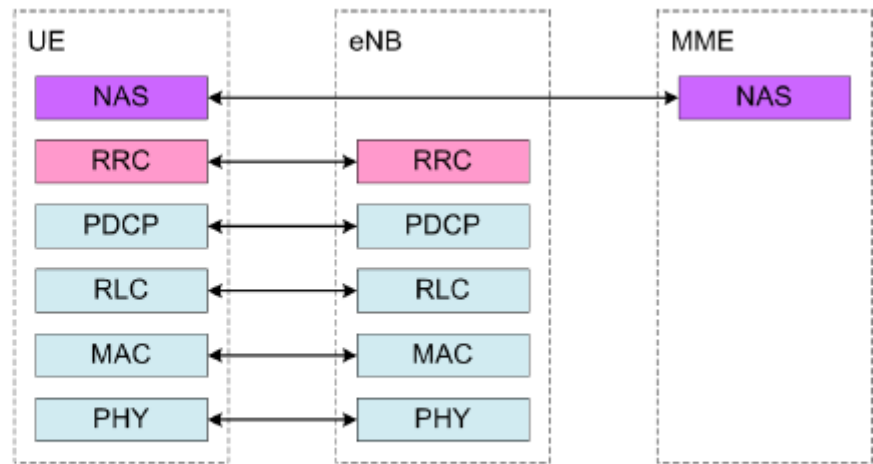
source: Rhode & Schwarz: NB-IoT White paper



slot structure at 3.75 kHz spacing



User Plane



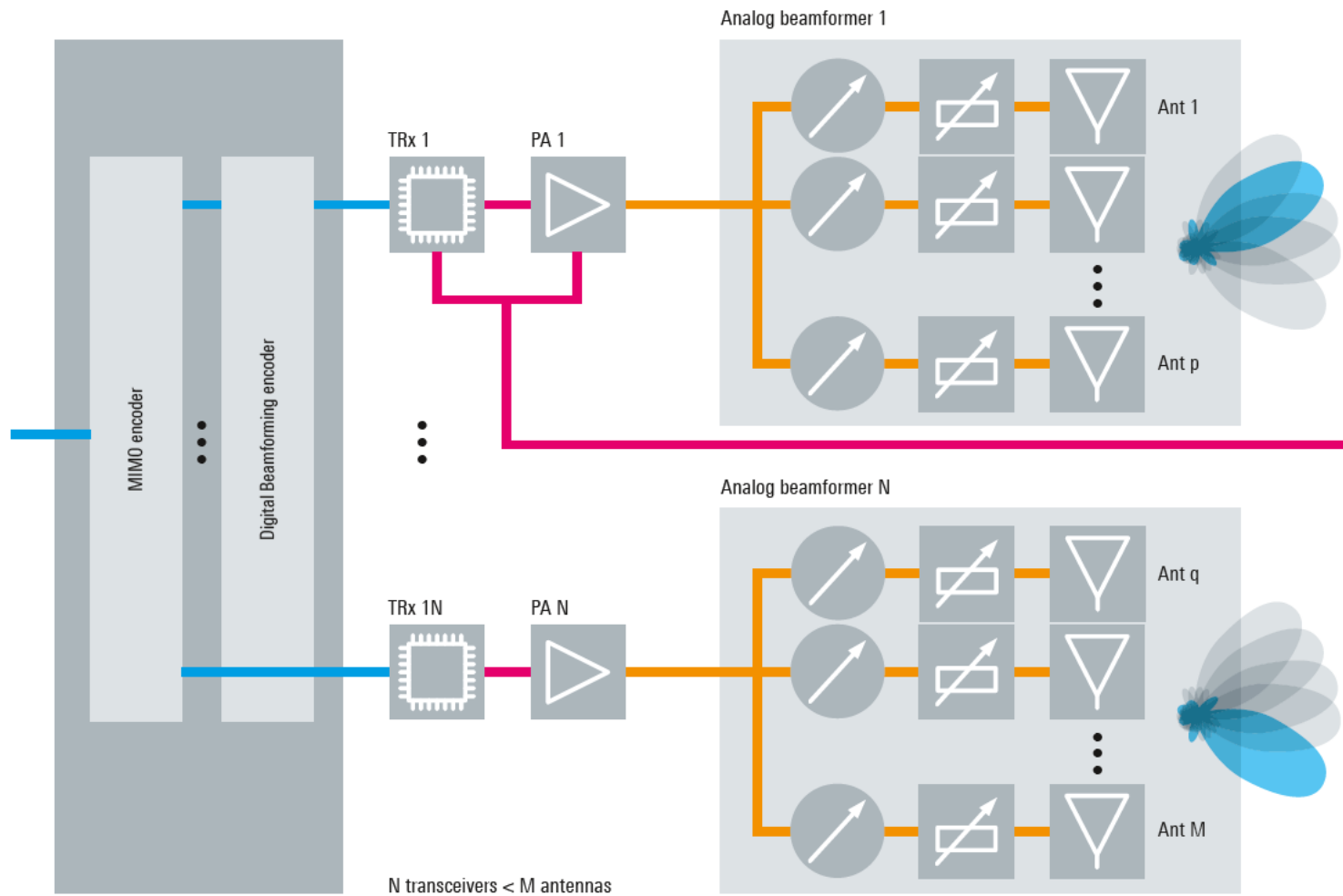
Control Plane

### NB-IoT protocol structure

source: Rhode & Schwarz: NB-IoT White paper

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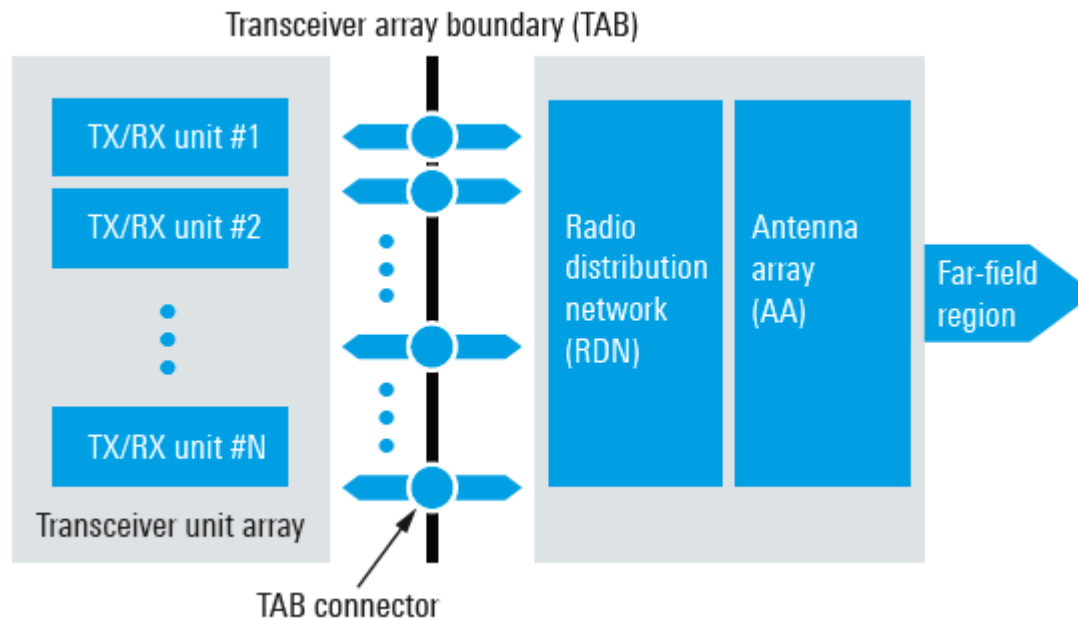


## Massive MIMO system architecture

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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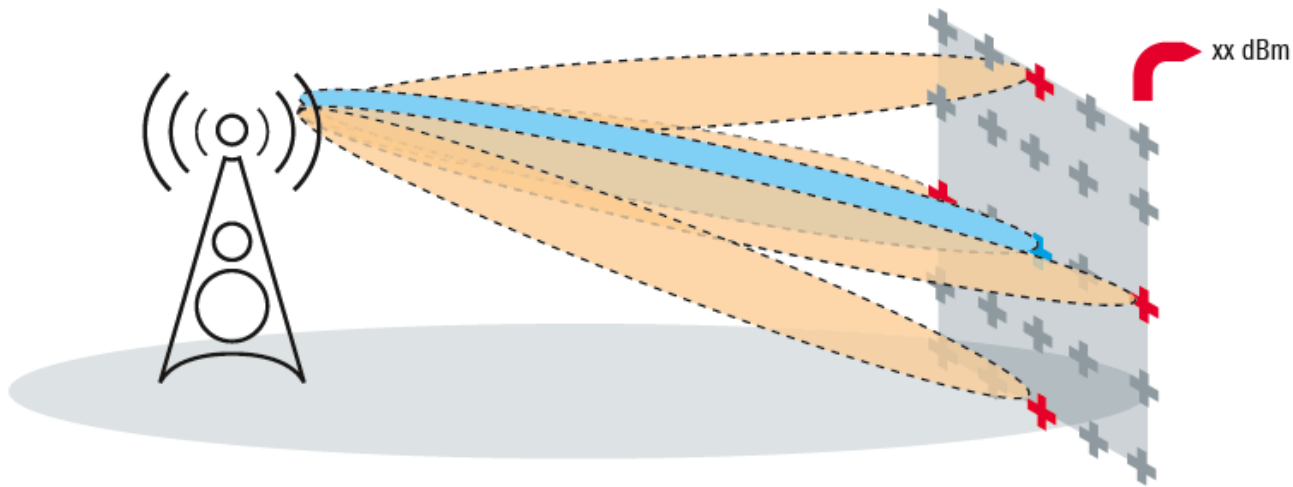


general AAS architecture

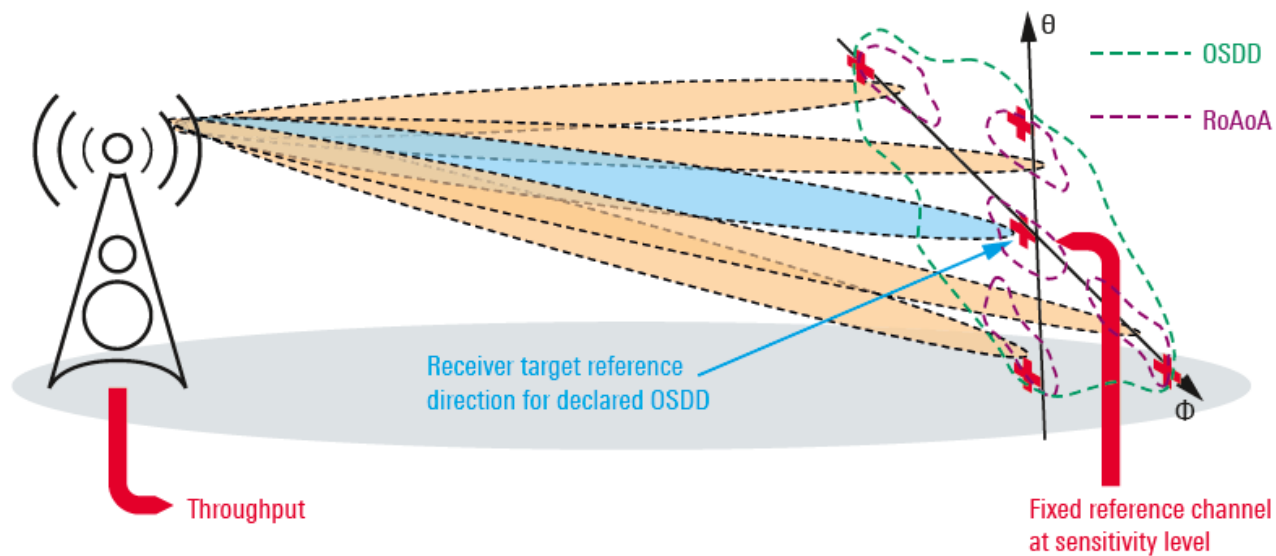
source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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example of AAS intermittent TX traffic (DL direction)

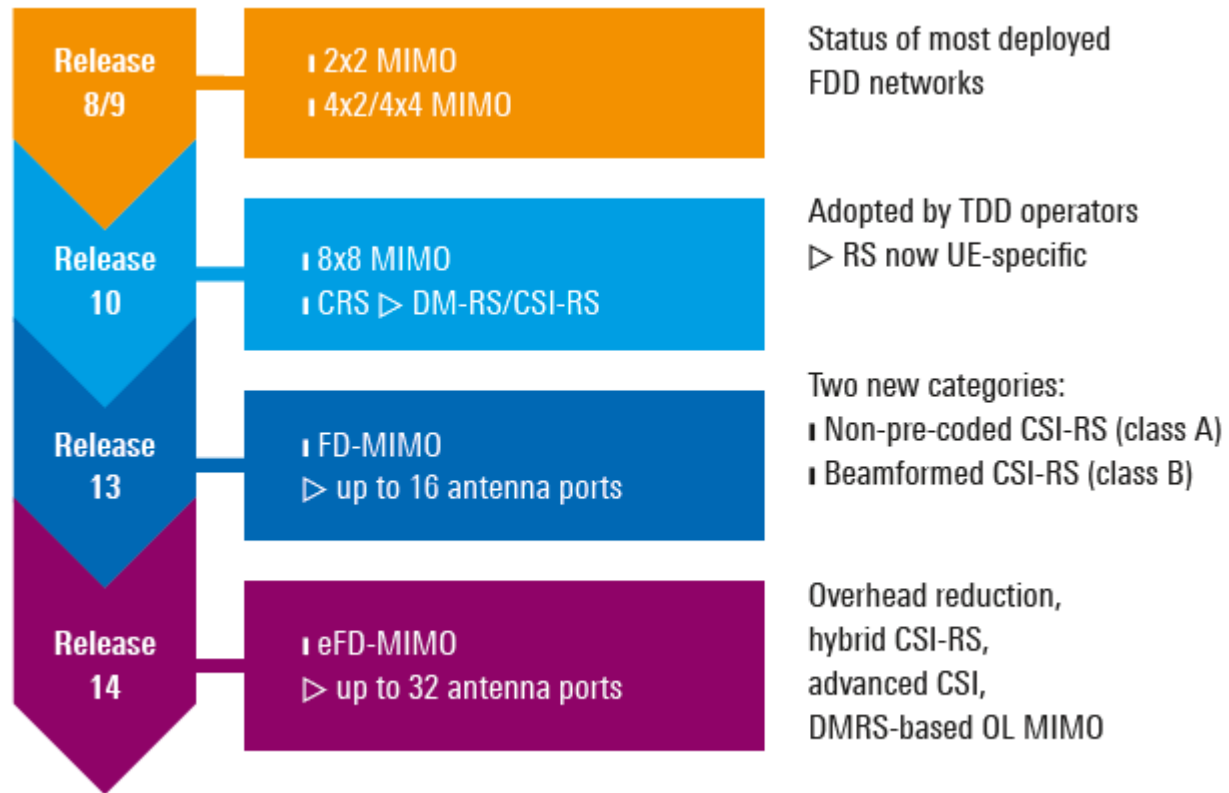


example of AAS OSDD (UL direction)

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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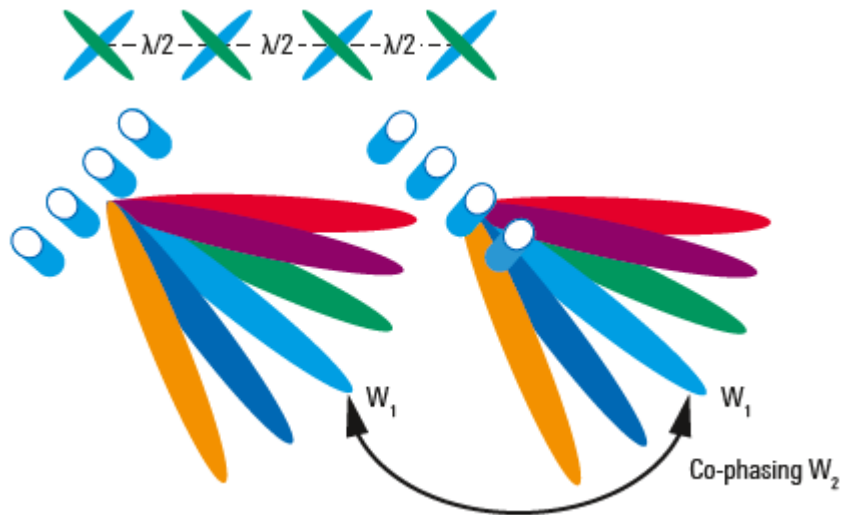


### MIMO application development in LTE

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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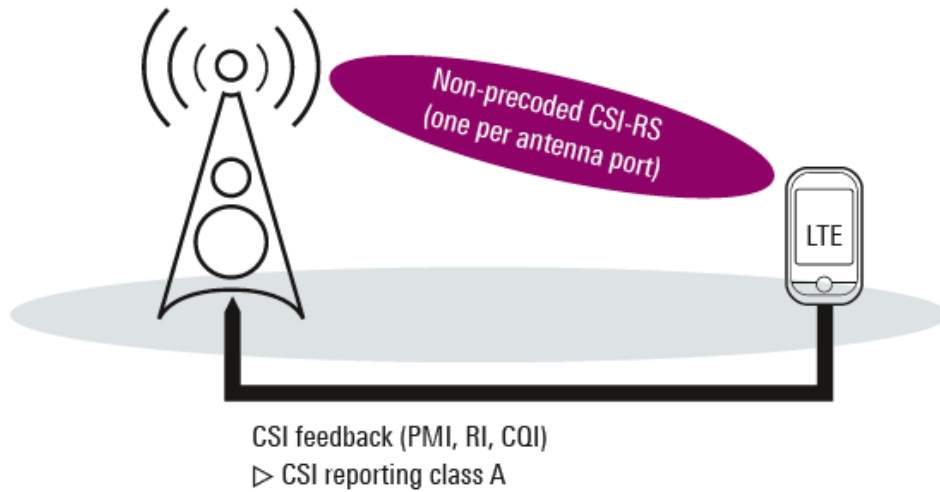


beam selection for polarization group using PMI

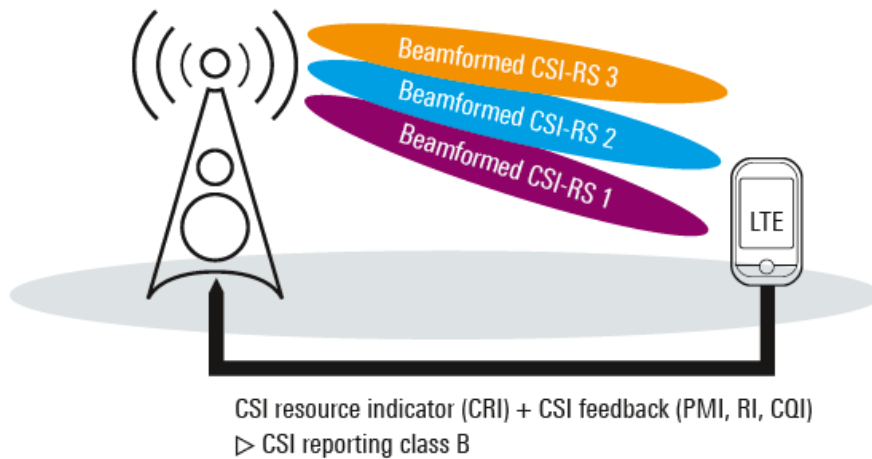
source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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non-precoded CSI-RS traffic

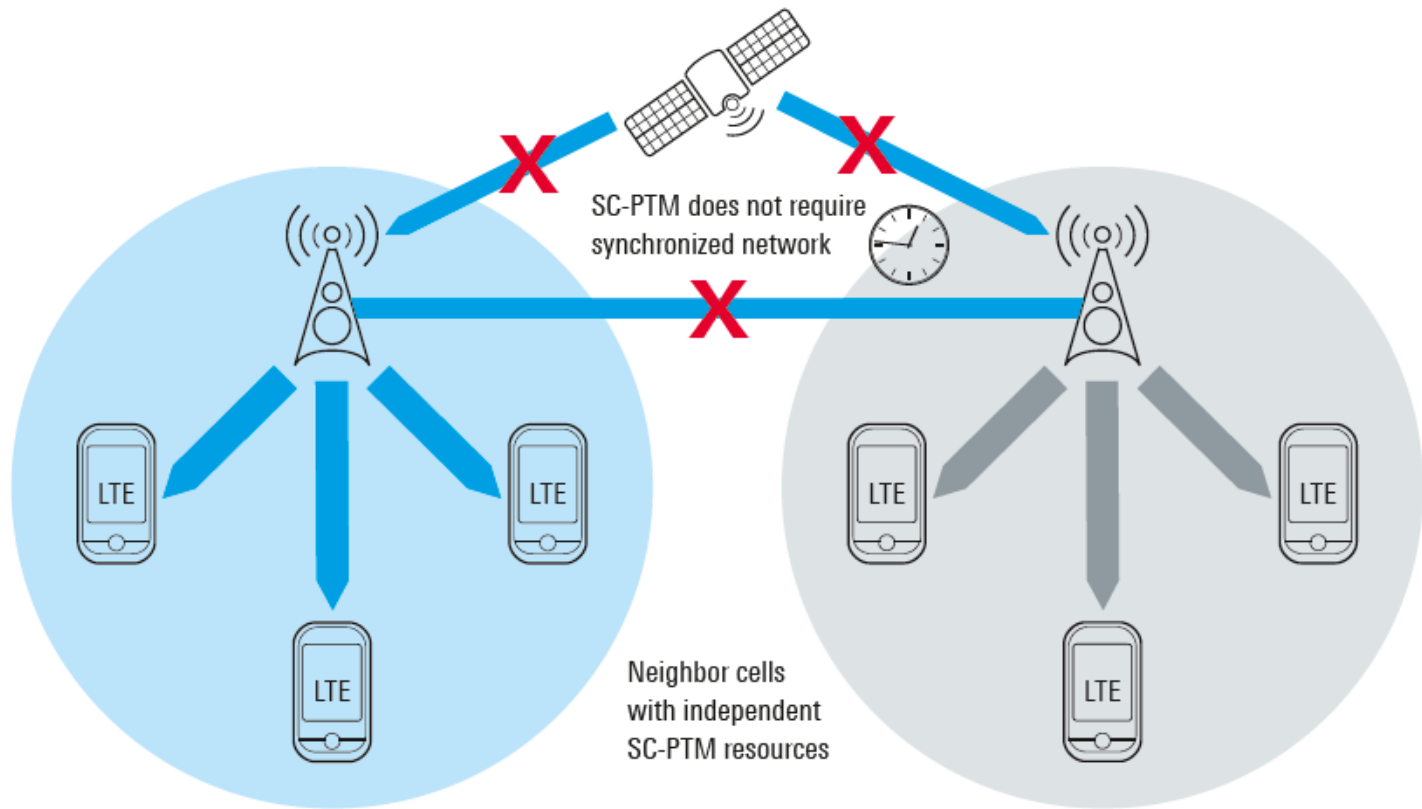


CSI-RS operation with beamforming

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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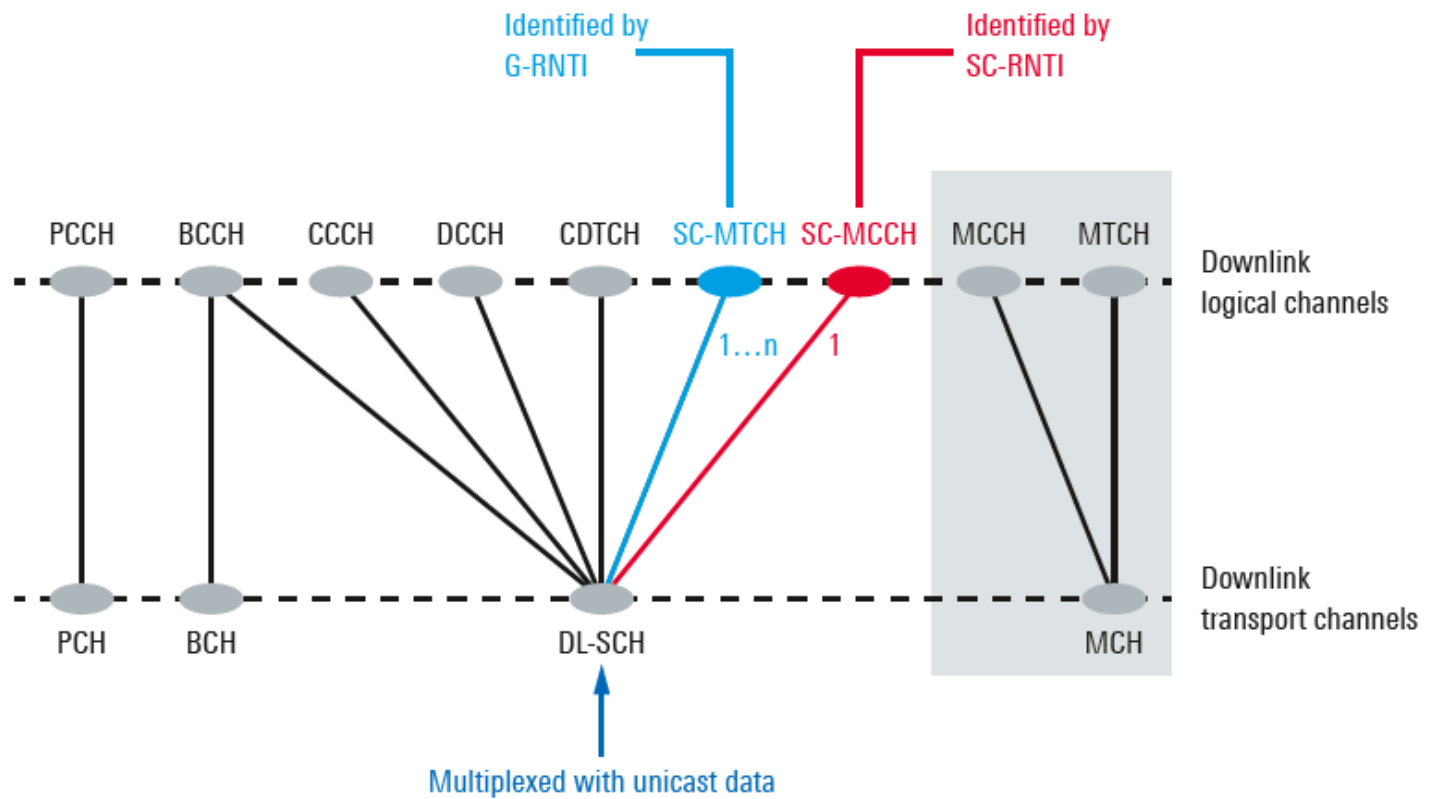


## SC-PTM

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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SC-PTM - new logical channels

source: Rhode & Schwarz: LTE-Advanced Pro Introduction

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