5G/NR - Carrier Bandwith Part

BWP (BandWidth Part) in a Nutshell

- What is it ? BWP is a mechanism to configure/divide a whole channel band into multiple segments and switch among the subbands depending on situation
- BWPs can overlap in terms of frequency span and location
- Minimum bandwidth of a BWP should be equal or larger than SSB Bandwidth
- It is not mandatory for every BWP should transmit SSB
- Max number of BWP that can configured is 4, but only one of them can be active at a specific time.
- Each DL BWP should have at least one CORESET with UE Specific Search Space (USS)
- In Primary DL BWP, there should be at least one CORESET with Common Search Space (CSS)
- There are roughly 3 ways of BWP switching : Timer based, DCI based, RRC Based
- It would require a certain amount of time to switch between BWPs and the minimum switching time is up to UE capability which should be informed to network via UE capability Information.

BWP(Carrier Bandwidth Part) in Detail

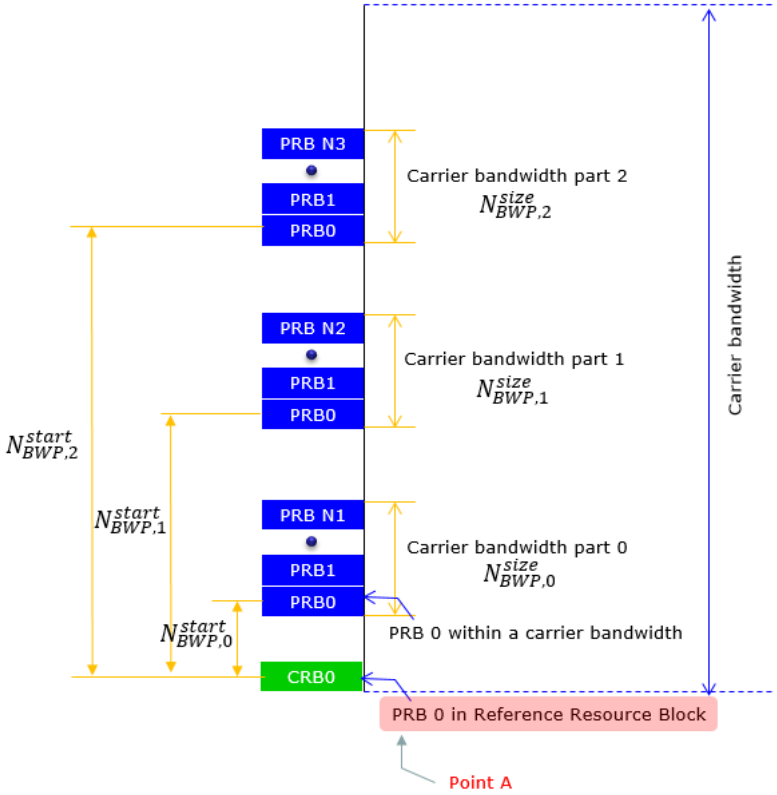
This page is about another new concept in NR called BWP(BandWidth Part). BWP is a part of the total channel bandwidth configured for a cell that is used for a UE at a specific moment of operation. Usually a cell configures multiple BWPs out of the total channel bandwidth and select a specific one at each moment of operation. I think the purpose and concept of BWP is very similar to NarrowBand in LTE M1.

Definition of BWP

According to 38.211 4.4.5, A carrier bandwidth part is defined as follows :

Carrier Bandwidth Part is a contiguous set of physical resource blocks,selected from a contiguous subset of the common resource blocks for a given numerology(u) on a given carrier. It can be illustrated as below.

NOTE : Maximum 4 BWP can be specified in DL and UL. Following illustration is only an example showing the case of 3 BWP. (NOTE : CRB in this illustration stands for Carrier Resource Block which is numbered from the one end through the other end of Carrier Band (this is a kind of global resource block), the PRB stands for Physical Resource Block is the resource blocks numbered within each BWP).



Point A indicates a common reference point for resource block grids and is obtained from the following higher-layer parameters as described in 38.211 - 4.4.4.2:

- PRB-index-DL-common for a PCell downlink represents the frequency offset between point A and the lowest subcarrier of the lowest resource block of the SS/PBCH block used by the UE for initial cell selection;
- PRB-index-UL-common for a PCell uplink in paired spectrum represents the frequency offset between point A and the frequency location based on ARFCN of the uplink indicated in SIB1;
- PRB-index-UL-common for a PCell uplink in unpaired spectrum represents the frequency offset between point A and the lowest subcarrier of the lowest resrouce block of the SS/PBCH block used by the UE for initial cell selection;
- PRB-index-DL-Dedicated for an SCell downlink represents the frequency offset between point A and the frequency location based on ARFCN in the higher-layer SCell configuration;
- PRB-index-UL-Dedicated for an SCell uplink represents the frequency offset between point A and the frequency location based on ARFCN in the higher-layer SCell configuration;
- PRB-index-SUL-common for a supplementary uplink represents the frequency offset between point A and the frequency location based on ARFCN in the higher-layer SUL configuration.

Carrier Bandwidth Part allocation for DL and UL

< Downlink >

- A UE can be configured with up to four carrier bandwidth parts
- The bandwidth of each BW should be equal or greater than SS Block BW, but it may or may not contain SS Block.
- Only one carrier bandwidth part can be active at a given time
- The UE is not expected to receive PDSCH, PDCCH, CSI-RS, or TRS outside an active bandwidth part.
- Each DL BWP include at least one CORESET with UE Specific Search Space (USS).
- In primary carrier, at least one of the configured DL BWPs includes one CORESET with common search space (CSS)

< Uplink >

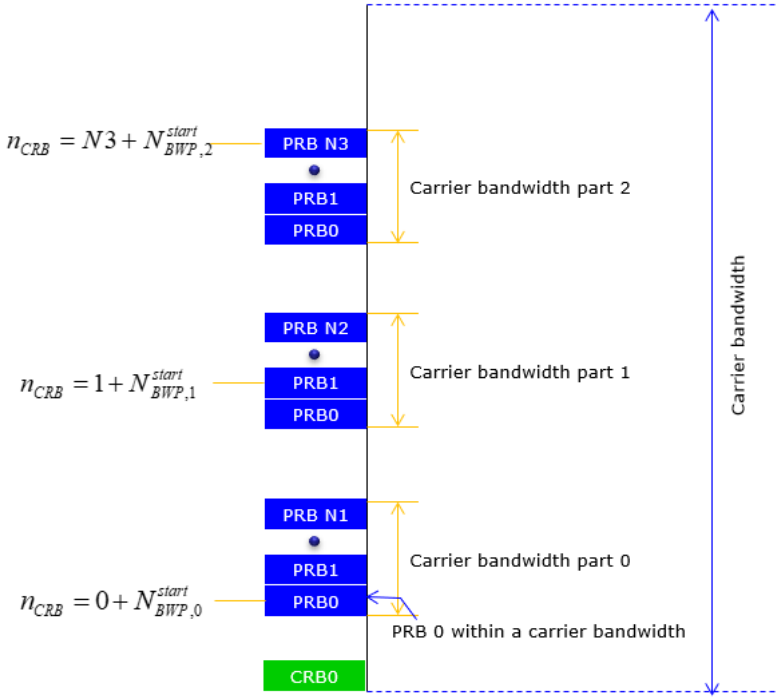
- A UE can be configured with up to four carrier bandwidth parts
- Only one carrier bandwidth part can be active at a given time
- If a UE is configured with a supplementary uplink
  - The UE can in addition be configured with up to four carrier bandwidth parts in the supplementary uplink
  - Only one carrier bandwidth part can be active at a given time
- The UE shall not transmit PUSCH or PUCCH outside an active bandwidth part.

Mapping between nCRB and nPRB

nCRB indicates a resource block location in common resource block, nPRB indicates a resource block within a specific carrier bandwidth part. In other words, you can think of nCRB is a position in an absolute (reference) coordinate system and nPRB is a position in a relative coordinate system. The relationship between nCRB and nPRB is defined as follows (38.211 v2.0.0 - 4.4.4.4).

$$n_{CRB} = n_{PRB} + N^{start}_{BWP,j}$$

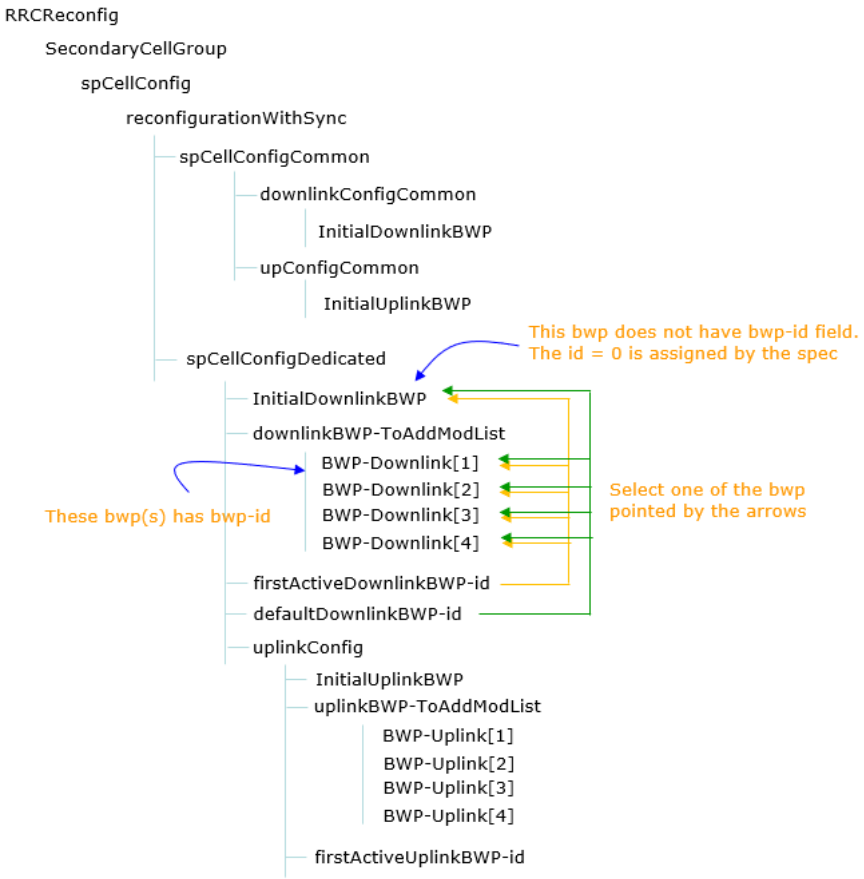
This can be illustrated as an example shown below.



BWP types

There are several different types of BWPs : Initial BWP, firstActiveBWP, Default BWP and (regular) BWPs. These are defined in RRC message as follows. Regarding the role of each BWP, refer to the diagram in this section and RRC parameter description in this section.

< BWP configuration in ENDC RRCReconfig >



RRC Parameters for BandwidthPart Configuration

Following is based on 38.331 v15.7.0

ServingCellConfig ::= SEQUENCE {
tdd-UL-DL-ConfigurationDedicated TDD-UL-DL-ConfigDedicated OPTIONAL,-- Cond TDD
initialDownlinkBWP BWP-DownlinkDedicated OPTIONAL, -- Cond ServCellAdd
downlinkBWP-ToReleaseList SEQUENCE (SIZE (1..maxNrofBWPs)) OF BWP-Id OPTIONAL,

```
  downlinkBWP-ToAddModList      SEQUENCE (SIZE (1..maxNrofBWPs)) OF BWP-Downlink OPTIONAL
  firstActiveDownlinkBWP-Id     BWP-Id     OPTIONAL,   -- Need R
  bwp-InactivityTimer       ENUMERATED {ms2, ms3, ms4, ms5, ms6, ms8, ms10, ms20,
                            ms30, ms40,ms50, ms60, ms80, ms100, ms200,
                            ms300, ms500, ms750, ms1280, ms1920, ms2560,
                            spare10, spare9, spare8, spare7, spare6,
                            spare5, spare4, spare3, spare2, spare1 } OPTIONAL,
  defaultDownlinkBWP-Id     BWP-Id     OPTIONAL,   -- Need M
  uplinkConfig          UplinkConfig   OPTIONAL, -- Cond ServCellAdd-UL
  supplementaryUplink       UplinkConfig   OPTIONAL, -- Cond ServCellAdd-SUL
  pdsch-ServingCellConfig    SetupRelease { PDSCH-ServingCellConfig } OPTIONAL, -- Need M
  csi-MeasConfig          SetupRelease { CSI-MeasConfig } OPTIONAL,   -- Need M
  carrierSwitching        SetupRelease { SRS-CarrierSwitching} OPTIONAL,  -- Need M
  sCellDeactivationTimer     ENUMERATED {ms20, ms40, ms80, ms160, ms200, ms240, ms320,
                            ms400, ms480, ms520, ms640, ms720, ms840,
                            ms1280, spare2,spare1} OPTIONAL,-- Cond
  .....
  }

maxNrofBWPs INTEGER ::= 4

UplinkConfig ::=   SEQUENCE {
  initialUplinkBWP        BWP-UplinkDedicated OPTIONAL,   -- Cond ServCellAdd.
  uplinkBWP-ToReleaseList    SEQUENCE (SIZE (1..maxNrofBWPs)) OF BWP-Id OPTIONAL,-- Need N
  uplinkBWP-ToAddModList     SEQUENCE (SIZE (1..maxNrofBWPs)) OF BWP-Uplink  OPTIONAL,
  firstActiveUplinkBWP-Id    BWP-Id  OPTIONAL,   -- Need R
  pusch-ServingCellConfig    SetupRelease { PUSCH-ServingCellConfig } OPTIONAL,
  ...
}


BWP-Downlink ::=   SEQUENCE {
  bwp-Id          BWP-Id,
  bwp-Common        BWP-DownlinkCommon
  bwp-Dedicated     BWP-DownlinkDedicated
  ...
}


BWP-DownlinkCommon ::=     SEQUENCE {
  genericParameters  BWP,
  pdcch-ConfigCommon  SetupRelease { PDCCH-ConfigCommon }
  pdsch-ConfigCommon  SetupRelease { PDSCH-ConfigCommon }
  ...
}

BWP-DownlinkDedicated ::=  SEQUENCE {
  pdcch-Config        SetupRelease { PDCCH-Config }
  pdsch-Config        SetupRelease { PDSCH-Config }
  sps-Config       SetupRelease { SPS-Config }
  radioLinkMonitoringConfig  SetupRelease { RadioLinkMonitoringConfig }
  ...
}


BWP-Uplink ::=     SEQUENCE {
  bwp-Id          BWP-Id,
  bwp-Common        BWP-UplinkCommon
  bwp-Dedicated     BWP-UplinkDedicated
  ...
}


BWP-UplinkCommon ::=   SEQUENCE {
  genericParameters  BWP,
  rach-ConfigCommon  SetupRelease { RACH-ConfigCommon }
  pusch-ConfigCommon  SetupRelease { PUSCH-ConfigCommon }
  pucch-ConfigCommon  SetupRelease { PUCCH-ConfigCommon }
  ...
}


BWP-UplinkDedicated ::=    SEQUENCE {
  pucch-Config             SetupRelease { PUCCH-Config }          OPTIONAL,--Need M
  pusch-Config             SetupRelease { PUSCH-Config }          OPTIONAL,--Need M
  configuredGrantConfig       SetupRelease { ConfiguredGrantConfig }     OPTIONAL,--Need M
  srs-Config               SetupRelease { SRS-Config }            OPTIONAL,--Need M
  beamFailureRecoveryConfig     SetupRelease { BeamFailureRecoveryConfig }  OPTIONAL,--Need M
  ...
}


BWP ::=    SEQUENCE {
  locationAndBandwidth      INTEGER (0..37949),
  subcarrierSpacing       SubcarrierSpacing,
  cyclicPrefix          ENUMERATED { extended }
}
```

initialDownlinkBWP : The dedicated (UE-specific) configuration for the initial downlink bandwidth-part. As described in 38.331, this is the dedicated (UE-specific) configuration for the initial downlink bandwidth-part (i.e. DL BWP#0). If any of the optional IEs are configured within this IE, the UE considers the BWP#0 to be an RRC configured BWP (from UE capability viewpoint). Otherwise, the UE does not consider the BWP#0 as an RRC configured BWP (from UE capability viewpoint). Network always configures the UE with a value for this field if no other BWPs are configured. Network always configures the UE with a value for this field if no other BWPs are configured. If the dedicated part of initial UL/DL BWP configuration is absent, the initial BWP can be used but with some limitations. For example, changing to another BWP requires RRCReconfiguration since DCI format 1_0 doesn't support DCI-based switching.

firstActiveDownlinkBWP-Id: This is the BWP to be active right after the initial attach (or NR addition) is completed.
If configured for an SpCell, this field contains the ID of the DL BWP to be activated upon performing the reconfiguration in which it is received. If the field is absent, the RRC reconfiguration does not impose a BWP switch (corresponds to L1 parameter 'active-BWP-DL-Pcell'). If configuredfor an SCell, this field contains the ID of the downlink bandwidth part to be used upon MAC-activation of an SCell. The initial bandwidth part is referred to by BWP-Id = 0

defaultDownlinkBWP-Id : This indicates the BWP that UE/NW automatically switches when there is no activity in current BWP until bwp-InactivityTimer. If this field is set to 0, it means the defaultDownlinkBWP is same as initialDownlinkBWP. ID of the downlink bandwidth part to be used upon expiry of the BWP inactivity timer. This field is UE specific. When the field is absent the UE uses the initial BWP as default BWP.

bwp-InactivityTimer : The duration in ms after which the UE falls back to the default Bandwidth Part. The value 0.5 ms is only applicable for carriers > 6 GHz. When the network releases the timer configuration, the UE stops the timer without swithching to the default BWP

initialUplinkBWP : If configured for an SpCell, this field contains the ID of the DL BWP to be activated upon performing the reconfiguration in which it is received. If the field is absent, the RRC reconfiguration does not impose a BWP switch (corresponds to L1 parameter 'active-BWP-UL-Pcell'). If configured for an SCell, this field contains the ID of the uplink bandwidth part to be used upon MAC-activation of an SCell. The initial bandwidth part is referred to by BandiwdthPartId = 0

firstActiveUplinkBWP-Id : The dedicated (UE-specific) configuration for the initial uplink bandwidth-part.

BWP-Id : An identifier for this bandwidth part. Other parts of the RRC configuration use the BWP-Id to associate themselves with a particular bandwidth part. The BWP ID=0 is always associated with the initial BWP and may hence not be used here (in other bandwidth parts).
The NW may trigger the UE to swtich UL or DL BWP using a DCI field. The four code points in that DCI field map to the RRC-configured

- BWP-ID as follows: For up to 3 configured BWPs (in addition to the initial BWP) the DCI code point is equivalent to the BWP ID
  - (initial = 0, first dedicated = 1, ...). If the NW configures 4 dedicated bandwidth parts, they are identified by DCI code
  - points 0 to 3. In this case it is not possible to switch to the initial BWP using the DCI field.
  - Corresponds to L1 parameter 'UL-BWP-index' / 'DL-BWP-index'.

locationAndBandwidth : Frequency domain location and bandwidth of this bandwidth part. The value of the field shall be interpreted as resource indicator value (RIV). See here for the details

subcarrierSpacing : Subcarrier spacing to be used in this BWP for all channels and reference signals unless explicitly configured elsewhere. It corresponds to subcarrier spacing according to 38.211-Table 4.2-1. The value kHz15 corresponds to μ=0, kHz30 to μ=1, and so on. Only the values 15 or 30 kHz (<6GHz), 60 or 120 kHz (>6GHz) are applicable.

How BWP are defined ?

As mentioned in Carrier Bandwidth Part allocation for DL and UL, maximum 4 BWPs can be defined in DL and UL. Each of BWP are configured by RRC messages as described in RRC Parameters for BandwidthPart Configuration.

How BWP location and bandwidth is specified in RRC ?

The location (starting position and the bandwidth of a BWP is specified in RRC parameter called locationAndBandwidth and this parameter is specified as RIV that can be calculated according to the following specification.

< 38.213-12 Bandwidth part operation > states as follows :

> *a first PRB and a number of contiguous PRBs by higher layer parameter locationAndBandwidth that is interpreted as RIV according to TS 38.214, setting N_{BWP}^{size}=275, and the first PRB is a PRB offset relative to the PRB indicated by higher layer parameters offsetToCarrier and subcarrierSpacing*

< 38.214-5.1.2.2.2 Downlink resource allocation type 1> defines RIV as follows :

$$\text{if } (L_{RBs}-1) \le \lfloor N_{BWP}^{size}/2 \rfloor \text{ then}$$

$$RIV = N_{BWP}^{size}(L_{RBs}-1) + RB_{start} \quad \text{----------} \quad (1)$$

else

$$RIV = N_{BWP}^{size}(N_{BWP}^{size} - L_{RBs} + 1) + (N_{BWP}^{size} - 1 - RB_{start}) \quad \text{----------} \quad (2)$$

Combining the two specification mentioned above, I would come up with some examples as shown below. All these examples are based on the assumption that RB_start = 0, BWP takes up the maximum RB for the specified channel bandwidth and subcarrierspacing = 30 Khz, FR1

CBW	max RB	Equation	RIV Calculation	locationAndBandwidth
5	11	(1)	275*(11-1)+0	2750
10	24	(1)	275*(24-1)+0	6325
15	38	(1)	275*(38-1)+0	10175
20	51	(1)	275*(51-1)+0	13750
25	65	(1)	275*(65-1)+0	17600
30	78	(1)	275*(78-1)+0	21175
40	106	(1)	275*(106-1)+0	28875
50	133	(1)	275*(133-1)+0	36300

60	162	(2)	275*(275-162+1)+(275-1-0)	31624
70	189	(2)	275*(275-189+1)+(275-1-0)	24199
80	217	(2)	275*(275-217+1)+(275-1-0)	16499
90	245	(2)	275*(275-245+1)+(275-1-0)	8799
100	273	(2)	275*(275-273+1)+(275-1-0)	1099

Following is the table that I calculated for subcarrier spacing = 15 Khz based on the assumption that RB_start = 0, BWP takes up the maximum RB for the specified channel bandwidth

CBW	max RB	Equation	RIV Calculation	locationAndBandwidth
5	25	(1)	275*(25-1)+0	6600
10	52	(1)	275*(52-1)+0	14025
15	79	(1)	275*(79-1)+0	21450
20	106	(1)	275*(106-1)+0	28875
25	133	(1)	275*(133-1)+0	36300
30	160	(2)	275*(275-160+1)+(275-1-0)	32174
40	216	(2)	275*(275-216+1)+(275-1-0)	16774
50	270	(2)	275*(275-270+1)+(275-1-0)	1924

Following is the table that I calculated for subcarrier spacing = 120 Khz based on the assumption that RB_start = 0, BWP takes up the maximum RB for the specified channel bandwidth

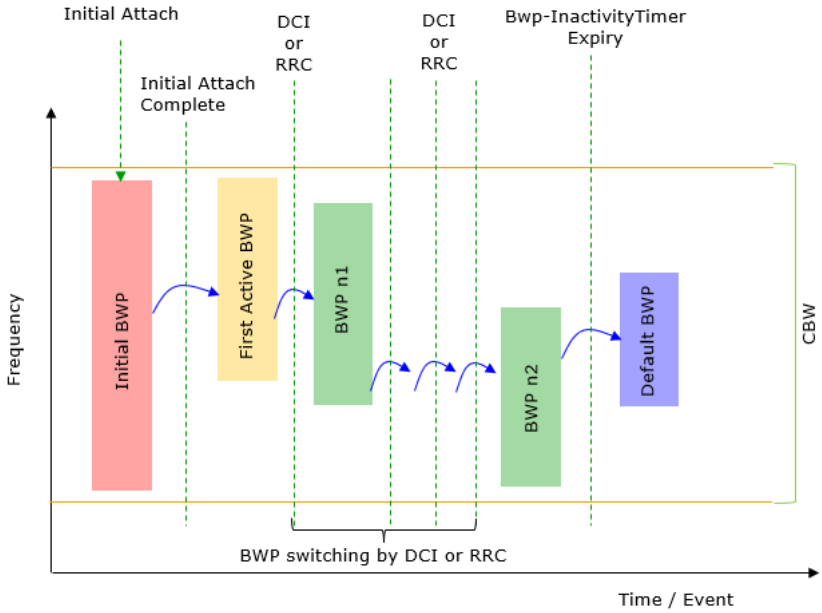
CBW	max RB	Equation	RIV Calculation	locationAndBandwidth
50	32	(1)	275*(32-1)+0	8525
100	66	(1)	275*(66-1)+0	17875
200	132	(1)	275*(132-1)+0	36025
400	264	(2)	275*(275-264+1)+(275-1-0)	3574

How a specific BWP is selected (BWP switching) ?

Even though multiple (max 4) BWPs can be defined in DL and UL, only one BWP can be active at each specific moment. It implies there is some mechainism to select a specific BWP as the active one. According to 38.321-5.15 Bandwidth Part (BWP) operation, BWP selection (or BWP switching) can be done by several different way
s as listed below.

- By PDCCH (i.e, DCI) : A specific BWP can be activated by Bandwidth part indicator in DCI Format 0_1 (a UL Grant) and DCI Format 1_1 (a DL Schedule)
- By the bwp-InactivityTimer : ServingCellConfig.bwp-InactivityTimer
- By RRC signalling
- By the MAC entity itself upon initiation of Random Access procedure

With using the mechanisums listed above, a specific BWP become active depending on various situations in the call processing.The switching process can be summarized in illustration as follows.



Followings are some of the examples of BWP switching for specific cases based on the statement in 3GPP specification. If you have overall understanding as shown above, following description would sound clearer to you.

Case 1 : Upon initiation of the **Random Access procedure** on a Serving Cell (based on 38.321 - 5.15)

if PRACH occasions are not configured for the active UL BWP:
For UL,set the active UL BWP = initialUplinkBWP;
For DL,

if the Serving Cell is a SpCell:
set the active DL BWP = initialDownlinkBWP.

if PRACH occasions are configured for the active UL BWP
For UL,set the active UL BWP = the configured UL BWP
For DL,
if the Serving Cell is a SpCell:
set the active DL BWP = DL BWP with the same bwp-Id as the active UL BWP.

Perform RACH procedure with the active BWP selected as above.

NOTE : What if initialDownlinkBWP is not configured ? According to 38.213-12 Bandwidth part operation, it is stated as follows.

an initial DL BWP is defined by a location and number of contiguous PRBs, starting from a PRB with the lowest index and ending at a PRB with the highest index among PRBs of a CORESET for Type0-PDCCH CSS set, and a SCS and a cyclic prefix for PDCCH reception in the CORESET for Type0-PDCCH CSS set ==> It mean that the initialDlBWP takes up the full RBs defined in FrequencyInfoDL (i.e, Full RB in the CBW)

Case 2 : Rrc **Reconfiguration** with sync (based on 38.331 - 5.3.5.5.2)

"Reconfiguration with sync" is a common mechanism of activing NR cell in NSA (i.e, Adding NR Cell to LTE cell). In this case, Active BWP for DL and UL is set to be as follows .

- Active BWP for DL = firstActiveDownlinkBWP-Id
- Active BWP for UL = firstActiveUplinkBWP-Id

Case 3 : **DCI with Bandwidth part indicator** is recieved

Check if there is any on-going RACH procedure. If there is no on-going RACH procedure or RACH procedure is just completed by the received DCI (masked with C-RNTI).
set the active BWP = the BWP specified by the DCI

NOTE : BWP-id for DL / UL in TDD (unpared spectrum). 38.213-12 Bandwidth part operation states as follows.

For unpaired spectrum operation, a DL BWP from the set of configured DL BWPs with index provided by BWP-Id is linked with an UL BWP from the set of configured UL BWPs with index provided by BWP-Id when the DL BWP index and the UL BWP index are same. ==> Simply put, DL BWP id = UL BWP id

NOTE : Center Frequency of DL/UL BWP in TDD(unpared spectrum)

For unpaired spectrum operation, a UE does not expect to receive a configuration where the center frequency for a DL BWP is different than the center frequency for an UL BWP when the BWP-Id of the DL BWP is same as the BWP-Id of the UL BWP ==> Simply put, Center frequency of DL BWP = Center Frequency of UL BWP

BWP Switching Delay

Changing BWP (Switching BWP) is the process of changing huge set of configurations. So it would need at least a certain amount of time to complete the switching. This time delay can be illustrated as follows based on 38.133-8.6.2

Time Delay for DCI based BWP switching

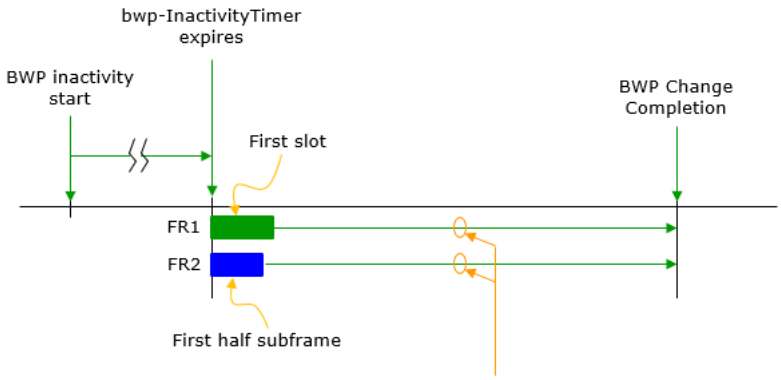
< 38.133-Table 8.6.2-1: BWP switch delay >

μ	NR Slot length (ms)	BWP switch delay $T_{BWPswitchDelay}$ (slots)	
		Type 1 [Note 1]	Type 2 [Note 1]
0	1	1	3
1	0.5	2	5
2	0.25	3	9
3	0.125	6	18

Note 1: Depends on UE capability.
Note 2: If the BWP switch involves changing of SCS, the BWP switch delay is determined by the smaller SCS between the SCS before BWP switch and the SCS after BWP switch.

- Y=0, if the serving cell where UE receives DCI for BWP switch request is same as the serving cell on which BWP switch occurs
- Y=1, if the serving cell where UE receives DCI for BWP switch is different from the serving cell on which BWP switch occurs for any involved serving cell

Time Delay for Timer based BWP switching



< 38.133-Table 8.6.2-1: BWP switch delay >

μ	NR Slot length (ms)	BWP switch delay $T_{BWPswitchDelay}$ (slots)	
		Type 1 Note 1	Type 2 Note 1
0	1	1	3
1	0.5	2	5
2	0.25	3	9
3	0.125	6	18
Note 1: Depends on UE capability. Note 2: If the BWP switch involves changing of SCS, the BWP switch delay is determined by the smaller SCS between the SCS before BWP switch and the SCS after BWP switch.			

RRC for BWP Switching

```
ServingCellConfig ::= SEQUENCE {
  ...
  firstActiveDownlinkBWP-Id     BWP-Id
  bwp-InactivityTimer         ENUMERATED {ms2, ms3, ms4, ms5, ms6, ms8, ms10, ms20, ms30,
                                  ms40,ms50, ms60, ms80,ms100, ms200,ms300, ms500,
                                  ms750, ms1280, ms1920, ms2560, spare10, spare9, spare8,
                                  spare7, spare6, spare5, spare4, spare3, spare2, spare1 } OPTIONAL,
...
```

UE Capability

```
Phy-ParametersCommon ::=   SEQUENCE {
  ...
  bwp-SwitchingDelay            ENUMERATED {type1, type2}     OPTIONAL,
  bwp-SwitchingMultiCCs-r16       CHOICE {
                        type1-r16 ENUMERATED {us100, us200},
                        type2-r16 ENUMERATED {us200, us400, us800, us1000}
                      }
  ...
}

BandNR ::=  SEQUENCE {
  bwp-WithoutRestriction      ENUMERATED {supported}              OPTIONAL,
  bwp-SameNumerology            ENUMERATED {upto2, upto4}         OPTIONAL,
  bwp-DiffNumerology            ENUMERATED {upto4}                OPTIONAL,
  ...
}
```

bwp-SameNumerology : Indicates whether UE supports BWP adaptation (up to 2/4 BWPs) with the same numerology, via DCI and timer. For the UE capable of this feature, the bandwidth of a UE-specific RRC configured DL BWP includes the bandwidth of the CORESET#0 (if CORESET#0 is present) and SSB for PCell and PSCell (if configured). For SCell(s), the bandwidth of the UE-specific RRC configured DL BWP includes SSB, if there is SSB on SCell(s).

bwp-DiffNumerology : Indicates whether the UE supports BWP adaptation up to 4 BWPs with the different numerologies, via DCI and timer. For the UE capable of this feature, the bandwidth of a UE-specific RRC configured DL BWP includes the bandwidth of the CORESET#0 (if CORESET#0 is present) and SSB for PCell and PSCell (if configured). For SCell(s), the bandwidth of the UE-specific RRC configured DL BWP includes SSB, if there is SSB on SCell(s).

bwp-SwitchingDelay : (According to 38.306) Defines whether the UE supports DCI and timer based active BWP switching delay type1 or type2 specified in clause 8.6.2 of TS 38.133. It is mandatory to report type 1 or type 2. This capability is not applicable to IAB-MT. See BWP Switching Delay section in this page for further details.

bwp-WithoutRestriction : (According to 38.306) Indicates support of BWP operation without bandwidth restriction. The Bandwidth restriction in terms of DL BWP for PCell and PSCell means that the bandwidth of a UE-specific RRC configured DL BWP may not include the bandwidth of CORESET #0 (if configured) and SSB. For SCell(s), it means that the bandwidth of DL BWP may not include SSB.

Why BWP ?

When I first saw the descriptions on BWP, I asked myself 'why we need this ? We already has pretty flexible mechanism of changing Bandwidth dynamically. Just by changing the number of RBs and starting RB, we can change the operation bandwidth. Then, why we still need another mechanism of restricting bandwidth ?'.
The purpose of BWP is more for UE rather than for Network, especially for low end UEs which cannot afford to such a wideband operation.

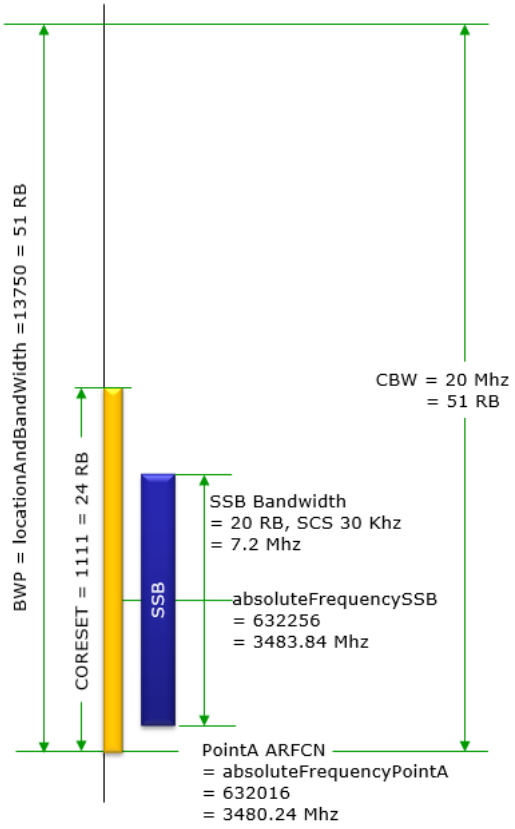
In most case, NR would operate in very wideband and there wouldn't be any issues for the network (gNB) and high end UEs to handle the full operating band, but we cannot expect every types of UE to be able to work with this kind of wideband. So we need another special mechanism to tell some UEs 'Hey... we are operating in this wide band, but you don't need to worry about covering the full band. this is a fraction of spectrum you only need to care'. This is how (and why) we came out with the new concept called BWP. It would remind you of NarrowBand in LTE M1. (Refer to Ref[1] if you want to know more detailed stories on various alternatives on NR Wideband operation).

BWP Configuration Examples

Example 01 > Band78, CBW 20 Mhz

Following is an example configuration from Amarisoft. (NOTE : You may need additional knowledge about Coreset Bandwidth. Refer to this note for CORESET interpretation)

```
spCellConfig {
  servCellIndex 0,
  reconfigurationWithSync {
    spCellConfigCommon {
      physCellId 500,
      downlinkConfigCommon {
        frequencyInfoDL {
          absoluteFrequencySSB 632256,
          frequencyBandList {
            78
          },
          absoluteFrequencyPointA 632016,
          scs-SpecificCarrierList {
            {
              offsetToCarrier 0,
              subcarrierSpacing kHz30,
              carrierBandwidth 51
            }
          }
        },
        initialDownlinkBWP {
          genericParameters {
            locationAndBandwidth 13750,
            subcarrierSpacing kHz30
          },
          pdcch-ConfigCommon setup: {
            commonControlResourceSet {
              controlResourceSetId 1,
              frequencyDomainResources '111100000000000000000000'
              duration 1,
              cce-REG-MappingType nonInterleaved: NULL,
              precoderGranularity sameAsREG-bundle
            },
            commonSearchSpaceList {
              {
                searchSpaceId 1,
                controlResourceSetId 1,
                monitoringSlotPeriodicityAndOffset sl1: NULL,
                monitoringSymbolsWithinSlot '10000000000000'B,
                nrofCandidates {
                  aggregationLevel1 n0,
                  aggregationLevel2 n0,
                  aggregationLevel4 n1,
                  aggregationLevel8 n0,
                  aggregationLevel16 n0
                },
                searchSpaceType common: {
                  dci-Format0-0-AndFormat1-0 {
                  }
                }
```



NOTE : CBW = 20 is just based on the Bandwidth specification : 38.101-1 Table 5.3.2-1: Maximum transmission bandwidth configuration NRB : FR1 . The physical bandwidth accupied by 51RB is 18.36 Mhz.

BWP Switching Operation Examples

Example 1 > BWP Switching by DCI

This is an example from Amari Callbox with a commercial UE showing the BWP switching triggered by DCI.

[1] and [2] in the following RRC log is the places where all the BWP is configured.

RAN	UE ID	Cell	SFN	RNTI	Info	Message
RRC		1		1	BCCH-NR	SIB1
RRC	1	1			CCCH-NR	RRC setup request
RRC	1	1		2	CCCH-NR	RRC setup
RRC	1	1			DCCH-NR	RRC setup complete
RRC	1	1			DCCH-NR	DL information transfer
RRC	1	1			DCCH-NR	UL information transfer
RRC	1	1			DCCH-NR	DL information transfer
RRC	1	1			DCCH-NR	UL information transfer
RRC	1	1			DCCH-NR	DL information transfer
RRC	1	1			DCCH-NR	UL information transfer
RRC	1	1			DCCH-NR	DL information transfer
RRC	1	1			DCCH-NR	UL information transfer
RRC	1	1			DCCH-NR	Security mode command
RRC	1	1			DCCH-NR	Security mode complete
RRC	1	1			DCCH-NR	UE capability enquiry
RRC	1	1			DCCH-NR	UE capability information
RRC	1	1				NR band combinations
RRC	1	1			DCCH-NR	UE capability enquiry
RRC	1	1			DCCH-NR	UE capability information
RRC	1	1			DCCH-NR	RRC reconfiguration
RRC	1	1			DCCH-NR	RRC reconfiguration complete

Following is the sequence of physical channels showing the PDCCH/PDSCH before and after BWP switching.

SFN	RNTI	Info	Message
5.856.6	0x4601	PDCCH	ss_id=2 cce_index=0 al=2 dci=1_1
5.856.6	0x4601	PDSCH	harq=10 prb=3:48 symb=2:12 k1=12 nl=2 CW0: tb_len=8709 mod=8 rv_idx=2 cr=0.69 retx=2
5.856.15	0x4601	PDCCH	ss_id=2 cce_index=6 al=2 dci=1_1
5.856.15	0x4601	PDSCH	harq=9 prb=3:48 symb=2:12 k1=4 nl=2 CW0: tb_len=8709 mod=8 rv_idx=3 cr=0.69 retx=3
5.857.5	0x4	PDCCH	ss_id=2 cce_index=12 al=2 dci=1_1
5.857.5	0x4	PDSCH	harq=10 prb=3:48 symb=2:12 k1=4 nl=2 CW0: tb_len=8709 mod=8 rv_idx=3 cr=0.69 retx=3
5.858.1	0x4	PDCCH	ss_id=2 cce_index=2 al=2 dci=0_1 k2=7
5.858.12	0x4	PDCCH	ss_id=4 cce_index=4 al=2 dci=1_1
5.858.12	0x4	PDSCH	harq=0 prb=0:106 symb=2:12 k1=7 nl=2 CW0: tb_len=22026 mod=8 rv_idx=0 cr=0.83 retx=0
5.858.13	0x4601	PDCCH	ss_id=4 cce_index=12 al=2 dci=1_1
5.858.13	0x4601	PDSCH	harq=1 prb=0:106 symb=2:12 k1=6 nl=2 CW0: tb_len=22026 mod=8 rv_idx=0 cr=0.79 retx=0
5.858.14	0x4601	PDCCH	ss_id=4 cce_index=8 al=2 dci=1_1
5.858.14	0x4601	PDSCH	harq=2 prb=0:106 symb=2:12 k1=5 nl=2 CW0: tb_len=22026 mod=8 rv_idx=0 cr=0.79 retx=0
5.858.8	0x4	PUSCH	harq=0 prb=101:3 symb=0:14 CW0: tb_len=141 mod=4 rv_idx=0 cr=0.61 retx=0 crc=KO snr=-0.4 ep
5.858.15	0x4601	PDCCH	ss_id=4 cce_index=2 al=2 dci=0_1 k2=4
5.858.15	0x4601	PDCCH	ss_id=4 cce_index=6 al=2 dci=1_1

[1] SIB1

Check on this for full message.

```
 message c1: systemInformationBlockType1: {
  ....
  servingCellConfigCommon {
   downlinkConfigCommon {
    frequencyInfoDL {
     frequencyBandList {
      {
       freqBandIndicatorNR 78
      }
     },
     offsetToPointA 30,
     scs-SpecificCarrierList {
      {
       offsetToCarrier 0,
       subcarrierSpacing kHz30,
       carrierBandwidth 106
      }
     }
    },
    initialDownlinkBWP {    // DL BWP 0
     genericParameters {
      locationAndBandwidth 12928,
      subcarrierSpacing kHz30
     },
....
    },
    uplinkConfigCommon {
     frequencyInfoUL {
      scs-SpecificCarrierList {
```

```
        {
          offsetToCarrier 0,
          subcarrierSpacing kHz30,
          carrierBandwidth 106
        }
       }
      },
      initialUplinkBWP {    // UL BWP 0
       genericParameters {
        locationAndBandwidth 12928,
        subcarrierSpacing kHz30
       },
....
}
```

[2] RrcSetup

Check on this for full message.

```
{
 message c1: rrcSetup: {
  rrc-TransactionIdentifier 0,
  criticalExtensions rrcSetup: {
...
     spCellConfig {
      spCellConfigDedicated {
       initialDownlinkBWP {
...
        downlinkBWP-ToAddModList {
         {
          bwp-Id 1,
          bwp-Common {     // DL BWP 1
           genericParameters {
            locationAndBandwidth 28875,
            subcarrierSpacing kHz30
           },
...
          bwp-Dedicated {
           pdcch-Config setup: {
...
           },
           pdsch-Config setup: {
...
        },
        firstActiveDownlinkBWP-Id 0,
        uplinkConfig {
         initialUplinkBWP {
          pucch-Config setup: {
..
           },
...
         },
         uplinkBWP-ToAddModList {
          {
           bwp-Id 1,
           bwp-Common {
            genericParameters {   // UL BWP 1
             locationAndBandwidth 28875,
             subcarrierSpacing kHz30
            },
            pusch-ConfigCommon setup: {
...
            },
            pucch-ConfigCommon setup: {
...
            }
           },
           bwp-Dedicated {
            pucch-Config setup: {
...
             },
             resourceToAddModList {
...
            },
            pusch-Config setup: {
...

         },
         firstActiveUplinkBWP-Id 0,
...
        },
....
       }
      }
     }
    }
   }
}
```

[3] PDCCH

Message: ss_id=2 cce_index=12 al=2 dci=1_1

Data:
  bwp=0

rb_alloc=0x5f
time_domain_rsc=0
mcs1=21
ndi1=0
rv_idx1=3
harq_process=10
dai=0
tpc_command=1
pucch_rsc=0
harq_feedback_timing=4
antenna_ports=2
srs_request=0
dmrs_seq_init=0

[4] PDSCH

Message: harq=10 prb=3:48 symb=2:12 k1=4 nl=2 CW0: tb_len=8709 mod=8 rv_idx=3 cr=0.69 retx=3

[5] PDCCH

Message: ss_id=2 cce_index=2 al=2 dci=0_1 k2=7

Data:
bwp=1
rb_alloc=0x139
time_domain_rsc=0
mcs=9
ndi=1
rv_idx=0
harq_process=0
dai=3
tpc_command=1
antenna_ports=0
srs_request=0
dmrs_seq_init=0
ul_sch_indicator=1

[6] PDCCH

Message: ss_id=4 cce_index=4 al=2 dci=1_1

Data:
bwp=1
rb_alloc=0xd3
time_domain_rsc=0
mcs1=23
ndi1=0
rv_idx1=0
harq_process=0
dai=0
tpc_command=1
pucch_rsc=0
harq_feedback_timing=1
antenna_ports=2
srs_request=0
dmrs_seq_init=0

[7] PDSCH

Message: harq=0 prb=0:106 symb=2:12 k1=7 nl=2 CW0: tb_len=22026 mod=8 rv_idx=0 cr=0.83 retx=0

[8] PUSCH

Message: harq=0 prb=101:3 symb=0:14 CW0: tb_len=141 mod=4 rv_idx=0 cr=0.61 retx=0 crc=KO snr=-0.4 epre=-124.0 ta=8.8

Example 2 > BWP Switching by RRC

This is an example from Amari Callbox with Amari UEsim

Time	Diff	RAN	UE ID	Cell	SFN	RNTI	Info	Message
09:58:15.277	+0.160	RRC		1		1	BCCH-NR	SIB1
09:58:43.139	+27.862	RRC	1	1			CCCH-NR	RRC setup request
-		RRC	1	1		2	CCCH-NR	RRC setup
09:58:43.179	+0.040	RRC	1	1			DCCH-NR	RRC setup complete
09:58:43.180	+0.001	RRC	1	1			DCCH-NR	DL information transfer
09:58:43.219	+0.039	RRC	1	1			DCCH-NR	UL information transfer
09:58:43.220	+0.001	RRC	1	1			DCCH-NR	DL information transfer
09:58:43.259	+0.039	RRC	1	1			DCCH-NR	UL information transfer
09:58:43.260	+0.001	RRC	1	1			DCCH-NR	Security mode command
09:58:43.299	+0.039	RRC	1	1			DCCH-NR	Security mode complete
-		RRC	1	1			DCCH-NR	UE capability enquiry
09:58:43.339	+0.040	RRC	1	1			DCCH-NR	UE capability information
-		RRC	1	1				NR band combinations
-		RRC	1	1			DCCH-NR	RRC reconfiguration
09:58:43.379	+0.040	RRC	1	1			DCCH-NR	RRC reconfiguration complete
-		RRC	1	1			DCCH-NR	UL information transfer
-		RRC	1	1			DCCH-NR	UL information transfer
09:58:43.380	+0.001	RRC	1	1			DCCH-NR	DL information transfer
-		RRC	1	1			DCCH-NR	RRC reconfiguration
09:58:43.419	+0.039	RRC	1	1			DCCH-NR	RRC reconfiguration complete
09:58:52.922	**+9.503**	**RRC**	**1**	**1**		**3**	**DCCH-NR**	**RRC reconfiguration**
09:58:52.959	+0.037	RRC	1	1			DCCH-NR	RRC reconfiguration complete
09:59:15.999	+23.040	RRC	1	1			DCCH-NR	UL information transfer
09:59:16.000	+0.001	RRC	1	1			DCCH-NR	RRC release

Time	Diff	RAN	UE ID	Cell	SFN	RNTI	Info	Message
09:58:52.685	+0.040	PHY	1	1	4.332.9	0x4601	PUCCH	format=2 prb=4 prb2=49 symb=8:2 csi-
09:58:52.698	+0.013	PHY	1	1	4.334.3	0x[4]01	PDCCH	ss_id=2 cce_index=8 al=2 dci=1_1
-		PHY	1	1	4.334.3	0x4601	PDSCH	harq=0 prb=50 symb=2:12 k1=6 nl=
09:58:52.705	+0.007	PHY	1	1	4.334.9	0x4601	PUCCH	format=1 prb=50 prb2=3 symb=0:14 cs
09:58:52.725	+0.020	PHY	1	1	4.336.9	0x4601	PUCCH	format=2 prb=4 prb2=49 symb=8:2 csi-
09:58:52.765	+0.040	PHY	1	1	4.340.9	0x4601	PUCCH	format=2 prb=4 prb2=49 symb=8:2 csi-
09:58:52.805	+0.040	PHY	1	1	4.344.9	0x4601	PUCCH	format=2 prb=4 prb2=49 symb=8:2 csi-
09:58:52.845	+0.040	PHY	1	1	4.348.9	0x4601	PUCCH	format=2 prb=4 prb2=49 symb=8:2 csi-
09:58:52.885	+0.040	PHY	1	1	4.352.9	0x4601	PUCCH	format=2 prb=4 prb2=49 symb=8:2 csi-
09:58:52.922	+0.037	RRC	1	1			DCCH-NR	RRC reconfiguration
-		PHY	1	1	4.356.11	0x4601	PDCCH	ss_id=3 cce_index=0 al=4 dci=1_0
-		PHY	1	1	4.356.11	0x4601	PDSCH	harq=0 prb=50 symb=2:12 k1=7 CW
09:58:52.929	+0.007	PHY	1	1	4.356.18	0x4601	PUCCH	format=1 prb=0 prb2=105 symb=0:14 c
09:58:52.944	+0.015	PHY	1	1	4.358.8	0x4601	PUCCH	format=1 prb=0 prb2=105 symb=0:14 c
-		PHY	1	1	4.358.15	0x4601	PDCCH	ss_id=3 cce_index=0 al=4 dci=0_0 k
09:58:52.950	+0.006	PHY	1	1	4.358.19	0x4601	PUSCH	harq=0 prb=18:2 symb=0:14 CW0: t
09:58:52.952	+0.002	PHY	1	1	4.359.11	0x4601	PDCCH	ss_id=3 cce_index=0 al=4 dci=0_0 k
09:58:52.959	+0.007	PHY	1	1	4.359.18	0x4601	PUSCH	harq=0 prb=5:2 symb=0:14 CW0: tb
-		RRC	1	1			DCCH-NR	RRC reconfiguration complete
-		PHY	1	1	4.360.5	0x[5]01	PDCCH	ss_id=4 cce_index=8 al=2 dci=1_1
-		PHY	1	1	4.360.5	0x4601	PDSCH	harq=0 prb=0 symb=2:12 k1=4 nl=2

[1] SIB1

Following is bwp related parts in SIB1. See this for the whole message.

```
{
  message c1: systemInformationBlockType1: {
   ...
    servingCellConfigCommon {
      downlinkConfigCommon {
        frequencyInfoDL {
          frequencyBandList {
            {
              freqBandIndicatorNR 78
            }
          },
          offsetToPointA 30,
          scs-SpecificCarrierList {
            {
              offsetToCarrier 0,
              subcarrierSpacing kHz30,
              carrierBandwidth 106
            }
```

```
        }
       },
       initialDownlinkBWP {
        genericParameters {
         locationAndBandwidth 12928,
         subcarrierSpacing kHz30
        },
        ...
      uplinkConfigCommon {
       frequencyInfoUL {
        scs-SpecificCarrierList {
         {
          offsetToCarrier 0,
          subcarrierSpacing kHz30,
          carrierBandwidth 106
         }
        }
       },
       initialUplinkBWP {
        genericParameters {
         locationAndBandwidth 12928,
         subcarrierSpacing kHz30
        },
        ...
}
```

[2] RrcSetup

Following is bwp related parameters in RrcSetup. See this for the whole message.

```
{
 message c1: rrcSetup: {
  rrc-TransactionIdentifier 0,
  criticalExtensions rrcSetup: {
   radioBearerConfig {
    ...
    spCellConfig {
     spCellConfigDedicated {
      initialDownlinkBWP {
       ....
      downlinkBWP-ToAddModList {
       {
        bwp-Id 1,
        bwp-Common {
         genericParameters {
          locationAndBandwidth 28875,
          subcarrierSpacing kHz30
         },
      ....
      firstActiveDownlinkBWP-Id 0,
       ....,
       uplinkBWP-ToAddModList {
        {
         bwp-Id 1,
         bwp-Common {
          genericParameters {
           locationAndBandwidth 28875,
           subcarrierSpacing kHz30
          },
      ....
      firstActiveUplinkBWP-Id 0,

}
```

[3] RrcReconfiguration

```
{
 message c1: rrcReconfiguration: {
  rrc-TransactionIdentifier 0,
  criticalExtensions rrcReconfiguration: {
   nonCriticalExtension {
    masterCellGroup {
     cellGroupId 0,
     spCellConfig {
      spCellConfigDedicated {
       firstActiveDownlinkBWP-Id 1,
       uplinkConfig {
        firstActiveUplinkBWP-Id 1
       },
       tag-Id 0
      }
     }
    }
   }
  }
 }
}
```

[4] PDCCH @ SFN = 334.3

Message: ss_id=2 cce_index=8 al=2 dci=1_1

Data:
 bwp=0

rb_alloc=0x2f
time_domain_rsc=0
mcs1=9
ndi1=1
rv_idx1=0
harq_process=0
dai=0
tpc_command=1
pucch_rsc=0
harq_feedback_timing=2
antenna_ports=2
srs_request=0
dmrs_seq_init=0

[5] PDCCH @ SFN = 360.5

Message: ss_id=4 cce_index=8 al=2 dci=1_1

Data:
bwp=1
rb_alloc=0x0
time_domain_rsc=0
mcs1=9
ndi1=1
rv_idx1=0
harq_process=0
dai=0
tpc_command=1
pucch_rsc=0
harq_feedback_timing=4
antenna_ports=2
srs_request=0
dmrs_seq_init=0

Reference

[1] NR Wide Bandwidth Operations by Jeongho Jeon, Intel Corporation
[2] Impact of Bandwidth Part (BWP) Switching on 5G NR System Performance (Fuad Abinader et al, IEEE)
[3] A Primer on Bandwidth Parts in 5G New Radio
[4] 5G NR BWP Types and BWP Operations

YouTube

[1] BandWidth Part (BWP): A 5G feature for improving spectrum flexibility and power savings
[2] 5G Course - 5G Bandwidth Parts (5G Initial BWP Active BWP Default BWP)