

The background of the entire page is a network diagram. It consists of numerous grey circular nodes, each containing a white silhouette of a person. These nodes are interconnected by a web of thin, grey lines, creating a complex, interconnected network structure. The nodes are distributed across the page, with some appearing larger and more prominent than others. The overall aesthetic is clean and technical, representing a network or communication system.

MEDIATEK

Bandwidth Part Adaptation

5G NR User Experience & Power Consumption
Enhancements

White Paper

Introduction

Efficient spectrum usage and utilization for different types of user applications is becoming increasingly important for future cellular network deployments, in order to cope with increased data rate and capacity demands. This, in turn, increases the need for applying new features and methods such that spectrum management, resource and latency improvement work to enhance the system performance and user experience. The exponential increase in the demand for data connectivity can put disproportionate pressure on either uplink or downlink performance, depending on the usage of the smartphones and applications.

Figure 1 shows the typical application types and throughput demand of smartphone traffic. As shown, users enjoy data-intensive streaming and social media services which are the most common usage of mobile internet. Applications can have different types of requirements for downlink/uplink throughput, packet latencies, Quality of Service, or resource assignment from the network scheduler. Therefore, the cellular ecosystem is gradually shifting the focus towards improving the end-user experience and providing the network capacity to meet many different types of data usage.

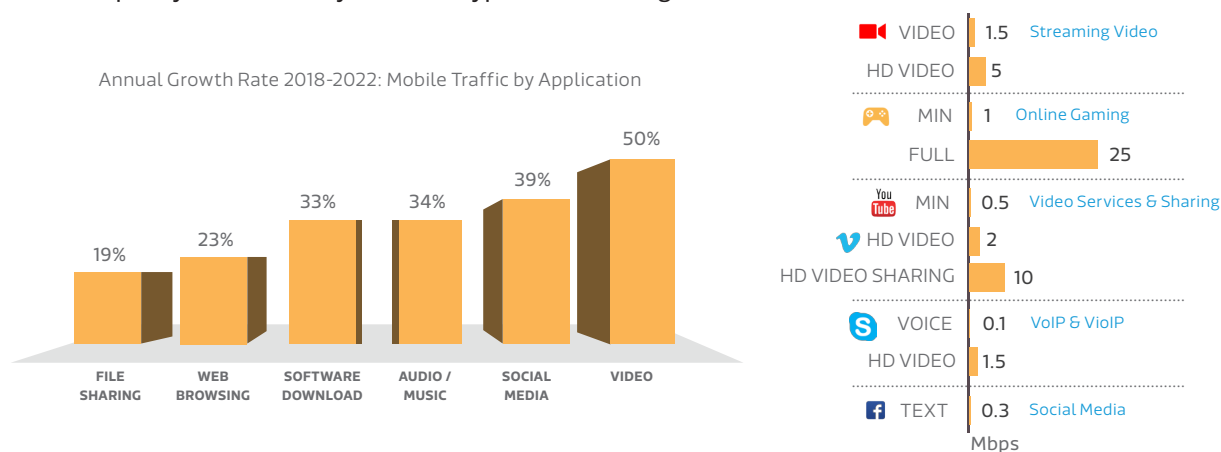


Figure 1: Service Evolution vs. User Throughput Demand

With the accelerated evolution in device form factors, features (big screen, improved operating systems) and the data connectivity demands for different types of applications; the pressure on power consumption is becoming a concern with the increased data rates expected in mobile broadband offered by 5G NR. The cellular technology evolution is continuously bringing wider spectrum allowance with higher bandwidths, advanced antenna techniques and modulation schemes, and carrier aggregation, which stand well to achieve higher data rates than previous cellular generations. However, achieving the highest possible data rates may not always be the main requirement of the application and user experience. This means that power consumption must be considered based on the traffic profile, for both high and low data rates, with regards to traffic types and data their data rate requirements.

For most devices, the maximum throughput scenario provides the most energy efficient mode of transferring data, in which the energy consumed for each bit transferred is a minimum. The uplink power will vary with the distance between the device and the cell site, but when the UE transmit power reaches its limit the only way to extend uplink coverage is to concentrate the same energy into fewer bits. In the downlink, increased throughput is provided by 5G NR using higher bandwidth carriers and increasing the number of MIMO layers that are used to transmit data. This reduces the energy per bit, however, it requires the device has more active receive paths and faster processing capacity to deal with the higher data rates, leading to higher UE power at maximum throughput. To meet the end-user expectations of battery lifetime that's at least not less than the previous generation, it is essential to provide a power profile that scales down in direct response to data rate fluctuation. This means that it should not be taken for granted that power consumption will linearly map to the reduction in data rate, especially where the device utilizes the full bandwidth to transmit lower data rate traffic profiles.

To illustrate how the power consumption scales against different data rates we use a video downloading scenario as an example. As one of the most important traffic types in cellular network, as shown before in figure 1, it demonstrates the effectiveness of dynamic bandwidth operation on power consumption. Three scenarios are evaluated:

- Scenario-1 (200MHz WB): UE always operates in wideband mode during ON period.
- Scenario-2 (20MHz NB): UE always operates in narrowband mode during ON period.
- Scenario-3 (200MHz Adaptive): UE alternates between narrowband and wideband modes.

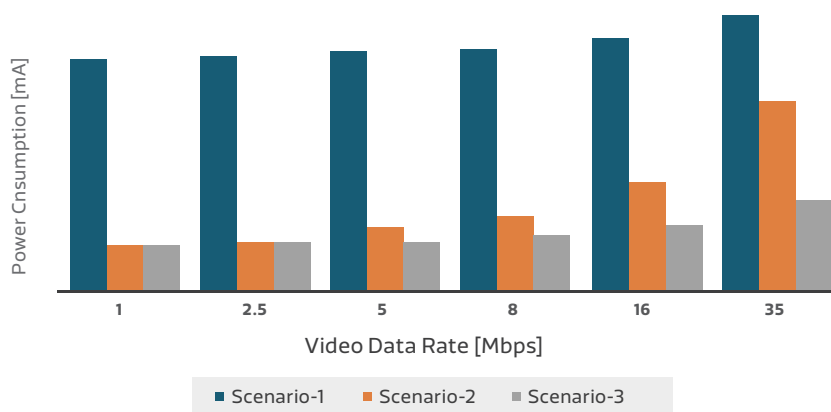


Figure 2: Power consumption for variable video data rates

As shown in figure 2, scenario-1 consumes the most power in all the data rate scenarios. This is mainly attributed to the fact that the device has to actively monitor the wideband control channel across the entire 200MHz bandwidth, even when no data or resources are present. On the other hand, scenario-2 shows lower power consumption by using narrower bandwidth for the data channel, reducing the power consumption in control channel-only scheduling, where no data is present. Comparing both scenarios 1 and 2, it is clear that the device power consumption is scaled with its operating bandwidth, thus it is more power efficient if a UE can adapt its operating bandwidth based on the traffic pattern. As a result, scenario-3 performs better than the other two scenarios, because it adaptively alternates between narrowband and wideband operations, striking a balance in power consumption depending on the data rate required. On average, scenario-3 provides 33% power saving over scenario-2, and a very significant 76% gain over scenario-1. However, in addition, the switching overhead must also be considered when adaptively switching between wideband and narrowband operation. This means that in low data rate scenario (e.g. ≤ 2.5 Mbps in figure 2), scenario-2 and scenario-3 have similar power consumption as data packets take less time to transmit than the switching period itself.

5G NR Release 15 offers new features that can help in balancing the data rate variations with an acceptable power consumption baseline for different bandwidth sizes and application experience. One such feature discussed in this paper is Bandwidth Part (BWP) adaptation, which can reduce the volume of data that the UE has to process when maximum throughput is not needed. It can also support devices that are not capable of full carrier bandwidth or have limited RF capability.

Background on Power Consumption

To assess the power consumption profile for different technologies and configurations, we must start with baseline power consumption, which is simply defined as the power (which is in direct correlation with the current drawn from the battery) used whenever the device is in active/connected mode with no data scheduled (throughput = Zero). This baseline power includes modem signaling processing like continuous PDCCH (Physical Downlink Control Channel) monitoring and decoding, power used by RF Front-end (RFFE) components, and all other active components in the device like the display, audio amplifiers for example

After setting the baseline power, a linear relation could be assumed between the throughput and the additional power consumption. For simplicity, the extra power required to decode 50 PRBs is double the power required to decode 25 PRBs, assuming the same MCS is used in both cases. With these definitions in mind, it came with no surprise there is a higher baseline power expected for a 5G NR device compared to LTE device, illustrated in figure 3. This can be attributed to the following factors:

- In PDCCH only mode, LTE UE uses 20 MHz of spectrum vs. 100 MHz in 5G NR – FR1.
- The higher the Subcarrier Spacing, the lower the symbol duration, which requires higher clock speeds for processing.

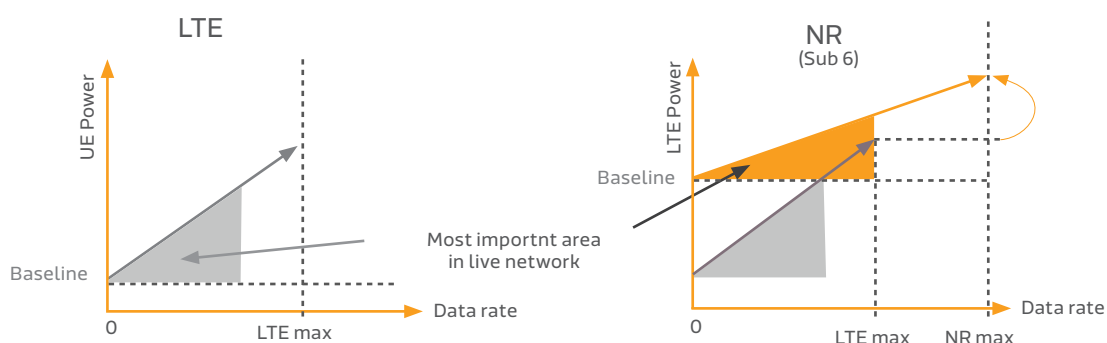


Figure 3: Power Consumption vs. Bandwidth NR FR1

Going a step further by comparing 5G-NR FR2 performance, we can expect even higher baseline power consumption with the wider bandwidth available and all the extra RF components required for operation in these bands (e.g. antenna arrays, power amplifiers), in addition to a higher peak power that provides a higher maximum throughput as shown in figure 4.

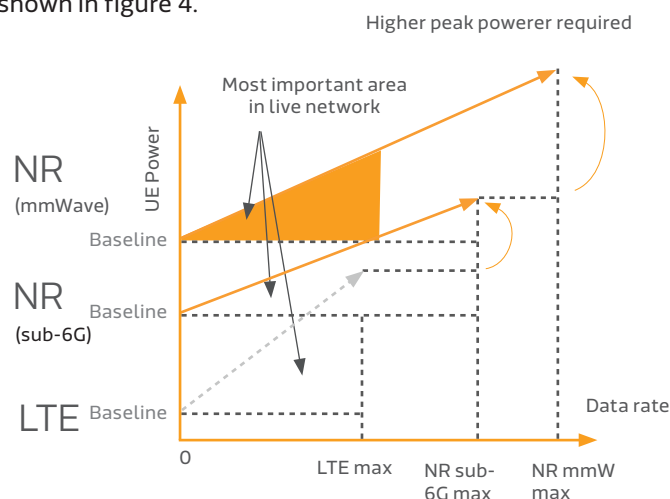


Figure 4: Power Consumption vs. Bandwidth NR FR2

But at the same time, if we try to estimate the power budget per Mbps for the different configurations at the maximum allowed throughput, we can expect that 5G will be able to deliver lower power, since the baseline power is divided by its higher achievable throughput, so a 5G system has better efficiency compared to LTE, which is in line with MediaTek power consumption study results illustrated in figure 5.

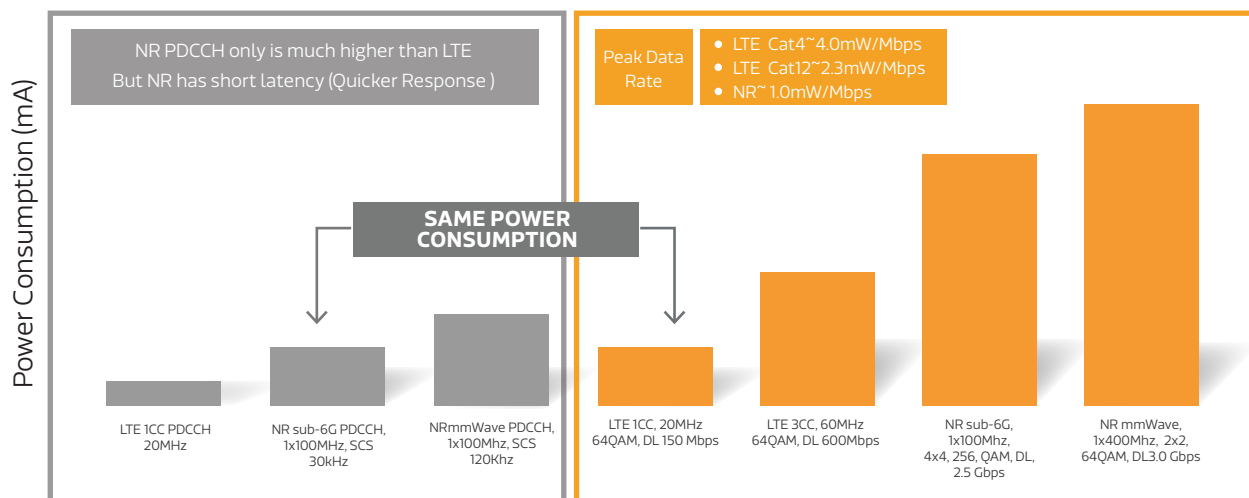


Figure 5: Estimated Current Consumption in Connected Mode for 5G NR Compared to LTE

Therefore, we can summarize these results as follows:

- PDCCH only scenario (UE in active/connected mode with no data) reflects the baseline power consumption, and it increases with the bandwidth and with higher SCS.
- For the maximum throughput scenario, the higher the throughput gets: the higher the power consumed, but at the same time the lower the power used per Mbps (4mW/Mbps in LTE compared to 1mW/Mbps in 5G NR).
- A 5G NR device with 100 MHz FR1 and SCS 30 KHz with ZERO throughput consumes the same power as a CAT4 LTE device downloading at its maximum throughput of 150 Mbps (figure 5 comparing 2nd and 4th data columns).

The last point highlights one of the main shortcomings of using wider bandwidth and higher SCS in 5G NR: operating 5G for low throughput applications will yield to huge modem power consumption and very low UE power efficiency, when compared to LTE devices. And it is here where the Bandwidth Part Adaptation feature has been driven by MediaTek in 3GPP, to become a new concept in NR physical layer. The feature was adopted as part of 3GPP Release 15, where it allows the UE to utilize narrower bandwidth in certain transmissions in order to save power among use cases detailed in the following sections.

Bandwidth Parts & Bandwidth Adaptation Basic Concepts

As per the definition in TS38.300, with Bandwidth Adaptation (BA), the receive and transmit bandwidth of a UE need not be as large as the bandwidth of the cell and can be adjusted: the width can be ordered to change, e.g. to shrink during period of low activity to save power; the location can be ordered to change, e.g. to allow different services. A subset of the total cell bandwidth of a cell is referred to as a Bandwidth Part (BWP), and BA is achieved by configuring the UE with BWP(s) telling the UE which of the configured BWPs is currently the active one.

BWP Configuration & Allocation

3GPP TS 38.211 specifies Bandwidth Parts (BWP) as a contiguous set of physical resource blocks, selected from a contiguous subset of the common resource blocks for a given numerology (μ) on a given carrier. And for a single UE configuration, the following rules apply and are depicted by figure 6 (example shown with three bandwidth parts):

- A UE can be configured with up to **four** bandwidth parts in the downlink, with a single downlink bandwidth part being active at one time.
 - The UE is not expected to receive PDSCH (Physical Downlink Data Channel), PDCCH, or CSI-RS (Channel State Information Reference Signal) outside an active bandwidth part.
- The same maximum four bandwidth parts can be configured for a UE in the uplink with a single uplink bandwidth part being active at once.
 - The UE shall not transmit PUSCH or PUCCH (Uplink Data and Control Channels) outside an active bandwidth part. For an active cell, the UE shall not transmit SRS (Sounding Reference Signal) outside an active bandwidth part.
- If a UE is configured with a supplementary uplink, it can additionally be configured with up to four bandwidth parts in the supplementary uplink, with a single supplementary uplink bandwidth part being active at a given time.
 - The UE shall not transmit PUSCH or PUCCH (Uplink Data and Control Channels) outside an active bandwidth part. For an active cell, the UE shall not transmit SRS (Sounding Reference Signal) outside an active bandwidth part.
- There are, however, exceptions as the UE may need to perform Radio Resource Management (RRM) measurements on the downlink or transmit SRS in the uplink, outside of its active BWP. This is therefore done via measurement gap.

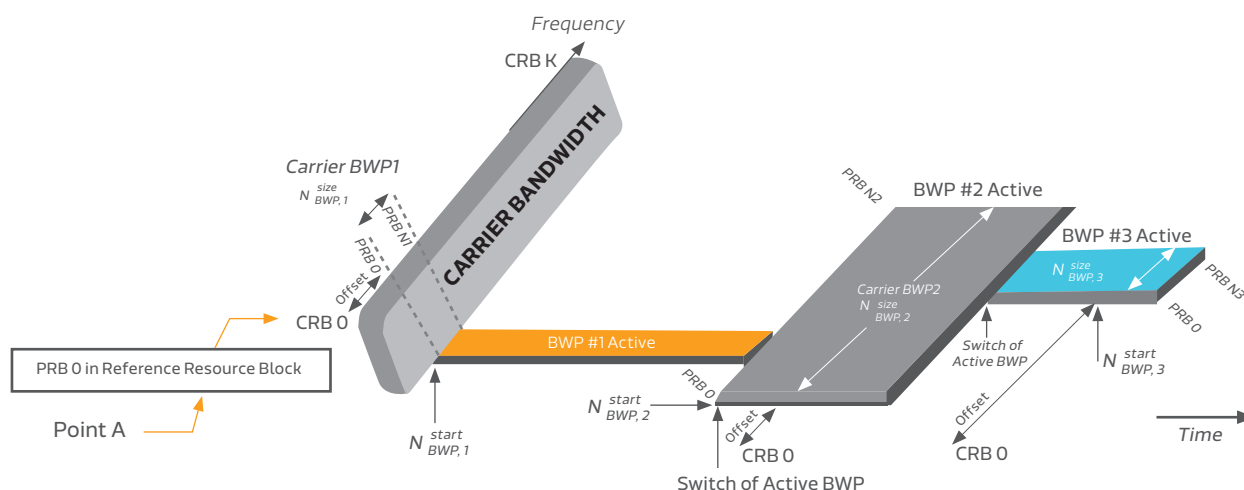


Figure 6: Bandwidth Parts (BWP) Concept and Configuration

By definition, Carrier Resource Block (CRB) provides the RB numbering throughout the overall carrier bandwidth from CRB0 to CRB_Max (for example CRB272 in case of 100 MHz in FR1 carrier), while Physical Resource Block (PRB) provides the RB numbering within each BWP.

Point A is a common reference point for resource block grids and is obtained by higher layer parameters – either `offsetToPointA` or `absoluteFrequencyPointA` according to 3GPP TS 38.211, and is used as the reference to apply frequency offsets that are signaled by the network to identify the lowest subcarrier of the lowest RB for a designated BWP.

Taking the BWP definition, and the fact that up to four BWP could be configured for a UE, different BWP allocation scenarios are possible and each could better serve certain use cases, as highlighted in figure 7.

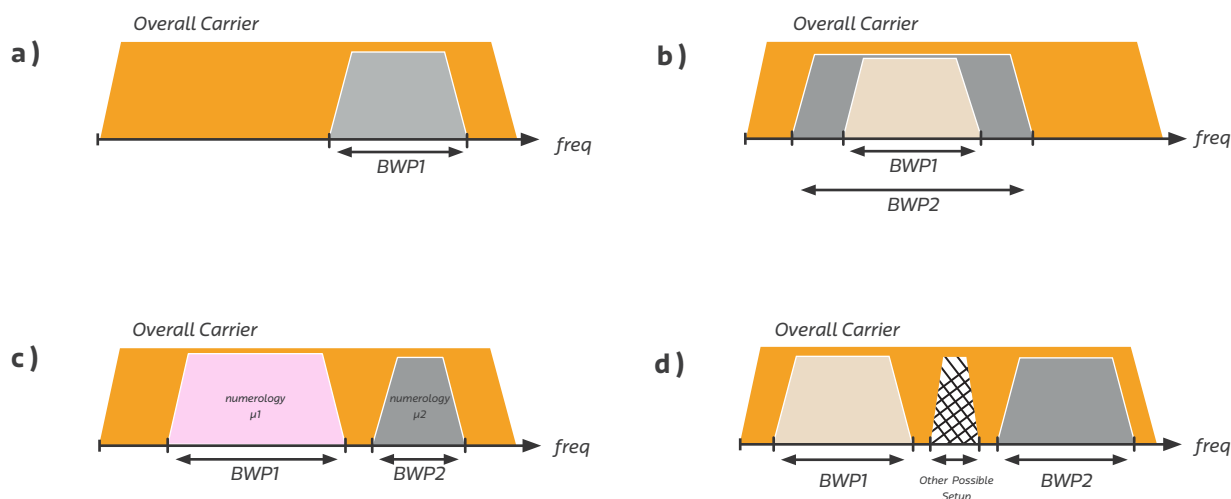


Figure 7: Bandwidth Parts Allocations

- **Allocation (a):** Supporting reduced UE bandwidth capability is especially helpful for devices with limited RF capability or those not capable of full carrier bandwidth.
- **Allocation (b):** Supporting reduced UE power consumption for intermittent and bursty traffic profiles.
- **Allocation (c):** Supporting two non-contiguous BWP with different numerologies allowing different services multiplexing.
- **Allocation (d):** Supporting non-contiguous spectrum, allowing services to be allocated between different BWPs. This is not yet part of Release 15 and could be added into future releases.

BWP Configuration & Allocation

Figure 8 represents the different BWPs types available for a UE

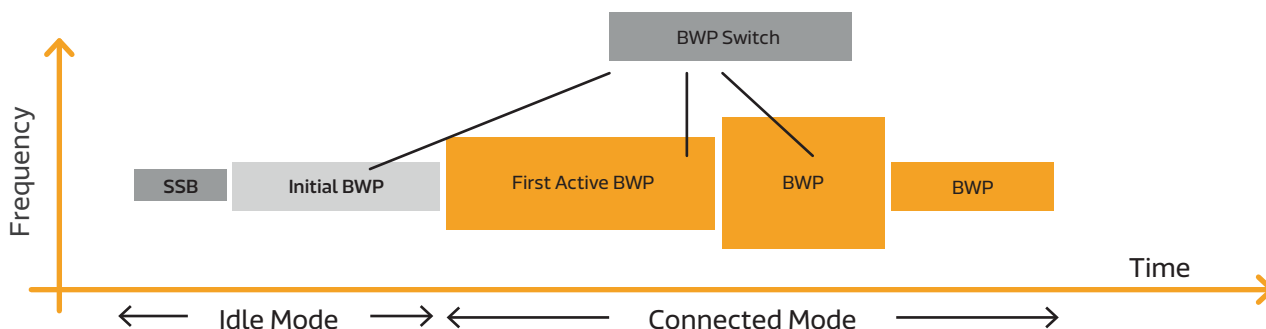


Figure 8: Bandwidth Parts Types

For typical use cases, Idle Mode BWP is smaller than Connected Mode BWPs, and three different BWP types are available: Initial BWP and two UE specific types, namely First active BWP and Default BWP. The summary of their characteristics is given in table 1.

Table 1: Bandwidth Parts Types

BWP Type		Description
Initial BWP		<ul style="list-style-type: none"> The BWP performs Initial Access Process Parameters including RMSI (Requested Minimum System Information), CORESET* and RMSI Frequency location/bandwidth/SCS 24~96 PRBs with different settings Relaxed to wider BWP after RMSI decoding
UE Specific BWP	UE Specific BWP	<ul style="list-style-type: none"> The BWP performs Initial Access Process The first BWP where UE starts data transfer after RRC configuration/reconfiguration First Active BWP should be different from the default BWP
	Default BWP	<ul style="list-style-type: none"> First Active BWP should be different from the default BWP UE would switch back to default BWP when BWP timer expires If not configured in RRC, Initial BWP is the default BWP

* CORESET is an equivalent to the control region in LTE subframe. In LTE, the frequency domain of the control region is always the same as the total system bandwidth, so no parameter is needed to define the frequency domain region for LTE control region. Time domain region can be {1, 2, 3} which is determined by PCFICH. However, in NR both frequency region and time domain region can be defined by RRC signaling message.

Bandwidth Parts Operations

BWP Parameters

The BWP parameters are used to configure the operator between the UE and the cell. According to 3GPP TS 38.331 for each serving cell the network configures at least an initial bandwidth part, comprising of downlink bandwidth part and one (if the serving cell is configured with an uplink) or two (if using supplementary uplink – SUL) uplink bandwidth parts. Furthermore, the network may configure additional uplink and downlink bandwidth parts.

The bandwidth part configuration is split into uplink and downlink parameters as well as into common and dedicated parameters. Common parameters (in BWP-UplinkCommon and BWP-DownlinkCommon) are "cell specific" and the network ensures the necessary alignment with corresponding parameters of other UEs. The common parameters of the initial bandwidth part of the PCell are also provided via system information. For all other serving cells, the network provides the common parameters via dedicated signaling.

Initial Access

UE flow of initial access when BWP is in use is shown in table 2.

Table 2: UE Flow in Initial Access with BWP

Step	Stage	DL BWP	UL BWP	Comments
1	MIB decode	N/A	N/A	After PSS/SSS searching, UE decode MIB and get CORESET0 configuration
2	RMSI decode	CORESET0	N/A	Get Initial DL-BWP and Initial UL-BWP setting for RMSI decoding
3	Msg-1-UE-TX		Initial UL-BWP	RACH sending
4	Msg-2-UE-RX	CORESET0		RAR from gNB
5	Msg-3-UE-TX		Initial UL-BWP	RRC connection request
6	Msg-4-UE-RX	CORESET0		<ul style="list-style-type: none"> • RRC connection setup • Configure UE specific BWP (default/1st active/ other) BWP • If not configured, still use initial BWP
7	Msg-5-UE-TX	1 st Active	1 st Active	<ul style="list-style-type: none"> • RRC set-up completed • Initial BWP is the 1st Active BWP if no additional configuration carried in Msg4

BWP Activation/Deactivation and Switching

The traffic patterns within one active data session can of course change frequently as the data rate may increase or decrease based on the type of traffic or the user behavior (accessing the internet and answering a phone call for example). In figure 2, we highlighted the importance of quick switching between different bandwidth parts because the data packets can be smaller than the period needed by the switching itself, so that the power consumption can be managed for different data rates.

According to TS 38.321 BWP selection and switching can be done with different mechanisms as listed below:

- **RRC-based adaptation:** It is more suitable for semi-static cases since the processing of RRC messages requires extra time, letting the latency reach ~10 msec. Due to longer switching latency and signaling overhead, a RRC-based method can be used for configuring a BWP set at any stage of the call, or for slow adaptation type services (e.g., voice) where the resource allocation is not changing rapidly within the same data session.

- **MAC CE (Control element):** used upon initiation of Random Access procedure
- **DCI-based adaptation:** it is based on PDCCH channel where a specific BWP can be activated by BWP indicator in DCI Format 0_1 (UL Grant) and Format 1-1 (DL scheduling). This method better fits on-the-fly BWP switching as using this method the latency is as low as 2 msec. However, this method requires additional considerations for error handling as UE may fail to decode the DCI with BWP activation/deactivation command.
- **Timer-based implicit fallback to default BWP** is a mechanism designed to mitigate possible DCI errors. If the UE is not explicitly scheduled with a BWP after the timer expires, it will automatically switch to the default BWP.

Bandwidth Parts Operations

MediaTek studies have demonstrated that using BWP can significantly reduce the UE power consumption in NR. Estimations were made for Voice over NR (VoNR), a Video Streaming Service and online gaming. The three case studies results are presented below.

Case Study 1: Mobile Gaming

Mobile gaming is on the rise globally and in 2017 42% used smartphones as the online gaming device of choice, versus 31% on PC and 27% on game consoles. Hence, with the launch of 5G and the continuous fast development of the online gaming ecosystem, it is expected to become a significant and ongoing revenue stream in the coming years.

Starting with LTE and studying the traffic profile of the popular title, King Of Glory, the distribution of allocated Resource Blocks (PRBs) is observed in figure 9. Here, allocation of PRB=4 accounts for up to 65%, and the allocation of PRB<50 accounts for up to 87% of the time. This distribution is a result of low rate data packets that occupy most of the time, at least for PCC.

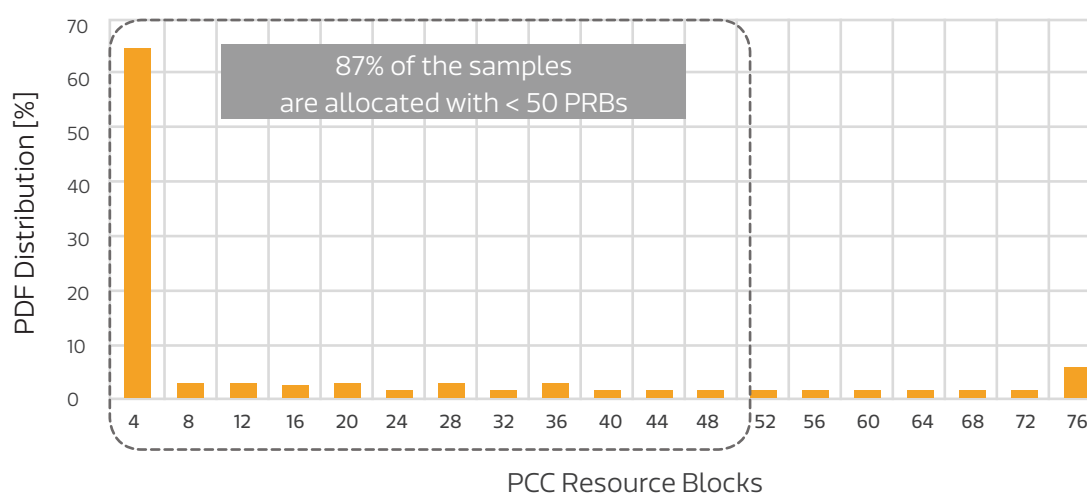


Figure 9: Online Game King Of Glory PRB allocation distribution

The same traffic model was applied to two different configurations:

- Configuration-1: No BWP – UE uses the whole carrier BW all the time.
- Configuration-2: BWP part applied, with first BWP = 10 MHz and the second is 100 MHz (whole carrier BW) and DCI-Based BWP adaptation is applied.

The results showed power efficiency gains of **up to 50%** in configuration-2 with BWP compared the configuration-1 where BWP was not applied. As a result, with BWP, it is possible to double online gaming time for users with same power consumption for the device.

Case Study 2: Voice over New Radio (VoNR)

Voice service is normally a low throughput service with a quasi-fixed burst traffic pattern that might also include periods of silence. It is due to this service characteristic that it might be very inefficient to budget power according to a wide bandwidth carrier of 100 MHz as expected for 5G deployment on FR1. Starting with the current VoLTE solution, its power consumption profile is demonstrated in figure 10. The profile is a typical case, assuming 40msec CDRX (connected mode discontinuous reception) configuration, three silence/listen/talk periods and data throughput ranging from 12 to 36 kbps, in 20 MHz LTE bandwidth.

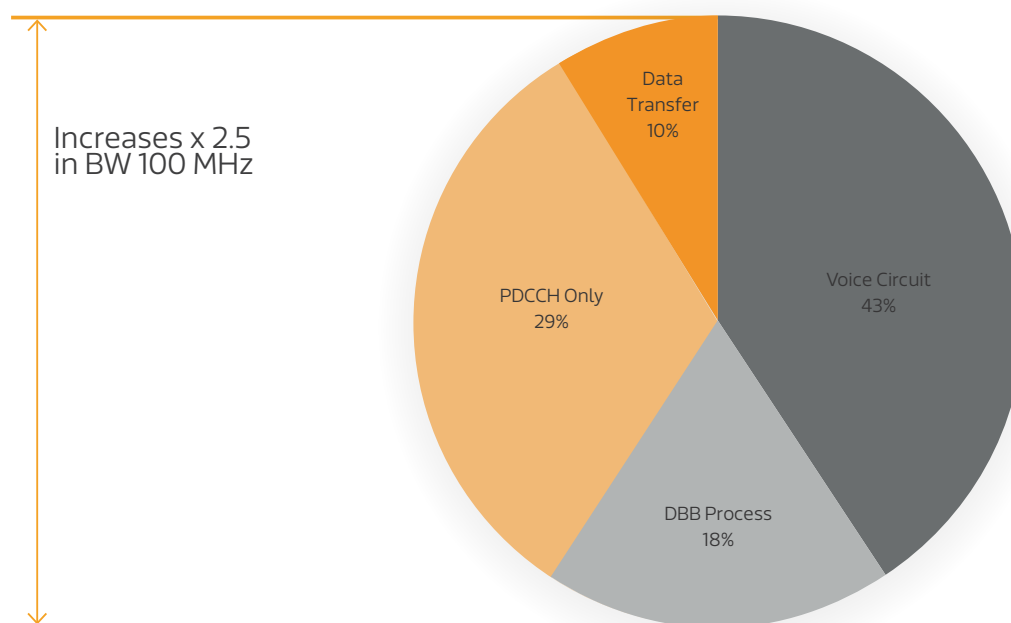


Figure 10: VoLTE Application Power Consumption Profile

As shown, Voice Circuit for the microphone, voice encoders/decoders, and speakers accounts for 43% of the power consumption. The Digital Baseband (DBB) processing of voice packets accounts for 18%.

The PDCCH-only accounts for 29% and the real voice data transfer accounts for 10% of the power. Based on MediaTek studies, increasing the bandwidth to 100MHz in NR vs. 20 MHz in LTE will increase the power consumption in PDCCH-only mode and in data transfer by up to 250% which will cause the total power consumption to surge by around 60%.

BWP perfectly fits this case as it can secure narrow bandwidth for voice calls, keeping the consumed power in LTE-like limits or even lower depending on the size of the BWP allocated. Both RRC-based and DCI-based BWP switching could be applicable for a VoNR scenario. As a result of applying BWP, the user can enjoy 40% more minutes or more in voice calls with same power consumption.

Case Study 3: Video Traffic

Video traffic profile, like YouTube or iQIYI, is characterized by a continuous data stream with relatively low throughput and sporadic high rate data bursts.

This is shown in figure 11 for LTE and NR scenarios assuming that LTE uses 2x20 MHz carrier aggregation, while NR utilizes single 100 MHz-wide carrier. In the figure, the video traffic profile typically requires the network scheduler to assign a continuous data stream on PCC, while assigning sporadic large data in SCC.

This may yield to small transport block size in PCC and larger ones in SCC, in order to achieve trunking efficiency in the carrier aggregation scenario.

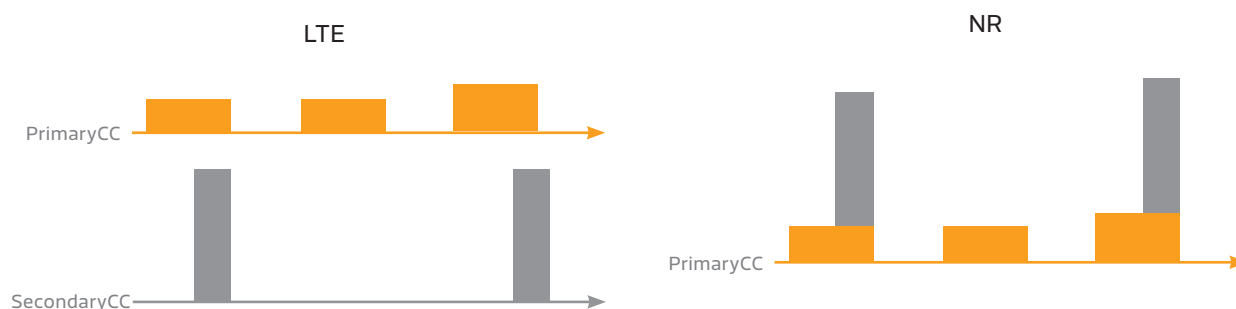


Figure 11: Video Streaming Traffic Profile

The traffic profile for NR can obviously benefit from the BWP concept. According to the current LTE network power consumption profile for the video streaming application, more than 60% of the energy is consumed by the UE in 2xCC PDCCH-only mode in the case of carrier aggregation, as illustrated in figure 12. Note that CDRX is the most efficient way in LTE to produce power saving when there are bursts of data transmissions. However, BWP can still provide further enhancements on top of CDRX as frequent small data in PCC may cause ineffective DRX, because the CDRX parameters may not change quickly enough based on the traffic profile.

Due to PDCCH only most of the time, applying a smaller BW for PDCCH decoding at the beginning (e.g. 20MHz) and switching to larger BW (e.g. 100MHz) whenever needed will yield considerable power savings. BWP operation affords a power consumption reduction of up to 2X, resulting in total reduction of more than 30%. Also note that the faster scheduling DCI-based switching is seen as the optimal BWP adaptation method for this case.

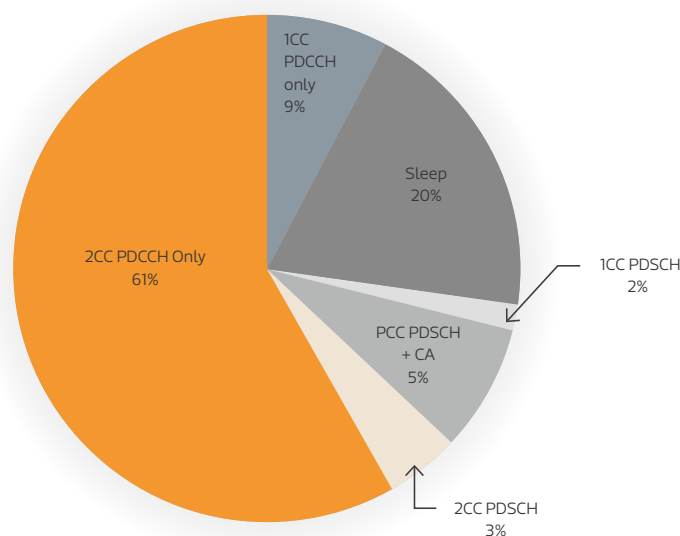


Figure 12: Power Consumption by Video Streaming Application

Conclusion & Way Forward

With the many features and enhancements enabled by 5G NR such as wider channels, higher throughputs, new frequency ranges, tighter processing times and many more, the device power consumption is becoming a crucial target of optimization to ensure end user adoption and satisfaction through all this new technology has to offer.

In the 'normal usage' scenarios of LTE smartphone modems we typically see when the device is engaged in data connectivity for 12% of the total usage time it is consuming 40% of the battery power. In addition, 5G NR devices with 100 MHz FR1 at zero throughput, consumes the same power as a CAT4 LTE device downloading at its maximum throughput of 150 Mbps, and the baseline power consumption can even go higher for FR2 devices operating at wider bandwidth. As a result, using 5G for low throughput applications yields a higher modem power consumption when compared to LTE devices. Therefore, Bandwidth Part Adaptation, through the allocation of different Bandwidth parts (BWP), allows the dynamic matching of the user services to the allocated resources, affording more power efficient performance and achieving the balance between the exciting 5G NR capabilities, in similar-to-better than LTE power budgets.

With 3GPP Release 15 defining the first 5G NR release, more work on power optimization is yet to come. As presented in this paper, the power saving gains introduced by BWP can be significant and applicable to different types of traffic profiles at different data rate requirements:

- **Video traffic (example by iQIYI)**
 - >30% power saving gain by BWP.
 - BWP=100MHz when large payload.
 - BWP=20MHz when small payload.
 - DCI-based BWP applied.

- **Voice traffic** (traffic pattern from VoLTE)
 - >40% power saving gain by BWP.
 - Assume three types of voice traffic periods: Silence/Listen/Talk.
 - If no BWP, NR bandwidth = 100MHz. With BWP, NR bandwidth = 20MHz.
 - Power saving from PDCCH and PDSCH processing.
- **Gaming traffic** (example by KingOfGlory)
 - Up to 50% power saving gain by BWP.
 - BWP bandwidth = 10MHz or 100MHz.
 - DCI-based BWP applied.

Additionally, as network loading fluctuates with time, depending on the number of users served in the cell during busy hours, capacity and power consumption saving gains can be achieved if system bandwidth is dynamically adapted accordingly. In an LTE carrier aggregation scenario, the cell deactivation mechanism (e.g. deactivating Scell for a given user in bad radio conditions) is a way for eNB to save dedicated resources, increasing the overall capacity and reducing the device power consumption. This process can typically take 30msec for LTE while the Scell activation/deactivation latencies can be higher for NR at up to 85msec. In addition, with larger numbers of carrier aggregation component carrier complicates the UE implementations, which means that depending alone on carrier aggregation for power consumption reduction may not be an efficient power reduction method for 5G devices. In NR, due to larger bandwidth operation of a cell, it is expected that finer-granularity energy savings can be achieved via BWP-based system bandwidth adaptation, and more capacity gains can be observed, while still utilizing the resources efficiently in heavy network loading scenarios for users in different radio conditions.

As a result of how useful the BWP feature is to the reduction of power consumption, more studies are extended to Release 16 work items such as “Study on UE power saving in NR” and “Energy efficiency of 5G”, with more evaluation and development to be expected for BWP adaptation – the capability to have several BWPs active at the same time and the support of more configurations.

Through it all, MediaTek maintains its active role working with the whole ecosystem to enhance and improve the user experience and ensure a more efficient 5G NR system. The Helio M70, among the industry’s first wave of 5G multi-mode modems with integrated baseband and 5Gbps download speeds, is designed in compliance with the 3GPP Release 15 and supports non-standalone (NSA) and standalone (SA) 5G network architectures. It is also currently the only 5G modem with LTE and 5G dual connectivity (EN-DC) and multi-mode support for every cellular connectivity generation from 2G-to-5G. MediaTek Helio M70 aims to simplify the design of 5G devices as much as possible, which yields many user benefits such as comprehensive power management for improved energy-efficiency, while device makers can design mobile devices with a smaller form factor, allowing other space for essential features such as larger batteries, unique features and more freedom to innovate. By working together in this ecosystem, we are helping global operators and smartphone brands achieve their network and product goals respectively in 2019.

References

- [1] GTI Sub-6GHz 5G Device White Paper
: <http://gtigroup.org/d/file/Resources/rep/2018-02-22/c9d31709d72643e625321d6f3724d761.pdf>
- [2] Ericsson Mobility Report : <https://www.ericsson.com/en/mobility-report>
- [3] 3GPP TS 38.300 15.4.0 “NR; Overall Description; Stage-2”
- [4] 3GPP TS 38.211 15.4.0 “NR; Physical Channels and Modulation”
- [5] 3GPP TS 38.331 15.4.0 “NR; Radio Resource Control (RRC); Protocol Specification”
- [6] 3GPP TS 38.321 15.4.0 “NR; Medium Access Control (MAC) Protocol Specification”
- [7] 3GPP TS 23.203: "Policy and charging control architecture."
- [8] 5G NR A New Era for Enhanced Mobile Broadband White Paper
: <https://cdn-www.mediatek.com/page/MediaTek-5G-NR-White-Paper-PDF5GNRWP.pdf>