WHITE PAPER

# 5G new radio architecture and challenges

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## 5G New Radio

One of the key enabling technologies for 5G will be New Radio (NR). 5G NR standardization began in April 2016, with a target commercial release before 2020. More recently, in an effort to bring forward 5G benefits, 3GPP determined a workplan that provides an intermediate milestone for 5G NR Non-standalone (NSA) mode. Targeting the enhanced Mobile Broadband (eMBB) use case, 5G NR NSA has a scheduled function and protocol freeze date of December 2017.

5G NR is the technical response to the commercial challenges of eMBB gigabit-per-second bandwidths, ultra-reliable and low-latency communications (uRLLC) for mission-critical applications and massive machine type communications (mMTC). NR is billed as a more capable air interface and will need to operate in both the frequencies below 6GHz and above 24GHz (mmWave) with a frame structure supporting both TDD and FDD, and operation in both licensed and unlicensed spectrum. This paper explores the aims, solutions and technical challenges of 5G NR.

## More efficient modulation

In addition to the existing LTE modulation schemes, NR introduces π/2-BPSK in the uplink (UL) path. π/2-BPSK is generated from the standard BPSK signal by multiplying the symbol sequence with a rotating phasor with phase increments per symbol period of π/2. π/2-BPSK has the same bit error rate performance as BPSK over a linear channel, however, it exhibits less envelope variation, peak-to-average power ration (PAPR), making it more suitable for transmission with nonlinear channels. This improves the power-amplifier efficiency cost in the mobile terminal at lower data rates.

Currently, modulations schemes beyond 256QAM are not specified as part of 5G NR DL. However, with 1024QAM already established in backhaul and the drive for more bits per symbol a key to achieving the higher 5G data rates, it seems reasonable to expect their arrival in future specification releases, with a corresponding move from 64QAM to 256QAM in the uplink (UL). A likely roadmap is the adoption of higher order modulation schemes at different times by different classes of user equipment (UE).

## Optimized waveform

Orthogonal Frequency Division Multiple Access (OFDMA) is the cornerstone of LTE with a history back to Wi-Fi, so unsurprisingly when looking to the future an optimized version of OFDM was selected for NR. OFDMA has low complexity and high spectral efficiency while supporting windowing and filtering enhancements to minimize out-of-band emissions.

A significant move is the adoption of cyclic prefix OFDMA (CP-OFDMA) for both the UL and DL. LTE uses SC-FDMA for the UL because it supports a lower PAPR, but having a common UL and DL waveform simplifies UE design, especially for UEs supporting device-to-device (D2D) communication. However, the option for the UE UL to use SC-FDMA is preserved to support higher average transmission power for the same maximum power limitation in areas with poor coverage.

## Scalable numerology

NR also adopts a scalable OFDM numerology and carrier spacing. Whereas LTE has carrier bandwidths up to 20MHz with a fixed 15kHz spacing between sub-carriers, the need for NR to also operate in mmWave bands with channel bandwidths of hundreds of MHz demands a sub-carrier that scales with the channel bandwidth. NR therefore has a fast Fourier transform (FFT) size with a basic sub-carrier spacing of 15kHz but which scales with the channel bandwidth or application in multiples of 2. This ensures that processing complexity does not increase but also retains time alignment of slots and symbols to support TDD networks. For example, the sub-carrier spacing for mmWave transmission could be 120kHz, supporting latency reduction.

5G NR is also being designed to accommodate different numerologies in the same deployment, allowing services that use different bandwidths to efficiently multiplex in the integrated framework. For example, using scalable numerologies, smaller sub-carrier spacing provides larger cyclic prefix which can be used to support broadcast service in the same carrier. The 5G NR unified air interface will also allow carrier aggregation across numerologies, such as aggregating mmWave and sub-6 GHz carriers to bring more robust and higher performance connectivity.

The target of NR is spectral utilization of over 90%, the current LTE limit. This will be achieved by stricter windowing and filtering of the signal.

## Dynamic frame structure

NR introduces a new self-contained TDD subframe design. Both UL and DL scheduling information, data and acknowledgements occur in the same sub-frame as a modular transaction, thus removing dependency on other frames. This supports greater flexibility in UL or DL-centric capacity configuration: a cell can dynamically switch UL and DL capacity on a per-subframe basis or have blank subframes and blank frequency resources. It can therefore include the multiplexing of different types of subframes to support new types of 5G service.

Another NR principle is the removal of strict timing relationships across frames, where possible, supporting low-latency use cases. For example, asynchronous HARQ is used instead of predefined retransmission times. This enables very low latency, fast HARQ acknowledgements. Mini-slots are another example, they are the smallest possible scheduling unit in NR and are smaller than a slot or subframe, they can be as short as one OFDM symbol and can start at any time. A slot can be complemented by mini-slots to support transmissions with a flexible start position and a duration shorter than a regular slot duration.

This philosophy is transposed into the FDD use case by overlapping DL and UL transmissions in time. For client-server communications, a client can issue requests using DL slot structure with the server using the UL slot structure for responses. D2D and M2M are use cases where this architecture is attractive.

## Non-continuous reference signals

Four main reference signals are introduced to NR: demodulation reference signal (DMRS); phase-tracking reference signal (PTRS); sounding reference signal (SRS); and channel-state information (CSI) reference signal (CSI-RS). Since NR removes the requirement for continuous transmission to reduce energy usage, these reference signals are only sent when required.

Here the SRS, for example, is also aided by the self-contained subframe. The common UL burst carries UL control information including the ACK and UL SRS. Thanks to channel reciprocity, the UL SRS can be used for downlink channel estimate in TDD. The timely knowledge of DL channel characteristics is key to enabling NR antenna techniques such as massive MIMO.

NR also introduces a new CSI framework for multi-antenna use cases. CSI measurement, reporting and DL transmission can be triggered on different beams to suit the antenna configuration, making use of the removal of strict timing in the self-contained subframe. NR CSI also supports Co-ordinated Multi-Point (CoMP) transmission and reception, allowing cell hand-over or a UE to be tracked by a cell beam as the UE roams.

## Multi-antenna transmissions

Massive MIMO is a key technology for transmission in the higher sub-6GHz frequency bands. Increasing the number of spatial data streams in multi-user MIMO (MU-MIMO) will increase spectral efficiency in this limited bandwidth region and using beamforming techniques can extend coverage without substantial power increases at cell sites. However, at sub-6GHz there is a limit to the number of antennas that can be accommodated due to their physical size: a 6GHz antenna will need an element spacing of 25mm. It is therefore expected that more antennas will be deployed at the base station at these frequencies, for example as 16x4 or 24x4 MIMO configurations using plank architecture arrays.

For mmWave, the element spacing falls to under 7mm, and at these geometries flat panel arrays of antenna mounted on a PCB become an option. Analog beamforming alone results in a single steerable beam, so a hybrid architecture of multiple beams with transmission diversity is likely to be used, with a phased array for analog beamforming for each diversity channel. This also reduces the cost and complexity of maintaining a separate digital channel for each antenna.

Beamforming is required at both the transmitter and receiver due to transmission loss at this frequency, and this results in the need for NR to introduce new methods for CSI acquisition. The UE must maintain a beam on the cell site and the cell beam must search for the UE with its beams.

## Advanced channel coding

In order to deliver higher performance and efficiency, NR needs a new channel coding using larger coding block sizes. NR specifies an advanced low-density parity-check (LDPC) for the data channel using a quasi-cyclic structure where a smaller base matrix is used for the parity check matrix. A smaller base matrix means reduced coding latency and complexity as the code rates increase, while also supporting lower rates than LTE turbo codes. NR LPDC therefore provides a full rate compatibility with incremental redundancy and block length flexibility.

Physical control channels typically have small block lengths and here Polar codes are proposed in NR. Polar codes are the first to achieve maximum channel capacity, closing the gap to the Shannon limit, and improve performance compared to LTE.

## Development approach

Clearly the additional computational complexity of 5G baseband solutions renders today's LTE system-on-chip (SoC) devices suitable only for the LTE anchor channel of a 5G NR Non-standalone (NSA) solution. NR algorithms need to be implemented using more flexible architectures such as those provided by field programmable gate arrays (FPGAs), either co-located on card designs for 5G NR NSA or by using modular scalable open architecture standards.

CommAgility's AMC-D24A4-RF4, for example, is a PICMG AdvancedMC® which provides a powerful combination of Texas Instruments (TI) TCI6638K2K LTE SoC, a Xilinx Kintex FPGA and four RF channels. Two channels can be used in 2x2 MIMO configuration directly with the CommAgility SmallCellPHY-TI software to provide an anchor channel for up to 360 connected and 120 active users. The second pair of RF channels can provide 2x2 MIMO for the development of the NR link, possibly connected to a mmWave beamforming array: the FPGA and discrete independent DAC/ADC channels support NR waveform development without impacting the anchor channel.

CommAgility's software support extends to a full end-to-end solution with source code availability and access to all protocol layers. Our Reference Chain and test vectors provide portability to 5G NR SoCs as they become available and support private network testing during initial roll-out. Partnering with CommAgility to remove the complexities of LTE transport in the anchor channel allows customers to focus on innovation in the upper layers, either for vertical market applications or as a precursor for 5G Stand Alone.

## Conclusion

In arriving at the NR NSA specifications, the 3GPP expects to achieve a step improvement to the efficiency and versatility of existing LTE radio. However, this NR flexibility and the implicit acknowledgement that future use cases are still under study mean that platform designers must address the NR challenges with a similar mindset. Existing system-on-chip solutions optimised for LTE will still have a part to play in this brave new world, but increasingly software defined radio, cloud-RAN architectures, and network function virtualisation will become the mainstay. 3GPP may have begun the journey in NR, but the road is long.

## About the author

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## About CommAgility

CommAgility, a Wireless Telecom Group company, is an award-winning developer of embedded signal processing and RF modules, and LTE PHY/stack software, for 4G and 5G mobile network and related applications. CommAgility designs the latest DSP, FPGA and RF technologies into compact, powerful, and reliable products based on industry standard architectures. CommAgility's LTE software for mobile devices and wireless infrastructure includes physical layer and protocol stack for small cells, physical layer and protocol stack for terminals, an advanced scheduler for small cells, and IP development in the areas of advanced PHY algorithms in multi-core SDR platforms. See www.commagility.com