INTRODUCTION

5G has transitioned from concept to real world with deployments of 5G infrastructure and 5G-enabled devices in late 2019 through 2020. The majority of these early 5G infrastructure shipments relied on Xilinx® Zynq® UltraScale+™ MPSoC and RFSoC products. Today, at the beginning of our 5G mass rollout journey, it is apparent that the 5G economy will not be a repeat of 3G or 4G but will need to address far more use cases and fragmented markets with divergent requirements.

To date, most 5G rollouts have been non-standalone (NSA), which anchors 5G coverage to an existing 4G connection and enhances data throughput. With Release 16 in June 2020, the standalone (SA) version of the 5G specification was completed, enabling the full feature set of 5G. Going forward, both NSA and SA 5G networks need to be supported.

These new challenges require adaptive solutions that can address complex and diverse requirements, while evolving with market needs. The Zynq RFSoC DFE meets these challenges. What makes the Zynq RFSoC DFE unique is that we integrated more hard IP logic than traditional soft logic, making it cost and power competitive with a custom ASIC while also retaining the Xilinx adaptable DNA. This optimum balance of hard IP and adaptable logic is required to meet the 5G needs of today and the future.

BACKGROUND AND HISTORY

Xilinx shipped the first Zynq RFSoC in 2018 and since then has released three generations of the product, each with improved performance and features to address existing and emerging markets. The Zynq RFSoC integrates up to 16 RF-ADCs and 16 RF-DACs, eliminating the need a the power-hungry JESD204 interface, which significantly reduces total power, board area, and complexity of a radio solution. This is most apparent in a 64T64R mMIMO radio, where up to 60 watts of total power can be saved[1]. The Zynq RFSoC DFE is based on the Zynq RFSoC product portfolio and includes not only the direct RF sampling converters but also a fully hardened digital front-end (DFE) subsystem with all the required signal processing blocks. A complete roadmap of the Zynq RFSoC product family is shown in Figure 1. The Zynq RFSoC DFE provides twice the signal processing compute per antenna compared to the Gen 3 device and requires half the power for the same use case.

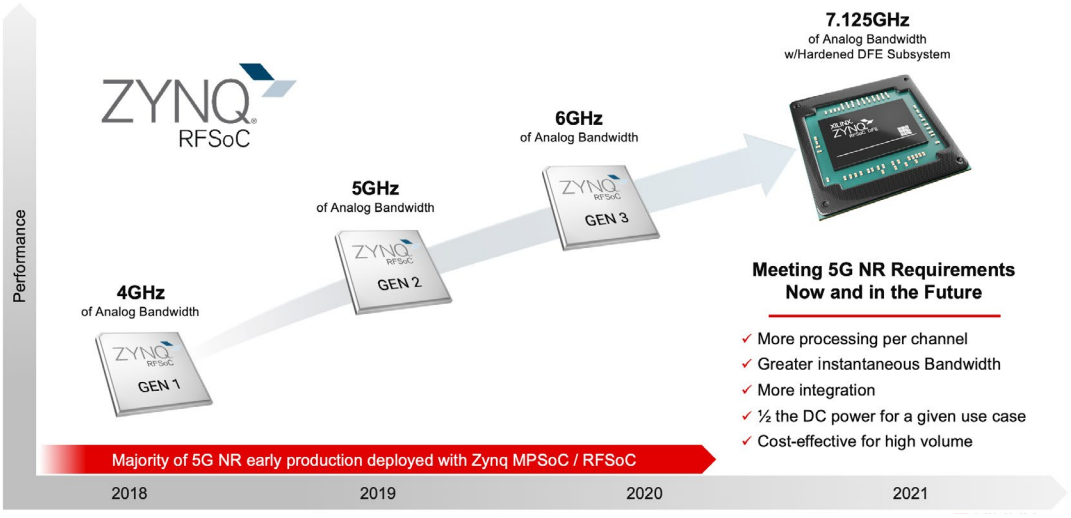

Figure 1. Xilinx Zynq RFSoC Roadmap

Xilinx's commitment to the Zynq RFSoC product portfolio is clear from Figure 1, with each new product released within less than a two-year cadence with protection of customer investments (hardware and software) at each step.

[1] Mobile Experts, 2020 Semiconductor RRH Fcst Update Mobile Experts 080820

CHALLENGES ON THE 5G FRONTIER

Even though operators have begun deploying 5G radios, there are challenges ahead. We group these challenges in three broad areas: 1) increasing radio performance and complexity, 2) 5G diverse use cases and evolving standards, and 3) 5G market disruption.

Increasing Radio Performance and Complexity

The need for wider bandwidth in the radio unit (RU) is not just about increasing data rates and performance; operators need to meet complex and diverse radio configurations for existing and new bands. The sheer number of global bands would be unmanageable if each required a unique radio. Radios are designed to support the widest possible bandwidth and seemingly random carrier configurations to meet these requirements. Early 5G radios supported bandwidths up to 200MHz, but future bandwidths up to 400MHz are being requested. These radios support multiple bands and hence are called multi-band. In some cases, vendors use multiple power amplifiers (PAs) to cover multiple bands; in other cases, advanced wideband GaN PAs are used, requiring state of the art wide-band digital pre-distortion (DPD). Zynq RFSoC DFE devices support both.

New frequency bands are the norm rather than the exception; for example, in 2019, Frequency Range 1 (FR1) was considered sub-6GHz because all 5G New Radio (5G NR) bands were below 6GHz. Currently, new bands up to 7.125GHz have been proposed in North America for additional 5G access.

In millimeter wave 5G NR or Frequency Range 2 (FR2), the Zynq RFSoC is used as an intermediate frequency (IF) transceiver because of the wide instantaneous bandwidth support. With the Zynq RFSoC DFE, we have increased the iBW support up to 1,600MHz in FR2.

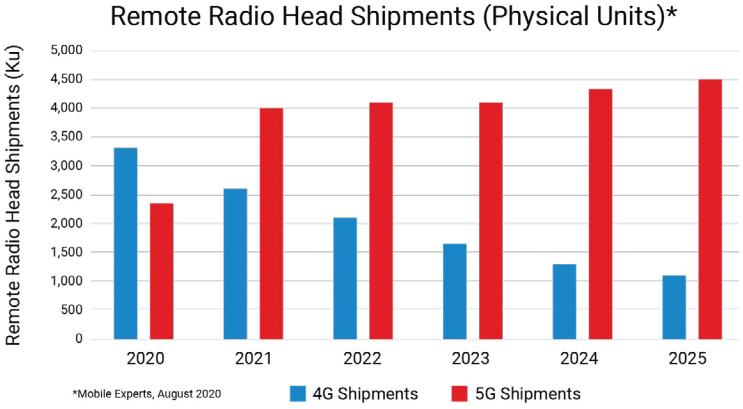

Figure 2. 4G and 5G Radio Unit Shipments Overlap

Even though 5G is the default wireless standard now, 4G shipments will continue in significant volume for many years, as shown in Figure 2, so when upgrading or installing a 5G network, operators need to provide legacy 4G coverage. This can be done in separate RUs, but since operators rent tower space by the unit and weight, there is motivation to combine 4G and 5G radios into one RU if possible. This requirement is known as multi-mode since the radio supports both 4G and 5G carriers. By implementing both carriers in a single radio, capex and opex costs are reduced.

Another complexity in 5G radios is the interface to the distributed unit (DU). Even though standard splits in the 5G transport layer are defined, vendors can choose different options depending on the application. In 5G, the typical splits are named 7.1, 7.2, and 7.3; for the best flexibility, the RU should support all of these.

Open Radio Access Network (O-RAN)[2] and Telecom Infra Project (TIP or OpenRAN)[3] are dedicated to defining physical and software interfaces between the DU and RU and have settled on split 7.2, but details are still being defined, requiring vendors to maintain flexibility. Even though significant effort has been expended on standardizing the DU to RU interface in O-RAN, there will be different implementations, e.g., small cells and interpretations that require adaptability at the RU.

[1] https://www.o-ran.org/
[2] https://telecominfraproject.com/openran/

5G DIVERSE USE CASES AND EVOLVING STANDARDS

To understand the challenges in 5G use cases, it is instructive to review the primary use cases of 3G and 4G.

3G, 4G, and 5G Use Cases

3G was about voice and texting; operators sold talk time in minutes and number of texts. 4G had one main use case: mobile data, which enabled the rise of the smart phone. Operators now sell data in Gb per month. This transition to mobile data enabled the rise of the smartphone with new applications and markets such as real-time, map-based traffic and navigation, and streaming audio services.

5G, on the other hand, has three main use cases as shown in Figure 3: enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC), and massive Machine Type Communication (mMTC). The eMBB use case provides data rates up to 100X faster. In addition to speed or data rate, latency, which is the fixed delay between sending and receiving information, is critical for high-speed and real-time applications. Latency in 5G networks is 10X faster. Lastly, the number of connected devices is critical to support smart cities and IoT, and 5G will support 100s more users. If each of these use cases were optimized separately, it would lead to very different network and radio solutions; 5G blends them into one standard.

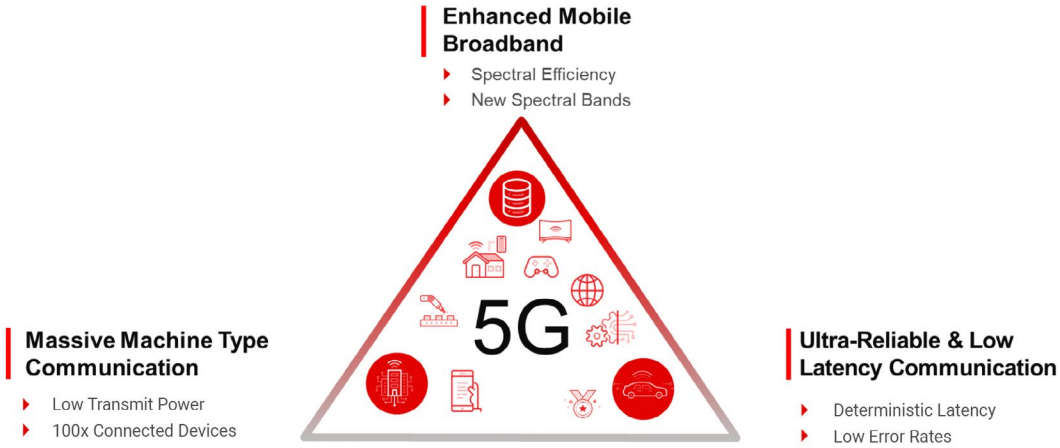

Figure 3. 5G Use Cases

Today's 5G is all about eMBB, and operators are in a race to deploy 5G to lure customers to the fastest network. eMBB is a significant enhancement to what is available today, enabling high data rate applications like virtual reality (VR).

Since URLLC and mMTC are brand new applications, there is no developed market or economy currently implementing them. The main application touted for URLLC is autonomous driving, but the 5G network will not assume a significant role in driving or collision avoidance. Those processes will need to operate in situ, and in fact, all auto manufacturers are developing some level of autonomous vehicles. The 5G network will more likely provide critical near real-time updates on local traffic situations. A viable URLLC use case would be vehicle or machine operation in situations too dangerous for onboard control like mining and disaster operations.

For the mMTC use case, metrics of up to 1 million connected devices per sqKm are presented. For most smart devices, especially home devices, WiFi works just fine and 5G will not replace it. The mMTC use case will be more important for industrial, commercial, and government applications, e.g., smart factories and smart cities.

These new applications and markets will need adaptable solutions to enable fast time-to-market.

Evolving Standards

The 4G LTE standard was finalized with 3GPP Release 9 in 2009 and then evolved over the next eight years with five 3GPP releases to 4G LTE Advanced as shown in Figure 4.

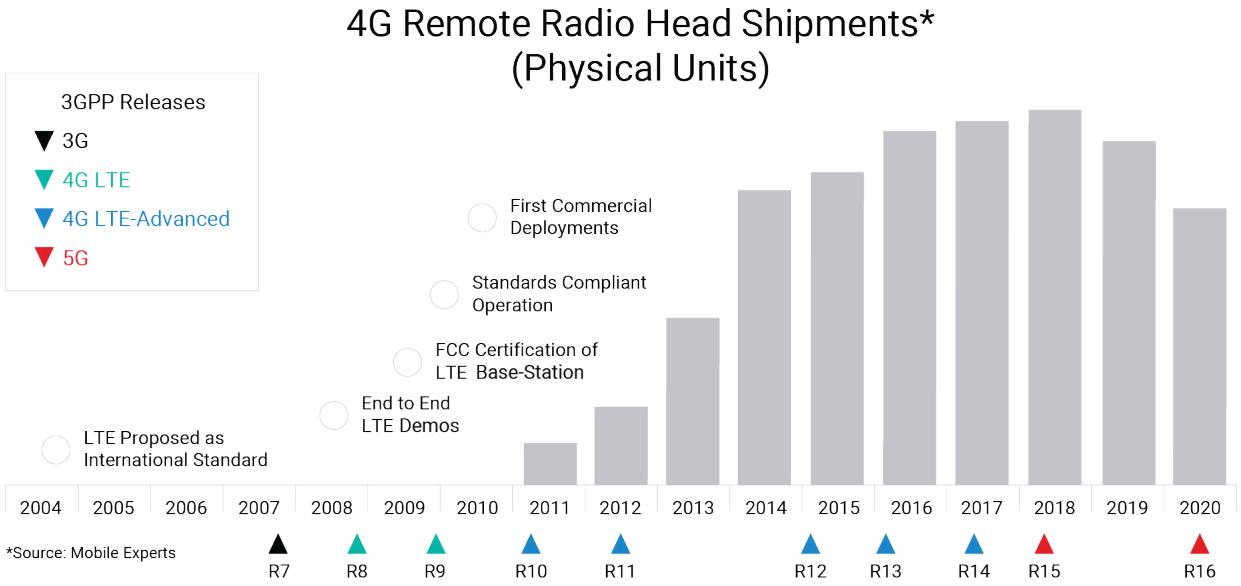

Figure 4. 4G Timeline and RRU Shipments

In Releases 10–14, significant changes to the radio network, like carrier aggregation, were defined and implemented, requiring radio vendors to adapt.

The first and second phases of 5G have been defined in Release 15 and Release 16 and cover the eMBB, mMTC, and URLLC basics. Work has started on Release 17, and Release 18 is already in planning. The 5G standard will evolve with market needs, and we can expect a decade of specification updates. Any 5G solution will need to adapt to future 3GPP releases. See Figure 5.

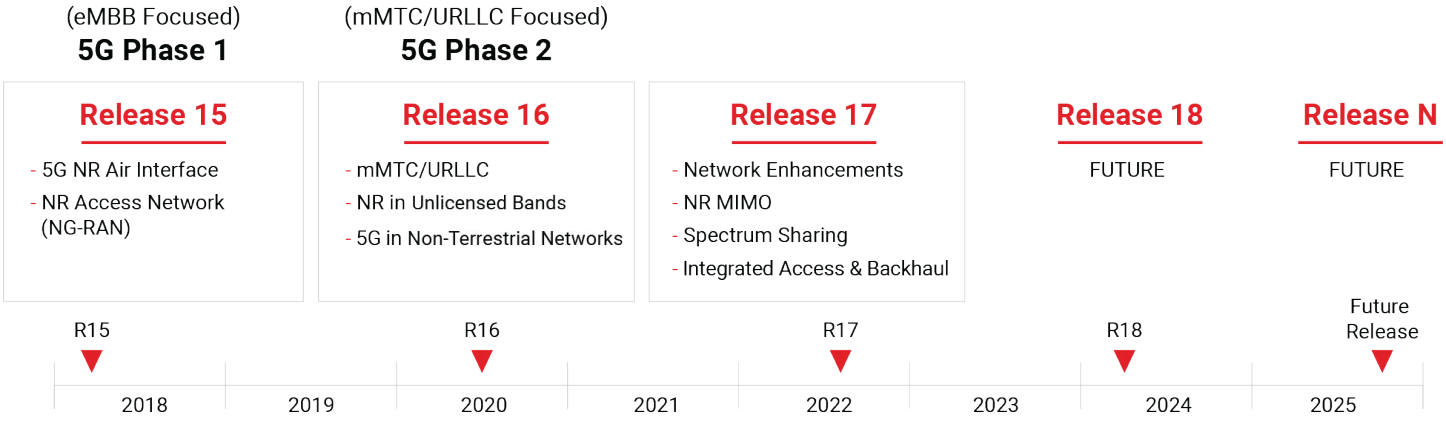

Figure 5. 5G Will Evolve to Market Needs

5G MARKET DISRUPTION

The third challenge for 5G can be broadly captured as market disruption. Looking back at the 4G market, it can be considered rigid. 4G had one use case, and the market consisted of traditional operators selling data to consumers and buying network infrastructure from traditional hardware OEMs.

Today, both the O-RAN Alliance and the Telecom Infra Project are gaining momentum and disrupting established business models by enabling innovation with smaller, more diverse suppliers. Disruptive 5G operators, like Dish, Rakuten, and RJIO, are challenging their peers and incumbent operators. In some cases, like Telefonica, traditional operators are endorsing O-RAN to offer new services. Traditional cable and satellite content providers are also acquiring spectrum and becoming operators. The result is a new dynamic 5G economy with new operators and suppliers as shown in Figure 6.

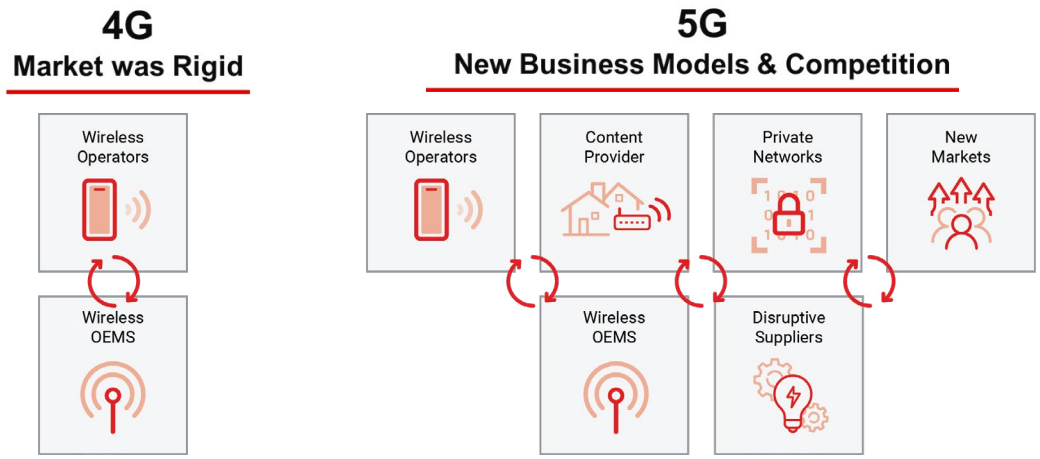

Figure 6. 5G: New Business Models, Markets, and Competition

Another key market innovation with 5G is the increase of private networks. As previously mentioned, 5G use cases mMTC and URLLC are defined in the standard, but today there is no business model or economy for these.

While traditional operators and OEM hardware providers chase the established eMBB market, true innovation of the 5G network will happen in private networks that use mMTC and URLLC features of the 5G network to provide complete enterprise solutions. The CBRS spectrum auction has enabled businesses to purchase spectrum for private networks. The disruption in the 5G business model will foster new wireless operators and new hardware providers, who will adapt the 5G RAN to suit their unique business needs and market. These new market solutions will create more software and hardware platforms that can be supported with the Zynq RFSoC DFE, enabling providers to adapt to the requirements cost-effectively with the fastest time-to-market.

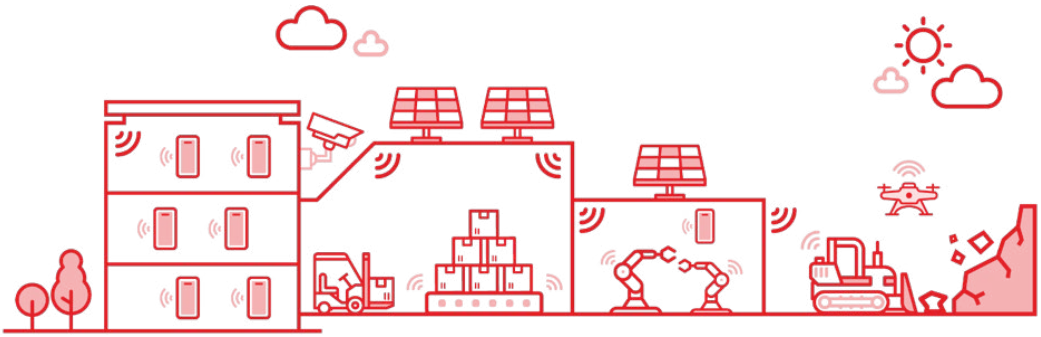

Figure 7. 5G Will Enable Innovation in Private Networks

Although 5G deployments have started, there are many challenges ahead for both operators and platform vendors. To meet these challenges, the market needs a new, innovative product that can adapt and scale with 5G while addressing the performance, cost, and power challenges of widespread deployments.

THE ZYNQ US+ RFSOC DFE MEETS CURRENT AND FUTURE 5G NEEDS

Figure 8. Zynq RFSoC DFE Integrates a Complete DFE Subsystem with Hard IP

The Xilinx Zynq RFSoC DFE, a new class of product, has more hard logic than soft, but remains adaptable to address new market requirements, new services, and customer needs. This innovative approach provides twice the DFE compute resources[4], is competitive with ASIC implementation on cost and power, and enables faster time-to-market.

The Zynq RFSoC DFE implements known and compute intensive DFE functions in a hardened or ASIC-like structure, which are also configurable for both legacy 4G and 5G NR standards.

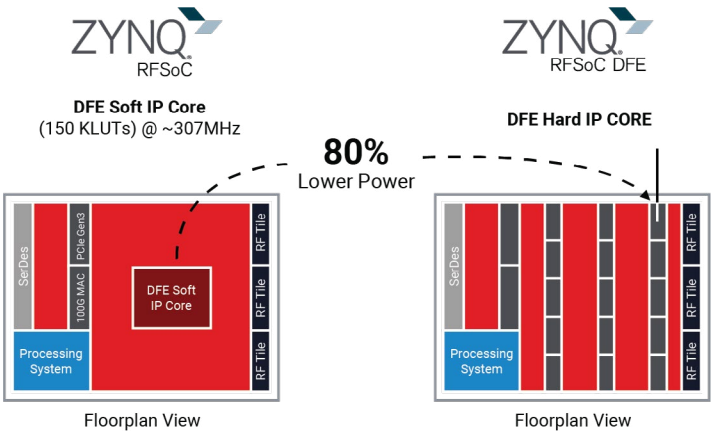

Figure 9. Benefits of Hard IP Implementation

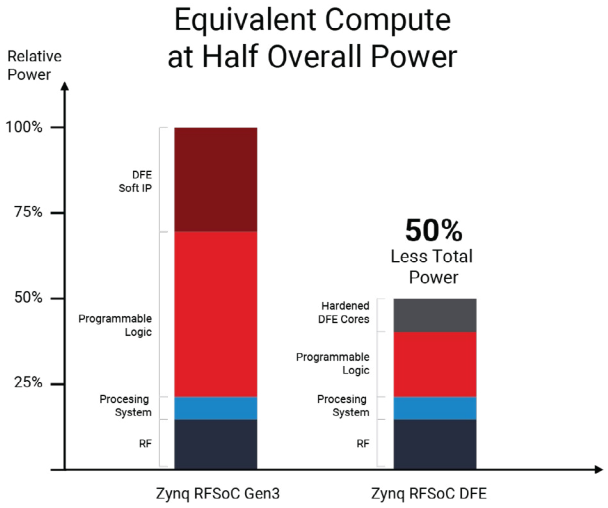

Figure 10. Zynq RFSoC DFE Provides 50% Power Reduction

These hardened cells occupy less silicon area and can reduce power consumption by up to 80% compared to traditional FPGA soft logic as shown in Figure 9. Since each hard IP core is physically smaller than soft logic, we can place more cores and increase total DFE compute compared to the Zynq RFSoC Gen 3. The Zynq RFSoC DFE has a minimum of 2X DFE processing capability compared to a fully utilized Zynq RFSoC Gen 3 device.

When fully utilizing the DFE hard IP blocks, the total power consumption of a Zynq RFSoC DFE device is about 50% lower than the same implementation in a Zynq RFSoC Gen 3 device as shown in Figure 10.

[4] Compared to RFSoC Gen 3

Figure 11 is a block diagram of the Zynq RFSoC DFE. The hard IP blocks, shown in gray, are placed physically on the device consistent with the data flow. Each hard IP component is composed of multiple IP instantiations so that the device can scale up or down depending on the application by invoking more, or less, IP instantiations. To provide the most flexibility, the user can bypass any block and add logic at any point in the datapath, conveniently using the adaptable logic. For example, a user may want to add their own unique IP, such as DPD. The user can leverage Xilinx's DPD by adding logic in parallel, or a fully custom DPD datapath can be inserted.

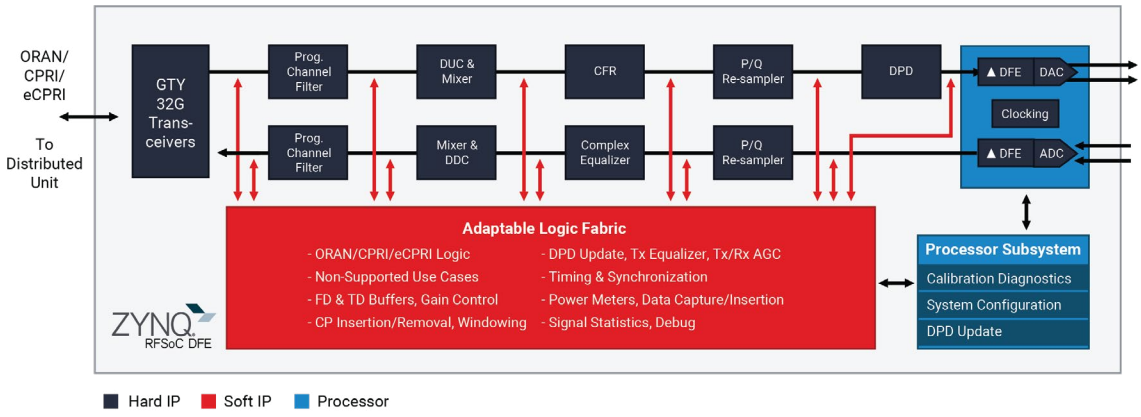

Figure 11. Functional Block Diagram of the Zynq RFSoC DFE

Customer IP or applications-specific functions like timing & synchronization and the DU interface are implemented in the adaptable logic. There is enough adaptable logic in the Zynq RFSoC DFE device to adapt to future requirements, providing a balance between device size and functionality.

The crest factor reduction (CFR) and DPD are based on Xilinx field-proven soft IP but are enhanced with the hard IP implementation. The CFR IP provides instantaneous operation up to 400MHz with improved cancellation while the DPD hard IP block can operate up to 2GSPS and supports the latest wideband GaN PAs to solve the most difficult radio requirements.

The hard channel filters, mixers, digital up- and digital down-converters (DUCs and DDCs) can be configured to implement any wireless frequency plan.

Additional signal processing IP blocks like resamplers and equalizers are included to aid in frequency planning and improve performance.

The Zynq RFSoC DFE supports single-band, multi-band, and multi-mode LTE and 5G NR carriers from 5MHz–100MHz in FR1 (up to 7.125GHz) and up to 400MHz for FR2. The instantaneous bandwidth supported is 400MHz and up to 1,600MHz in FR1 and FR2, respectively. Up to eight component carriers for 8T8R frequency division duplex (FDD) are supported.

The unique combination of standard-compliant hard IP with adaptable logic enables customers to adapt RUs to evolving requirements with minimal time-to-market impact. The Zynq RFSoC DFE provides the same benefits of a full custom ASIC without associated NRE—but also provides an adaptable platform for innovation.

In summary, the Xilinx Zynq RFSoC DFE, based on the successful Zynq RFSoC, includes all the critical and compute intensive digital processing blocks in a hardened, standard-compliant configuration, providing the benefits of an ASIC yet maintaining its adaptable and time-to-market Xilinx DNA by including adaptable logic for unknown future requirements and market needs.

CHALLENGES OF A FULL ASIC STRATEGY IN 5G

Even though there is a perception that ASICs displace FPGAs after early hardware shipments in wireless networks, the reality is different. There are always applications that a main-line ASIC cannot meet, and these will use FPGAs in production. In addition, not all hardware vendors follow an ASIC strategy for the RU. In the mature 4G era, FPGAs still accounted for 40% of all 4G shipments[5]. A 5G ASIC strategy cannot use the same playbook as 4G because 4G had one use case and a very defined network architecture and interface, although vendor specific.

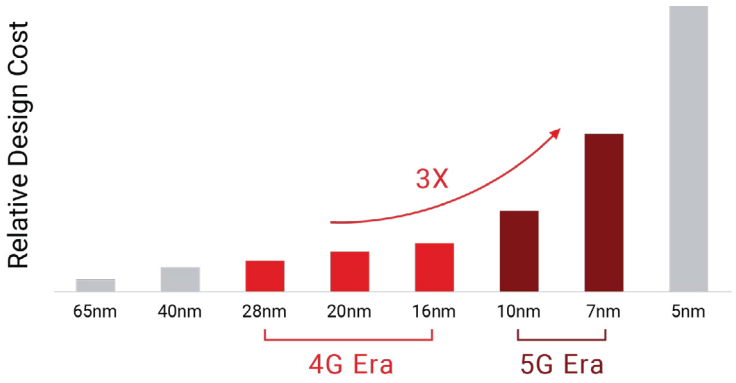

Figure 12. Relative ASIC NRE for 5G ASIC Compared to 4G Era

The diverse use cases, complexity in the network, and evolving standards will require multiple ASICs and/or more iterations to meet 5G market needs.

Another wrinkle is that the development cost of ASICs in 10nm and 7nm is much higher, and the benefits of lower unit cost and power are not being realized, making the value proposition less attractive.

The cost[6] of ASICs in the 5G era is about 3X that of the 4G era as shown in Figure 12.

When deciding on an ASIC strategy, the user must consider the total cost of ownership (TCO) crossover point of an ASIC and FPGA, as shown in Figure 13. In the 4G era, the accepted crossover point, where an ASIC migration had lower TCO compared to a traditional FPGA, was about 100K units[7]. In the 5G era, this crossover point can be up to 250K units depending on the process node and requirements. The DFE hard IP improves the Zynq RFSoC DFE cost competitiveness and increases the TCO crossover point. This analysis is for one ASIC and one iteration. The reality is, especially in the 5G era, the ASIC will require a revision, which increases the TCO, shown as the ASIC spin in Figure 13. The Zynq RFSoC DFE adaptable advantage extends the crossover point even higher because additional costs are not required to meet new requirements.

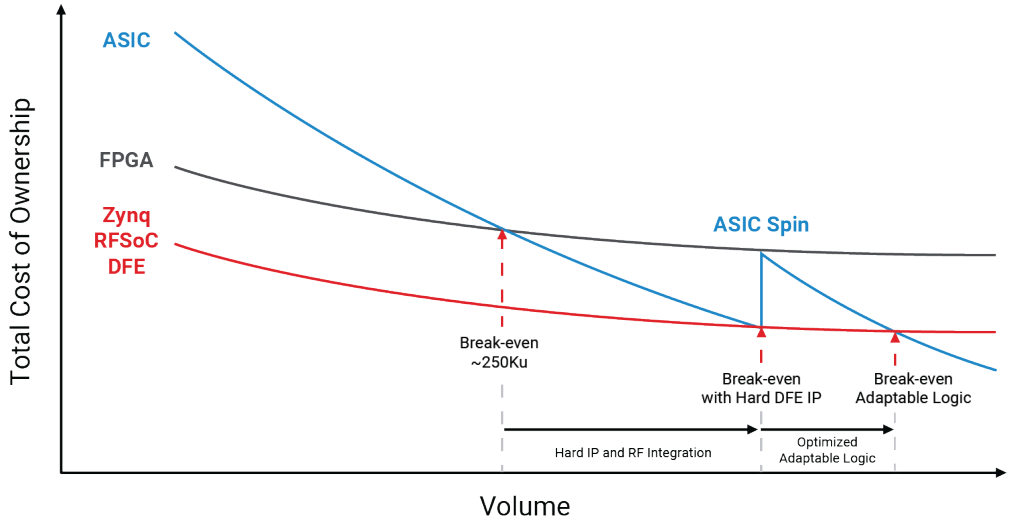

Figure 13. TCO Break-Even Curve for ASIC, FPGA, and Zynq RFSoC DFE

[5] Source Xilinx Estimates
[6] As Chip Design Costs Skyrocket, 3nm Process Node is in Jeopardy, Joel Hruska, June 22, 2018, Extreme Tech. https://www.extremetech.com/computing/272096-3nm-process-node
[7] Mobile Experts, 2020 Semiconductor RRH Fcst Update Mobile Experts 080820

Another point to mention is 80% of 5G radio shipments will be in China[8] as shown in Figure 14. Hardware zvendors need to consider this when planning an ASIC strategy.

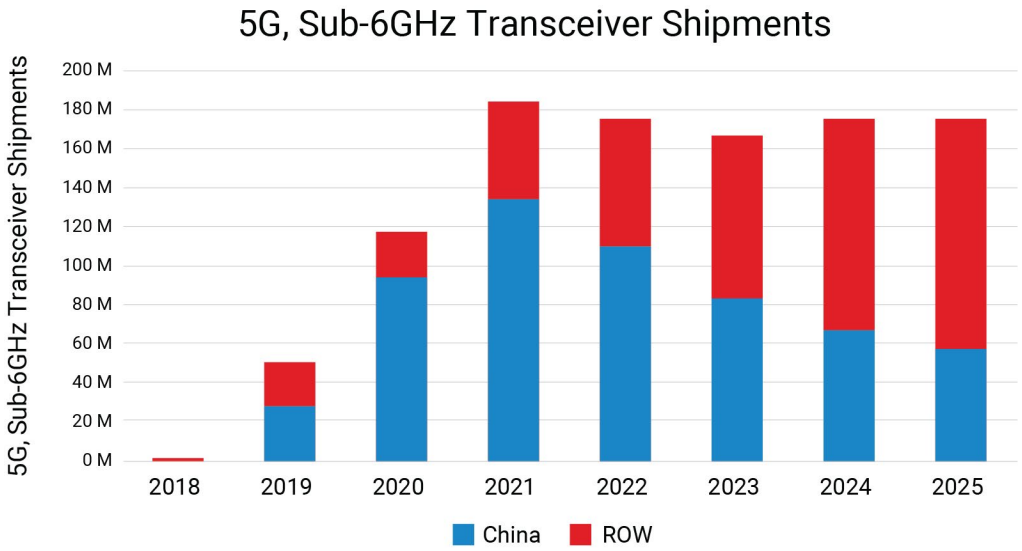

Figure 14. World-wide 5G Shipments

For all but the top hardware providers, maintaining a 5G ASIC strategy to meet evolving requirements will be difficult since the real TCO will be higher than expected and the return may be elusive. This is where the Zynq RFSoC DFE advantage is clear: it is cost and power competitive with an ASIC but adaptable for standard evolution, complex requirements, and niche markets. The Zynq RFSoC DFE is ideal for disruptive hardware providers, such as those enabled by O-RAN or TIP, who may not have an ASIC strategy, but also hardware providers with an ASIC strategy since it can reduce the number of ASICs or ASIC spins required.

For more information, go to Xilinx.com/rfsoc-dfe.com.

[8] Source Mobile Experts

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