Qualcomm snapdragon

ENABLING THE FULL 4K MOBILE EXPERIENCE: SYSTEM LEADERSHIP

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1 Executive summary

As mobile devices are becoming the center of everything we do, the display is becoming the window to life. The quality of the display impacts the visual experience for everything on a mobile device, including watching high quality videos, playing console quality games, viewing web content, photos, text, and immersive user interfaces (UIs). As a higher resolution[1] screen further enhances those experiences, the mobile industry is moving at breakneck speed to adopt new innovations in advanced display technologies. We are on the verge of a new era driven by visual experiences on mobile devices, and the next big thing is 4K Ultra HD[2], which supports four times the display resolution of Full HD 1080p.

Mobile will be a driving force behind 4K adoption and will change the way 4K content is generated and consumed. Qualcomm Technologies, Inc. ("Qualcomm Technologies") is leading the way in redefining the visual experience on mobile devices through its 4K innovations. The new Qualcomm® Snapdragon™ 805 processor is the mobile industry's first, truly end-to-end 4K Ultra HD platform. It enables *a **full 4K experience***, which allows consumers to enjoy a broad range of high-quality 4K content beyond video, both on device and via Ultra HD TVs.

Enabling an end-to-end 4K solution requires the system-on-chip (SoC) to handle four times as many pixels in the same amount of time, resulting in two key challenges: 1) the *increased processing requirements* for different engines, and 2) the *higher data bandwidth* needed to accommodate increased traffic. Meeting these challenges on a mobile device, while maintaining long battery life and thermal efficiency, requires taking a holistic approach to system design across the SoC. This holistic system approach relies on two key pillars:

1) *An optimal heterogeneous computing approach* that takes advantage of all the specialized processing engines within the SoC
2) An *efficient system architecture* that smartly manages system resources, including memory bandwidth and power consumption

2 The rise of 4K – Mobile is a driving force

The display has emerged as one of the most important features for consumers when it comes to making a mobile device purchase decision[3]. In a 2013 survey by Qualcomm Technologies, four of the top seven features driving a consumer's next phone purchase are related to different aspects of the display, such as touchscreen capability, display size, display quality, and display resolution.[4]

2.1 What is 4K Ultra HD?

The mobile industry is on the verge of moving to the next generation of display technology for smartphones and tablets, offering far better picture quality and viewing experiences. The new display technology is called 4K or Ultra HD. These terms are sometimes used interchangeably to describe a

[1] The number of distinct pixels in each dimension (i.e. vertical & horizontal), where a pixel is a single point that uniquely represents a color.
[2] For the purposes of this paper, 4K or Ultra HD will refer to 3840 x 2160 pixels (~8 megapixels (MP).
[3] For the purposes of this paper, the term "mobile device" refers to either a smartphone or a tablet.
[4] According to a 2013 survey commissioned by Qualcomm Technologies, regarding the most requested smartphone features.

single resolution, when in fact they refer to a *range* of resolutions. For the purposes of this paper, 4K or Ultra HD will refer to 3840 x 2160 pixels (~8 megapixels (MP)[5]).

Figure 1: Devices with 4K resolution have four times as many pixels as those with 1080p.

2.2 Does 4K really make a difference?

The display resolution is the number of distinct pixels across the width and height of a display. For example, a 1080p display has 1920 x 1080 pixels. However, pixel density, measured in pixels per inch (PPI), along with viewing distance is the more accurate determinant of display crispness and clarity. A higher pixel density provides more detail, boosting text and graphics clarity.

As you move further from the device, you may not be able to discern individual pixels. This characteristic of our vision is known as visual acuity and corresponds to the ability of the eye to resolve two nearby dots. Visual acuity is determined by the diameter of a single photoreceptor in the central area of the retina. At around the distance of 10 inches, people with average vision can discern an image with ~344 PPI, and people with perfect vision can discern an image with higher resolution up to ~573 PPI[6].

However, visual acuity alone can't explain the complexity of the human vision system and the ability to discern even higher PPI, as illustrated by another characteristic of our vision called vernier acuity[7]. Tests of vernier acuity (distinguishing the relative alignment of two line segments) show that the human eye can distinguish details 5-10x smaller than visual acuity would suggest[8]. Because of vernier acuity, it is possible to distinguish the offset of a pair of line segments even when the offset is much smaller than the diameter of a single photoreceptor in the retina. The ability to discern this greater pixel density is possible because a line stimulates many photoreceptors in the retina, and neural processing fine-tunes object locations based on the inputs from these photoreceptors at later visual processing stages. According to a study by Sharp Devices Europe, study participants rated higher resolution images significantly better for all images and types, leading to the conclusion that many consumers can and do perceive differences in resolution far beyond 440 PPI.[8]

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[5] 3840 x 2160 = 8,294,400 pixels
[6] Phil Plait, "Resolving the iPhone resolution"
[7] http://michaelbach.de/ot/lum_hyperacuity/index.html
[8] Lee Spencer, Sharp Devices Europe, "How much higher can mobile display resolution go?"

This suggests that there is a big opportunity for improvements in pixel density to catch up with what our vision system allows us to discern. For example, a 10-inch tablet screen with 1080p resolution would only have ~220 PPI. The same size screen at 4K resolution would have ~440 PPI, providing finer detail, but still below the level that the human eye can perceive.

Qualcomm Technologies' images taken of 1080p 11.6'' and 4K 10.1'' tablets

Figure 2: Higher PPI dramatically enhances text readability

Ultra HD technology is taking image quality to another level, as it provides finer detail, greater texture, and sharper graphics. Users report that once they've experienced a high PPI screen, they don't want to go back. Premium smartphones of the past, which at the time looked pristine, have aged quickly due to their discernibly low PPI. One way to illustrate the benefit of 4K-display technology is to consider the additional quality and level of detail of photos taken from a 2 MP versus an 8 MP camera. However, pixel density is just one variable affecting the visual experience. In addition to offering a higher resolution, Ultra HD-technology can also offer greater color depth, so more of the colors in the real world can be represented, which improves the "sense of realness" and the overall visual experience.

Ultra HD will raise the bar of the visual experience for everything we do on mobile devices. Consumers will be able to enjoy life in 4K by watching theatre quality movies on the go, streaming family photos and movies to a 4K TV, enjoying more vivid images, reading eBooks with print-quality fonts, and experiencing rich websites and immersive gaming in 4K resolution on their smartphones and tablets.

Figure 3: 4K display technology provides consumers with richer mobile experiences.

2.3 Mobile will drive 4K adoption

Just as it has disrupted many industries, mobile will change the way 4K content is generated and consumed. The short life cycle and high penetration rate of mobile devices have resulted in accelerated innovation and faster adoption of new technologies in mobile. Camera technology in mobile devices has dramatically improved, and its resolution has increased significantly. Pressure to increase camera resolution as well as frame rates will continue. During their 2013 Analyst Day, Samsung indicated that they expect camera resolution to increase from 13 MP in 2013 to 20 MP in 2015.[9] In fact, today's camera sensors for premium mobile devices already have resolutions greater than 40 MP, with 60 to 100 MP foreseeable in the near future. For example, Nokia is already using 41 MP in the Lumia 1020.

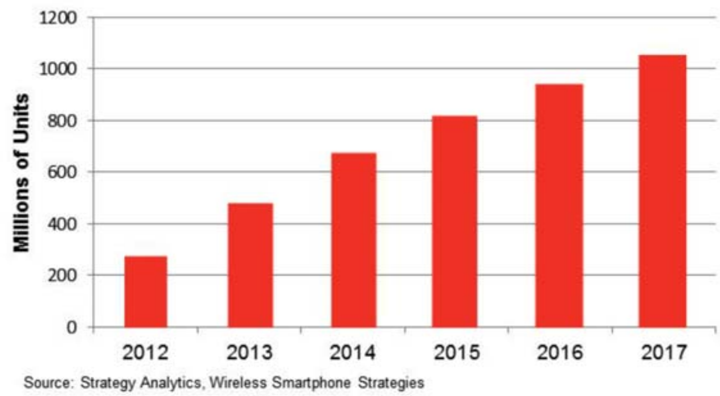

Figure 4: Smartphone unit forecast with camera resolution ≥ 8MP

While TV was the driving force behind Full HD display adoption, mobile devices with 4K recording capabilities will be the key driver for 4K adoption. The Snapdragon 800 for example, which is shipping in mobile devices today, supports 4K recording capability. With premium features quickly moving to high-volume devices and the increased prevalence of user-generated content, the bulk of 4K content is expected to be generated from smartphones and tablets. This will accelerate consumer adoption of 4K.

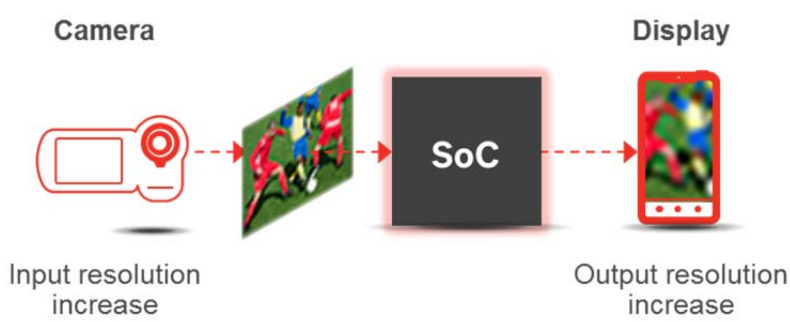

Figure 5: Dramatic increase in input and output resolutions requires SoC innovation

To catch up to the input resolution coming from the camera, display resolution on mobile devices has steadily increased since the introduction of smartphones with touchscreens (e.g., the iPhone, which debuted in 2007). From 2007 to 2013, the number of pixels in smartphones increased by 9x. Tablets,

9 NS (Stephen) Woo, Ph.D., Samsung System LSI Business slides (Samsung Analyst Day 2013)

beginning with the launch of the iPad in 2010, have seen similarly dramatic increases in display resolution. The number of pixels in tablets increased four-fold between 2010 and 2013.

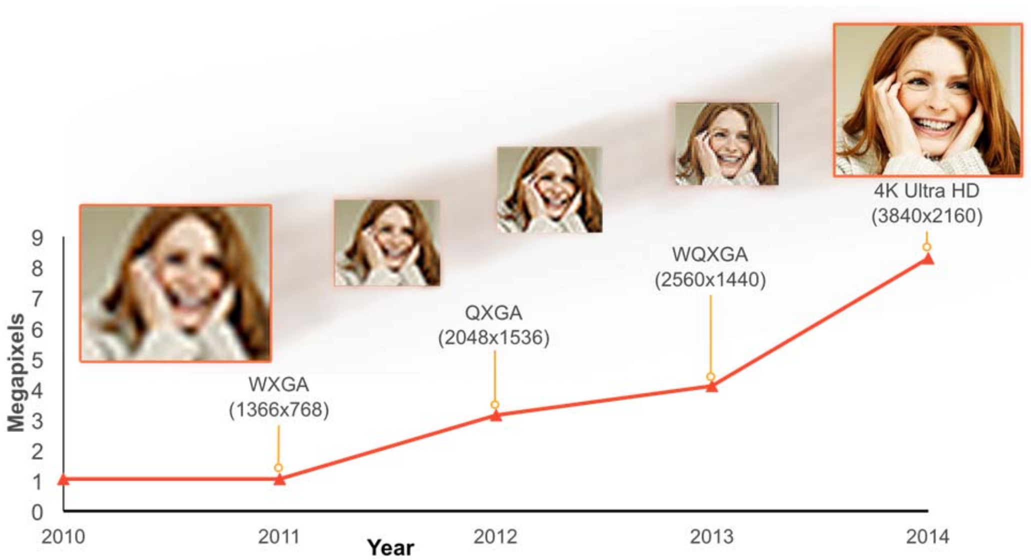

Figure 6: The maximum resolution of tablet displays has increased rapidly.

Today, premium smartphones and tablets pack more pixels than most laptops. This trend is expected to continue, with the display resolution of premium tablets reaching 4K in 2014, followed by premium smartphones in 2015. According to NPD DisplaySearch, global shipments of 4K smartphones are forecasted to reach 23 million units in 2015.[10]

With the increased resolution of the camera and display, consumers still expect a smooth and responsive experience on their mobile devices. This requires the whole ecosystem, including SoC providers, to innovate in order to deliver this experience.

Looking ahead, mobile devices will lead the way for 4K adoption. Consider this prediction from CCS Insights:

> *Over the next three years, mobile devices, not TVs, will be the driving force behind 4K high-resolution displays*.[11] — Geoff Blaber, Vice President Research, Americas

Indeed, mobile devices with 4K recording and viewing capabilities will drive 4K adoption due to their affordability and shorter replacement cycles.

2.4 4K on mobile — why now?

Consumer demand for better visual experiences is voracious, and several other key ecosystem drivers and technology advancements are expected to further accelerate the adoption rate of 4K.

10 http://www.prweb.com/releases/2014/02/prweb11549691.htm.
11 Geoff Blaber, “CCS Insight Predictions for 2014 and Beyond”

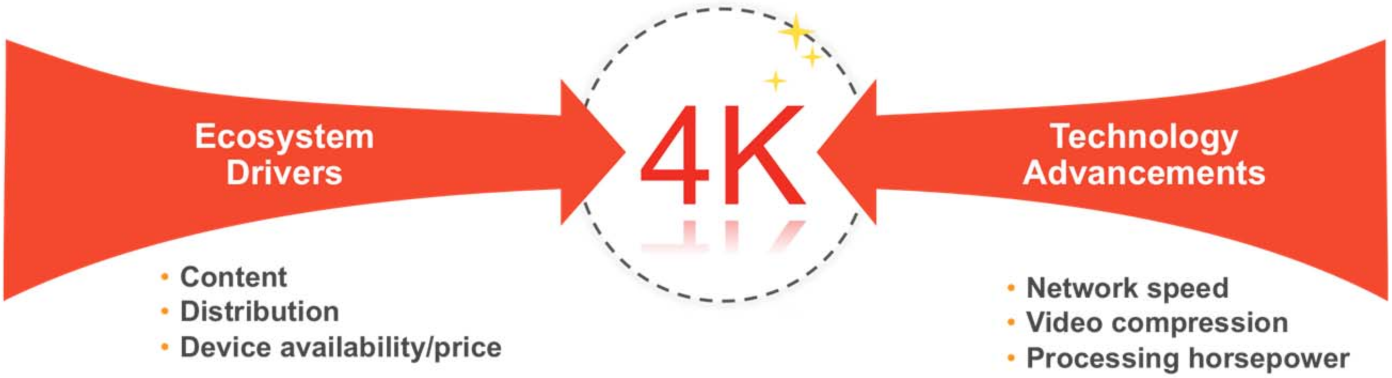

Figure 7: 4K ecosystem drivers and technology advancements

2.4.1 Ecosystem drivers

Content availability — it's rapidly growing: In addition to the 4K user-generated content produced by mobile devices, premium 4K content already exists today. In recent years, a growing number of theatrical movies have been digitally captured and mastered in 4K (or higher) resolution. To boost sales of its Ultra HD TVs, Sony has mandated that all new TV shows from its Sony Entertainment division be shot in 4K. Ultra HD premium content is the most valuable asset to studios, and hence they are mandating enhanced end-to-end security solutions to protect their 4K content. The industry is moving to ratify security specifications on generating, streaming, storing, and playing back 4K content. The Secure Content Storage Association (SCSA) is among these leading initiatives for securing premium 4K video content.

Content distribution — it's going beyond traditional methods: Although traditional digital distribution methods such as, optical discs, cable, satellite and broadcast channels require significant capital investments and take time to implement and deploy, the industry is moving forward to deliver 4K. For example, Japan's Ministry of Internal Affairs and Communications plans to broadcast the final game of the 2014 FIFA World Cup from communications satellites[12]. Given that the World Cup is the world's most widely viewed sporting event[13], football enthusiasts will cherish the opportunity to see the dramatic final game in 4K resolution, spurring 4K adoption.

Standards for distribution are also being ratified. For example, the Digital Video Broadcasting (DVB) project defines commercial requirements and technical specifications that are adopted in Europe and globally for distribution to broadcast receivers including terrestrial, satellite, IPTV, and cable. DVB has recently approved the Commercial Requirements for a first Ultra HD broadcast format (UHD-1 Phase 1) and the technical specifications are under preparation, with publication expected in Q2 2014. The specification is intended for services beginning in 2014 or 2015[14]. At the 2013 IFA consumer electronics trade fair, DVB along with Eutelsat and Kabel Deutschland demonstrated delivery of 4K Ultra HD TV via DVB-S2 (satellite) and DVB-C2 (cable)[15]. And countries around the world are ratifying similar broadcast standards to support the delivery of 4K.

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[12] http://www.reuters.com/article/2013/01/27/us-japan-hdtv-idUSBRE90Q02520130127
[13] http://www.fifa.com/aboutfifa/worldcup/
[14] David Wood, "UHDTV: New evidence and new questions for DVB"
[15] Phil Kurz, "DVB demonstrates satellite, cable 4K transmission with second-generation standards"

However, the transition to 4K is not limited by these traditional distribution methods. With the more recent adoption of over-the-top (OTT) distribution models, access to 4K content is happening now. For example:

- Netflix and Amazon announced their 4K content plans at CES 2014.[16]
- Sony launched the "Video Unlimited 4K" service, a 4K video download service, with access to an expanding library of native 4K feature films and TV shows.[17]
- Comcast, the largest U.S. cable company, will launch an Xfinity TV 4K app on Samsung TVs in 2014 to stream 4K movies and TV shows on demand.[18]
- YouTube, the world's largest video sharing community, showed off its lower-bandwidth 4K streaming based on VP9 at CES 2014.[19]

Availability of affordable 4K devices — prices are trending downward: Devices with 4K displays already exist today. There are many 4K TV models for sale, and prices of 4K TVs are dropping quickly, which will make them more attractive to consumers. For example, Vizio announced an affordable 4K TV for less than $1000 at CES 2014[20]. The 4K trend is not only for large screens; the ecosystem is also developing 4K display panels for smaller screens. For example, Toshiba unveiled the world's first 15.6-inch 4K display laptops at CES 2014[21], and Japan Display has developed a 12.1-inch 4K LCD module[22].

Figure 8: Snapdragon 805 MDP with 4K screen

As shown in Figure 8, Qualcomm Technologies has developed and is demonstrating a 10.1-inch 4K display on a Mobile Development Platform (MDP) at the 2014 Mobile World Congress. The 436 PPI display panel is manufactured by Japan Display and utilizes Qualcomm® frame buffer compression (FBC) to enable 4K over low-power, dual-Display Serial Interface (DSI).

As the 4K ecosystem becomes more competitive and component price premiums decrease, the price gap between 4K and 1080p devices will continue to narrow. In fact, the manufacturing cost of many

[16] Janko Roettgers, "Netflix bets big on 4K, strikes partnerships with four TV vendors"
[17] http://blog.sony.com/press/sony-launches-worlds-first-4k-ultra-hd-video-download-service-and-expands-4k-ultra-hd-tv-line/
[18] Joan E. Solsman, "Samsung teams with Amazon, Comcast, studios on 4K video"
[19] Janko Roettgers , "YouTube goes 4K, Google signs up long list of hardware partners for VP9 support"
[20] Timothy J. Seppala, "Vizio's 4K Ultra HD TVs start at $1,000 for a 50-inch set"
[21] http://www.reuters.com/article/2014/01/06/ca-toshiba-idUSnBw065449a+100+BSW20140106
[22] Mat Smith, "4K 12-inch tablets are going to be a thing and Japan Display can prove it"

components that make up a 4K versus a 1080p panel is similar. For example, one of the primary drivers of the bill of materials (BOM) for a display panel is the glass component. Assuming equivalent yield, the cost of the glass is proportional to the screen size and does not scale with resolution. Thus, the actual cost of a 10-inch glass, whether with 4K or 1080p resolution, should be about the same. In fact, the cost of glass should continue to fall, as next generation fabs allow for more efficient production by using larger mother glass.

2.4.2 Technology advancements

The following technology advancements are necessary to enable superb 4K experiences:

Higher speed networks: To transfer 4K content over the network, new connectivity technologies, such as 802.11ac Wi-Fi and 4G LTE Advanced, can deliver information and entertainment at hundreds of megabits per second.

More efficient video compression: To efficiently store and transfer 4K content over the network, the large 4K files need to be compressed. The new HEVC (H.265) codec reproduces the same image quality at half the video bit rate compared to the already efficient H.264 codec.

More on-chip performance: To handle the increased processing demand of 4K, modern mobile SoCs, through architectural improvements and Moore's Law, deliver increased computing performance and memory bandwidth in a power efficient manner.

Advanced display technologies: Considerable effort has gone into display technology innovation to deliver 4K while staying within the power envelope of mobile devices. Display power is dominated by backlight. Squeezing more pixels into the same area results in smaller holes (apertures) through which backlight travels. To handle the increase in pixel density while staying within the same power envelope, innovations in pixel layout, process technologies, aperture design, and materials have improved backlight transmittance. For example, transistor scaling helped keep the aperture ratio of 4K panels the same as previous generation displays of lower resolution. With these innovations, 4K displays are expected to have a power profile similar to today's 1080p and Quad HD (QHD) panels[23].

	QHD (2560x1440)	4K (3840x2160)
-5.4V	216mW	157mW
5.4V	216mW	189mW
1.8V	90mW	306mW
30 LEDs	1800mW	1800mW
Total	**2322mW**	**2452mW**

Figure 9: Display power comparison

3 Enabling the full 4K experience on mobile

3.1 A full 4K experience — beyond video content on 4K mobile screens

Qualcomm Technologies is the undisputed technology leader in mobile 4K. Snapdragon 800 was the first mobile processor to support both 4K video encode and decode. Today, some smartphones, such as the Samsung Galaxy Note 3 (enabled by the Snapdragon 800), are capable of recording a 4K video

[23] Power for displays utilized on Qualcomm® MDP reference designs

and playing it back. To take mobile 4K to the next level, we introduced the mobile industry's first truly end-to-end 4K solution, the Snapdragon 805 mobile processor. It is the first mobile processor to enable a full 4K experience, allowing consumers to:

- **Watch 4K content on <u>4K mobile screens</u>:** Snapdragon 805 not only allows you to watch 4K content on an external Ultra HD TV, but also on the 4K display of your mobile device.
- **Go <u>beyond video content</u>:** Snapdragon 805 not only enables 4K videos, but also a broad range of other content at 4K resolution, including the highest-quality gaming, imaging, web browsing, text, UI assets (e.g. icons, wallpapers), and more.

3.2 Enabling the full 4K experience represents a major challenge

The full 4K experience extends beyond video to other types of content like high-end gaming. Enabling the full 4K experience has two key challenges, which are further magnified by the power and thermal constrains of mobile.

Challenge 1: **Increased processing requirements:** As seen in the simplified image below, each processing engine within a mobile processor excels at handling specific kinds of content. To handle the increased processing requirements for these various types of 4K content, several engines need to be upgraded. For example, the GPU needs to be upgraded to enable gaming at 4K resolution. Additionally, the display engine needs to be upgraded to drive the mobile device display at 4K resolution.

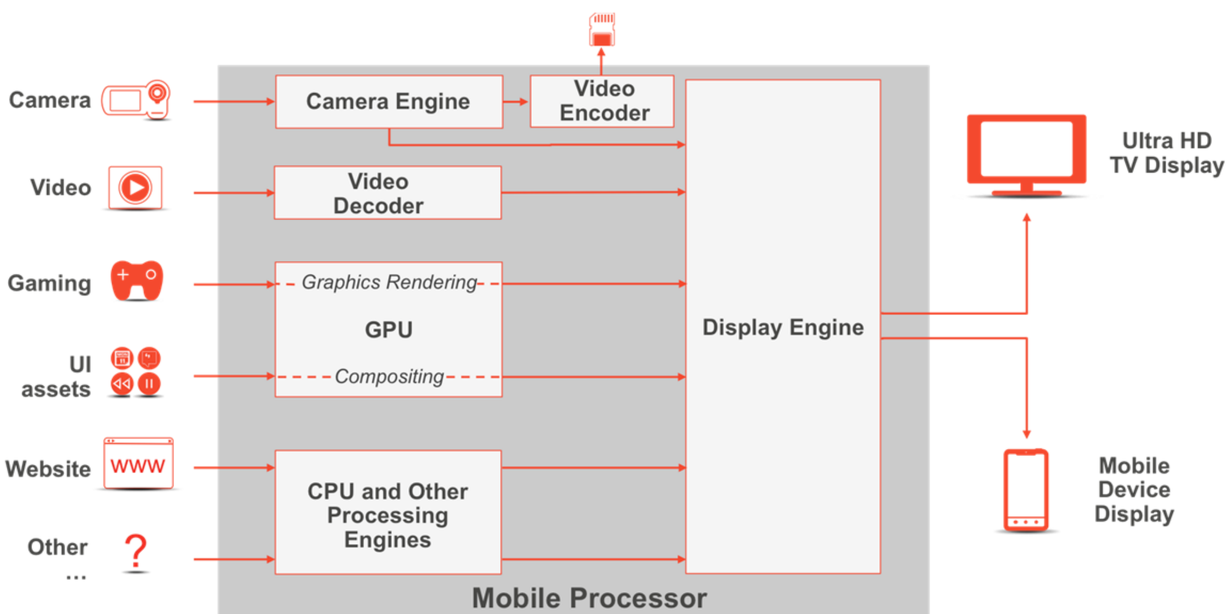

Figure 10: Specialized processing engines for efficient user experiences

***Challenge 2*:** **Higher data bandwidth demand:** As shown in Figure 11, a system-wide bandwidth increase of up to 4x is required to handle the increased amount of traffic generated by different processing engines within the SoC.

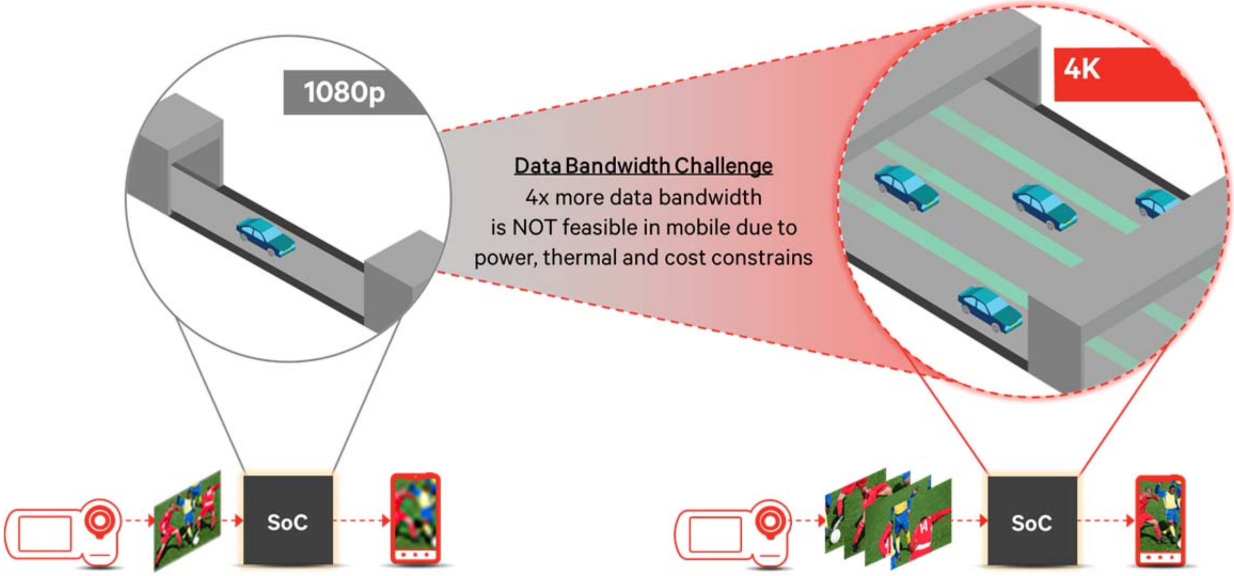

Figure 11: Upgrading from 1080p to 4K requires up to 4x more data bandwidth

To illustrate these challenges, consider what it takes to enjoy a stunning 4K, multi-layer UI on a mobile device with zero stutter. The image below illustrates a potential scenario of transitioning from a camera application to home screen when the user presses the home button. During the transition, the SoC needs to blend multiple layers into a single layer, which is called compositing. Compositing multiple 4K layers requires significant processing and data bandwidth. Google provides the Android Flatland UI benchmark to measure the capability of the SoC in compositing a multi-layer UI.

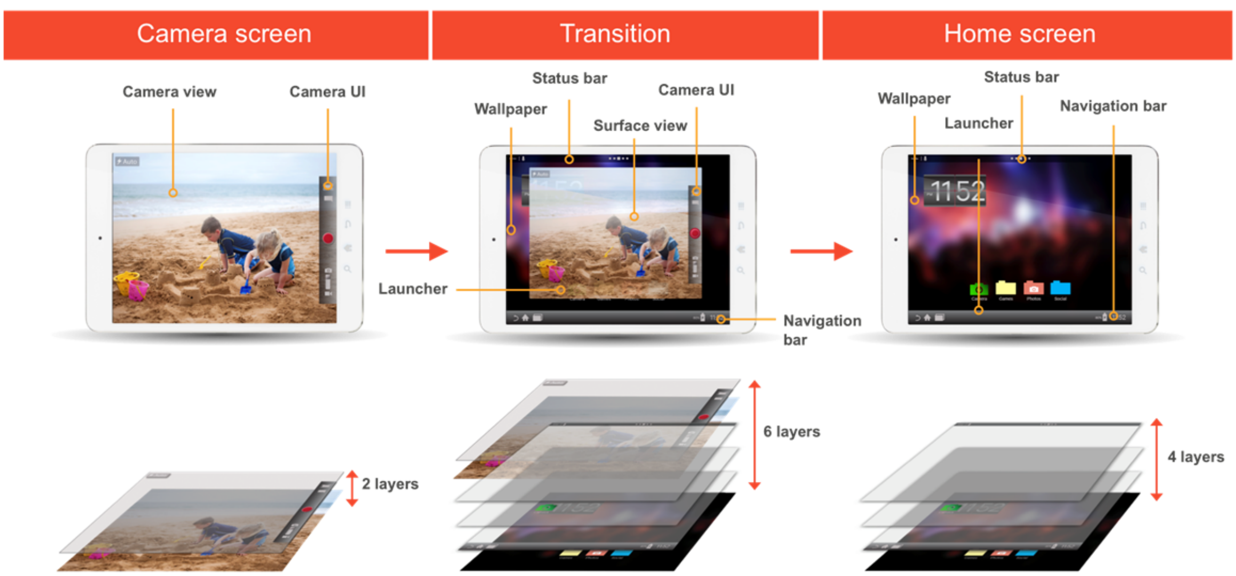

Figure 12: Compositing multiple UI layers for a transition from camera to home screen

During the “*Transition*” stage, there are six active layers of different sizes, which are approximately equivalent to “four to five” full 4K layers that would need to be composited. The bandwidth required to read or write just one 4K layer can take up to 2GB/s[24]. The total bandwidth required to composite the multi-layer UI is proportional to the number of associated full 4K layers. Besides the compositing bandwidth, the additional bandwidth required to generate and to post-process those layers across the SoC would magnify the challenge.

A true 4K system must be able to handle the performance requirements created by concurrency and complex use cases, while still running within the power and thermal constraints of mobile devices. An example of a more complex use case is multi-player gaming, which includes a video chatting component, on a mobile device while streaming content to an external TV.

4 Snapdragon 805 enables the full 4K experience

Qualcomm Technologies is uniquely positioned to meet the challenge of enabling 4K on mobile due to its long heritage in custom designing key technology blocks across the SoC. This allows us to:

- Take the optimal mobile heterogeneous computing approach to meet the challenge of increased processing requirements of 4K at low power.
- Design an efficient SoC architecture that smartly manages system resources to meet the challenge of the higher data bandwidth demand, without exceeding the power and thermal envelopes of mobile devices.

4.1 Heterogeneous computing — specialized engines for efficient processing

Qualcomm Technologies has a long history of taking a heterogeneous computing approach that intelligently utilizes specialized engines to enable new experiences, while maximizing battery life and thermal efficiency. Taking this approach was driven by a vision that the CPU alone would not be enough to deliver breakthrough experiences on mobile devices – and 4K is a great case in point.

In fact, custom designing our own processing engines sets us apart in the mobile industry. It allows us to understand the unique strengths of each engine, and hence better evolve its capabilities for emerging user experiences (e.g. full 4K support) in a timely fashion.

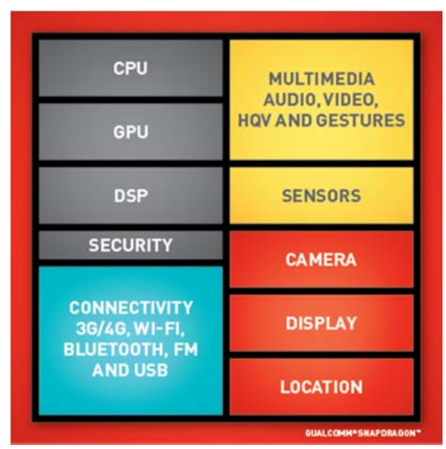

Figure 13: Snapdragon processing engines

This section provides examples of how Snapdragon 805 uses the optimal heterogeneous computing approach to run some of the key 4K tasks on the most appropriate processing engines. This required us to evolve the capabilities of existing custom-designed engines, introduce new kinds of specialized engines, and coordinate between these engines to enable the full 4K experience.

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[24] Memory bandwidth = (Frames per Second) x (Pixels per Frame) x (Bytes per Pixel) ≈1.99GB/s, assuming 60 Frames per Second, 8,294,400 Pixels per Frame, and 4 Bytes per Pixel (32-bit aRGB format)

4K video playback — HEVC specialized engine: To playback encoded 4K video, the Snapdragon 805 has a specialized video engine that is capable of efficiently decoding HEVC videos at 30 frames per second (fps). As shown in the graph, running HEVC decode on a specialized video engine versus a CPU reduces power consumption while still meeting the frame rate requirements.[25]
As you go to higher resolutions and more complex codecs, a specialized engine becomes even more important for efficient decoding. 4K decode is a case in point.

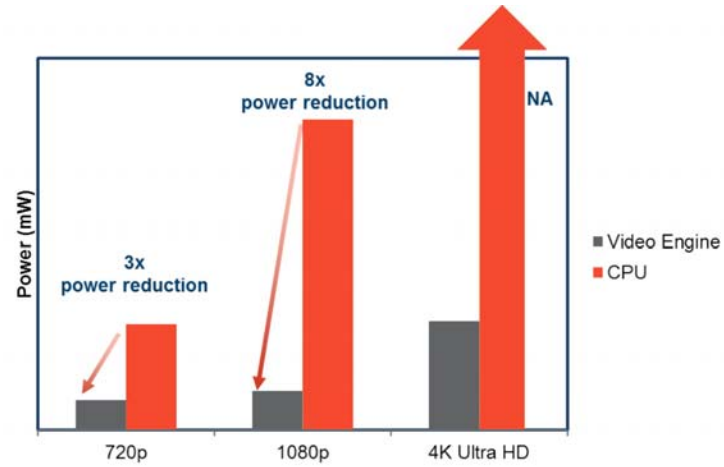

Figure 14: Power reduction by running HEVC decode on specialized video engine versus the CPU

4K video capture — handling more pixels: Snapdragon 805 tightly coordinates the specialized camera and video engines to capture 4K video and store the file in a compressed format. To capture 4K videos at a high frame rate, Snapdragon 805 has the world's first commercial, mobile 1.2 GP/s camera engine that packs a large increase in throughput and quality, enabling sharper, higher-resolution photos with advanced pre- and post-processing noise reduction features for low-light conditions in both snapshot and video modes. The dedicated camera engine has a dual pipeline, which provides support for image resolution up to 55 MP, picture-in-picture from dual cameras, and seamless 4K video encode with high resolution snapshot.

Image quality reigns supreme for 4K — a new specialized engine: At 4K resolution, the importance of high quality images is only increased since every detail is magnified and image artifacts are more noticeable. Snapdragon 805 introduced a new specialized engine Hollywood Quality Video™ (HQV) to provide pristine image and video quality. It has innovative image enhancement algorithms that add detail to low-resolution images and adjust color and contrast to give crisp, clear images on your display. It also takes incoming video streams at lower resolutions and scales them to produce the highest possible image quality — approaching native 4K.

Snapdragon 805 also added a range of image enhancement features to other specialized engines, including display, CPU, GPU, DSP, camera, and video engines. For example, the display engine performs a range of color-correction and picture-adjustment functions. It has high quality post-processing algorithms for superior picture quality, including picture adjustment, color enhancement, contrast enhancement, scaling, sharpening and more. It can map between the standard source color gamut (sRGB) and extended or contracted display color gamuts. Users can adjust the hue, saturation,

[25] Estimated numbers based on Qualcomm Technologies internal testing

and intensity of the display, but the display engine is smart enough to identify and lock down foliage, sky, and skin tones when adjusting other picture elements.

Based on the kind of content and associated use case, these engines work as a team to deliver the required performance at the lowest power, for superior picture quality. In a computational photography use case, Snapdragon uses the heterogeneous computing capabilities of CPU, GPU, and DSP in performing advanced computational techniques to produce a richer, more vivid image than the original image received from the camera

Highly immersive gaming — first to 4K: The new Qualcomm® Adreno™ 420 GPU is the first commercial mobile GPU to enable console-quality gaming of up to 4K on smartphones and tablets. Adreno 420 delivers up to 40% more graphics performance than Adreno 330. Snapdragon 805 with Adreno 420 also uses an average of 20% less chipset power for the same workload than Snapdragon 800 with Adreno 330. With its new architecture, the Adreno 420 is a great example of how Qualcomm Technologies is able to evolve its own GPU engine in a timely manner for emerging mobile use cases.

To support DirectX 11.2 and OpenGL ES 3.0 and later APIs, the Adreno 420 GPU extended its unified shader architecture by adding several completely new shaders: hull, domain, and geometry.

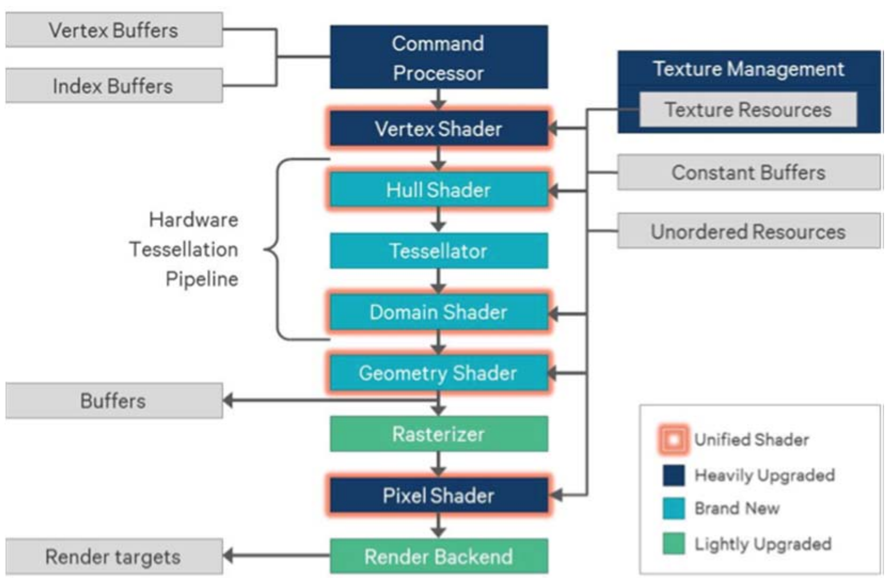

Figure 15: Adreno 420 GPU unified shader architecture

Adreno 420 is the first commercial mobile GPU to support hardware tessellation. Hardware tessellation enables greater detail for more visually realistic scenes in a manner that requires less memory bandwidth and lower power consumption.

Traditionally, in order for most 3D graphics games to be visually immersive, the game programmer must include a substantial amount of geometric detail per object. The denser the geometric mesh used to create a human or monster (for example) in a game, the more realistic it will typically appear to be. In traditional mobile GPUs, these additional geometry assets required for improved visual realism, are written by the CPU to system memory and eventually read into the GPU for further processing. There is a problem with this rudimentary approach though – it either increases the memory bandwidth usage and power consumption to unsustainable levels for console quality games, or it significantly limits the geometric complexity (and thus visual realism) a programmer could deploy within the memory bandwidth and thermal budget of passively cooled, thin mobile devices. Hardware tessellation solves this problem by allowing the GPU to generate additional geometry on-chip, without requiring additional data transfers from off-chip, system memory. Hardware tessellation can significantly reduce bandwidth and power consumption. The image below shows the additional detail that tessellation provides to both the wireframe and final image rendered. For this simple "Hornet" graphics scene, hardware tessellation delivers a bandwidth savings of ~360MB/s, and memory footprint savings of ~20MB. The memory footprint savings could actually be in the GBs though for much larger games.

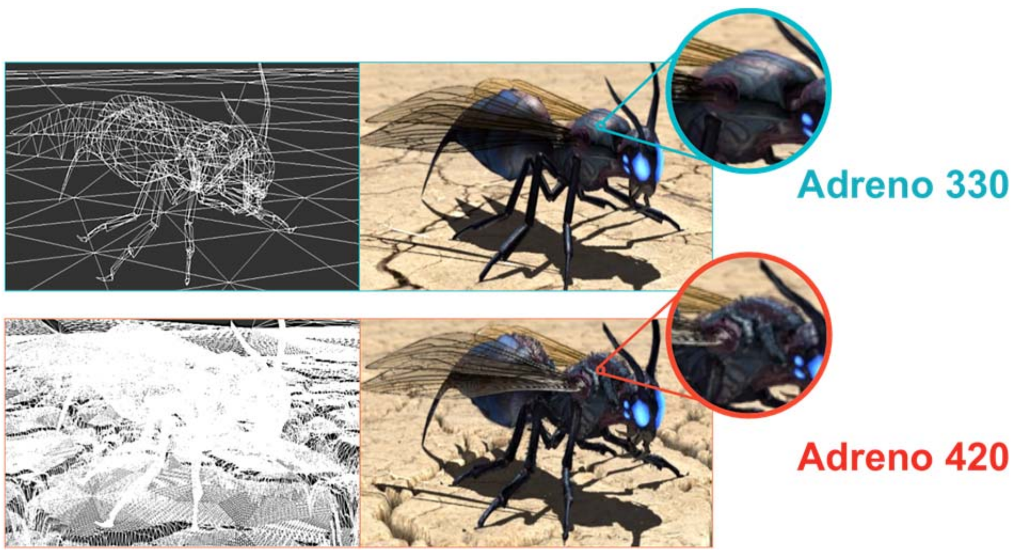

Figure 16: Tessellation (ON: bottom row, OFF: top row) provides more realistic and detailed graphics.

By providing more detail, tessellation will significantly improve the gaming experience, not only for 4K content, but also for non-4K content that needs to be upscaled.

The Adreno 420 is a great demonstration of our commitment to redefining the mobile experience by bringing console-quality gaming to mobile devices.

> *It's the most aggressive move in mobile graphics by any company, to add all the shader types, and HW tessellation, on top of what they did in Subdiv for Motorola, shows Qualcomm [Technologies, Inc.] as the most committed mobile graphics supplier today. It really is bringing console class graphics to mobile devices*[26] — Jon Peddie, Jon Peddie Research.

Premium 4K video content protection — end-to-end security: To provide end-to-end protection of premium video content, the Snapdragon 805 uses Qualcomm® Snapdragon StudioAccess™, a suite of built-in technologies that includes:

- Secure applications running inside the Qualcomm Technologies secure execution environment, which utilizes ARM TrustZone® technology. The secure execution environment is isolated from the high-level operating system.
- Hardware-based access control units that are distributed across different components on the SoC (including the video, display, crypto engines, memory controller and other blocks). These

[26] Jon Peddie, "Qualcomm Moves to 4K with Snapdragon 805"

units are well coordinated to enable system memory protection of both the compressed and uncompressed video buffers.

- The SecureMSM™ platform provides the fundamental security mechanisms of the chipset, such as secure boot. The SecureMSM platform has specialized hardware cryptographic engines, which decrypt data in a power-efficient manner, and at high throughputs that meet the high bandwidth needs of 4K content.

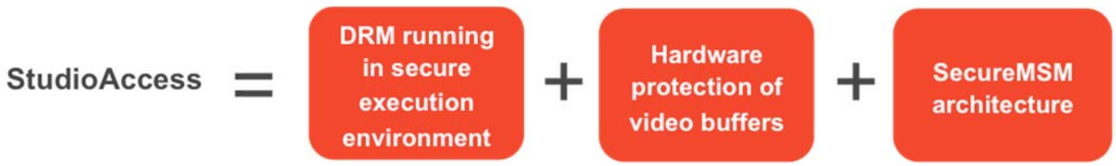

Figure 17: Snapdragon StudioAccess

Snapdragon StudioAccess provides pre-integrated solution for content protection schemes. For example, Qualcomm Technologies has collaborated with the SCSA and prototyped a solution on the Snapdragon 805 that utilizes the security capabilities of StudioAccess to provide end-to-end protection for video formats defined by SCSA.

Stunning multi-layer UIs — efficient compositing: Compositing plays a key role in creating stunning, multi-layer UIs with smooth transitions. Both the display engine and the GPU have compositing capabilities. Through its heterogeneous computing architecture, the Snapdragon 805 processor dynamically distributes the compositing task between the display engine and the GPU, based on the use case and the availability of system resources. The display engine is typically more efficient at compositing. By having the display engine composite when possible (rather than the GPU), the system saves power and memory bandwidth.

4.2 Efficient SoC architecture — smart management of system resources

To meet the challenge of higher data bandwidth demand without exceeding the power and thermal envelopes of mobile devices, an efficient SoC architecture is required.

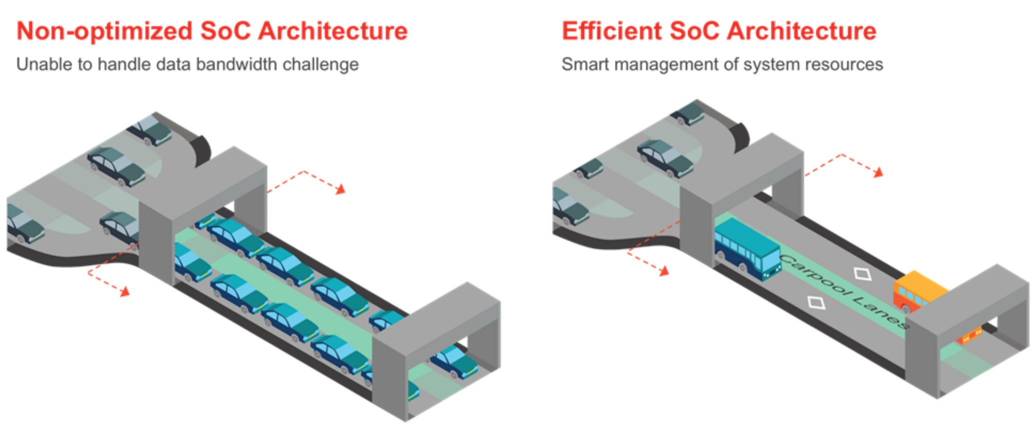

Figure 18: Solving the data bandwidth challenge is only possible through an efficient SoC architecture

Linearly scaling the system-wide bandwidth to match the resolution increase doesn't work for mobile. Beyond optimally increasing the system-wide bandwidth (i.e. carefully increasing the number of lanes), smart management techniques are required to reduce system traffic (i.e. carpooling).

Snapdragon 805 has introduced several innovations to optimize and smartly manage scarce system resources, including:

- An optimal increase of system-wide bandwidth
- Advanced memory management techniques
- Cutting-edge power management technology

These innovations allowed Snapdragon to reduce the required bandwidth and power per pixel.

An optimal increase of system-wide bandwidth: The Snapdragon 805 is the first SoC to deliver system memory bandwidth of up to 25.6 GB/s[27]. To put this in perspective, this is comparable to the bandwidth of laptops, but in a mobile form factor.

Qualcomm Technologies made all the buses in the system wider to support the increased 4K bandwidth requirement. The DRAM interface has been widened to 128-bit (versus the 64-bit in the previous Snapdragon 800). To take advantage of the increased DRAM bandwidth, the system interconnect topology has been re-engineered and widened to accommodate the varying latency and throughput requirements of the processing engines. For example, there is a new bus that connects the Adreno GPU more closely to the DRAM, reducing latency and increasing bandwidth.

Qualcomm Technologies introduced an innovative new packaging design that routes 128 data lines (plus address and control signals) to pads on top of the package in a stacked package on package (PoP) configuration[28]. This offers better thermal properties for sustained performance and a thin package height of 1.2mm, making it optimal for smartphone and tablet form factors.

Besides increasing the memory bandwidth, the throughput of external interfaces needs to be optimized to support 4K. The throughput of the DSI has been optimized to support a 4K on-device display. Snapdragon 805 can simultaneously drive the primary display (through DSI) and an external 4K TV through HDMI. To store 4K videos to class 10 SD cards, Snapdragon 805, supports e.MMC v5.0 and Universal Flash Storage (UFS).

Advanced memory management techniques: To minimize power consumption, the memory controller increases memory utilization by minimizing the overhead associated with memory transactions. It is designed to deliver high quality of service (QoS) for different throughput and latency requirements of different engines, while still maximizing the memory utilization.

Snapdragon 805 deploys smart caching mechanisms in many processing engines to minimize the need for frequent DRAM access. For example, more cache memory was added to the Adreno 420 to reduce memory bandwidth requirements and save power. The Snapdragon 805 also supports internal FBC. This feature automatically compresses and decompresses data as it moves to and from DRAM, which reduces memory traffic and power consumption.

Cutting-edge power management technology: Snapdragon deploys sophisticated algorithms that manage power, based on workload requirements. It supports a wide range dynamic clock and voltage scaling (DCVS). DCVS dynamically varies the clock frequencies and voltages of the processing engines. For example, the Adreno 420 GPU now has more granular DCVS power control levels, so it

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[27] 25.6 GB/s is the peak theoretical memory bandwidth, but the actual bandwidth delivered is dependent on the use-case concurrency and bandwidth demand.

[28] PoP is a packaging method where two chips (in this case DRAM memory and Snapdragon) are stacked directly on top of each other.

can run most use cases at a nominal voltage state and save power. Qualcomm Technologies has also re-architected the power rails and islands in Snapdragon 805. For example, the video engine has multiple power islands, which allows intraframe power collapsing of all stateless power islands during idle periods.

Several of the Snapdragon engines have innovative, power-saving techniques. For example, the display engine uses content adaptive backlight (CABL) algorithms to reduce backlight or brightness levels depending on the image being shown. CABL delivers up to 30% power savings with no visible artifact. [29] Qualcomm Technologies uses a proprietary compression scheme for external FBC, which compresses display data by up to 50% in a visually lossless manner before transmission to the display panel.[30] The Adreno 420 GPU also has an increased Z-reject rate for graphics rendering. Z-reject means that pixels that are not going to be visible (because they are blocked by a pixel on top) are not processed. An increased Z-reject rate means lower power per pixel — and improved performance.

5 Conclusion

Ultra HD experiences will become ubiquitous, and mobile will be a key driving force. Qualcomm Technologies' new Snapdragon 805 processor redefines the mobile experience by enabling full 4K support to smartphones and tablets. It is designed not only to enable mobile video, but also a broad range of other content at 4K resolution, including the highest-quality gaming, imaging, web browsing, text, UI, and more, both "on device" and via Ultra HD TVs.

Enabling an end-to-end 4K solution is a major challenge, as it requires the SoC to handle four times as many pixels in the same amount of time, which results in a significant increase in system resources. To address the challenge on mobile devices, Qualcomm Technologies has built on its heritage in taking a system approach to mobile design, by enhancing all aspects of the SoC.

By taking the optimal heterogeneous computing approach, Qualcomm Technologies met the challenge of delivering the required processing for 4K at low power. In addition, Qualcomm Technologies has designed an efficient SoC architecture that smartly manages system resources to meet the higher data bandwidth demand without exceeding the power and thermal envelopes of mobile devices.

Enabling a full 4K experience on mobile is yet another example of how Qualcomm Technologies is once again re-inventing the mobile world we live in.

[29] Qualcomm Technologies internal metrics
[30] Qualcomm Technologies internal metrics