Qualcomm December 10, 2020 @Qualcomm_tech

Enabling the rise of the smartphone:

Chronicling the developmental history at Qualcomm

Qualcomm Technologies, Inc.

Mobile smartphones are an amazing technical achievement

Mind-blowing performance

Processing power greater than the most advanced super computers of the early 1990s

High-quality multimedia

High-quality music playback
Immersive surround sound
8K UltraHD video player/recorder
HD gaming console
High resolution, multi-sensor digital camera

Location-based navigation

Knows your current location and can help guide you to your destination

Broadband speeds

Blazing fast multi-Gbps data rates

Internet connectivity anywhere

Access information, shop online, connect with friends, share photos and videos

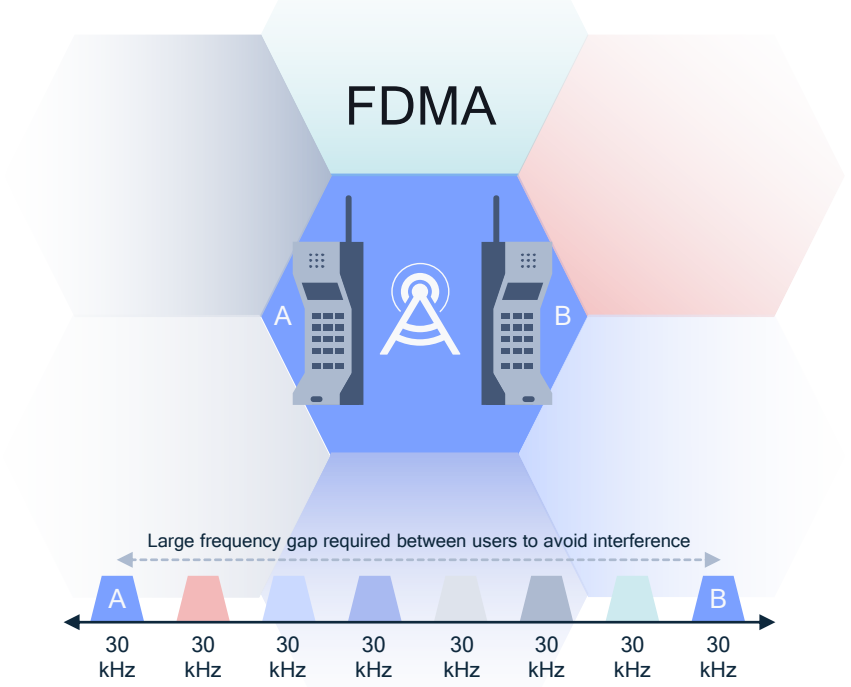
Long battery life

The ability to power all these amazing experiences with less energy than it takes to power a light bulb for 15 minutes

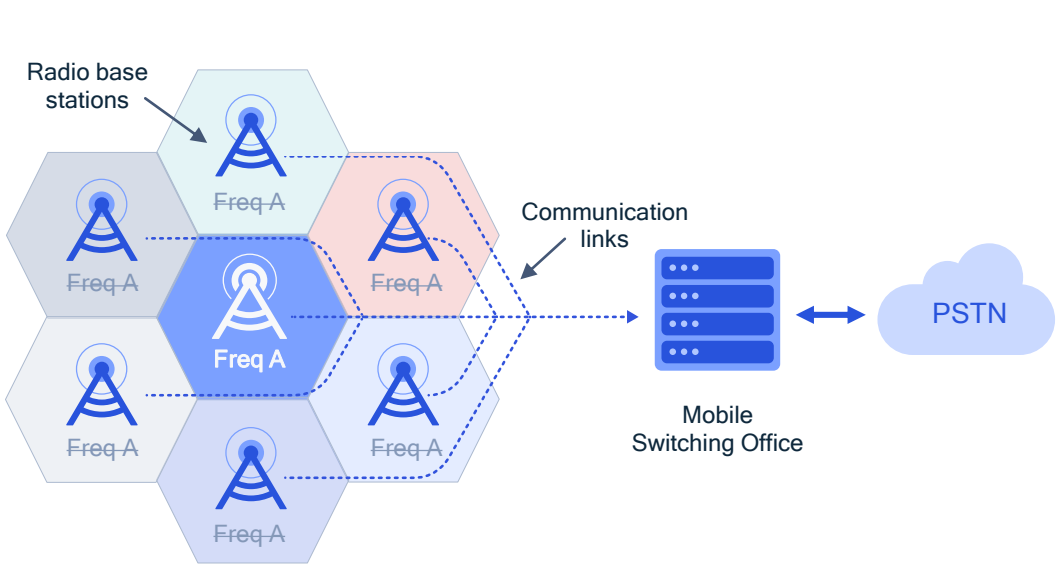
How did this come about?
How did the capabilities of these handheld devices evolve so quickly?

1983: Introduction of 1G cellular wireless (AMPS)

Frequency Division Multiple Access (FDMA) using 30kHz FM-modulated voice channels



Each user in a call was assigned to a pair of 30 kHz frequency bands



Poor frequency reuse led to inefficient use of spectrum (higher cost)

Big, bulky phones

Limited user capacity due to inefficient use of spectrum (expensive)
Analog system suffered from noise/interference issues: desire to go digital

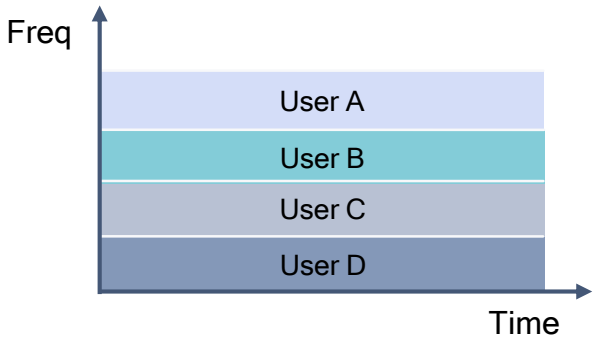
Late 80’s to early 90’s: 2G digital cellular wireless

U.S. industry was already moving down the TDMA path (standardized as IS-54 in 1990)

Analog

Frequency-Division Multiple Access (FDMA)

Only one user per radio channel

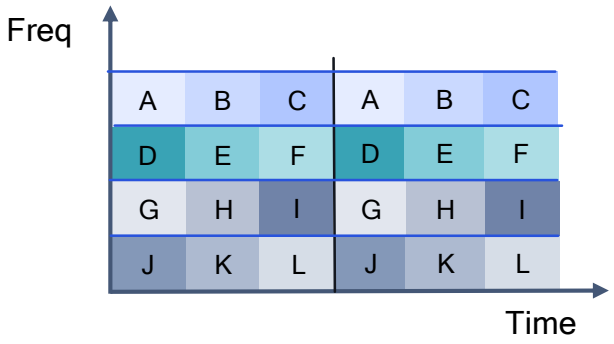


Existing AMPS Analog System
1x capacity

Digital

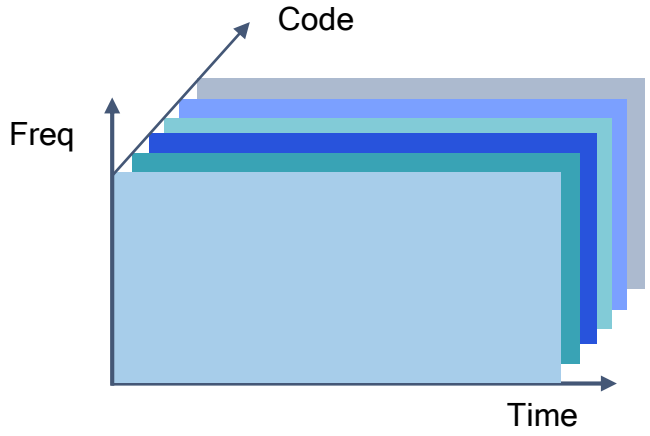
Time-Division Multiple Access (TDMA)

Three users per radio channel



Divide each channel into 3 timeslots so 3 users can share the same frequency band
3x capacity

Code-Division Multiple Access (CDMA)



Spread-spectrum technology: allow all users to share time and frequency by assigning each user a unique code
10x-20x capacity

Qualcomm proposed CDMA as a better digital alternative to TDMA.
Capacity is important because it translates into cost.

Seminal CDMA memo by Klein Gilhousen

Analyzed the use of CDMA for digital cellular compared with FDMA

A CDMA SYSTEM FOR CELLULAR RADIO WITH COMPARISON TO FDMA

by

Klein S. Gilhousen
QUALCOMM, Inc.
November 11, 1988

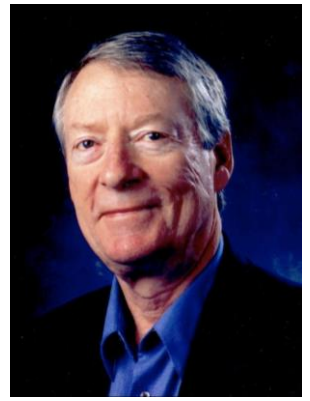
Consider a cellular radio system consisting of a large set of mobile terminals and a set of fixed base stations spaced at regular intervals. It is convenient to locate the base stations at the vertices of a set of equally sized hexagons, forming the "cell" structure that gives cellular radio its name. Typically, each base station is equipped with a phased array antenna system that allows the cells to be further subdivided using the antenna gain to increase isolation.

In traditional FDMA frequency reuse plans for cellular radio, the available spectrum is divided into seven sets of frequencies to be used by all terminals. The system relies on the spatial separation provided by the cell structure and the base station antenna gain to provide adequate isolation between two terminals using the same frequency. The analog FM voice modulation used requires at least 20 dB isolation to provide adequate performance. Digital modulation techniques require similar isolation.

In the following, we consider a new approach to cellular radio systems that utilizes CDMA instead of FDMA. In this approach, we utilize the orthogonal code structure

Summary

"I consider these results to be so staggering that I would like everyone given a copy of this memo to recheck the assumptions and the results. Clearly, there is a business opportunity here."

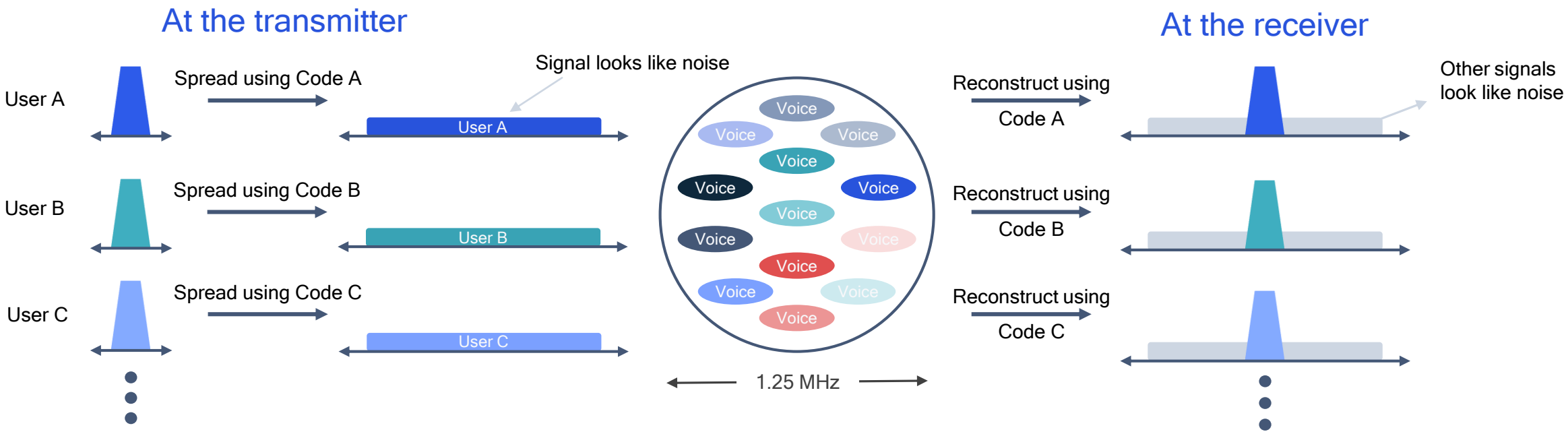


Klein Gilhousen
1942-2016

The theoretical capacity gain of CDMA over FDMA was "staggering"

How does CDMA work?

Each user creates a small amount of interference for the other users



To take advantage of voice activity (each user only talks around 3/8 of the time), the system uses a variable-rate vocoder to reduce interference and leverage statistical averaging across users

All users share the same bandwidth, leverages statistical averaging for voice activity so that spectrum is used efficiently

CDMA was met with skepticism by the industry

Significant doubt that CDMA could be deployed successfully for commercial use

"It's too late. We're already down the TDMA path."

"It won't work in the real world the way they claim."

"It's too complex."

"CDMA violates the laws of physics!"

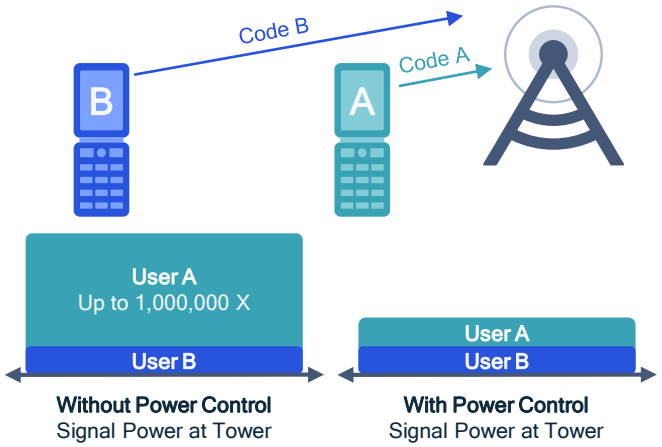
Qualcomm was forced to build the entire system to prove that CDMA worked, including the chips, phones, and base stations.

Why the skepticism? What were the big challenges?

1. Near-far power challenge

Users close to the tower overpower the uplink signal minimizing capacity on the shared channel

Solution: Continuous control of transmit power based on signal strength



2. Cell-edge challenge

High interference caused by users at the cell edge due to the large path loss

Solution: Soft handoff: users communicate with multiple cells simultaneously to leverage diversity gain and reduce transmit power

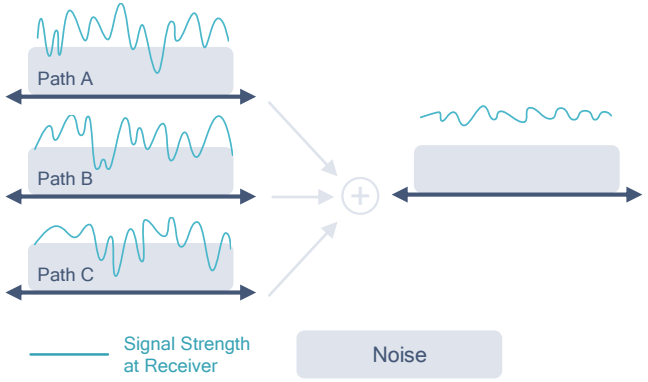
Soft (vs. hard) handoffs

Communicating with multiple cells simultaneously led to more reliable handoffs and fewer dropped calls

3. Multipath fading challenge

Destructive interference caused by reflections from the same signal over multiple paths interfering with each other

Solution: Advanced “rake” receivers align and combine energy from multiple signal paths constructively



Qualcomm engineers figured out how to address each of these challenges

November 7, 1989: The CDMA demo in San Diego

Pacific Telesis in LA (PacTel) was the sole carrier receptive to CDMA technology

Demonstrate soft-handoff
between 2 cell sites

IEEE Milestone Award

This successful demo started the industry shift towards acceptance of CDMA as a viable approach

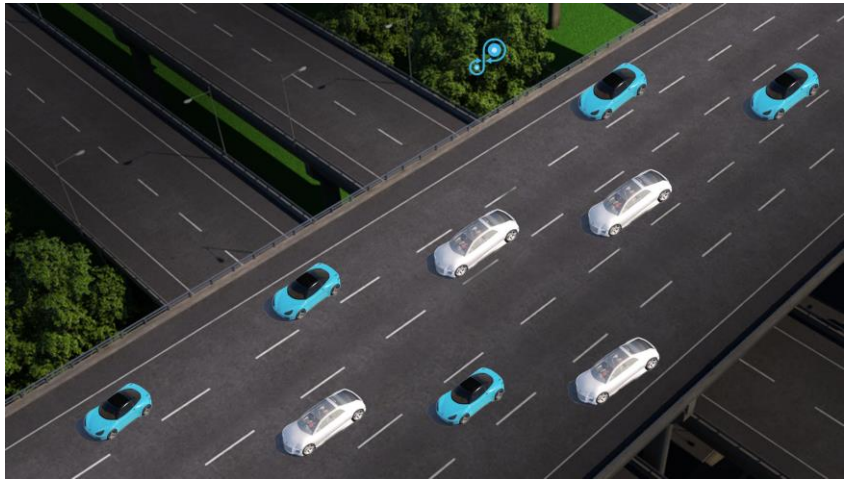
Many more CDMA demonstrations and testing

Need to prove the system worked as advertised in the real world

February 1990: NYC (Nynex)

To prove CDMA worked in an urban environment with significant multipath

Nov 1991: CDMA capacity testing



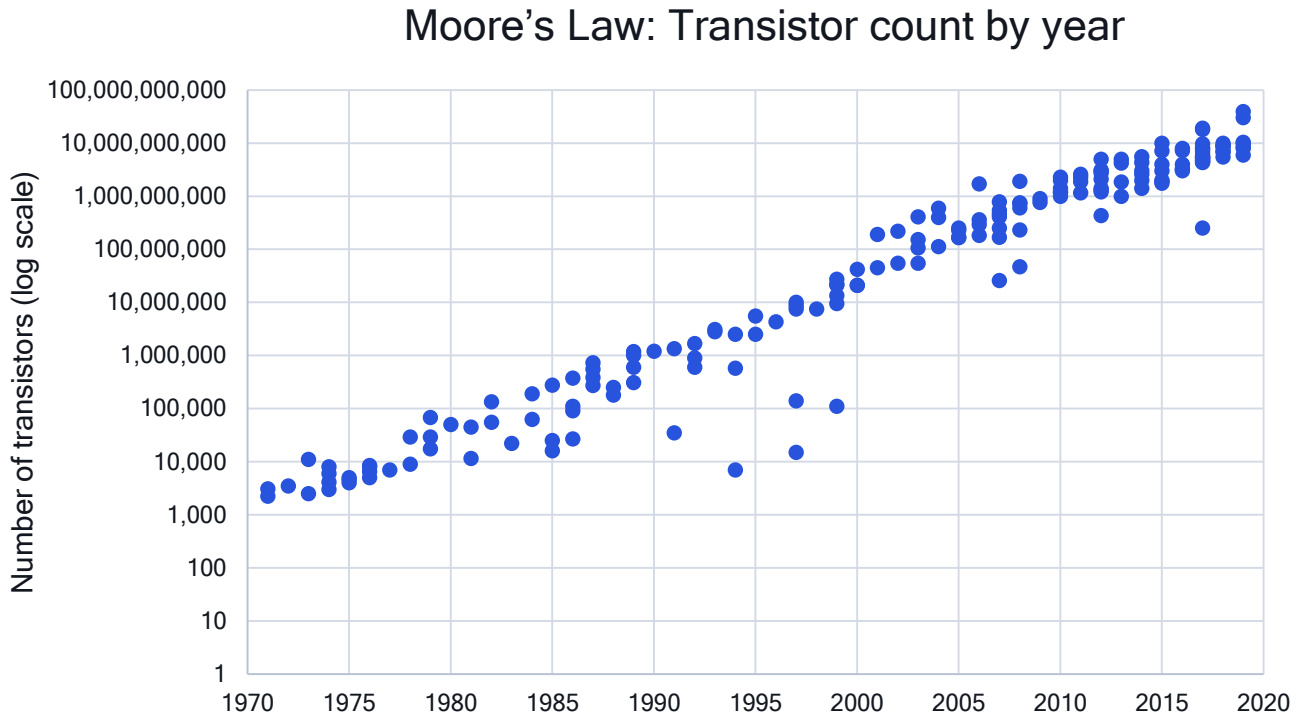
Qualcomm employees loaded mobile devices in their cars and drove continuously along pre-defined routes to allow computation of capacity

CDMA mobile circa 1991

All these demos used Qualcomm-developed CDMA equipment

CDMA complexity challenge mitigated by Moore's Law

The number of transistors per square inch on an integrated circuit will double approximately every 2 years



Source: wikipedia

Since the processing power of an IC doubles every 2 years, complexity of design is not a big problem–process technology will enable it

The power of Moore's Law in shrinking our early phone designs

Qualcomm Alpha II phone
3 chip CDMA chipset in 1.2μ process

Qualcomm Beta phone
Single-chip CDMA MSM in .8μ process

Qualcomm QCP-800 phone
MSM2 in .5μ process

Every process node change allowed a big reduction in phone form factor

CDMA standardization and commercialization timeline

CDMA credibility continued to grow, leading to some major deployment announcements

1992	
June	CTIA asks TIA to expedite adoption of CDMA standard in North America
September	First CDMA network equipment ordered (U.S. West New Vector, Seattle market)
1993	
April	South Korea adopts CDMA as its national cellular telephone system
July	U.S. TIA adopts CDMA (IS-95A) as a North American digital cellular standard
December	CDMA Development Group (CDG) is founded
1994	
October	Field tests of CDMA networks in China successfully completed
October	First Korean CDMA system unveiled
1995	
June	PCS PrimeCo selects CDMA for its PCS network
July	Sprint PCS adopts CDMA for its PCS network
November	World's first commercial CDMA handsets shipped
December	World's first commercial launch of CDMA service (Hutchison Telecom, Hong Kong)
December	CDG develops 13 kbps vocoder for high-quality voice communications
December	CDMA (IS-95A) standardized for U.S. PCS band (ANSI J-STD-008)
1996	
March	First North American launch of cellular IS-95A service (Bell Atlantic Mobile)
April	First Korean launch of cellular IS-95A service in Seoul (SK Telecom)
October	First launch of PCS IS-95A service (PrimeCo, now Verizon Wireless)
December	First Latin America launch of IS-95A (Telefonica del Peru)
December	More than 1 million CDMA subscribers worldwide

Source: cdg.org; RCR Wireless 6/19/95

Primeco to build PCS network using Qualcomm's technology

RCR Wireless

By RCR Wireless Staff on JUNE 19, 1995

When PCS PrimeCo L.P. announced earlier this month plans to build its personal communications services networks using Code Division Multiple Access technology, CDMA developer Qualcomm Inc. received its first major U.S. customer and coverage in more than three-quarters of the country.

AirTouch Communications Inc., U S West Inc., Bell Atlantic Corp. and Nynex Corp.-the companies comprising PrimeCo-intend to deploy CDMA-based wireless service not only in the partnership's 11 major broadband PCS markets, but in each of its own cellular markets. Plans call for voice, vehicular fax, data and short messaging services to be offered.

CDMA was standardized by TIA/EIA as IS-95A in July 1993

Qualcomm built everything to jump-start the CDMA industry

Industry skepticism about CDMA caused traditional equipment suppliers to get a late start

Chips

Phones

(Partnership with Sony 1994)

Sold to Kyocera in 2002

Infrastructure equipment

(Partnership with Nortel 1994)

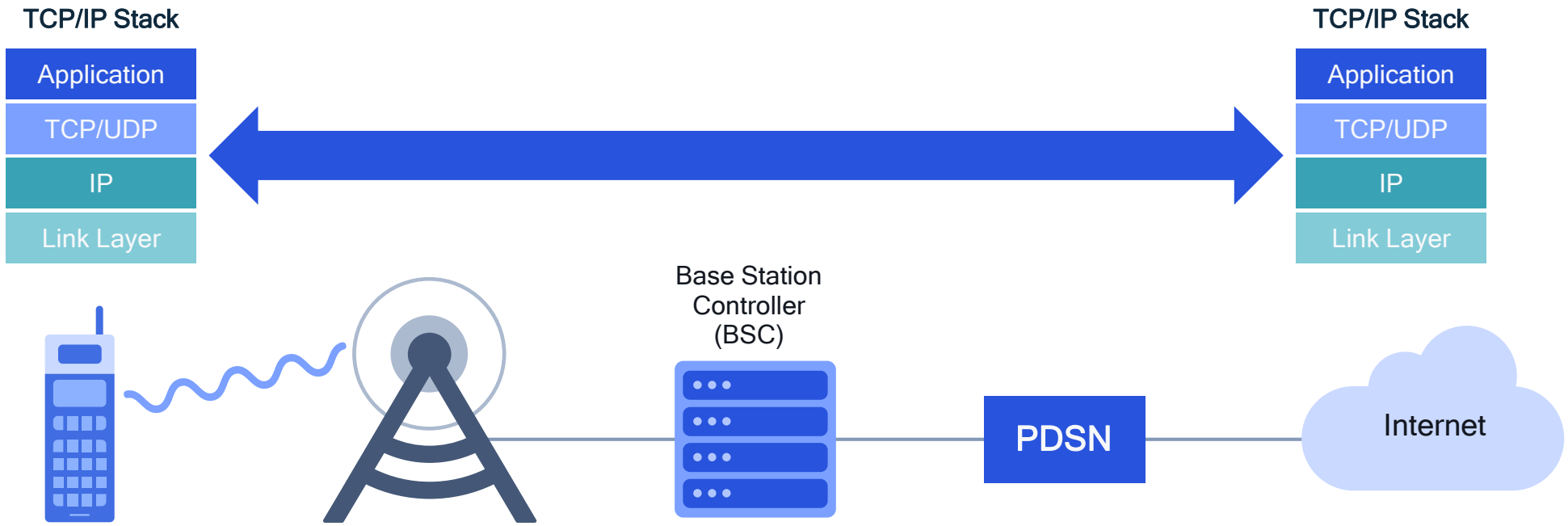
Sold to Ericsson in 1999

MSM is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.

Qualcomm grew from 1,262 employees in 1993 to 11,200 in 1999

Data: The next frontier for 3G

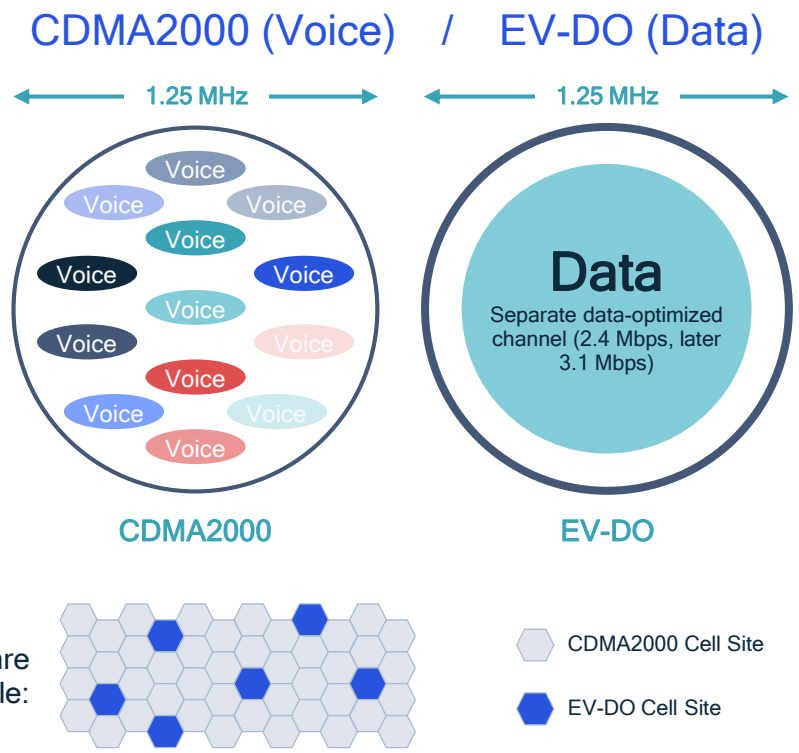
Qualcomm advocated packet-switched data using the TCP/IP stack



Qualcomm helped drive the industry towards direct internet connectivity, which enabled cellphones to become another internet client using TCP/IP protocols

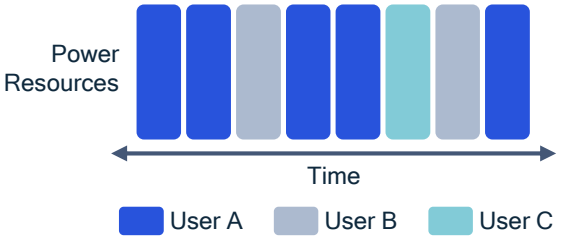
Designing a CDMA system optimized for packet data

Data has different characteristics than voice; goal is to optimize total data throughput



Channels are compatible:

1 Optimize data throughput by sending maximum data rate to a single user at any instant; other users are time-multiplexed into different time slots.



2 Base station scheduler monitors channel conditions for each user and modifies the modulation based on the data rate it thinks the user can sustain.

1: High Data Rate (HDR) renamed as EV-DO (Evolution - Data Optimized) after standardization in Nov 2000 as EIA/TIA-856

Several of the concepts from EV-DO[1] served as a foundation for 4G/5G

The importance of the EV-DO scheduler is recognized

Slate selected the scheduling code as one of the 36 most impactful pieces of software of all time

The Lines of Code That Changed Everything

Apollo 11, the JPEG, the first pop-up ad, and 33 other bits of software that have transformed our world.

October 14, 2019

Proportional Fair Scheduling for Wireless Networks

Date: Circa 2003. ← (Date is incorrect)

The solution that makes cellphone networks possible

```
[~, b_user] = max(drc(i, :)./avg_thruput(i, :));
avg_thruput(i+1, :) = (i/(i+1))*avg_thruput(i, :);
avg_thruput(i+1, b_user) = (i/(i+1))*avg_thruput(i, b_user)+drc(i,
b_user)/(i+1);
```

US006449490B1

(12) **United States Patent**
Chaponniere et al.

(10) **Patent No.: US 6,449,490 B1**
(45) **Date of Patent: *Sep. 10, 2002**

(54) **TRANSMITTER DIRECTED CODE DIVISION MULTIPLE ACCESS SYSTEM USING PATH DIVERSITY TO EQUITABLY MAXIMIZE THROUGHPUT**

(75) Inventors: **Etienne F. Chaponniere**, Paris (FR); **Peter J. Black**; **Jack M. Holtzman**, both of San Diego, CA (US); **David Ngar Ching Tse**, Berkeley, CA (US)

(73) Assignee: **Qualcomm Incorporated**, San Diego, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/345,700**

(22) Filed: **Jun. 30, 1999**

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* cited by examiner

Primary Examiner—Daniel Hunter
Assistant Examiner—Yemane Woldetatios
(74) *Attorney, Agent, or Firm*—Philip R. Wadsworth; Kent D. Baker; Sean English

Source: Slate, 10/14/19

"The solution that makes cellphone networks possible"

1st Amazon Kindle enabled EV-DO internet connectivity

Amazon Kindle Official Details: $399, "Whispernet" EV-DO, the "iPod of Reading"

Gizmodo, 11/18/07

There's a lot to digest in Newsweek's seven-page all-out feature. Amazon CEO Jeff Bezos sums it up: "This isn't a device, it's a service." Kindle starts shipping tomorrow for $399 and is "a perpetually connected Internet device" running off of EV-DO–it calls the service "Whispernet." It's totally computer independent: You browse for books (88,000 at launch) and buy them in a "one-touch process," it comes with a personal Kindle email address and it can browse the regular internet–keyboard sounds useful now, doesn't it?

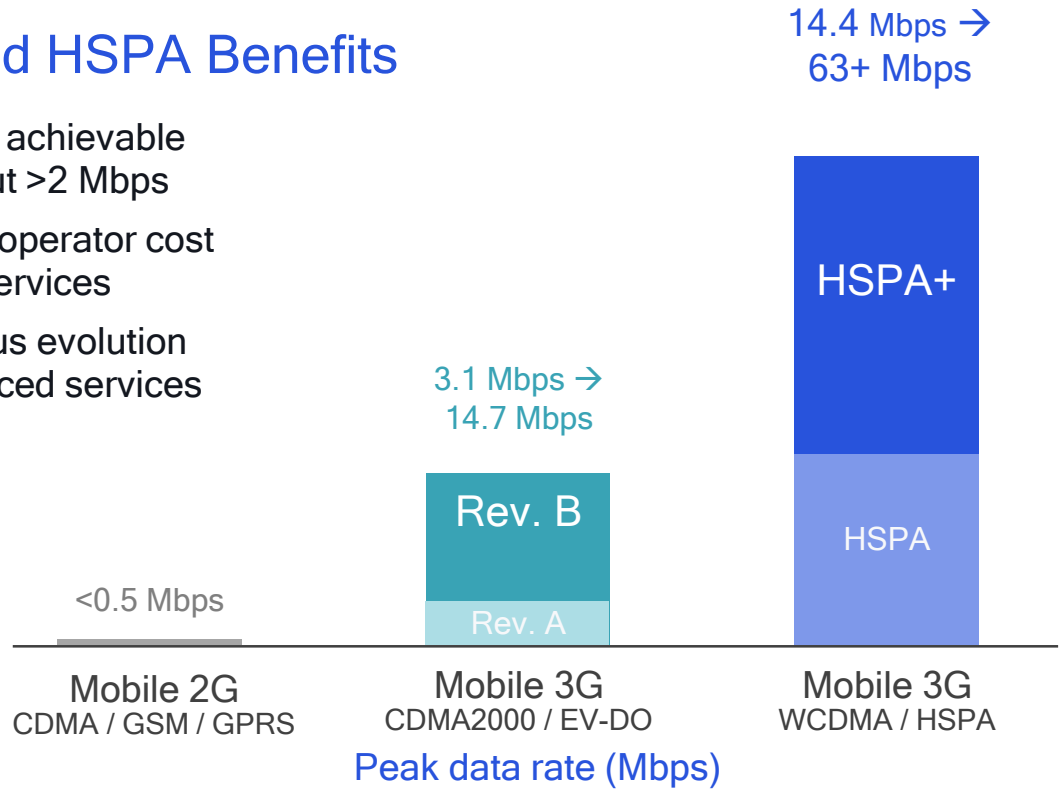
Source: Gizmodo, 11/18/07 © 2007 Gizmodo, www.gizmodo.com.

Amazon included the EV-DO service through Sprint to allow users to browse and buy Kindle books online

Data technologies continued to evolve in 3G

EV-DO and HSPA Benefits

- Delivered achievable throughput >2 Mbps
- Reduced operator cost for data services
- Continuous evolution for enhanced services



Mobile broadband timeline[1]

1999
Qualcomm introduces EV-DO

January 2002
First EV-DO commercial launch

Q4 2004
3GPP release 6 with HSPA is published based on WCDMA technology

Q1 2007
EV-DO passes 50 million connections

Q108
HSPA passes 50 million connections

June 2008
First HSPA+ (21 Mbps) commercial launch

September 2010
First DC-HSPA+ (42 Mbps) commercial launch

[1] Source: CDG (www.cdg.org) and 3GPP (www.3gpp.org)

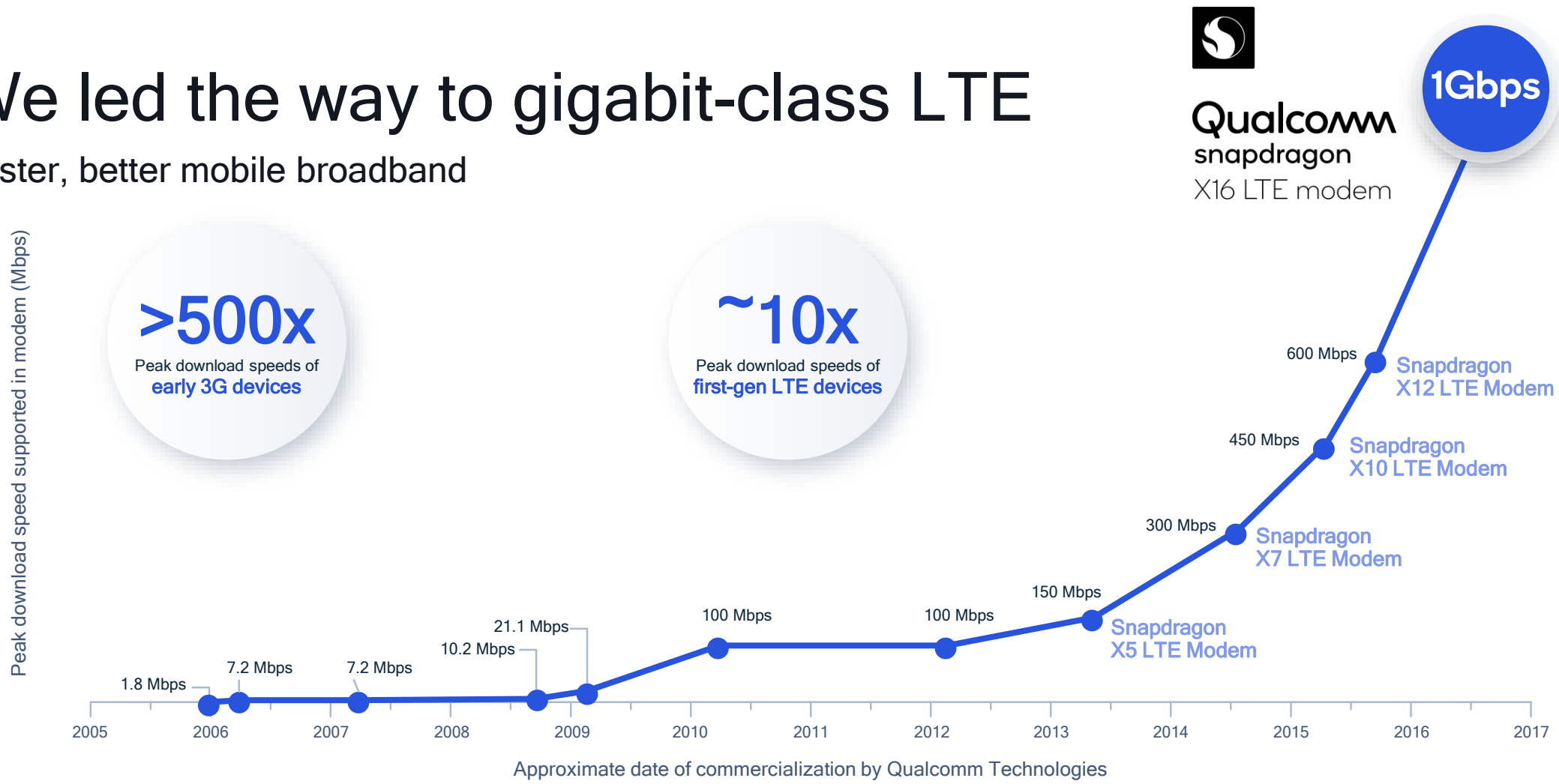
From EV-DO to HSPA (High-Speed Packet Access), to HSPA+

We led the way to gigabit-class LTE

Faster, better mobile broadband

>500x
Peak download speeds of
early 3G devices

~10x
Peak download speeds of
first-gen LTE devices



Multiple generations of improvements in LTE and LTE-Advanced

We led the evolution and expansion of LTE

Carrier aggregation

Hybrid ARQ

Fast link adaptation

OFDMA, SC-FDMA waveforms

CoMP

CSFB

LTE-U/LAA/ eLAA

MulteFire

Lower power consumption technologies, e.g. DTX/DRX

LTE Broadcast (eMBMS)

Small cells interference management

LWA

Handover procedure

Small cell self-configuration techniques

Advanced MIMO technologies, e.g. UL MIMO

LTE Direct and C-V2X

Our systems-level inventions are foundational to 5G

5G brings an enhanced air interface for unified connectivity

5G improvement over 4G

10x
Decrease in end-to-end latency

10x
Experienced throughput

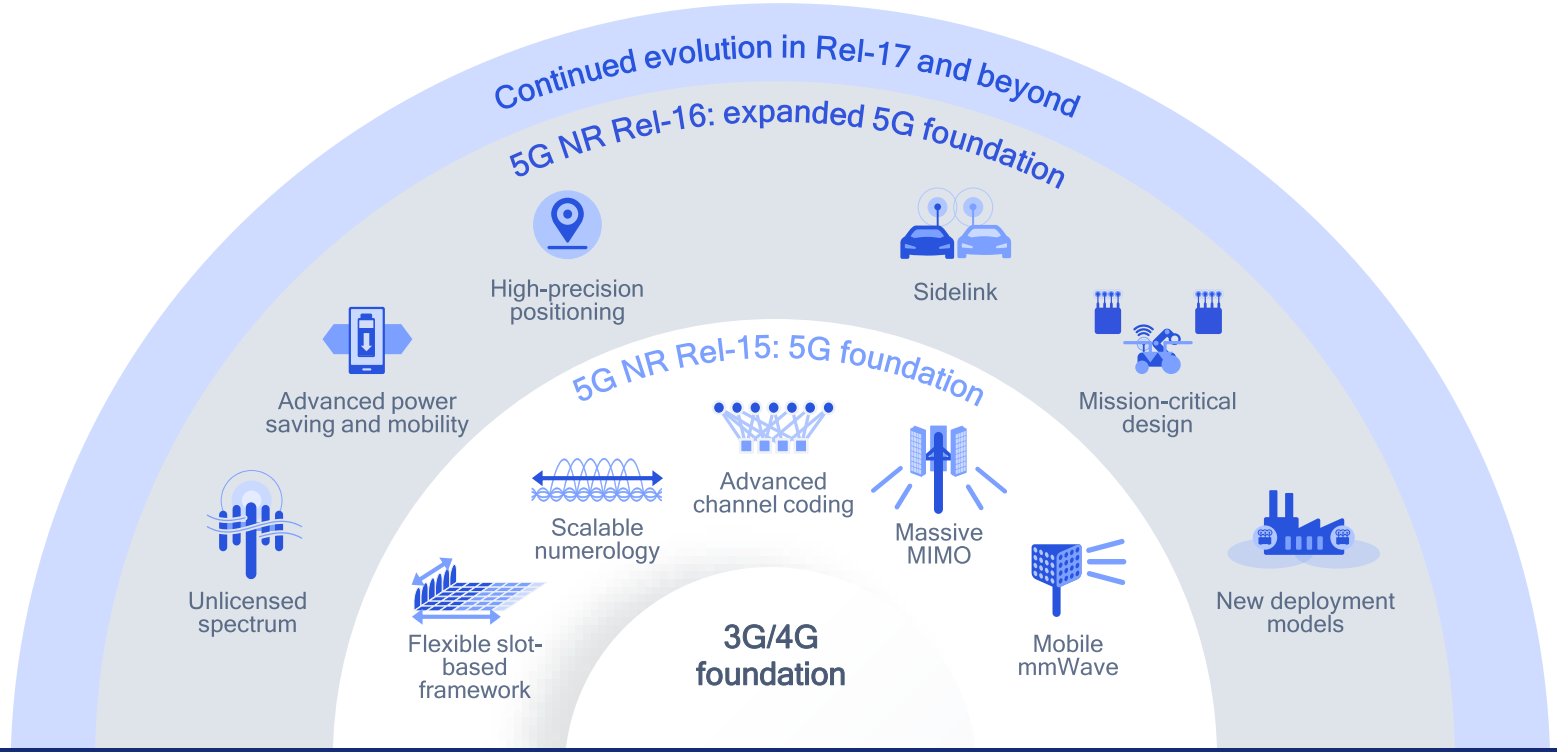
3x
Spectrum efficiency

100x
Traffic capacity

100x
Network efficiency

10x
Connection density

Our wireless inventions are leading the 5G evolution



Higher capacity will allow carriers to offer more cost-efficient unlimited data plans
Lower latency & higher reliability can enable new uses for wireless networks

Patent value is about quality rather than quantity

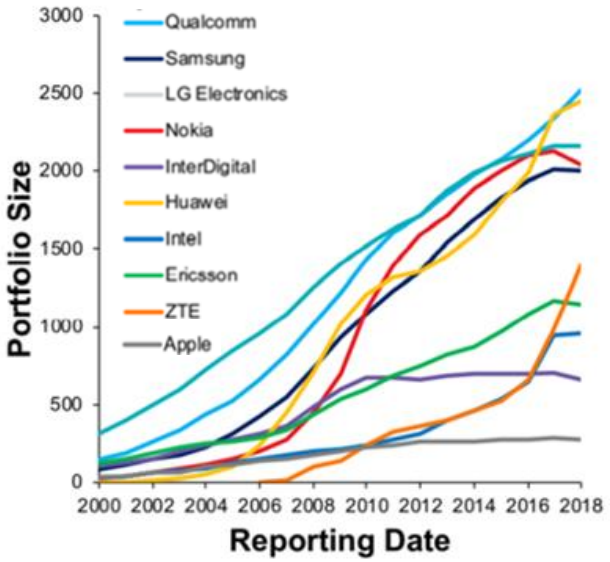
Why 5G Patent 'Value' Is More Important Than The 'Number' Of Patents

Patrick Moorhead
Moor Insights & Strategy, February 27, 2020

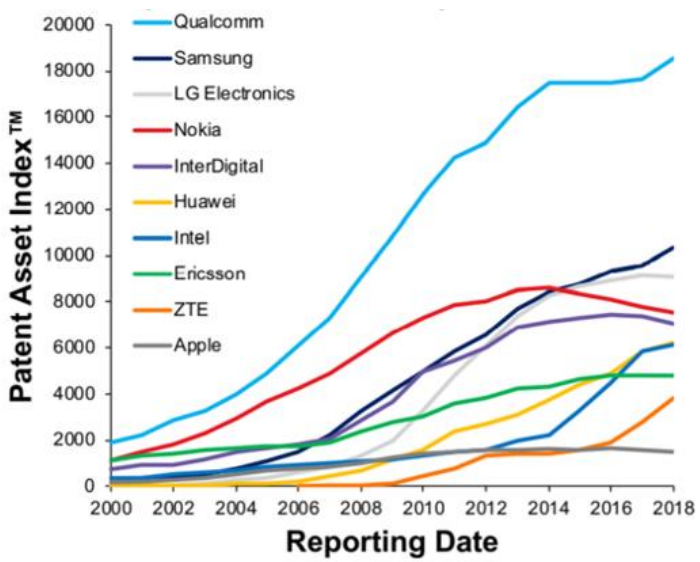
According to IPWatchdog, in a recent webcast (slides here), while many companies cluster in their patent portfolio size or number of patents, Qualcomm leads the pack in value and impact. Note how close the *number* of patents are between Qualcomm, Huawei, Intel (now Apple), and Samsung are, but when it comes to *value*, Qualcomm is considerably higher than the next competitor.

"Qualcomm leads the pack in value and impact"

Patent Count



Patent Value and Impact

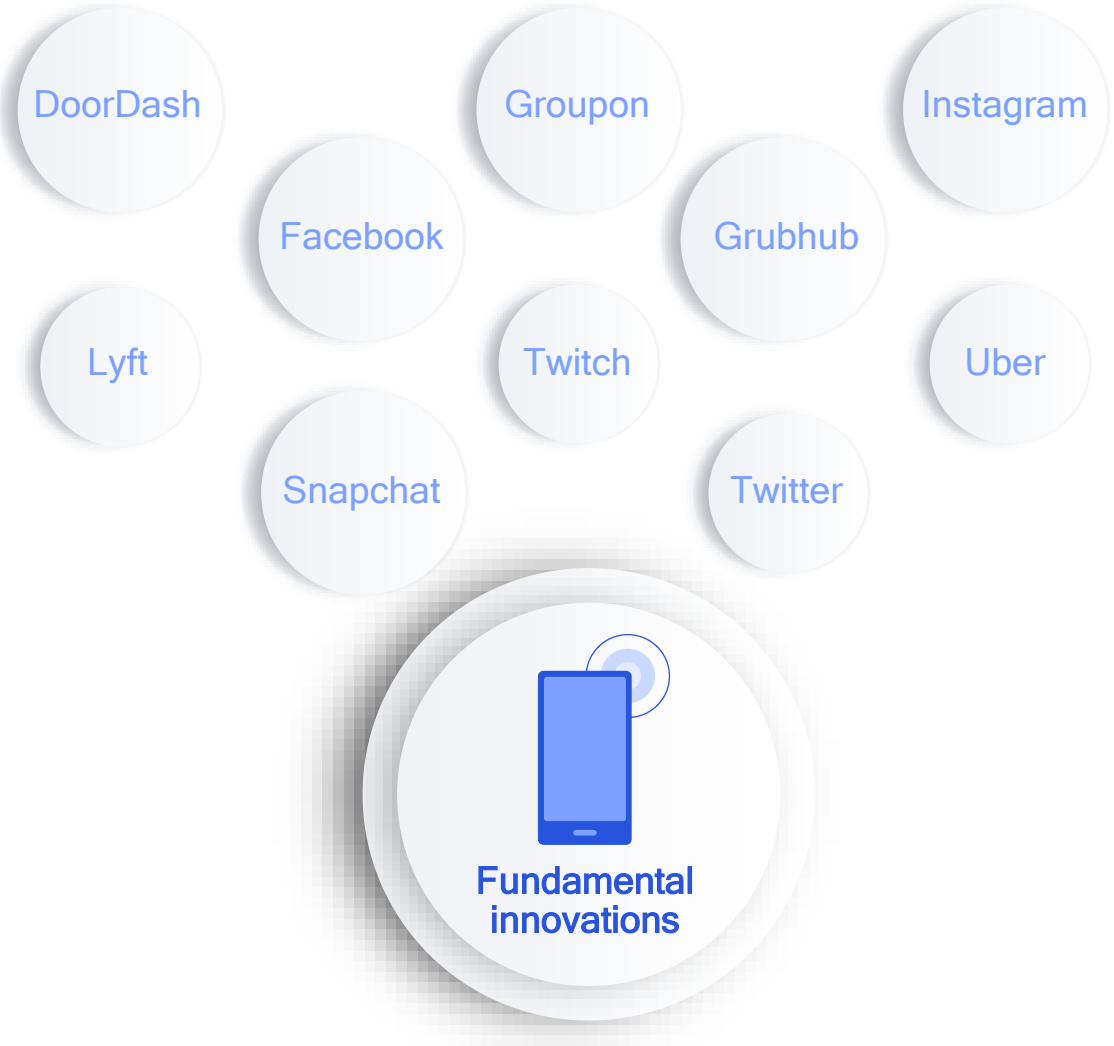


Source: Moor Insights & Strategy, 2/27/20; LexisNexis | PatentSight

Whereas many companies try to accumulate patents for "counting value", Qualcomm tries to patent valuable fundamental ideas

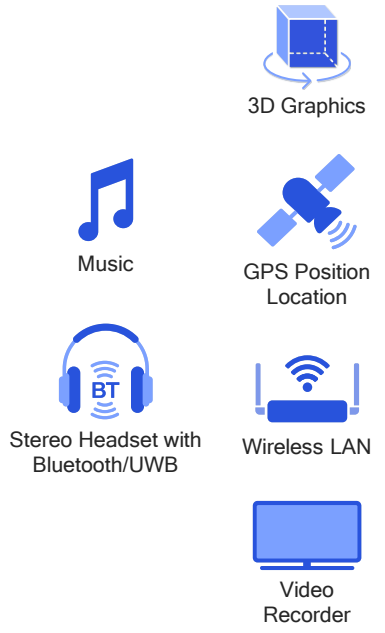
Where would many companies be without Qualcomm's inventions?

Foundational data technologies spurred new innovative services, experiences, and business models



Our fundamental research helped spawn entirely new industries

Integration of capabilities enabled by Moore's law



0.8 µ | 0.5 µ | 0.35 µ | 0.25 µ | 0.18 µ | 0.13 µ | 90 nm | 65 nm | 45 nm | 28 nm | 20 nm | 14 nm | 10 nm | 7 nm

MSM is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.

13 process node transitions between MSM1 and Snapdragon 865 (and counting)

2000: Integration of audio capability

Audio applications are run on our internally developed DSP

Audio MP3 Decoder

Allows people to listen to their digitized music

Compact Multimedia Extension (CMX)

Enables time-synchronized combining of Midi-based music, PNG graphics, animation, text, and speech

Allows custom ringtones, animation, greeting cards, karaoke, screen savers, etc.

Enable music listening and creation of simple mixed-media applications (predates the first iPod)

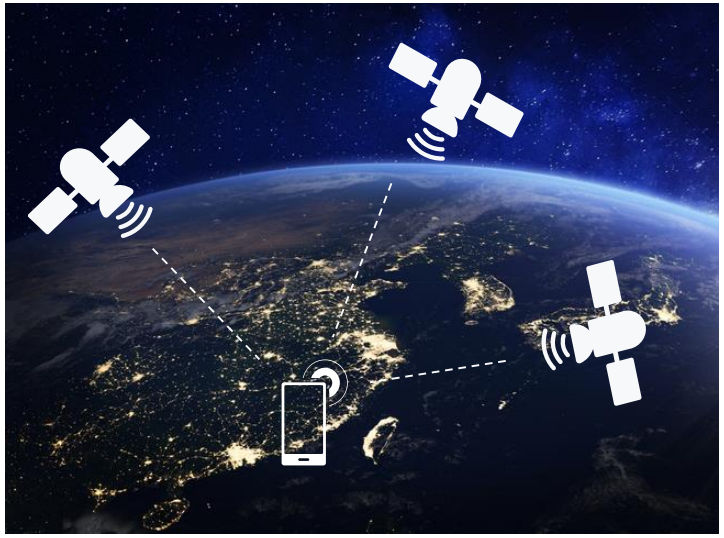
2000: Integration of Bluetooth and GPS

Expanding the utility of the cellphone beyond voice calls

Bluetooth

Low-power wireless connection to peripherals

GPS



Enable E911 and location-based services

1; Source: Bluetooth SIG Market Update 2020

Wireless Communications Public Service Act (911 act) was passed in 1999

2002: Integration of video capability

Video applications were initially run on an internally developed DSP

Qtv

MPEG4 / H.263 decoder

Qcamcorder

MPEG4 / H.263 encoder

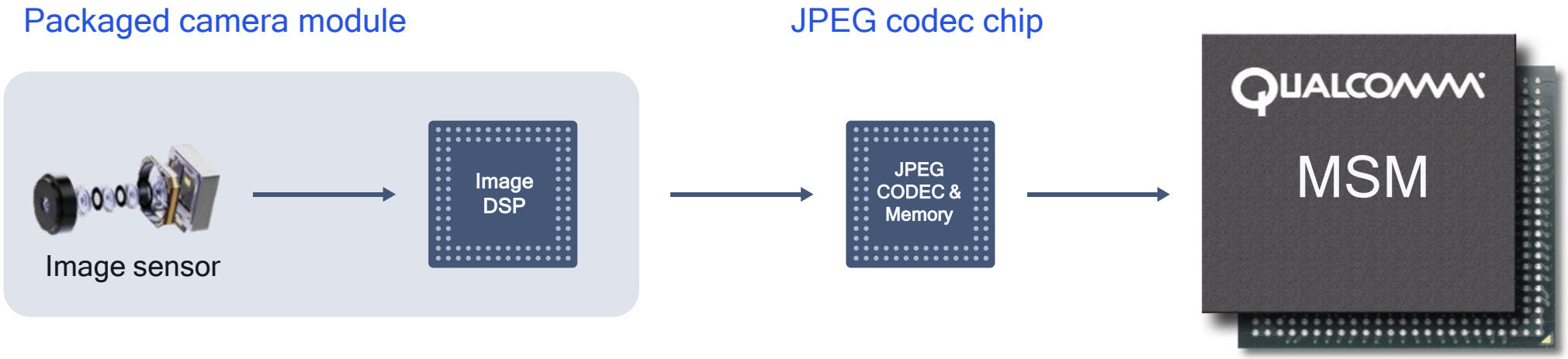
Qvideophone

MPEG4 / H.263 encoder/decoder

Enable playing and recording of video clips, and video telephony

2002: Integration of camera?

At this time, camera image processing was embedded inside the camera module, while JPEG image compression was performed in an external chip

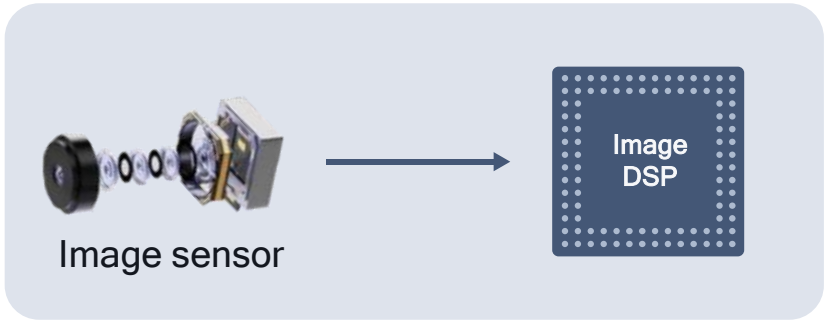


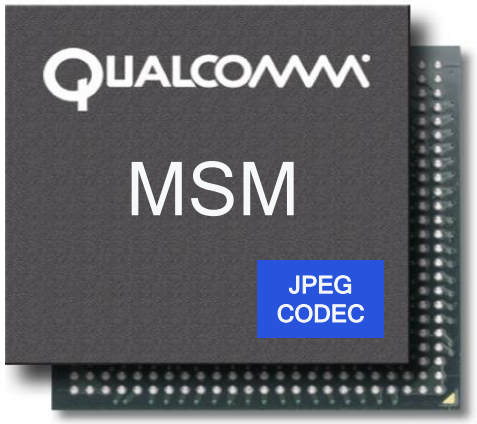
Camera modules were built by companies that built digital still cameras

2002: Integration of camera

Integration of the JPEG image compression was a natural first step

Packaged camera module





JPEG image processing standard could easily be handled by the MSM, and the integration saves both cost and board area

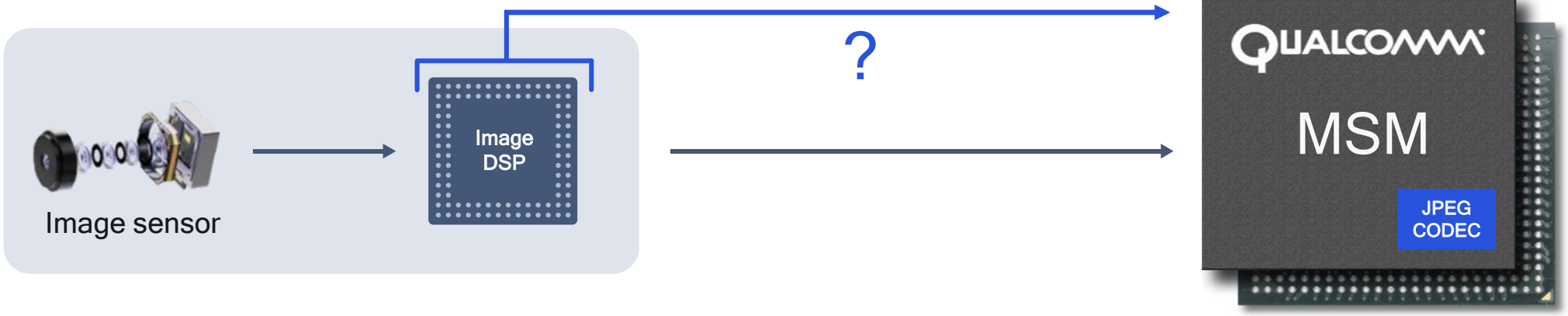
2002: Integration of camera?

Should we integrate the image processing as well?

Rationale for integration:

1. Could be a popular feature because your phone (and therefore your camera) is always with you
2. Photo sharing is a good application to drive demand for wireless data services
3. Integrating the image processing will save cost, because the cost of the silicon in the MSM will be smaller

Packaged camera module



Customer and vendor feedback was unfavorable

2002-2004: Integration of camera

Qualcomm culture motivated us to integrate the camera anyway

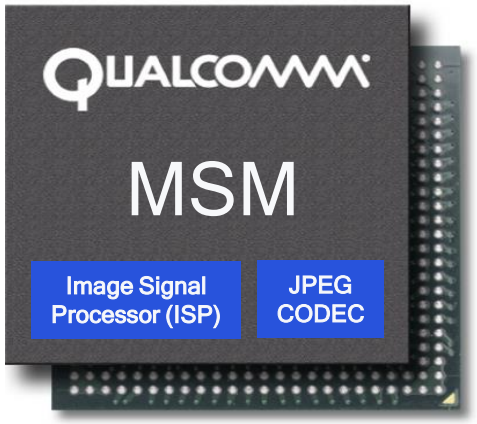
DSP-based HW-based

Rationale for integration:

1. Could be a popular feature because your phone (and therefore your camera) is always with you
2. Photo sharing is a good application to drive demand for wireless data services
3. Integrating the image processing will save cost, because the cost of the silicon in the MSM will be smaller

Image sensor

1st integration of the camera ISP into a mobile chip



We started work on two designs:

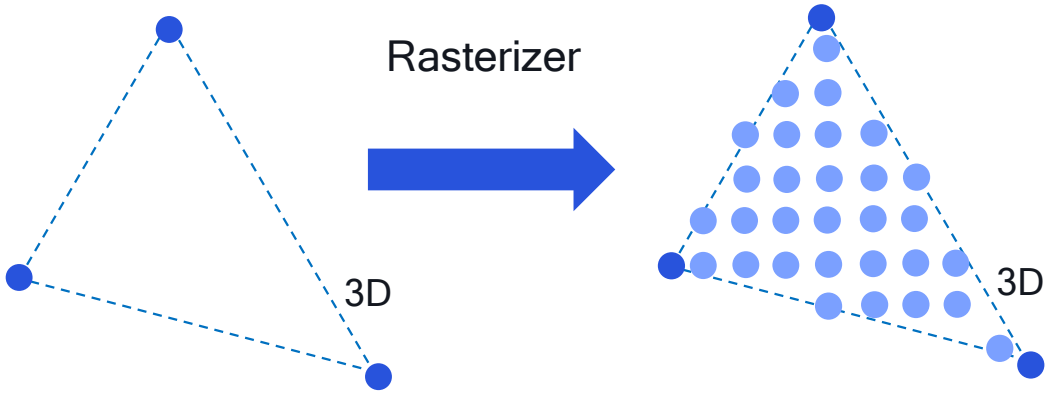
DSP-based (software) camera that supported 1.3MP images (MSM6500)

Hardware-based camera that supported 4MP images (MSM6550)

2002: Started work on 3D graphics

We thought people might want to play games on their phone during idle time

Learning 3D graphics from ground-up



Early demonstration content

We started building our knowledge of 3D graphics from scratch:
transformation, lighting, shading, triangle rasterization, texturing, z-test, and more

2004: Integration of 1st graphics core

Our design coincided with the OpenGL ES API development in the Khronos Group

QUALCOMM CDMA Technologies
Enhanced Platform

Targeted geometry performance to slightly exceed PlayStation 1

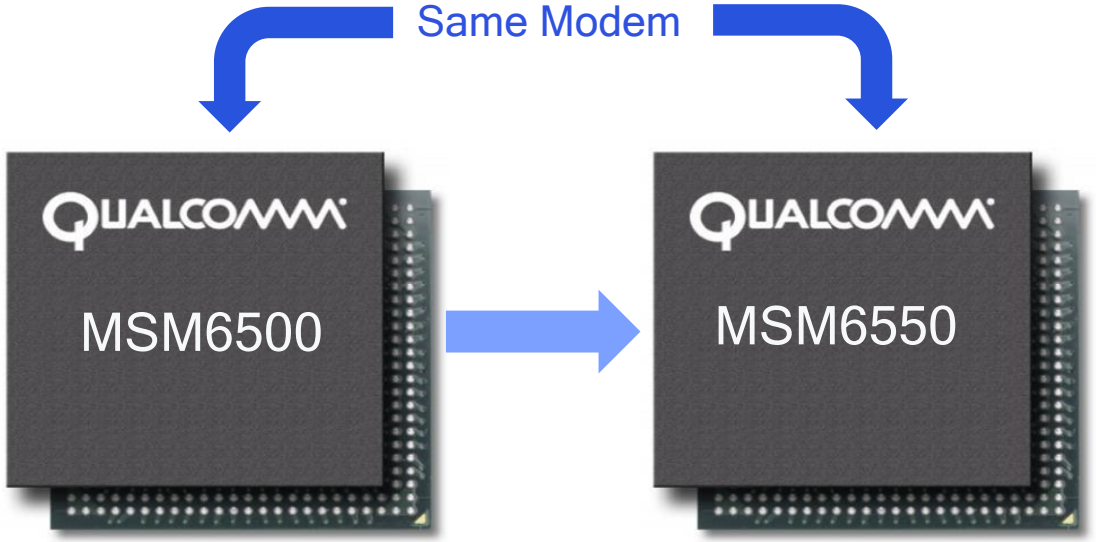
Some initial games we attracted to the platform

Game developers were interested because of the volumes of phones

2004: Integration of camera, video, and graphics hardware

MSM6550 was our first chip stressing multimedia capability (no change to the modem)

- cdma2000 1x, EV-DO, GSM/GPRS
- Combined 1x/EV-DO/GPS searcher
- DSP-based demodulation
- Direct-conversion RF front end
- DSP-based applications



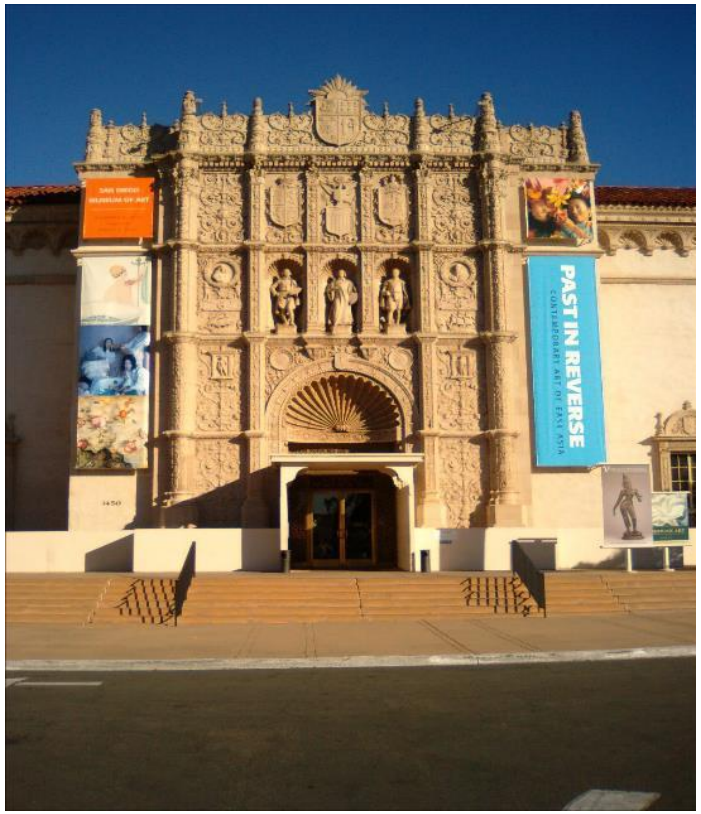
30M transistors
in .13μ process

58M transistors
in 90nm process

- Audio: MP3, AAC, AAC+ playback
- Camera: 4 MP snapshot
- Video: 30fps H.264 CIF playback
- Video: 15fps H.264 CIF recording
- Graphics: 100k triangles/s, 7MP/sec

New modem in MSM6500, added 1st multimedia hardware cores in MSM6550

2005: Images from our 1st hardware-based camera



High-quality images built confidence in our camera solution and shifted the whole industry towards bare sensor modules plus baseband-integrated ISP

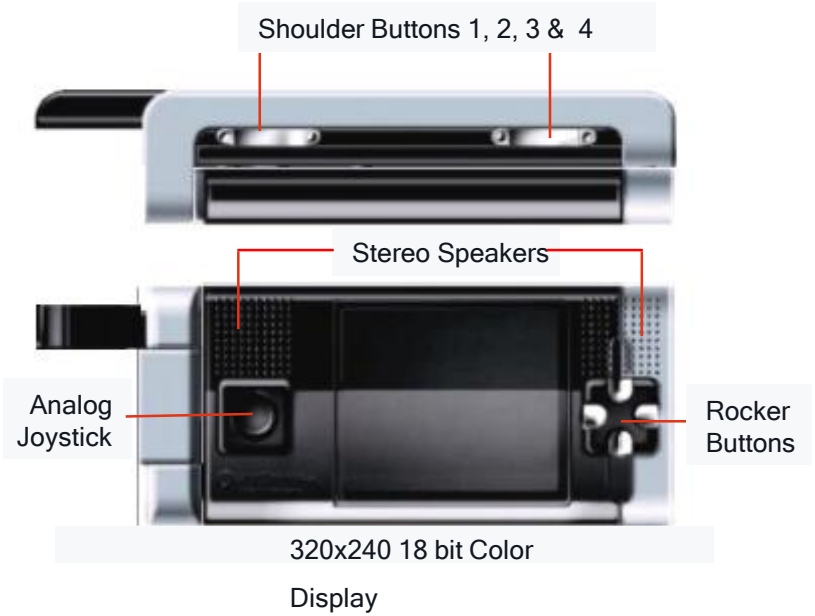
2004: Phone reference design for MSM6550

Dual display, 2MP camera with LED flash, stereo speakers, gaming controls, and more

Microphone Centered

External Connects

Gaming Mode



320x240 18 bit Color Display

A custom reference design to demonstrate our multimedia capabilities

Examples of phones using MSM6x50 (around 2005)

Clamshell phones with 2-inch displays and 1.3-2.0 megapixel cameras

Casio A5512CA (MSM6550)
2.2” QVGA Display (320x240)
1.3 MP camera

Toshiba W55T (MSM6550)
2.4” WQVGA Display (400x240)
2 MP camera

LGE U880 (MSM6250)
2” Mobile XGA Display (220x176)
1.3 MP camera

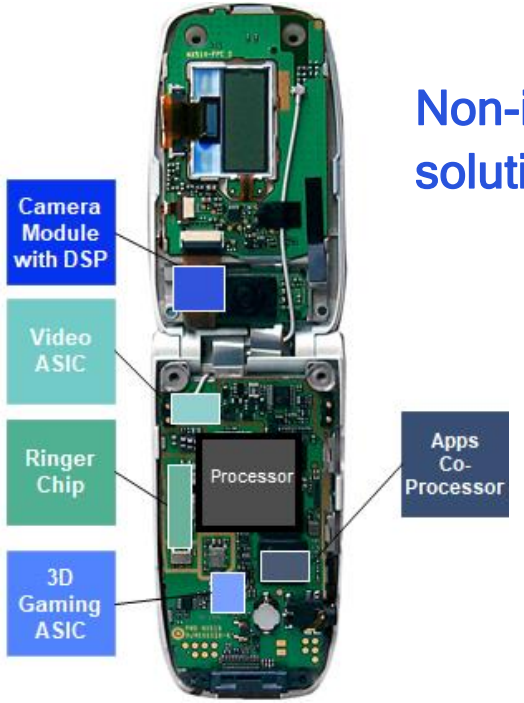
Samsung Z510 (MSM6250)
2” QVGA Display (320x240)
1.3 MP camera

Many of these clamshell thin phones were trying to emulate the look and feel of the Motorola Razr v3

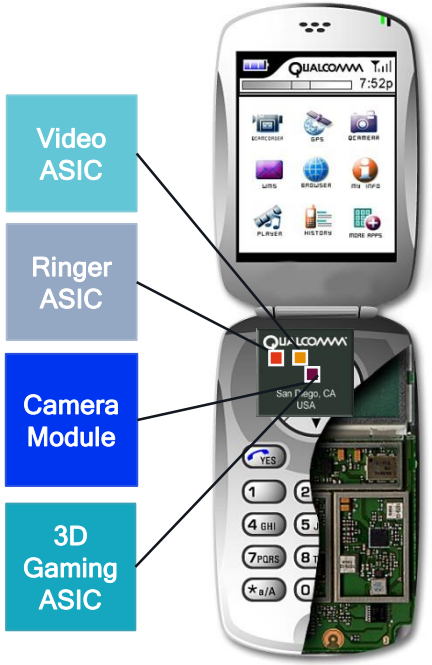
Motorola Razr v3

Advantages of integration

Integration strategy was winning over customers



Non-integrated solution



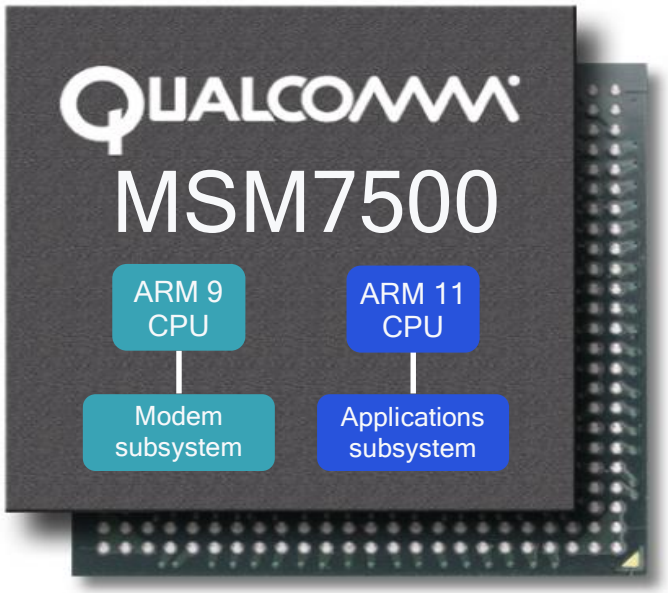
Our highly integrated solution

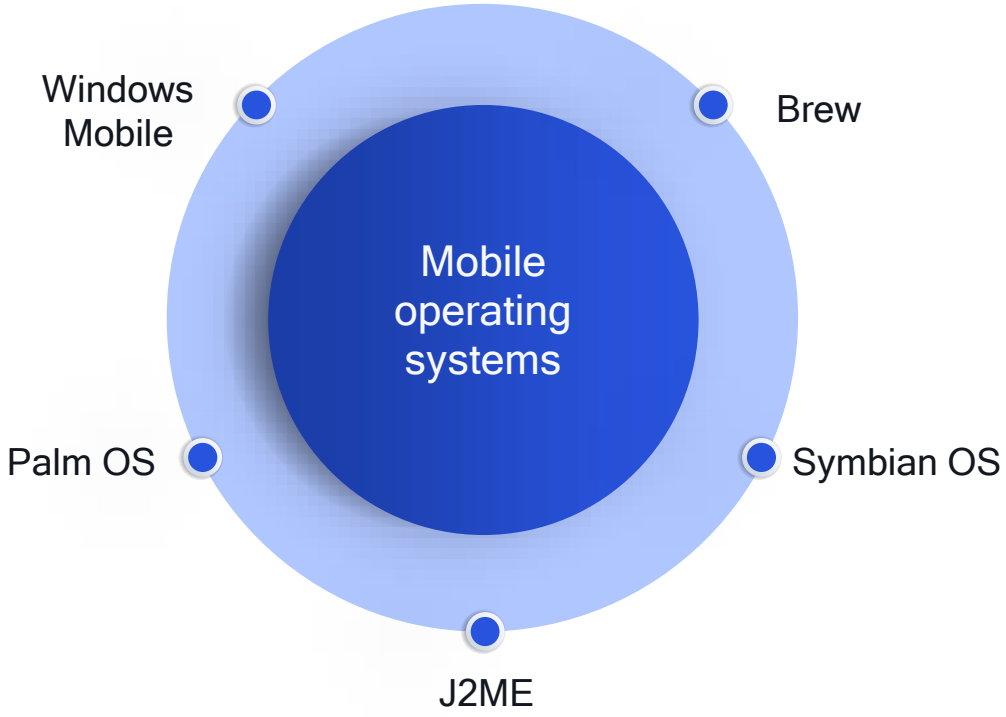
- Complete / integrated solution
- Lower device costs
- Faster time to market
- Proven interoperability

Lower silicon cost, fewer components, smaller board space allows sleeker form-factors and faster time-to-market

2005: Integration of 2nd CPU to support 3rd-party OS

MSM7500 was the first Qualcomm chip to separate the modem and applications subsystems





Need for an OS to manage all the applications and concurrencies

Multimedia: 6MP ISP, VGA-resolution video, and 1st Display Processor (MDP)

Examples of phones using MSM7xxx (around 2008-2009)

3rd-party OS, 2.8” – 3” displays, 3MP cameras, often with pullout QWERTY keyboards

Sony Ericsson Xperia X1 (MSM7200)
Microsoft Windows Mobile 6.1 Pro
3” WVGA Display (800x480)
3 MP camera

1st commercial Android device

T-Mobile G1 / HTC Dream (MSM7201A)
Google Android 1.6 (Donut)
3.2” HVGA Display (320x480)
3 MP camera

1st Samsung Galaxy device

Samsung I7500 Galaxy (MSM7200A)
Google Android 1.5 (Cupcake)
3.2” HVGA Display (320x480)
5 MP Camera

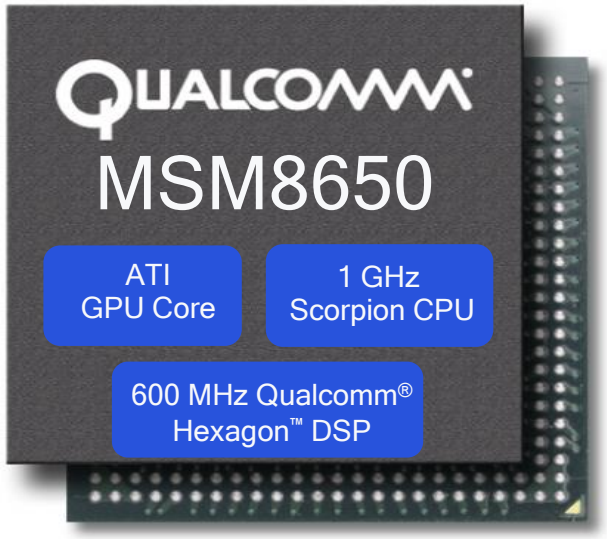
Many 3rd-party operating systems in play, including Windows Mobile, Symbian, Apple IOS, Palm WebOS, Blackberry OS, and Android

2007: Integration of 1 GHz CPU, 600MHz DSP, and ATI GPU

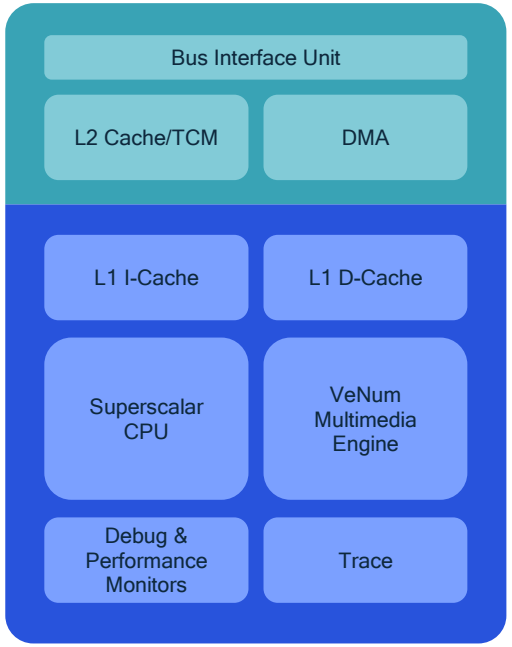
Qualcomm did a custom CPU implementation of the ARM v7 architecture

Xbox 360

Console GPU
scaled down for mobile



Custom, internally-designed DSP



Scorpion CPU
1st GHz ARM CPU

Phones became capable computing devices

Examples of phones using MSM8x50 (around 2010)

Larger WVGA displays, higher megapixel cameras, touchscreen keyboards

Toshiba TG01 (MSM8250)
Microsoft Windows Mobile 6.5
4.1” WVGA Display (800x480)
3 MP Camera

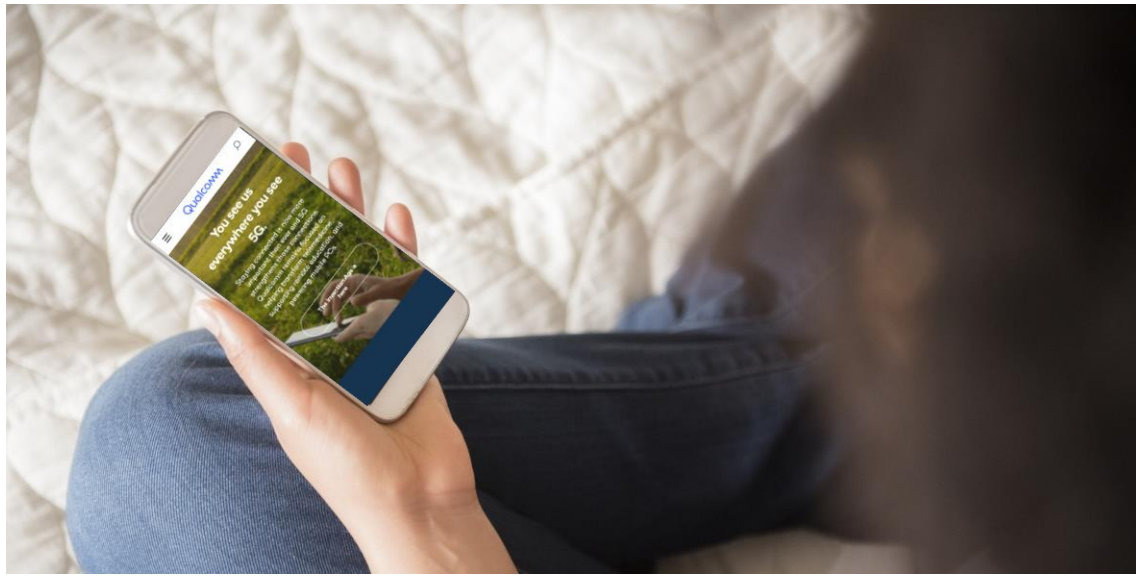
HTC Google Nexus One (MSM8250)
Android 2.1 (Éclair)
3.7” WVGA Display (800x480)
5 MP camera

HTC Droid Incredible (MSM8650)
Android 2.1 (Éclair)
3.7” WVGA Display (800x480)
8 MP camera

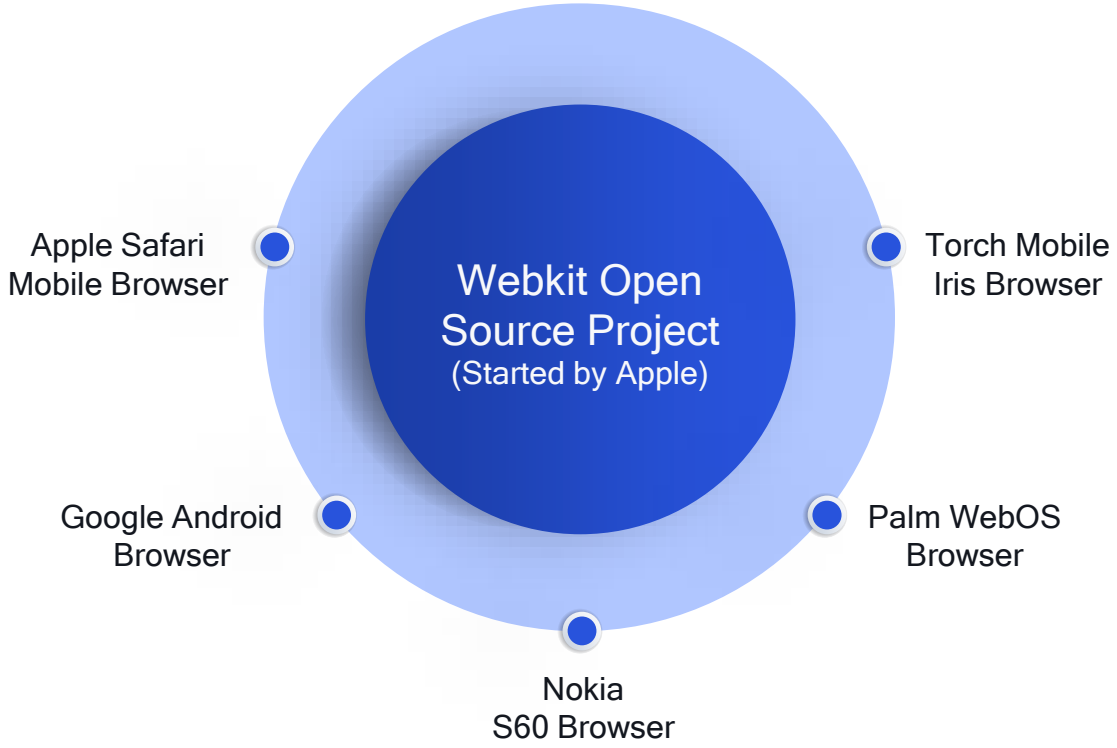
More GPU capability led to improved graphical user interfaces

Fast CPUs and larger displays drove mobile browser usage

Users could access web information anytime:
weather, stock quotes, travel schedules, …



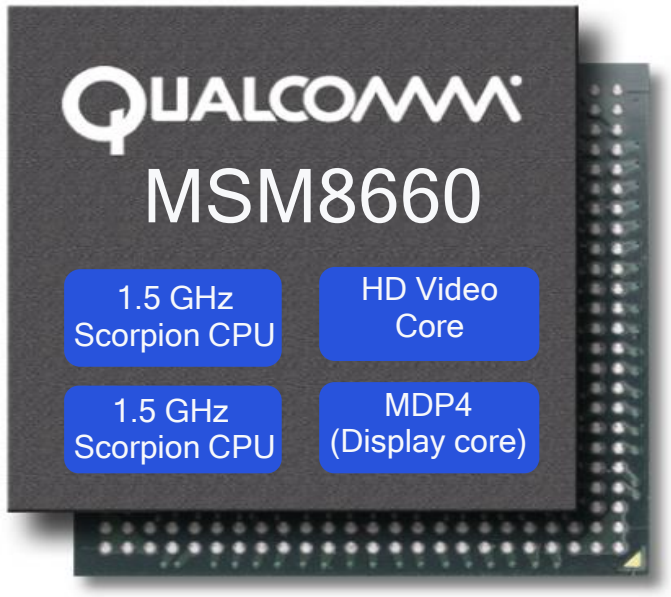
Webkit (open source browser engine) was used as a basis for many of the mobile browsers

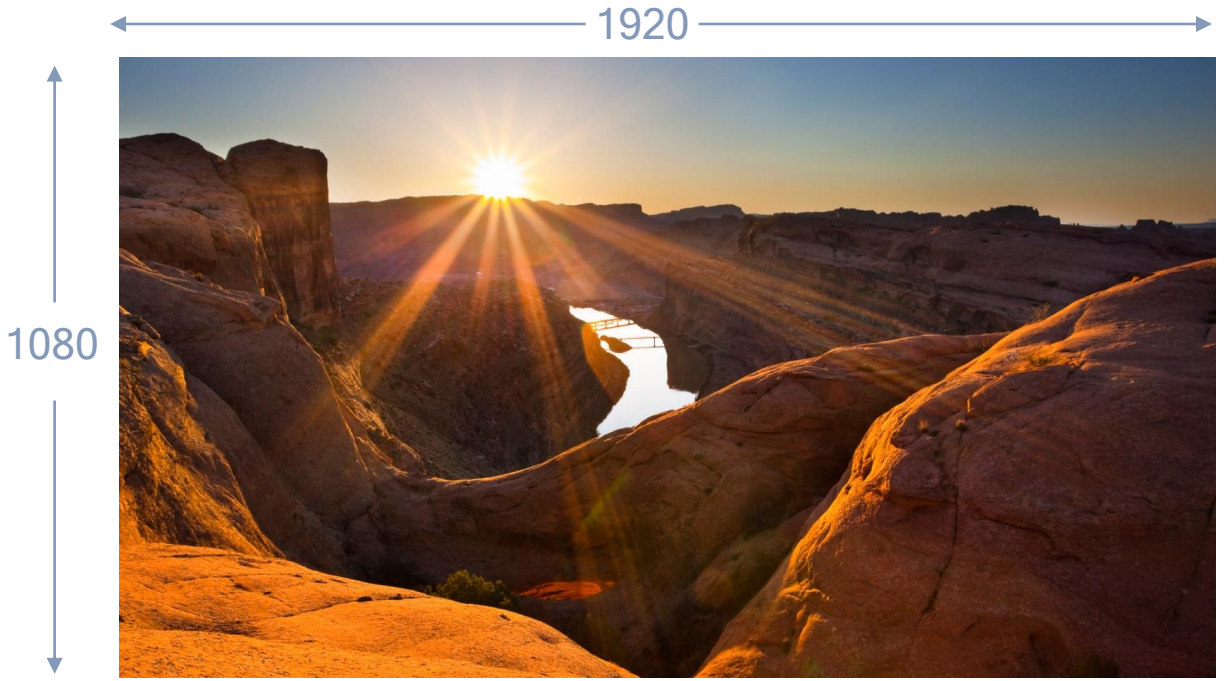


We built a team to optimize Webkit performance on our chips

2009: Integration of high-definition video (1080p) capability

Also upgraded the display core (scaling, contrast enhancement) and interfaces (HDMI)

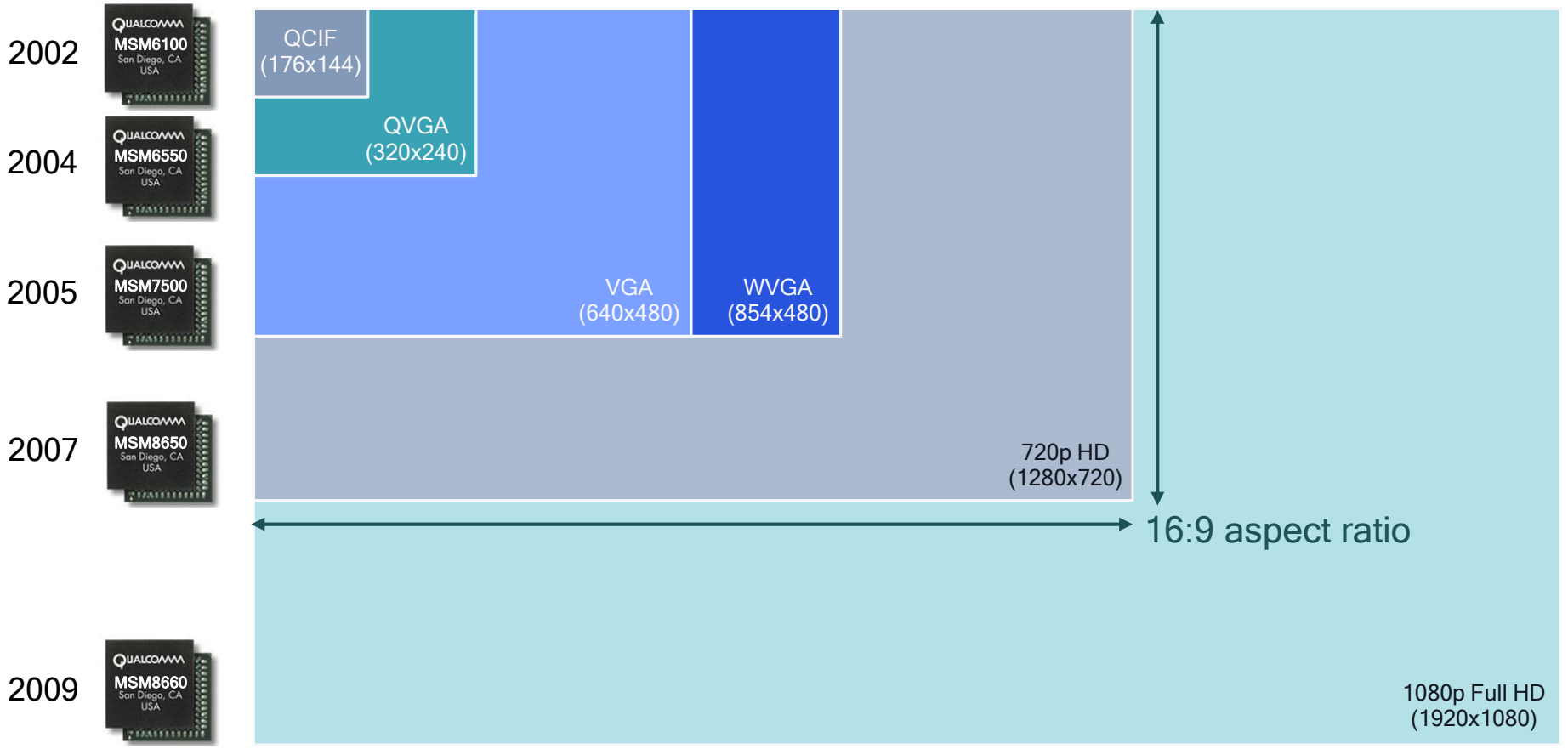




Encoding and decoding of video in full HD (1080p) resolution.
New interfaces allow the phone to drive TV displays and monitors.

Video playback resolution chart

> 80X increase in pixel resolution in less than 10 years



Another example of the expanding capabilities due to Moore's Law

Examples of phones using MSM8660 (around 2011)

4-inch plus displays, 8-megapixel cameras, high-definition (HD) displays, 1080p video

HTC Sensation (MSM8660)
Android 2.3 (Gingerbread)
4.3” QHD Display (960x540)
8 MP Camera, 1080p video

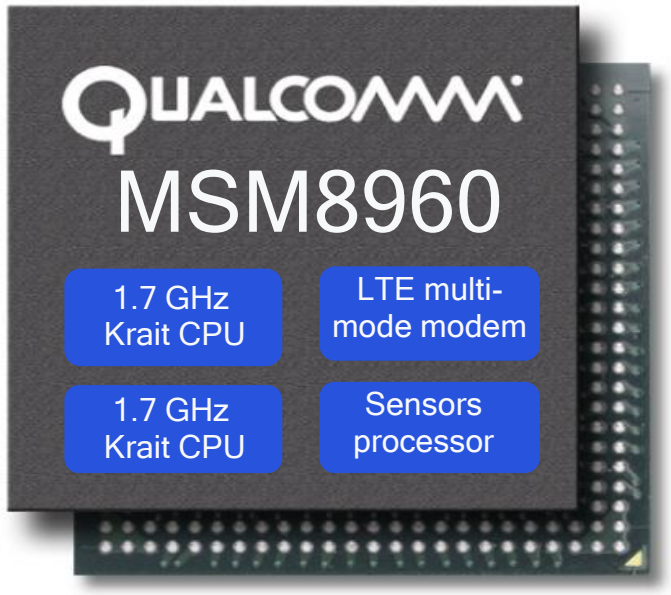
Samsung Galaxy S II HD (MSM8660)
Android 2.3 (Gingerbread)
4.65” HD Display (1280x720)
8 MP camera, 1080p video

LGE Optimus LTE (MSM8660)
Android 2.3 (Gingerbread)
4.5” HD Display (1280x720)
8 MP camera, 1080p video

Capable multimedia: feasible to watch video on you phone

2011: Integration of LTE modem (4G)

Also integrated a Wi-Fi modem and a sensors processor



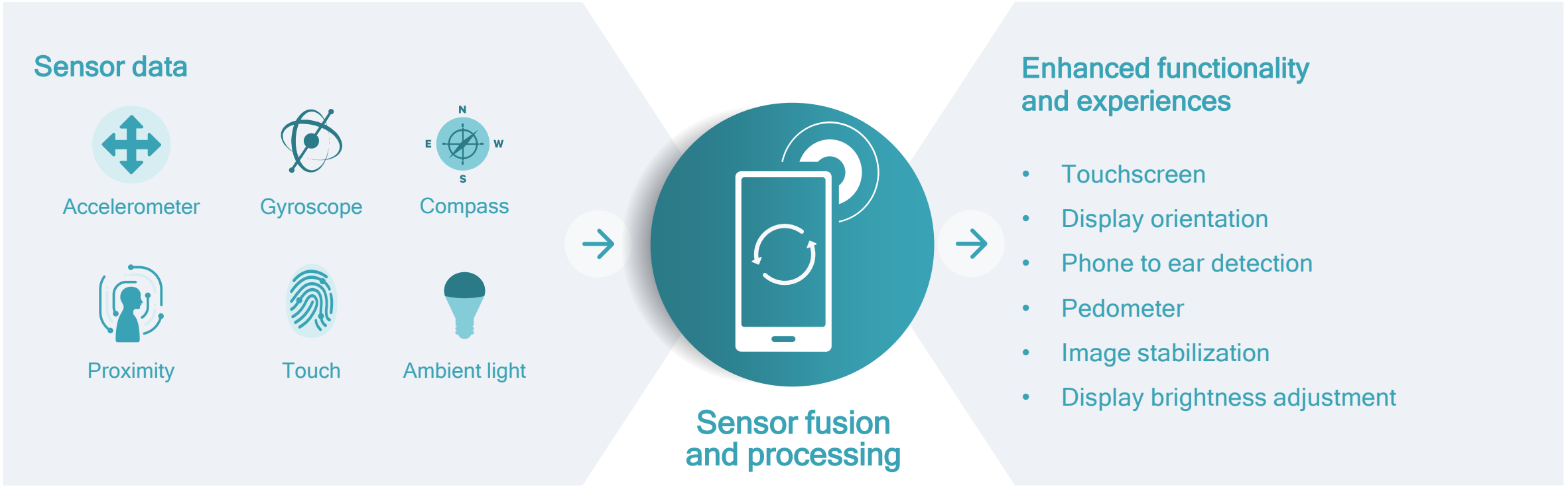
MSM8960 Cellular Support

LTE FDD	100 Mbps DL / 50 Mbps UL (Cat. 3, 3GPP Rel. 9)
LTE TDD	68 Mbps DL / 17 Mbps UL (Cat. 3, 3GPP Rel. 9)
UMTS	DC-HSPA+ 42 Mbps DL (Cat. 24) / 11 Mbps UL (Cat. 8)
CDMA2000	1xAdvanced, EVDO Rev.B (14.7 Mbps DL / 5.4 Mbps UL)
GSM	GSM/GPRS/EDGE
TD-SCDMA	TD-SCDMA 4.2 Mbps DL / 2.2 Mbps UL

Supported all leading broadband standards in the world (world phone)
Higher bandwidth, higher capacity allows more cost-efficient data plans

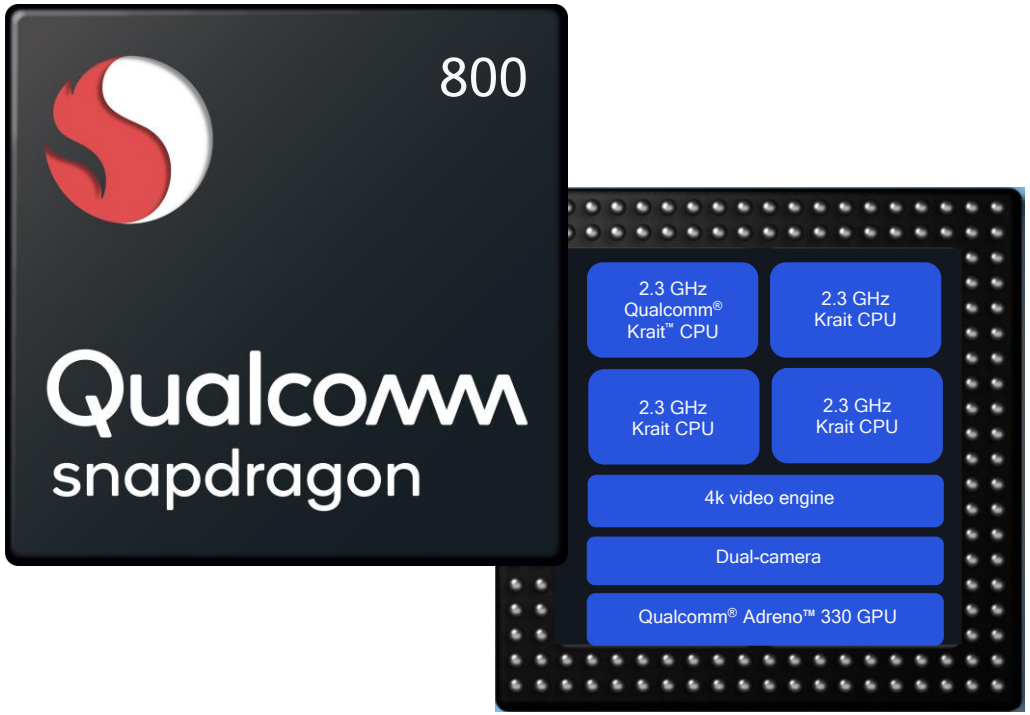
2011: Integration of sensors processor

Process sensor data at lower power (than the big CPU)

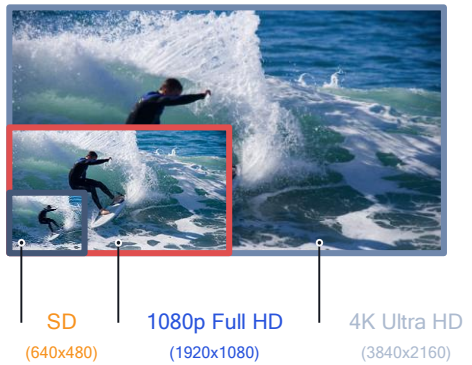


Use of sensors in the phone is growing rapidly

2012: Integration of quad-CPU, GPU shader core, 4k video



4k video capability



Dual-camera capability

GPU with fixed function pipeline

GPU with programmable shaders

Qualcomm Krait and Qualcomm Adreno are products of Qualcomm Technologies, Inc. and/or its subsidiaries.

The 1st Snapdragon chip provided a significant upgrade in multimedia capability and was hugely successful in the market

Examples of phones using Snapdragon 800 (around 2014)

Full HD (1080p) or larger displays; larger resolution front and rear cameras

LG G3 (Snapdragon 800)
Android 4.4.2 (Kit-Kat)
5.5” QHD Display (2560x1440) 538ppi
13 MP rear and 2.1 MP front cameras

1st cellphone with dual camera

HTC One M8 (Snapdragon 800)
Android 4.4.2 (KitKat)
5” FHD Display (1920x1080)
4+4 MP rear and 5 MP front cameras

Sony Xperia Z2 (Snapdragon 800)
Android 4.4.2 (Kit-Kat)
5.2” FHD Display (1920x1080)
20.7 MP rear and 2.2 MP front cameras

Large displays with high pixel density and high-resolution cameras are key selling points

Dual-camera experiences

Depth

Instant autofocus range measurement

Segmentation with background modification

Re-focus

Bokeh

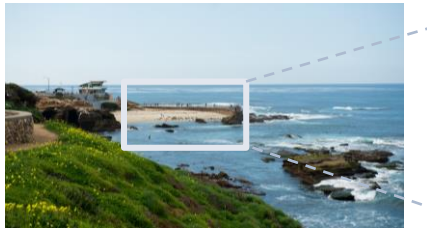
Fusion

Low light enhancement

High dynamic range

Zoom capability

Wide lens



Tele lens

Qualcomm Technologies was the 1st company to enable dual-camera capability

Fast forward: Evolution of our premium tier to the present

Our premium-tier chip is updated every year

20nm process

- Octa-core 64-bit CPUs
- Native 4k + external 4k display

14nm process

- 40% higher GPU perf
- Qualcomm® Quick Charge™ 3.0 Technology
- Added Galileo support
- Sensors power island

10nm process

- 1 Gbps LTE modem
- 2.45 GHz Octa CPUs
- Up to 32 MP camera
- Integrated Wi-Fi

10nm process

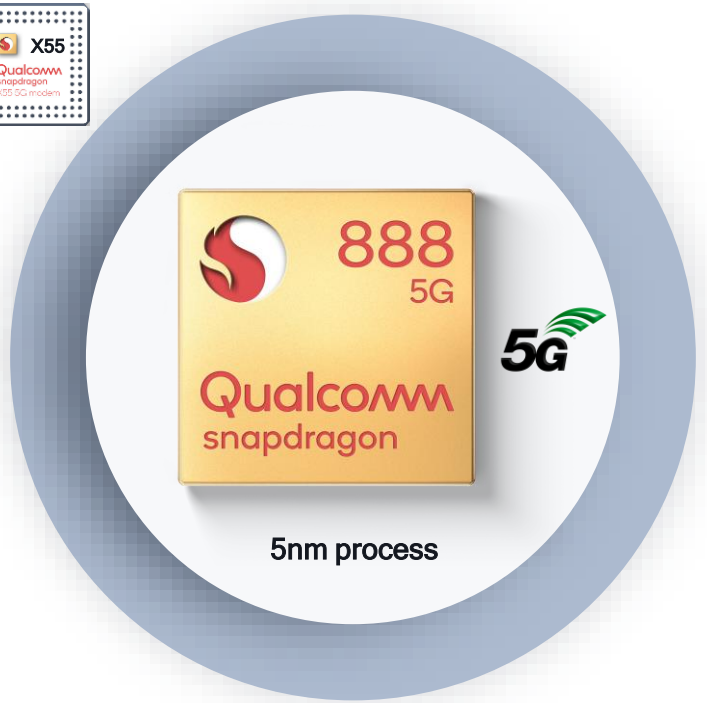
- 1.2 Gbps LTE modem
- 2.8 GHz Octa CPUs
- Camera noise reduction
- 802.11ad support

7nm process

- 2.0 Gbps LTE modem
- HDR10+ support
- 1st computer vision engine
- AI tensor hardware engine
- Security processor

7nm process

- 7.5 Gbps 5G modem
- Up to 200MP camera
- 8k video enc/dec
- Improved AI engine
- XR enhancements



- Integrated 5G modem
- Triple ISP
- Fused AI accelerator
- Variable rate shading
- Audio AI acceleration

Qualcomm Quick Charge is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.

Each technology team is continually innovating and rolling their latest technology into the next chip

Snapdragon 865-based phones: sleek and bezel-less with voice UI

All of these phones use our Qualcomm® Voice Activation for keyword detection

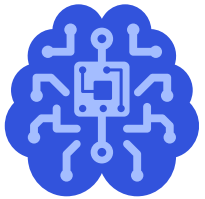
iQOO Neo3 5G
Snapdragon 865

Xiaomi Mi10 Pro 5G
Snapdragon 865

OnePlus 8 Pro
Snapdragon 865

LG V60 ThinQ 5G
Snapdragon 865

Bringing AI to the masses



Qualcomm Voice Activation is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.

Audio power island in the chip enables always-on listening at low power.
Audio algorithms have migrated to use machine learning.

Premium-tier phones all have multiple cameras

20 Megapixel Front camera

108 Megapixel camera

20 Megapixel
ultra wide-angle camera

12 Megapixel
short telephoto camera

8 Megapixel
Long telephoto camera

Xiaomi Mi 10 Pro

- Snapdragon 865 with Android 10.0
- 6.47” FHD+ (2340x1080) display with 90Hz refresh
- Quad (108 + 20 + 12 + 8) rear cameras + 20 MP front camera

32 Megapixel Front camera

48 Megapixel
camera

48 Megapixel
ultra wide-angle camera

13 Megapixel
telephoto camera

OPPO Find X2 Pro

- Snapdragon 865 with Android 10.0
- 6.7” QHD+ (3168 x1440) display with 120Hz refresh
- Triple (48 + 48 + 13) rear cameras + 32 MP front camera

The dual-camera capability we pioneered has expanded to 3, 4, or even 5 cameras, which automatically switch between themselves as you zoom

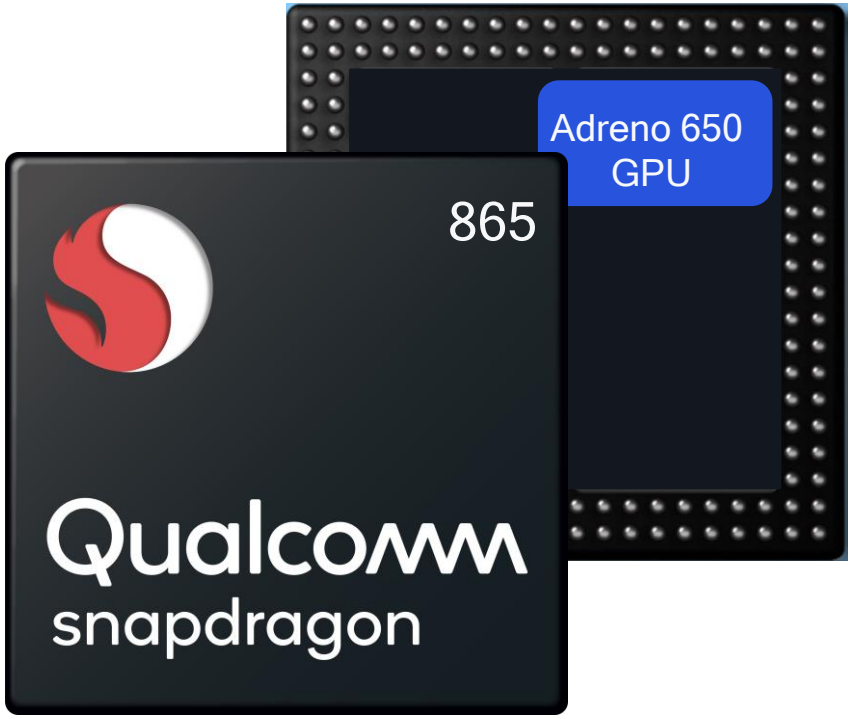
8K video recording on smartphones for the 1st time in history

Snapdragon Mobile Platform-enabled smartphones can now:

- Produce 8K videos
- Produce 4K HDR videos with 1 billion colors
- Take up to 200 MP photos
- Share virtually anytime and anywhere with 5G

Chinese National Geography Magazine used Snapdragon 865 to capture wildlife and nature videos in China to promote sustainability

Tremendous improvement in GPU performance



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Xbox One

The GPU in Snapdragon 865 has roughly equivalent performance to the Xbox One, enabling console-quality games to be ported to mobile devices

Mobile gaming is expanding rapidly

Asus ROG Phone 3
Snapdragon 865+ with Android 10.0
6.59” FHD+ (2340x1080) Display
(144Hz refresh)

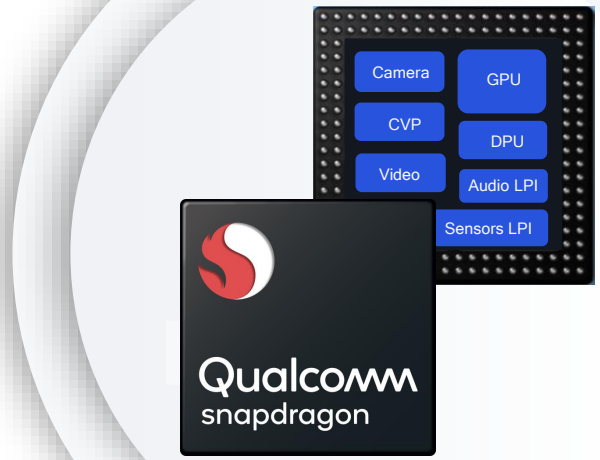
Xiaomi Black Shark 3 Pro
Snapdragon 865 with Android 10.0
7.1” QHD (3120x1440) Display
(90Hz refresh, 484 PPI)

Several phones are being custom-designed for online gaming
(controls, stereo speakers, haptics, high display refresh rates, thermal mitigation)

Snapdragon is the world's leading Extended Reality (XR) platform

Oculus Quest

Oculus Quest 2



Glass Enterprise Edition 2

XRSPACE MANOVA

Nreal Light

HTC VIVE Focus Plus

Leading technologies and optimized system design make Snapdragon the leading AR/VR solution

AI capability on Snapdragon 865

Real-time language transcription / translation on the device

The cellphone has transformed from 1995 to 2020

The power of integration driven by Moore's Law

Qualcomm QCP-800

Then (1995)

- 500nm process
- 1.4M transistors
- CDMA voice-only
- < 20 MHz Intel '186 CPU

Now (2020)

- 7nm process
- ~ 10B transistors
- 7.5 Gbps 5G modem
- 2.84 GHz Octa-core CPU
- GNSS location services
- 4 rear, 1 front camera
- 8k video encode/decode
- Xbox One class GPU
- 4k display capability
- Always-on voice UI
- Sensors hub
- CV & AI acceleration engines
- XR optimizations

Xiaomi Mi 10 Ultra

. . . and a lot of ingenuity and vision from our engineers

Qualcomm

Thank you

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