

June 2014

The Evolution of Mobile Technologies:

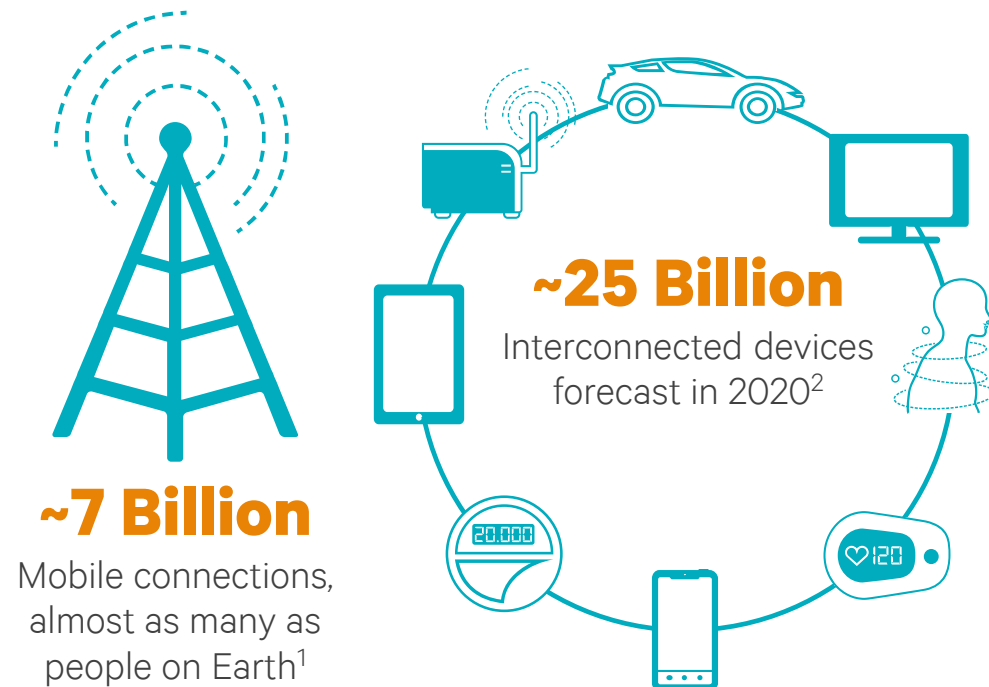
1G ⇌ 2G ⇌ 3G ⇌ 4G LTE

QUALCOMM®

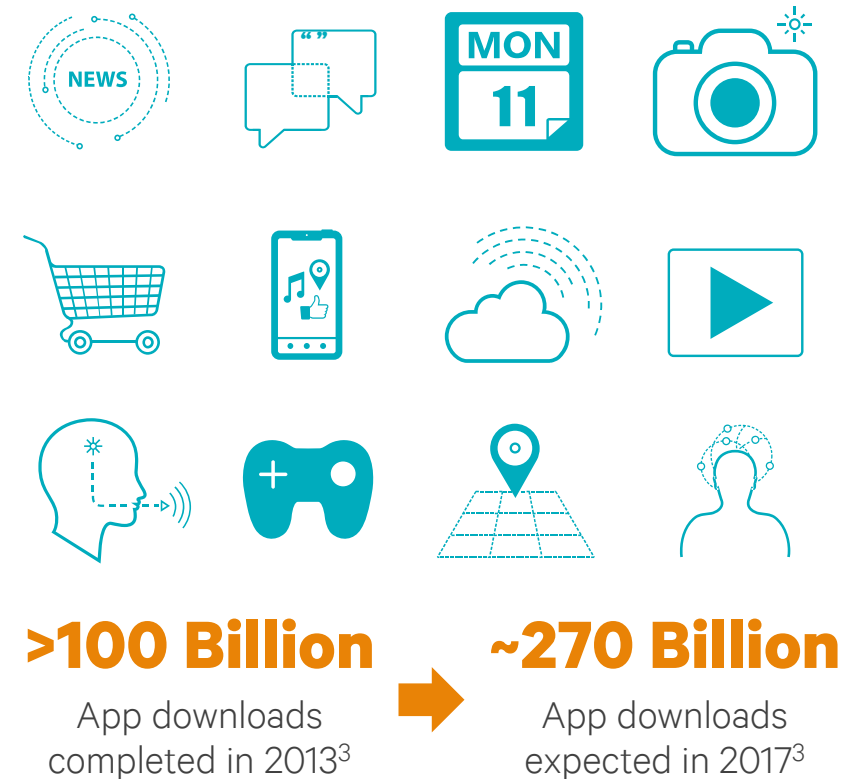


The mobile experience is expanding everywhere

Billions of Mobile Connections

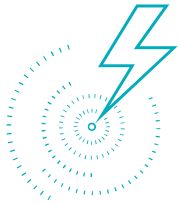


Billions of Mobile Experiences



¹ Source: GSMA Intelligence, Apr. '14; ² Source: Machina Research, '13; ³ Source: Gartner, Sep. '13

Mobile is an amazing technical achievement



Mind-blowing Performance

with processing power greater than the most advanced super computers of the early 1990s¹



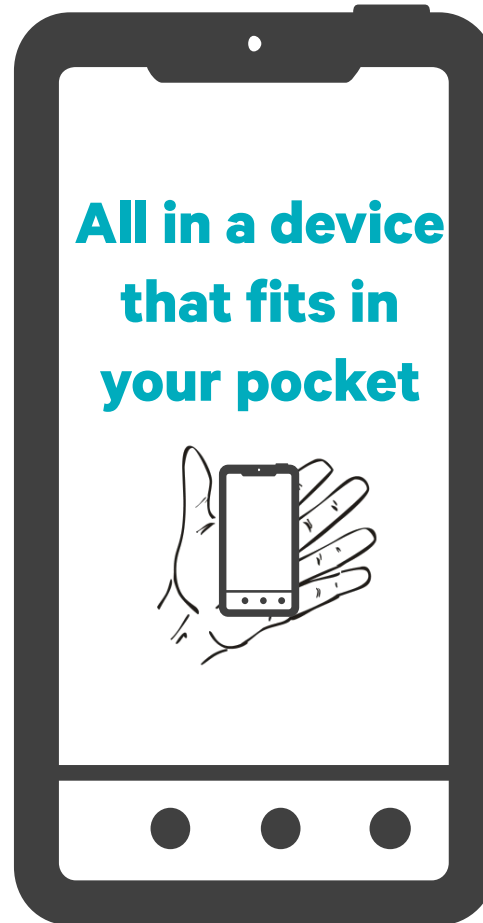
Jaw-dropping Graphics

with capability to process several thousand megapixels per second²



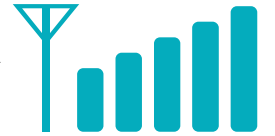
High Quality Multimedia²

4K UltraHD video player/recorder
HD gaming console
5.1/7.1 surround sound system
High resolution digital camera



Reliable Connectivity

overcoming signal loss resulting in receiving signal 100 trillion times weaker than when it originated³



Broadband Speeds

with blazing fast data rates capable of 300+ Mbps⁴



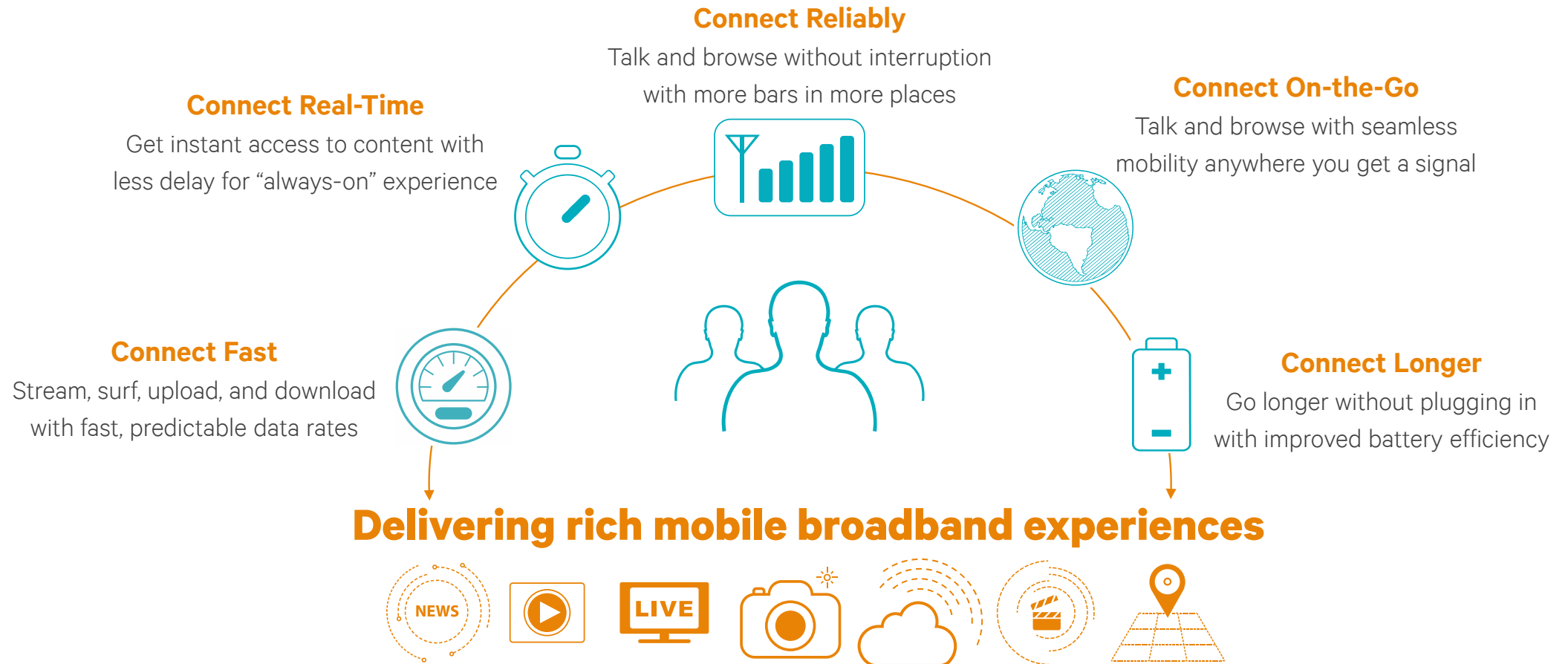
Long Battery Life

with ability to power all these amazing experiences with less energy than it takes to power a light bulb for 15 minutes⁵



¹ Source: Charlie White, Sep. '13 & giffgaff.com, Sep'13; ² Based on latest Qualcomm® Snapdragon™ 800 series processors; ³ Based on >140 dB path loss typical in mobile; ⁴ Based on peak data rates for LTE Advanced; ⁵ Based on >2,000 mAh smartphone battery and >60W light-bulb

Connectivity is the foundation of a great mobile experience



Powered by evolving mobile technologies for better experiences

Mobile 1G

AMPS, NMT, TACS



Mobile 2G

D-AMPS, GSM/GPRS, cdmaOne



Mobile 3G

CDMA2000/EV-DO, WCDMA/HSPA+, TD-SCDMA



Mobile 4G LTE

LTE, LTE Advanced



N/A

Analog Voice



<0.5 Mbps¹

Digital Voice + Simple Data



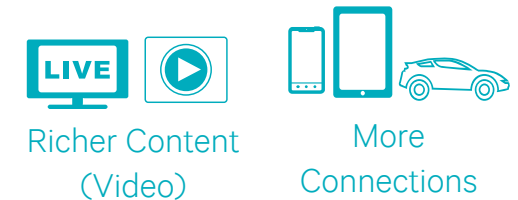
63+ Mbps²

Mobile Broadband



300+ Mbps³

Faster and Better



¹ Peak data rate for GSM/GPRS, latest Evolved EDGE has peak DL data rates capable of up to 12 Mbps; ² Peak data rate for HSPA+ DL 3-carrier CA; HSPA+ specification includes additional potential CA + use of multiple antennas, but no announcements to date; ³ Peak data rate for LTE Advanced Cat 6 with 20 + 20 MHz DL CA; LTE specification includes additional potential CA + additional use of multiple antennas, but no announcements to date

Evolving mobile technologies deliver great mobile experiences

Appreciating the magic of mobile requires understanding the evolution from 1G to 4G LTE

1



1G established seamless mobile connectivity introducing mobile voice services

3



3G optimized mobile for data enabling mobile broadband services, and is evolving for faster and better connectivity

2



2G digital wireless technologies increased voice capacity delivering mobile to the masses

4



4G LTE delivers more capacity for faster and better mobile broadband experiences, and is also expanding in to new frontiers

5



Qualcomm has been at the forefront of this evolution, pushing wireless boundaries to enable the best mobile experiences

Mobile 1G established the foundation of mobile

1

Licensed Spectrum

Cleared spectrum for exclusive use by mobile technologies

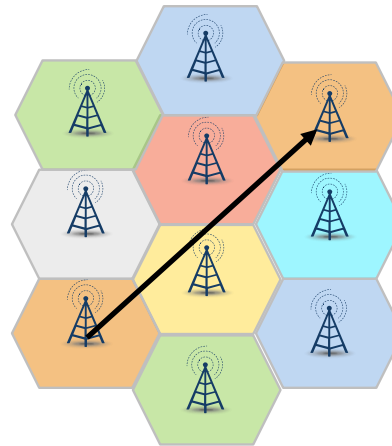


Operator-deployed **base stations** provide access for subscribers

2

Frequency Reuse

Reusing frequencies without interference through geographical separation

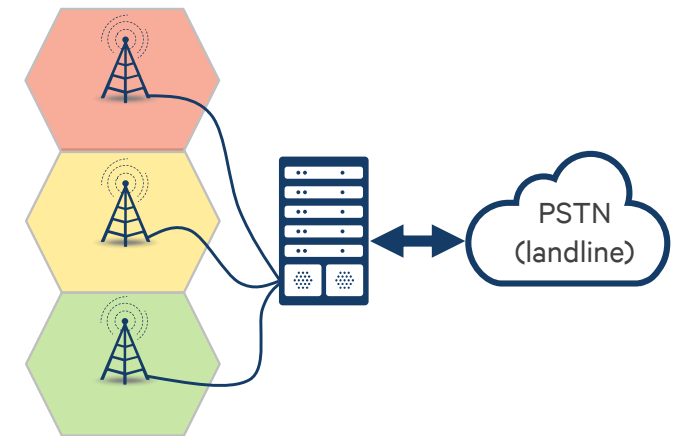


Neighboring **cells** operate on different frequencies to avoid interference

3

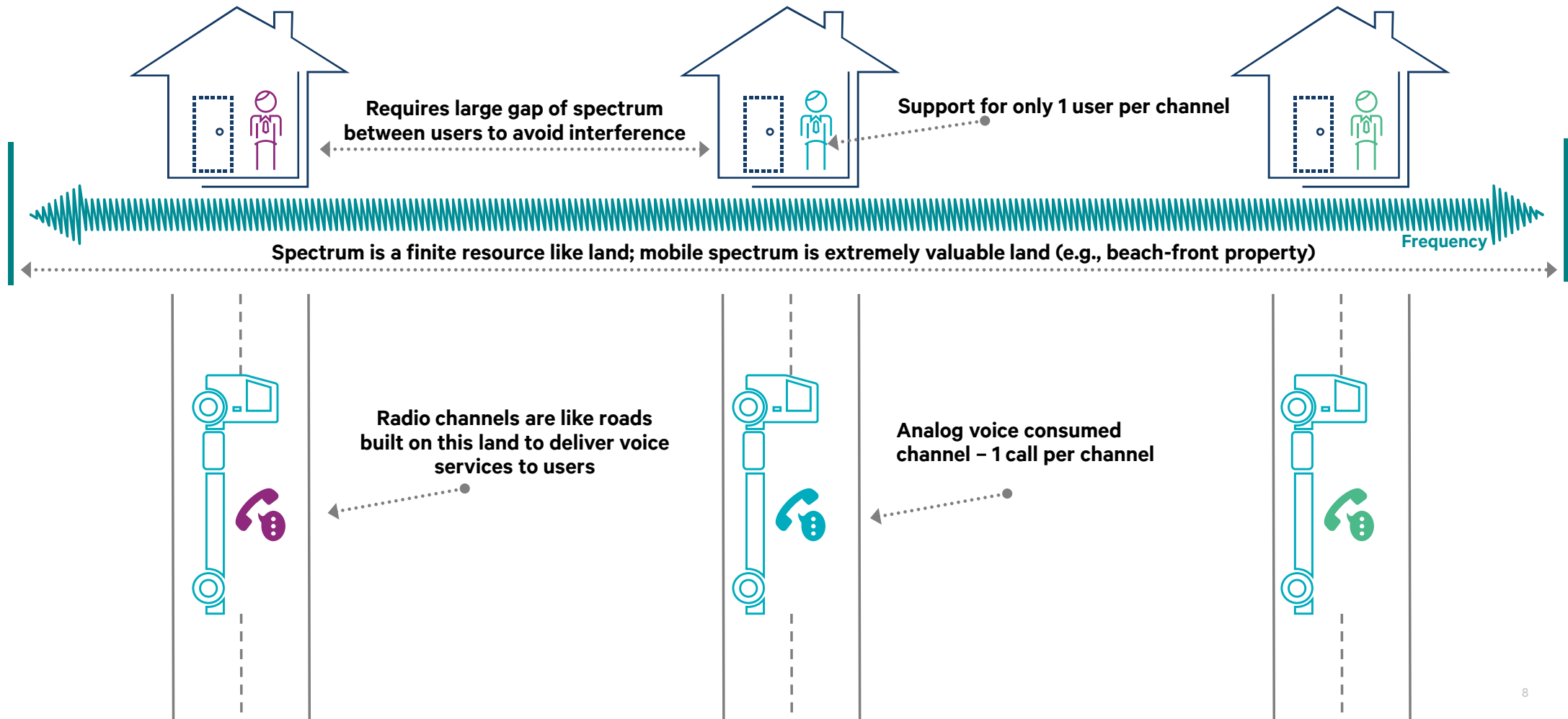
Mobile Network

Coordinated network for seamless access and seamless mobility



Integrated, transparent **backhaul network** provides seamless access

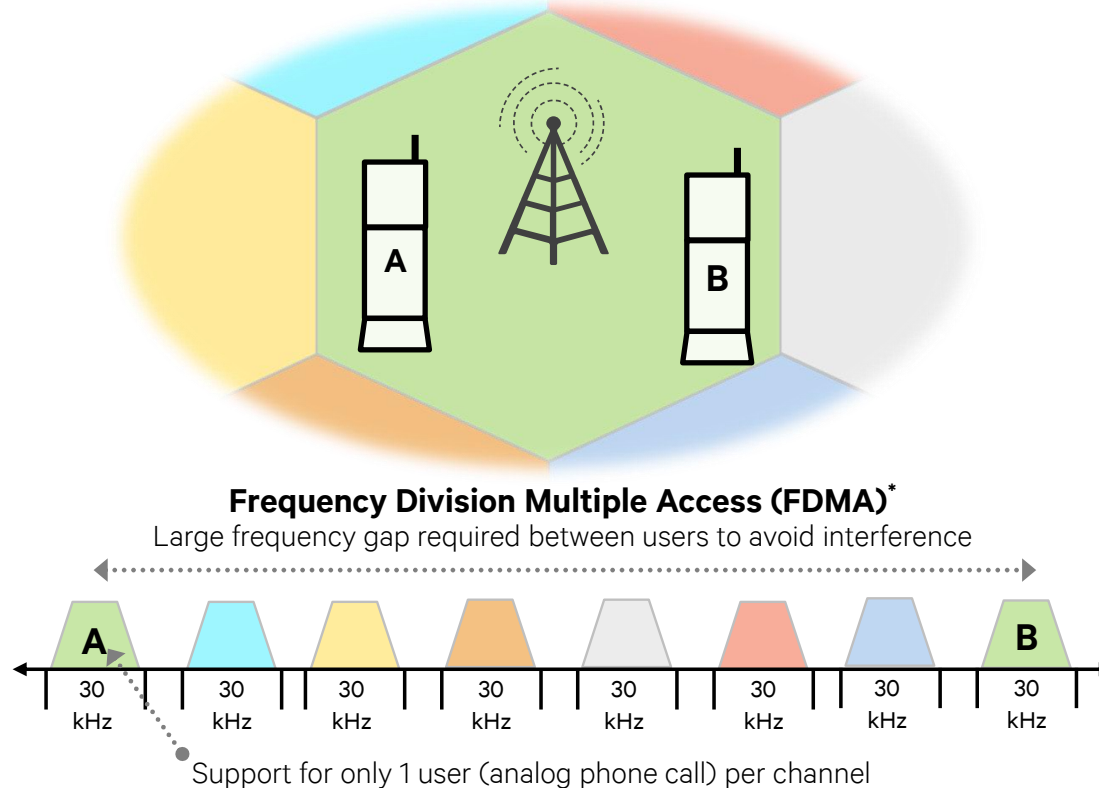
Mobile 1G was amazing, but limited



1G analog voice was amazing, but limited

Limited Capacity

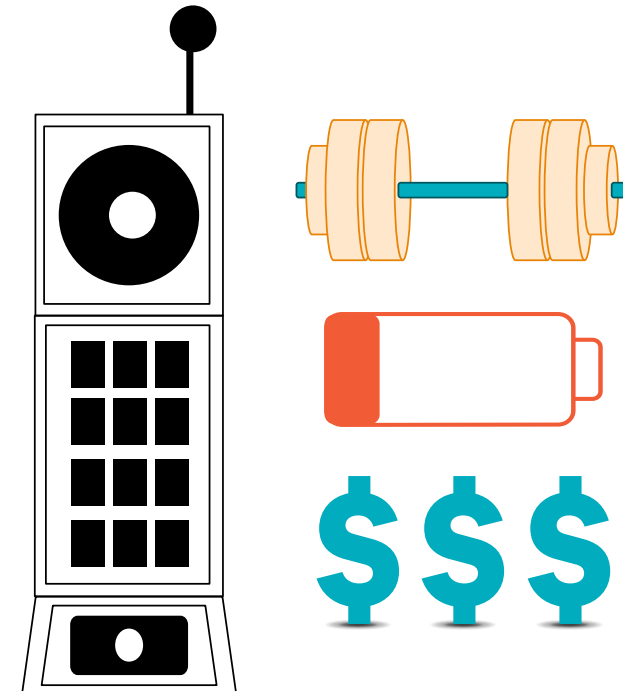
Analog transmissions are inefficient at using limited spectrum



* Example shown based on AMPS 1G technology

Limited Scalability

Analog devices are large/heavy, power inefficient, and high cost



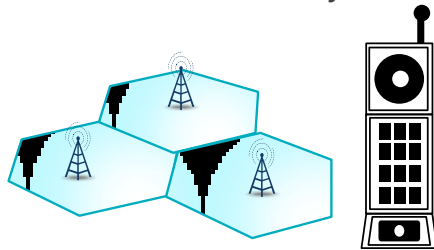
Mobile 2G digital technologies increased voice capacity

Delivering mobile voice services to the masses – more people, in more places

Mobile 1G

AMPS, NMT, TACS

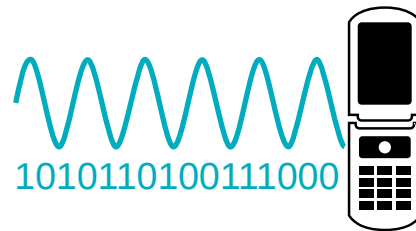
Foundation of Mobile
Seamless Mobility



Mobile 2G

D-AMPS, GSM/GPRS,
cdmaOne

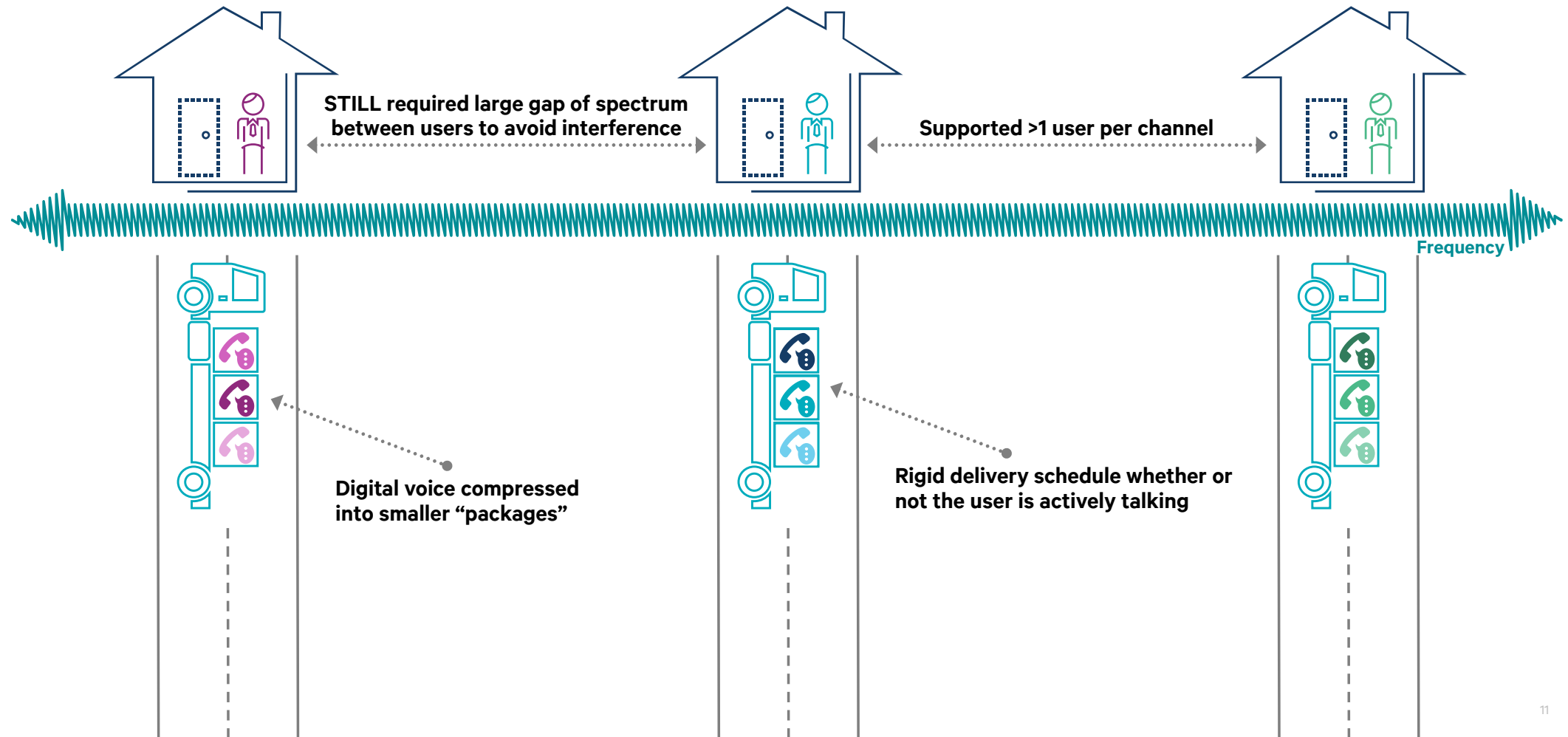
Mobile for the Masses
More Voice Capacity



1980s

1990s

Early Mobile 2G technologies enabled more users per channel

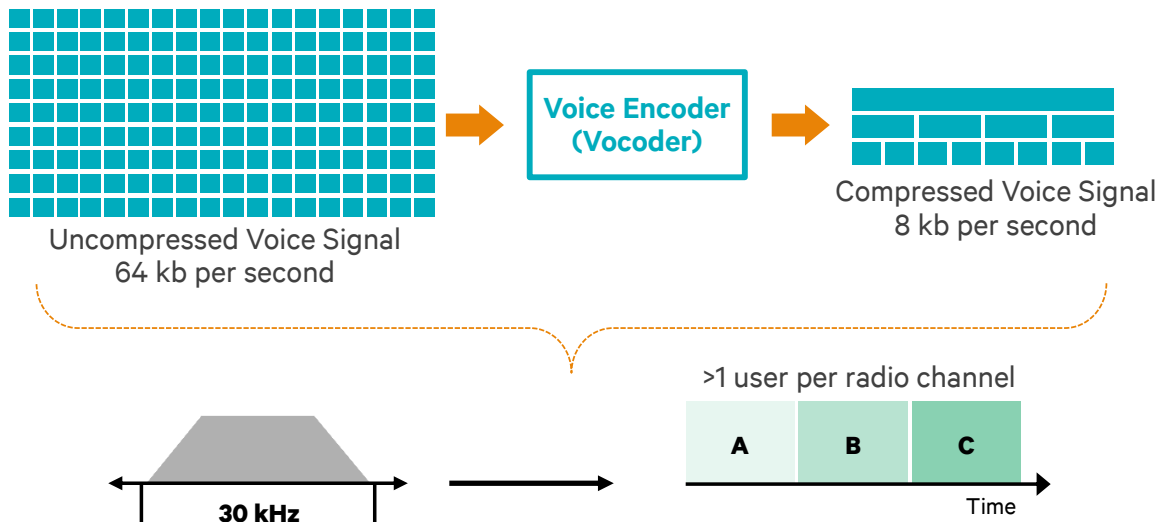


Mobile 2G digital wireless technologies enabled more users

Initial 2G technologies (D-AMPS, GSM) based on TDMA

More Voice Capacity

Digital transmissions enable compressed voice and multiplexing multiple users per channel

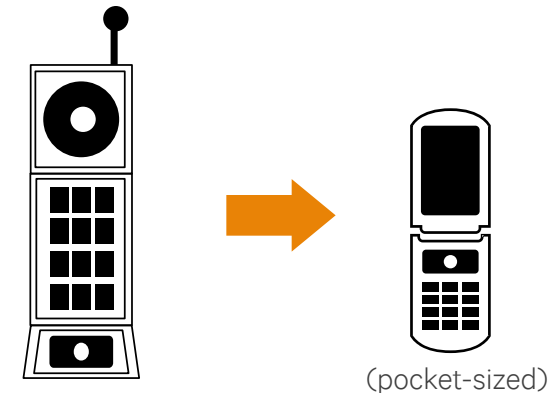


Time Division Multiple Access (TDMA)

Allows multiple users per radio channel with each user talking one at a time

Scalable Technology

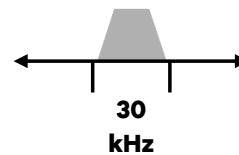
Digital components cost/weight far less plus deliver more secure signal



Different Mobile 2G TDMA techniques were standardized

Mobile 1G (Analog)

AMPS, NMT, TACS



Only one user per radio channel



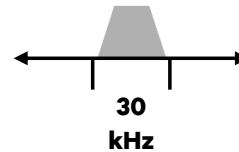
Mobile 2G (Digital)

D-AMPS

Standardized as IS-54 by TIA in 1992

Mainly in North America

No longer utilized



Three users per radio channel



Mobile 2G (Digital)

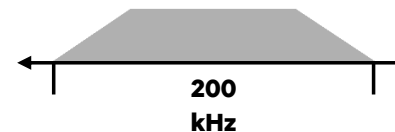
GSM

Standardized by ETSI in 1990 (phase 1)

Initiated in Europe

Still widely used today (>4B connections WW¹)

Simple data services with GPRS

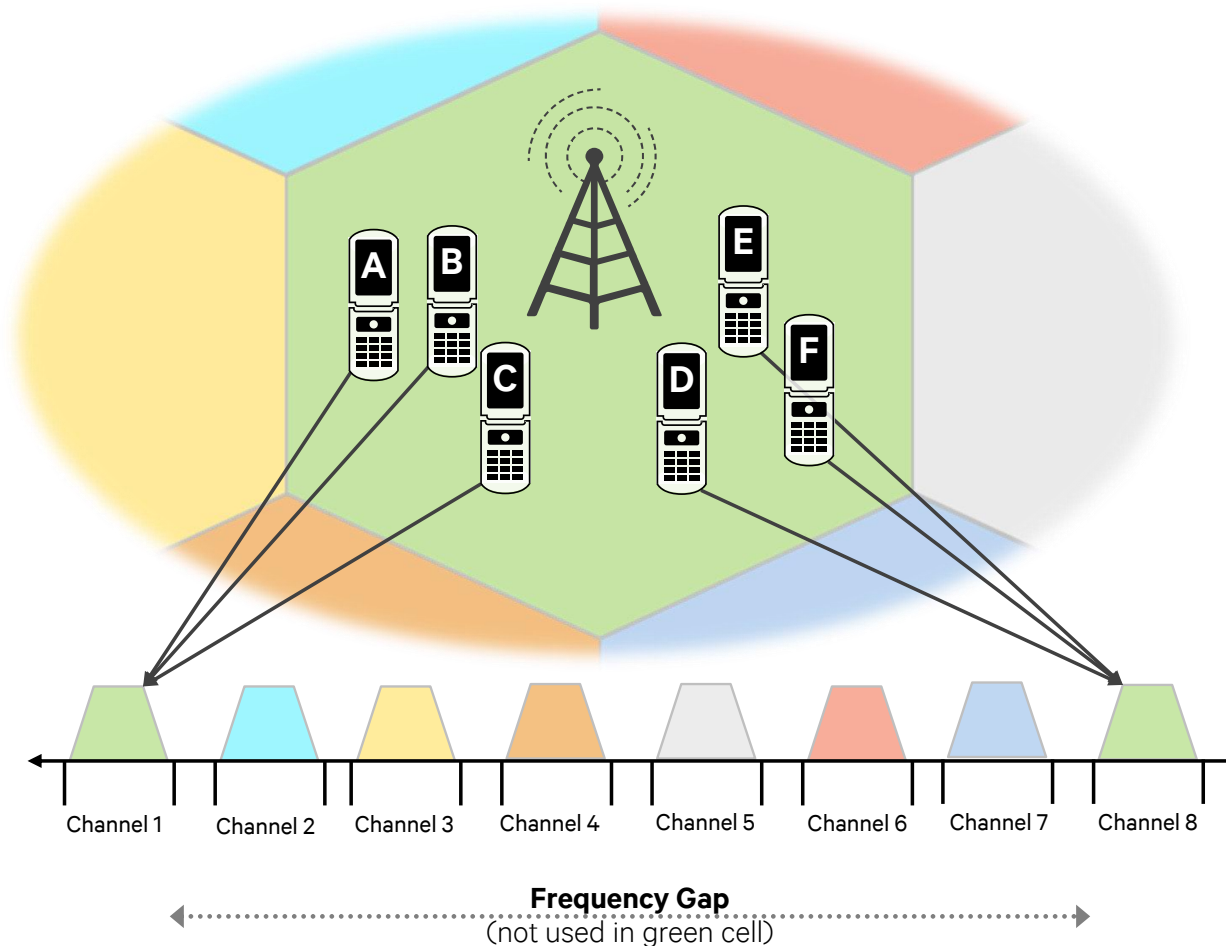


Eight users per radio channel



¹ Source: GSMA Intelligence, May '14

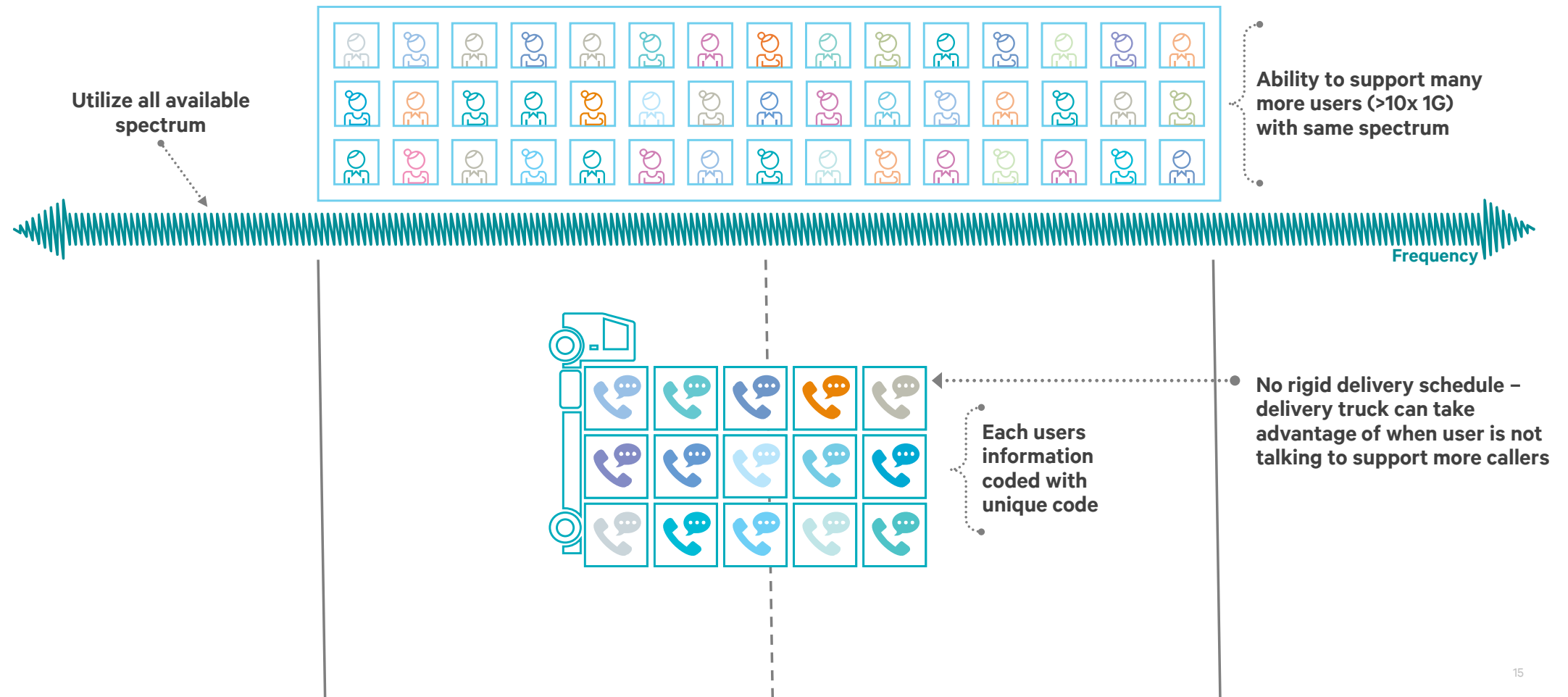
TDMA still required large frequency gaps to reduce interference



Also required potentially unreliable “hard” handoffs

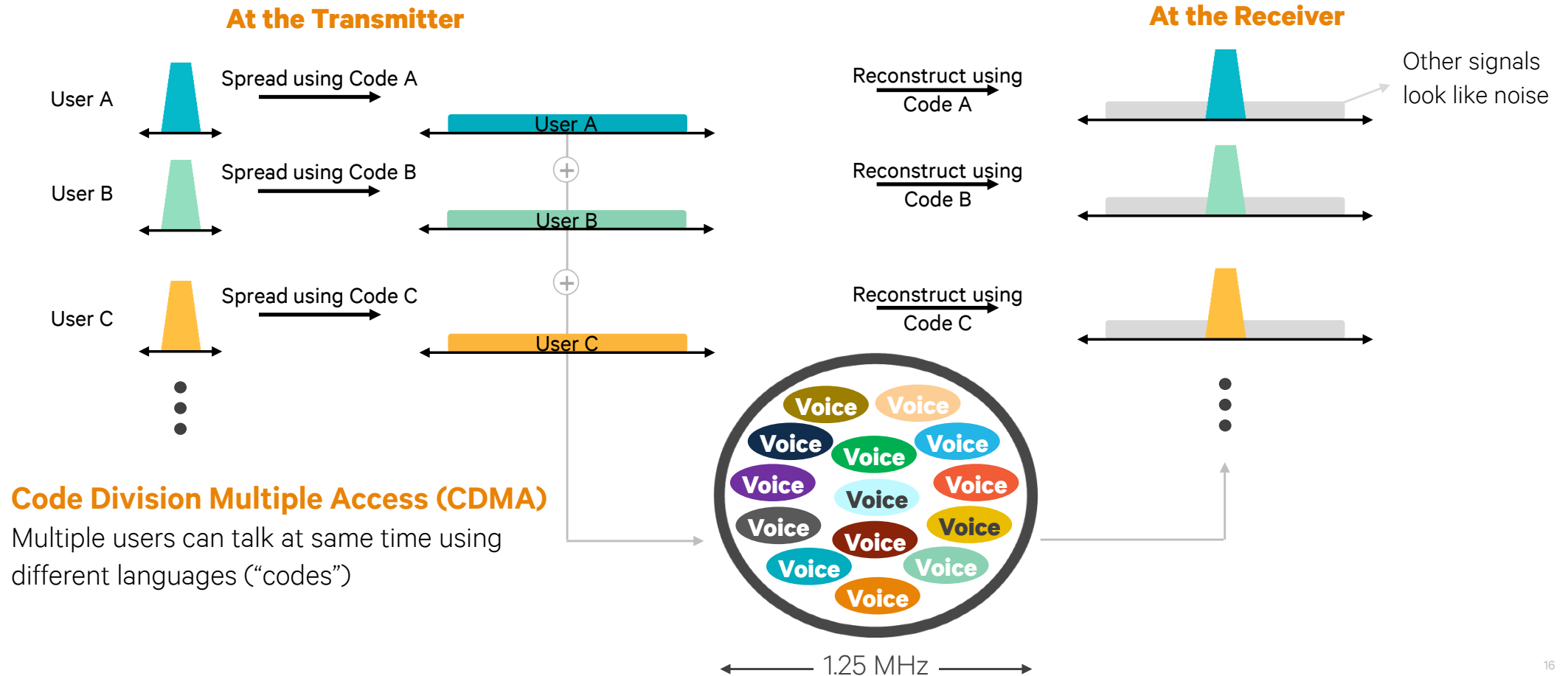
Switch channels between adjacent cells – potential for dropped calls

CDMA utilizes all the available spectrum to support more users



Qualcomm solved the seemingly impossible wireless challenge

CDMA enables users to share the same frequency and communicate at the same time



Qualcomm solved complex challenges to commercialize CDMA

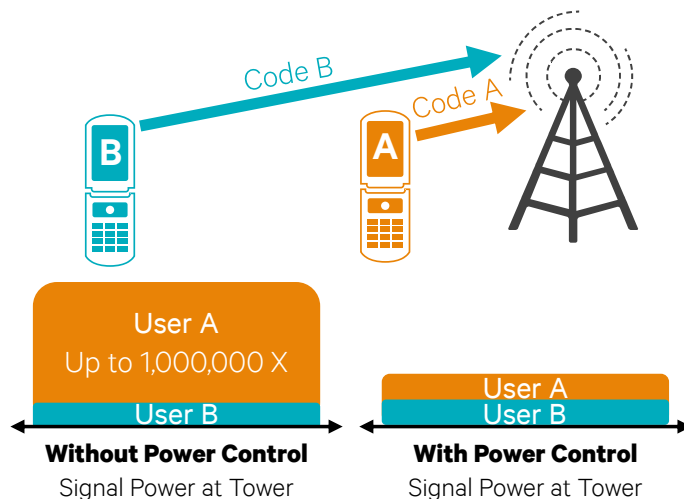
1

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



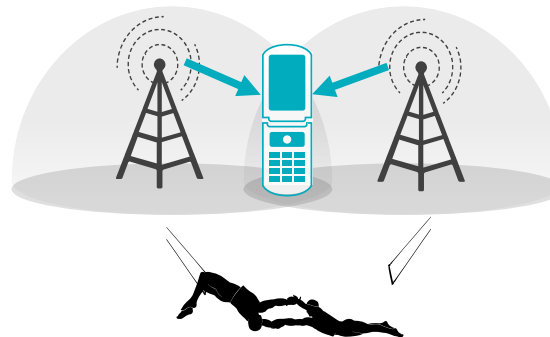
2

Cell-Edge Challenge

Interference caused by users in close proximity, on the same frequency, and communicating with different towers

Solution:

Users simultaneously communicate with multiple towers at cell edge



+ Soft (vs. Hard) Handoffs

Additional benefit of simultaneous connections – more reliable handoffs

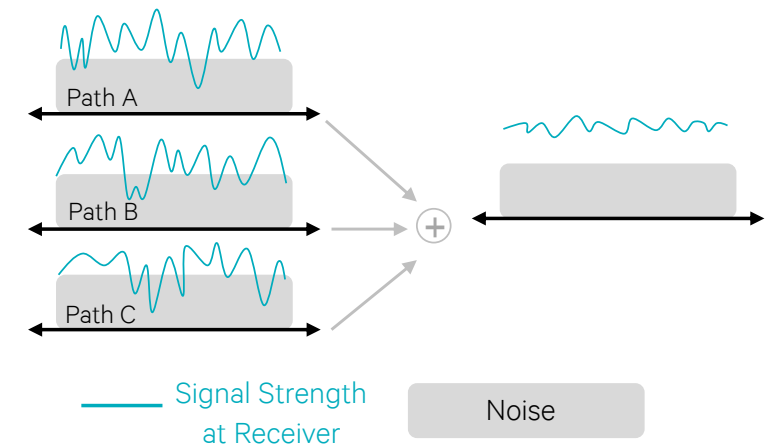
3

Multipath Fading Challenge

Interference caused by the reception of the same signal over multiple paths resulting in poor signal-to-noise ratio

Solution:

Advanced (“rake”) receivers combine energy of multiple signal paths

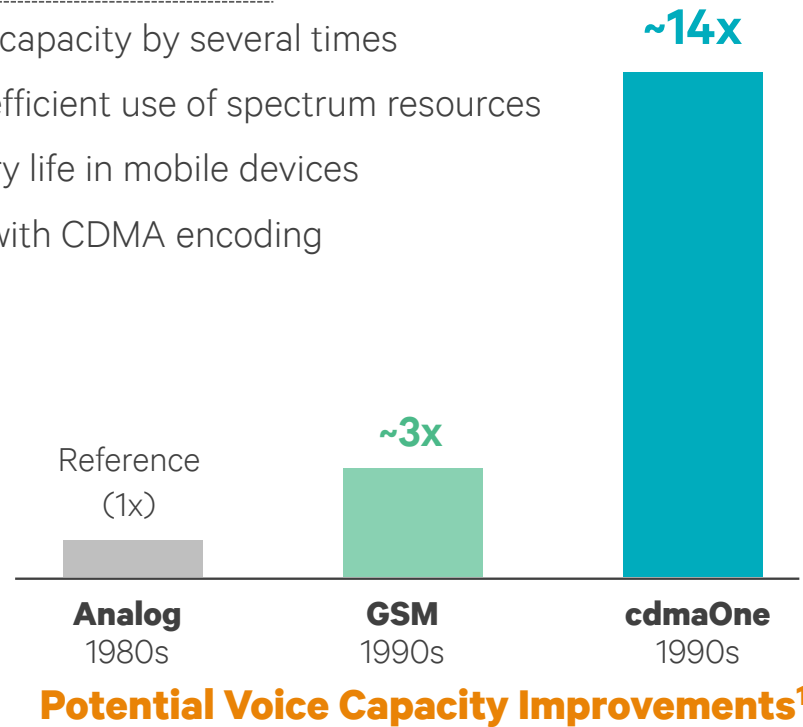


CDMA delivered unprecedented voice capacity and much more

Qualcomm efforts lead to new CDMA standard (IS-95) referred to as cdmaOne

CDMA Benefits

- Increased voice capacity by several times
- Provided more efficient use of spectrum resources
- Increased battery life in mobile devices
- Better security with CDMA encoding



CDMA Timeline²

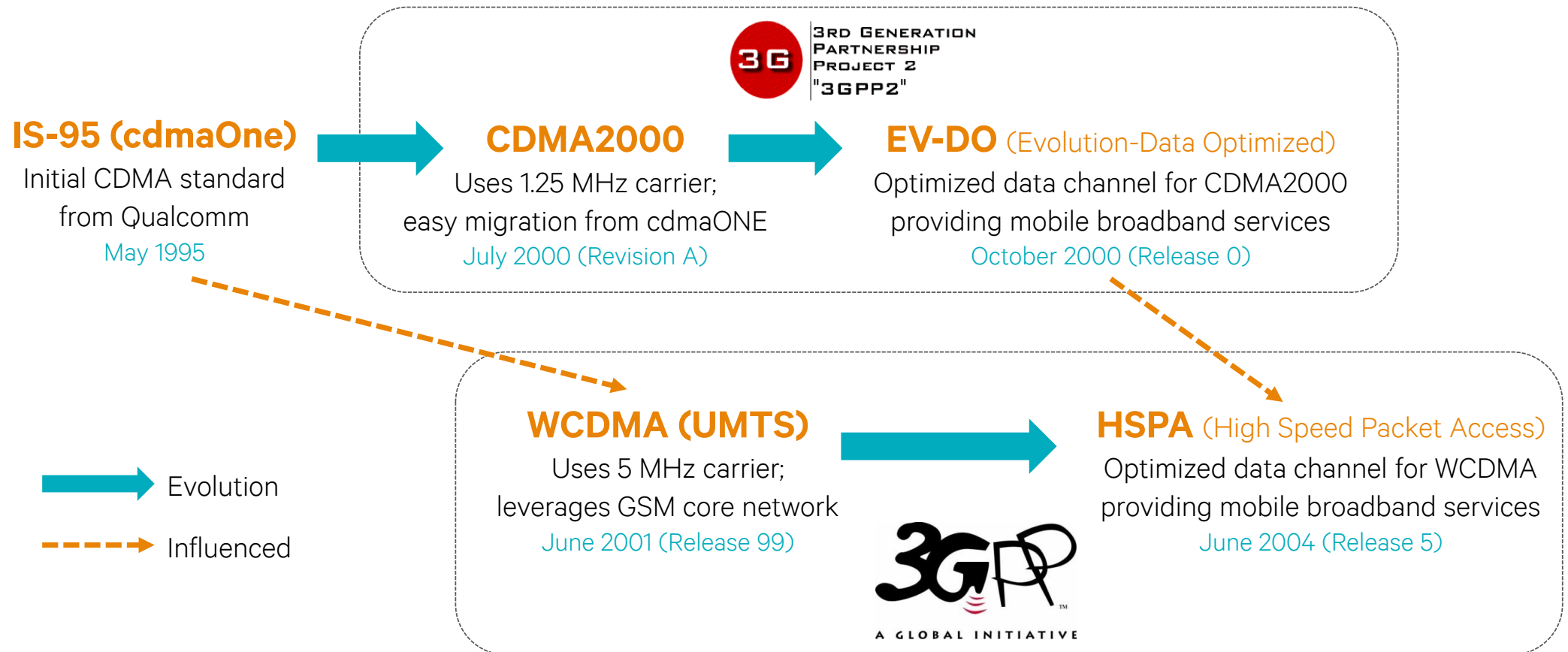
- February 1990**
First CDMA field trial completed by Qualcomm and NYNEX
- March 1992**
Standards committee formed in Telecommunications Industry Association
- May 1995**
IS-95 revision A (cdmaOne) released
- December 1995**
First commercial deployment
- December 1999**
cdmaOne subscribers pass 50 million worldwide (>80 operators in >30 countries)

CDMA is the foundation for Mobile 3G technologies

¹ Approximate total number of subscribers serviced within same spectrum based on AMPS (1G), GSM and cdmaOne technology commercial deployed in 1990s; ² Source: CDG, www.cdg.org

CDMA established the foundation for 3G technologies

Mobile 3G evolved into two competing standards both based on CDMA



Note: ITU IMT-2000 compliant 3G standards included EDGE, TD-SCDMA, and WiMAX; CDMA2000 and WCDMA were the most commercially successful

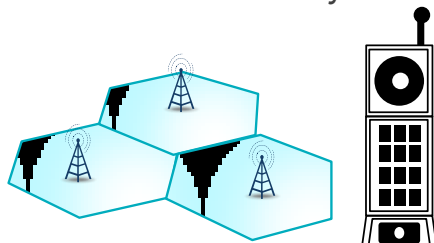
Mobile 3G evolved mobile for data

Introducing high-speed internet access for the first time

Mobile 1G

AMPS, NMT, TACS

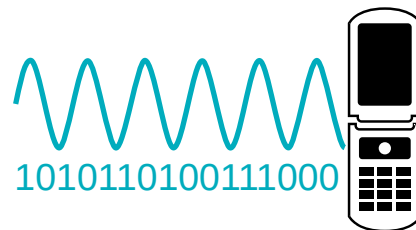
Foundation of Mobile
Seamless Mobility



Mobile 2G

D-AMPS, GSM/GPRS,
cdmaOne

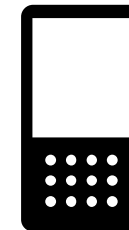
Mobile for the Masses
More Voice Capacity



Mobile 3G

CDMA2000/EV-DO,
WCDMA/HSPA+, TD-SCDMA

Mobile Broadband
Data Optimized



1980s

1990s

2000s

Mobile voice was amazing, but consumers wanted more

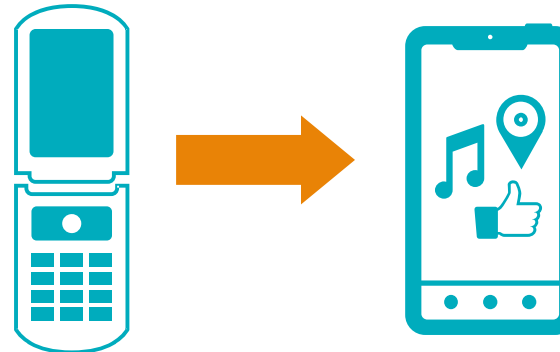
A new, insatiable demand for internet access and data services emerges

Broadband Internet



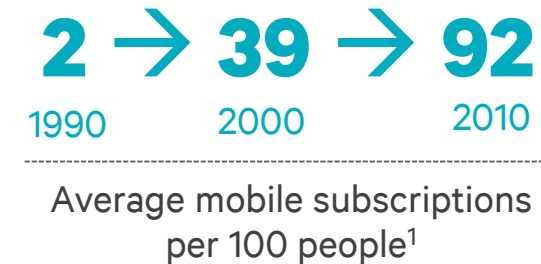
Consumers introduced to broadband internet access in the home/office

The Smartphone



Amazing innovations in device technology resulted in the era of the smartphone

Mobile Everywhere



Thanks to 2G technologies, more and more people had a mobile subscription

¹ Source: Worldbank.org for United States

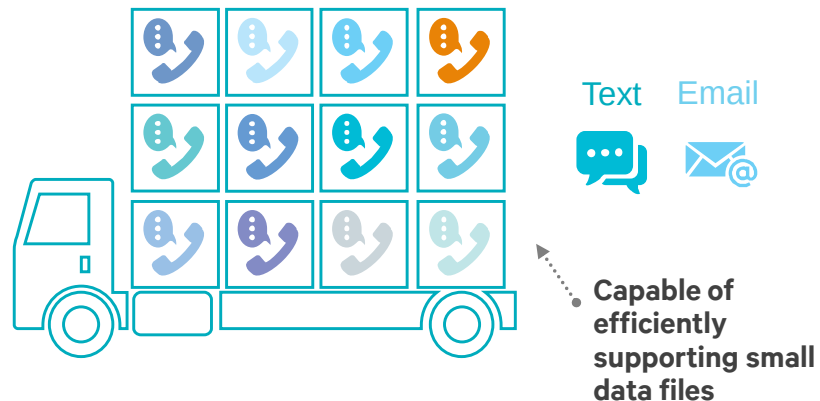
EV-DO optimized 3G for data enabling mobile broadband

Data Enabled

Simple Data Services

Mobile 2G

<0.5 Mbps¹

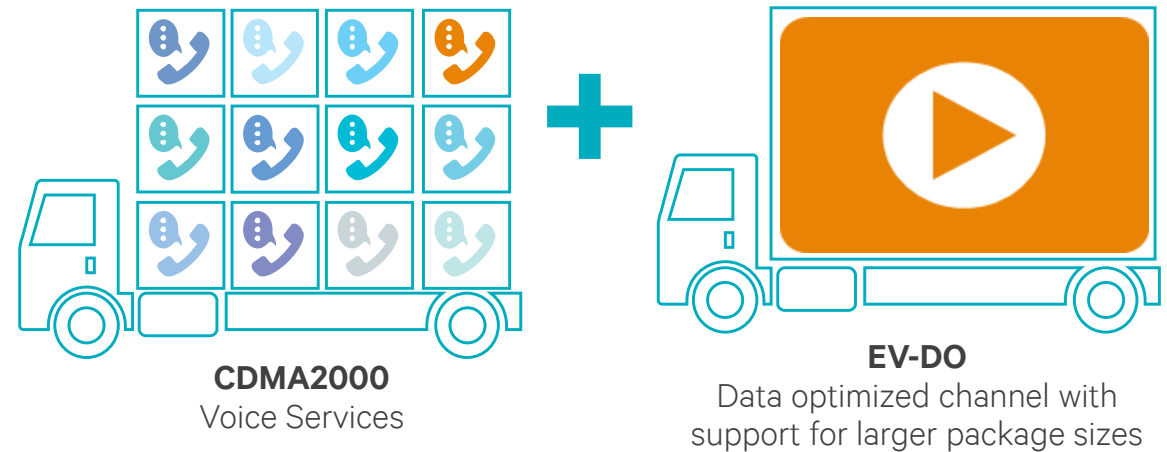


Data Optimized

Mobile Broadband

CDMA2000/EV-DO

14.7 Mbps²



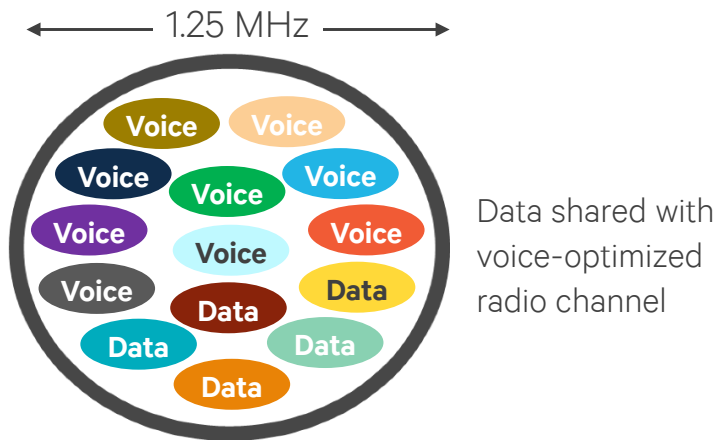
¹ Based on peak data rate – GSM/GPRS

² Based on peak data rate for downlink EV-DO Rev. B

Qualcomm pioneered EV-DO introducing mobile broadband

Mobile 2G

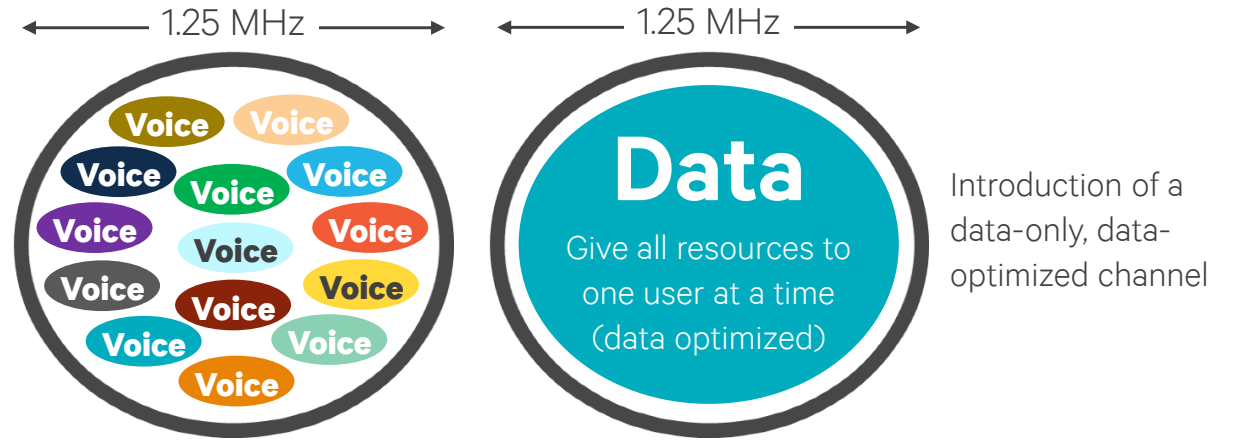
Data Enabled



Simple Data Services

CDMA2000/EV-DO

Data Optimized



Mobile Broadband Services

EV-DO inventions are the foundation to mobile broadband

1

Data Optimized Channel

Splits channel into time intervals enabling a single user to get all the resources at once

Enables richer content

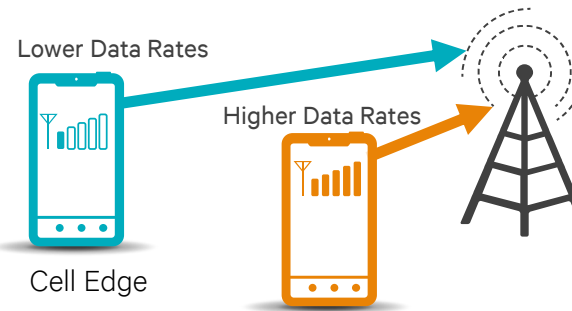


2

Adaptive Modulation

Uses higher order modulation to get more bps per Hz for users with good signal quality

Increases peak data rates

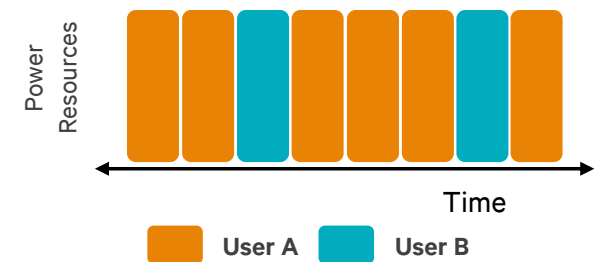


3

Opportunistic Scheduling

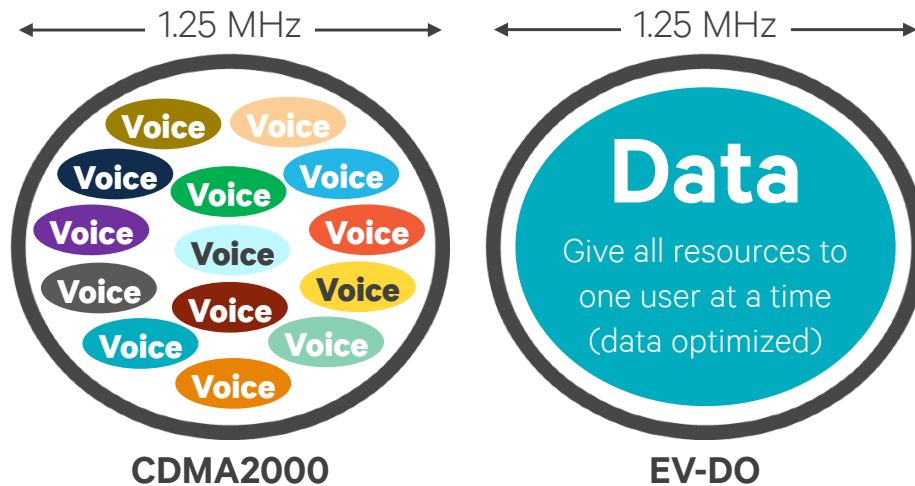
Optimizes channel by scheduling users at the time instances when users have good radio signal conditions (with fairness)

Increases overall capacity

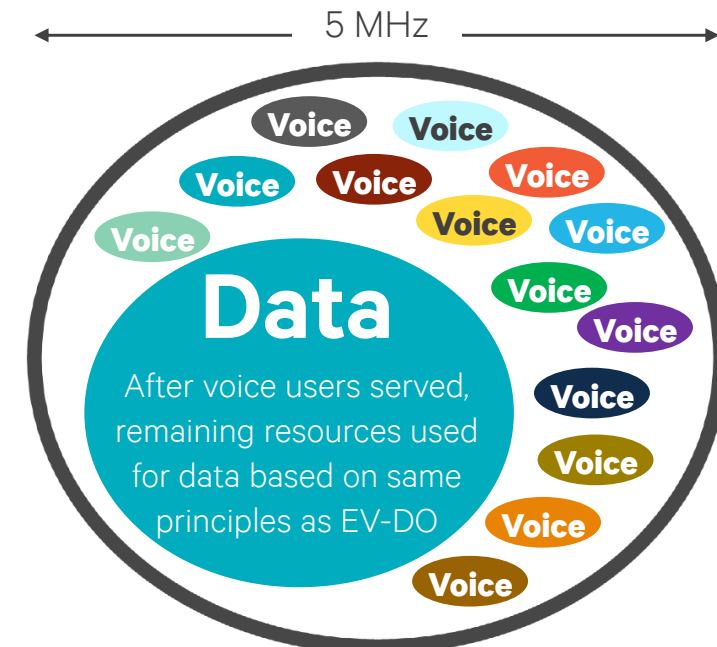


CDMA2000/EV-DO blazed the trail for WCDMA/HSPA

CDMA2000/EV-DO



WCDMA/HSPA

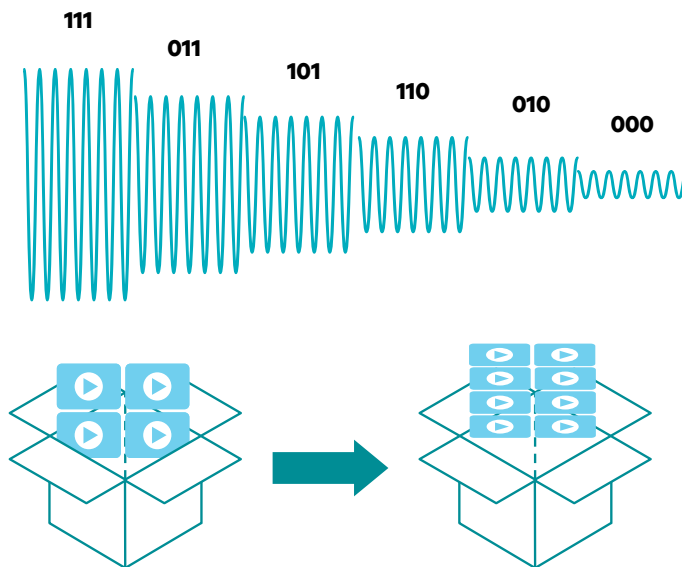


Mobile 3G evolved to HSPA+ and EV-DO Rev. B

Delivering higher data rates, more capacity, and enhanced mobile broadband experiences

Higher Order Modulation (HOM)

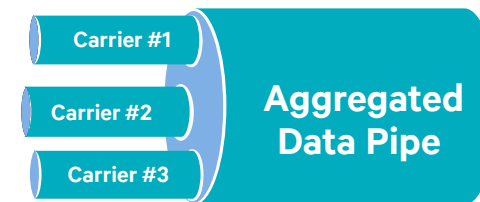
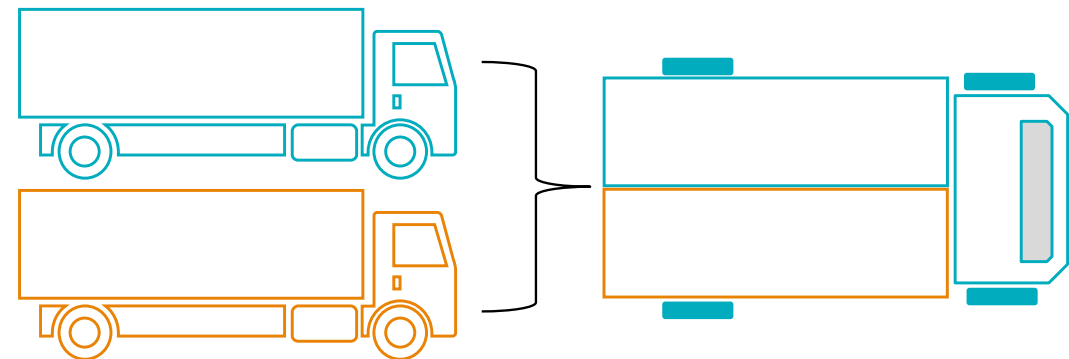
Introduces 64-QAM enabling 50% more bits per second per Hz (bps/Hz)



Enabling packing 50% more data into packages

Carrier Aggregation

Aggregating spectrum enabling increased user and peak data rates

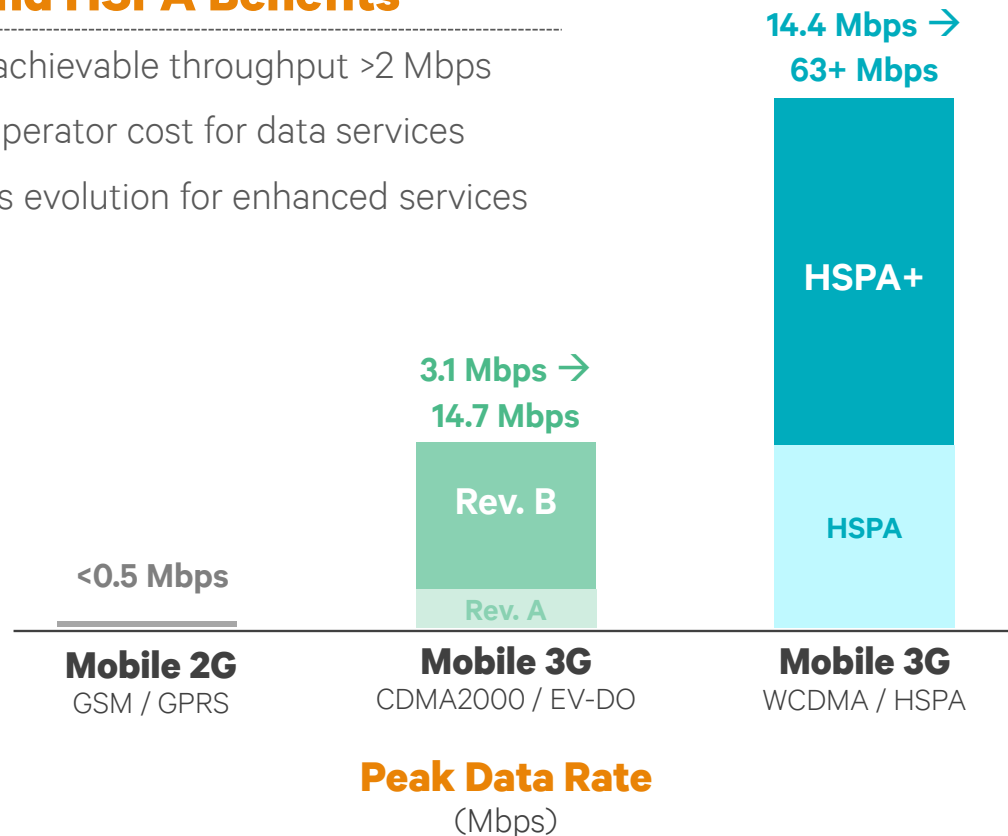


Aggregate channels for higher data rates

3G technologies optimized mobile for data

EV-DO and HSPA Benefits

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



Mobile Broadband Timeline¹

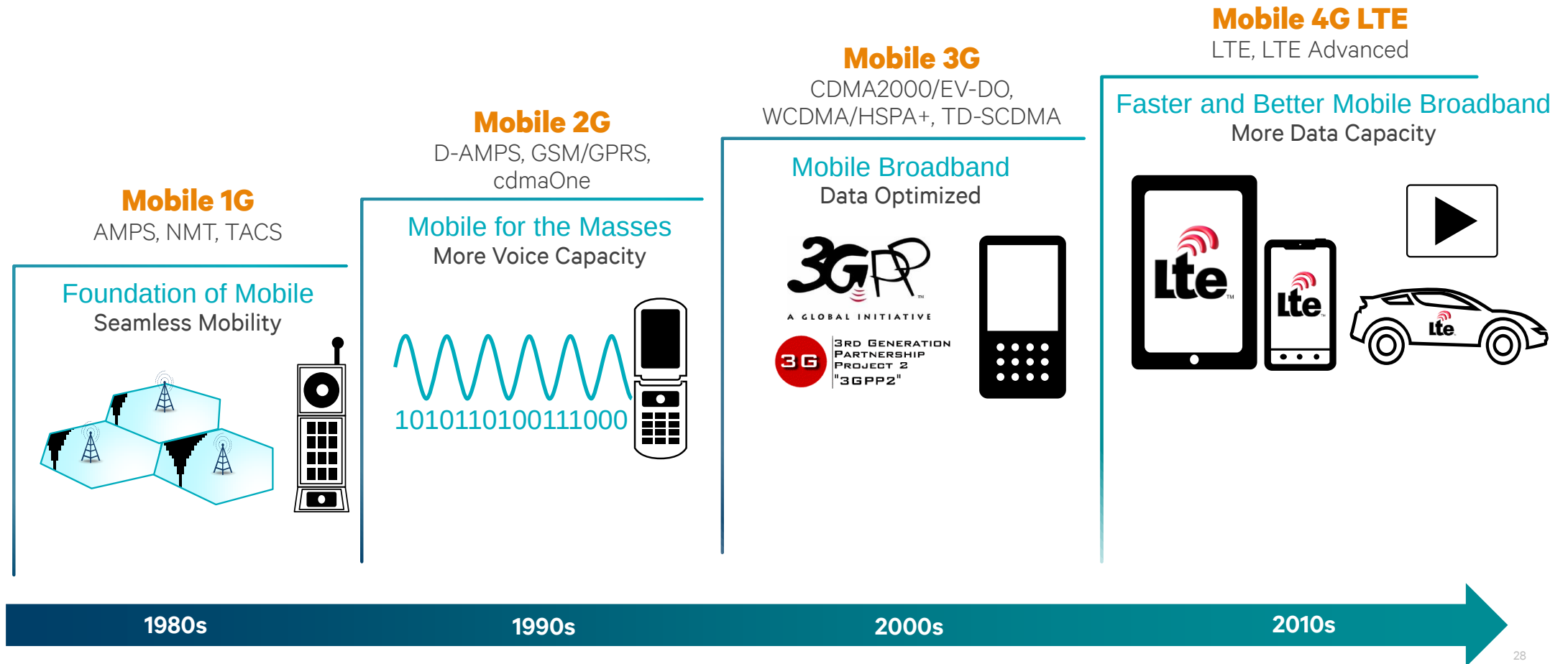
- 1999**
Qualcomm introduces EV-DO
- January 2002**
First EV-DO commercial launch
- Q4 2004**
3GPP release 6 with HSPA is published based on WCDMA technology
- Q1 2007**
EV-DO passes 50 million connections
- Q108**
HSPA passes 50 million connections
- June 2008**
First HSPA+ (21 Mbps) commercial launch
- September 2010**
First DC-HSPA+ (42 Mbps) commercial launch

3G technologies continue to evolve
Surpassed 2B connections in 2013²

¹ Source: CDG (www.cdg.org) and 3GPP (www.3gpp.org); ² Source: GSMA Intelligence, May '14

Mobile 4G LTE is evolving to provide more data capacity

Delivering faster and better mobile broadband experiences



Mobile 4G LTE complements 3G to boost data capacity

Multimode 3G/LTE is the foundation for successful 4G LTE

4G LTE

Providing more data capacity for richer content and more connections

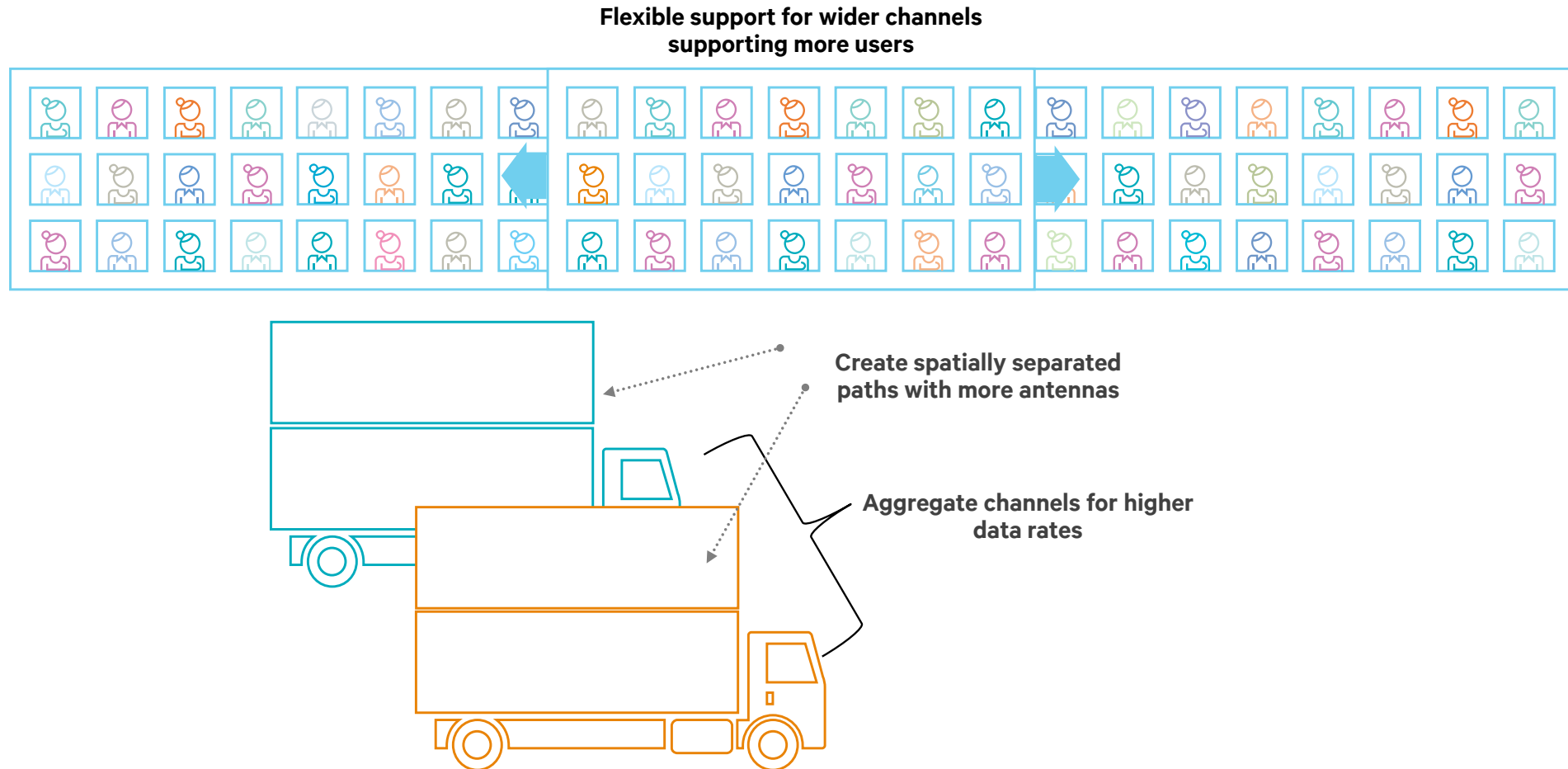
3G

Enabling a consistent broadband experience outside 4G LTE coverage
Delivering ubiquitous voice services and global roaming

Multimode

LTE FDD/TDD
WCDMA/HSPA+
CDMA2000/EV-DO
TD-SCDMA
GSM/GPRS

Mobile 4G LTE delivers more data capacity



Mobile 4G LTE delivers more data capacity

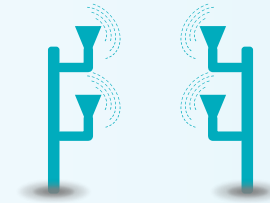
Download, browse, stream, and game faster than ever with faster and better connectivity

Connect Faster



Wider Channels

Flexible support for channels up to 20 MHz enabled with OFDMA



More Antennas

Advanced MIMO techniques to create spatially separated paths; 2x2 MIMO mainstream



Carrier Aggregation

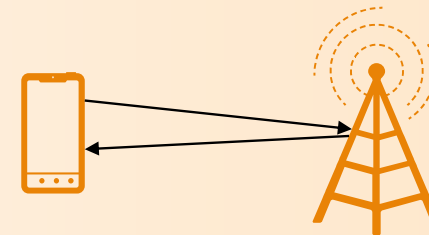
Aggregate up to 100 MHz for higher data rates – 2 carrier (2C) commercial; 3C announced¹

Connect Real-time



Simplified Core Network

All IP network with flattened architecture resulting in less equipment per transmission



Low Latencies

Optimized response times for both user and control plane improves user experience

¹ As of May 2014

Mobile 4G LTE is the first global standard for mobile broadband



Global LTE network launches

279

Launches

101

Countries

Large device ecosystem

1,563

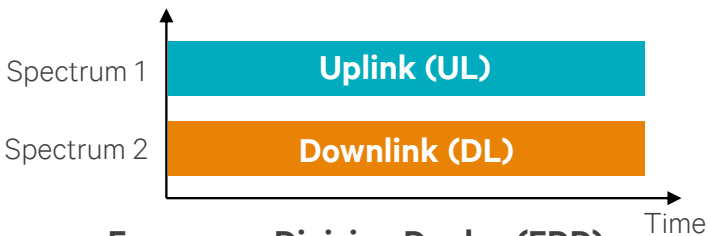
Devices

>100

Vendors

LTE FDD & LTE TDD

Two modes, common standard, same ecosystem



Frequency Division Duplex (FDD)

Paired spectrum enables better coverage

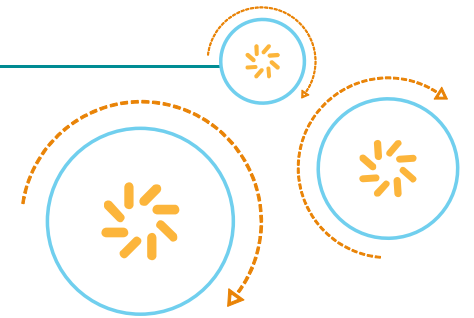


Time Division Duplex (TDD)

Unpaired spectrum enables asymmetrical DL/UL for more DL capacity



Mobile 3G and 4G technologies continue to evolve to deliver faster and better mobile broadband experiences



Mobile 3G and 4G LTE continue to evolve

Delivering a faster and better mobile broadband experiences

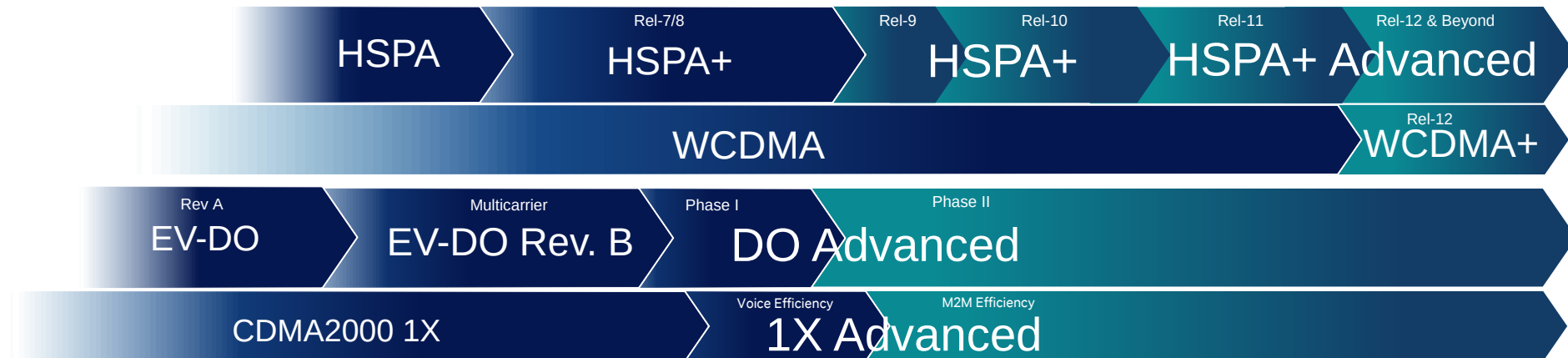
4G LTE has evolved to LTE Advanced

Providing more data capacity and expanding into new frontiers



3G networks have continued to evolve and improve—so much so some call it 4G

Providing a consistent broadband experience outside LTE coverage



Mobile 3G/4G technologies are evolving for more data capacity



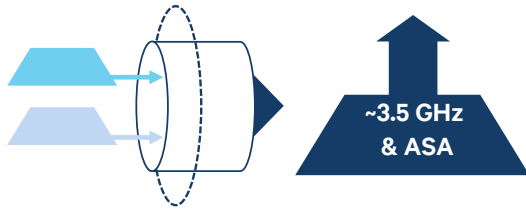
Shannon's Law

$$C \approx W \cdot n \cdot \log_2(1 + SNR)$$

Capacity **Spectrum** **Antennas** **Signal Quality**

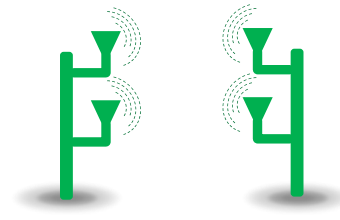


More Spectrum



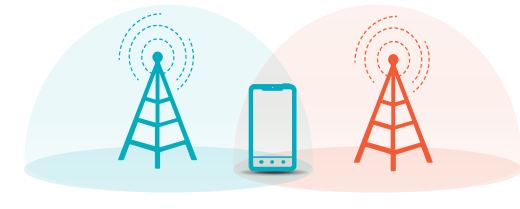
Making the best use of all spectrum types with more licensed spectrum as the top priority, e.g., ASA, ~3.5 GHz, unlicensed spectrum

More Antennas



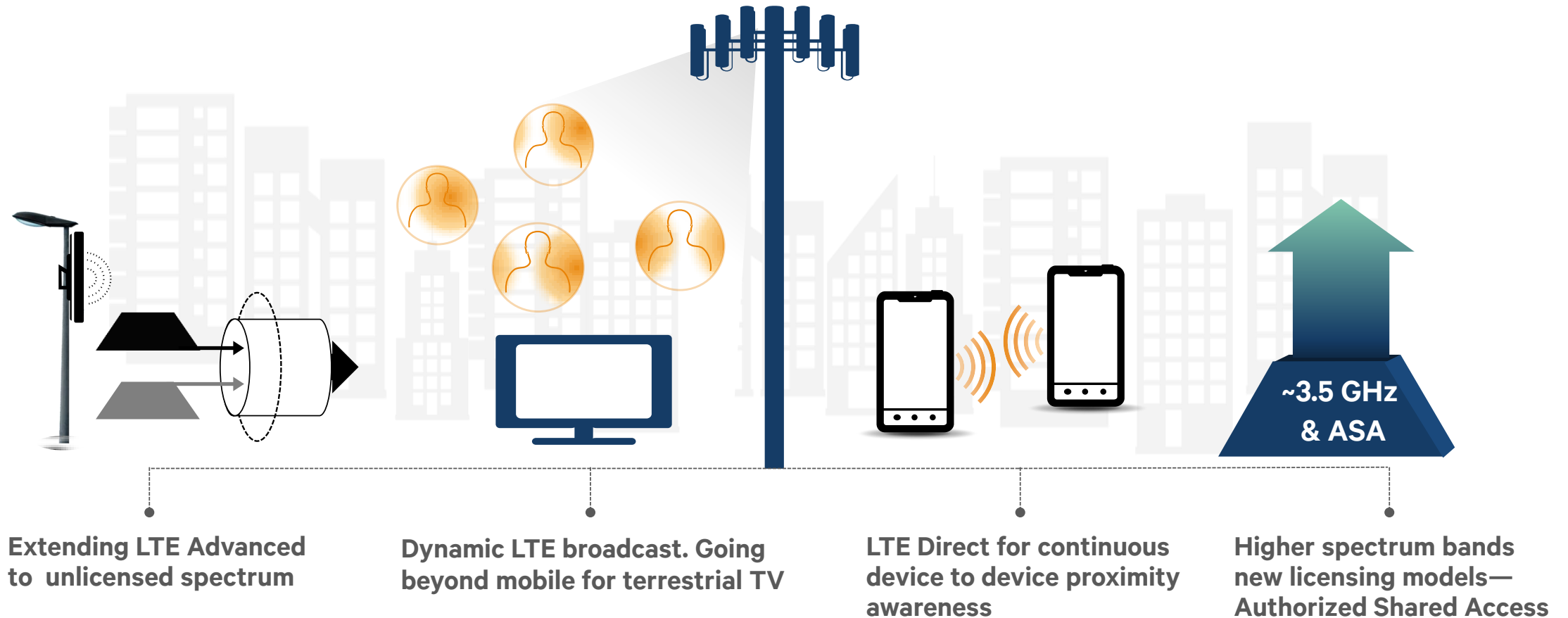
Advanced multiple antenna techniques to create spatially separated data paths, e.g., 4 way receive diversity, 4x4 MIMO

Interference Mitigation



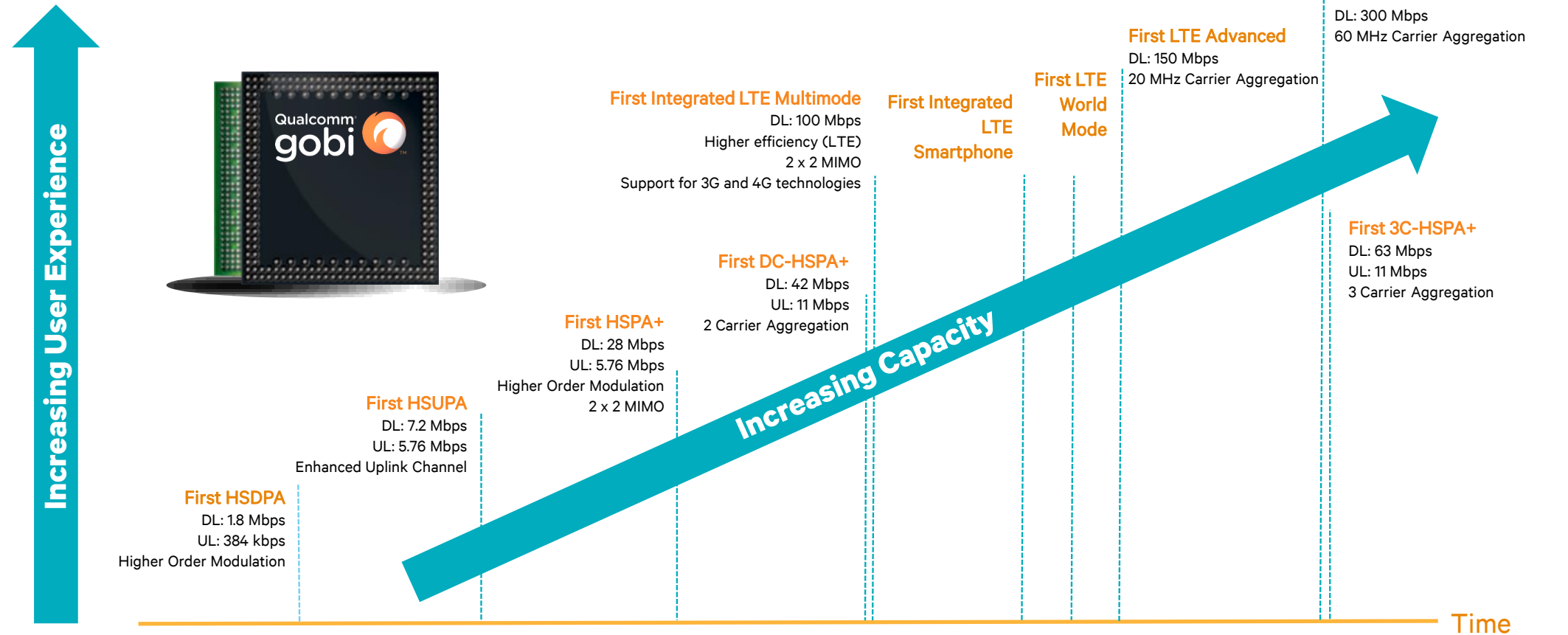
Advanced receivers and antenna techniques, e.g., LTE FeICIC/IC, HSPA+ advanced device receiver

LTE Advanced is evolving and expanding into new frontiers



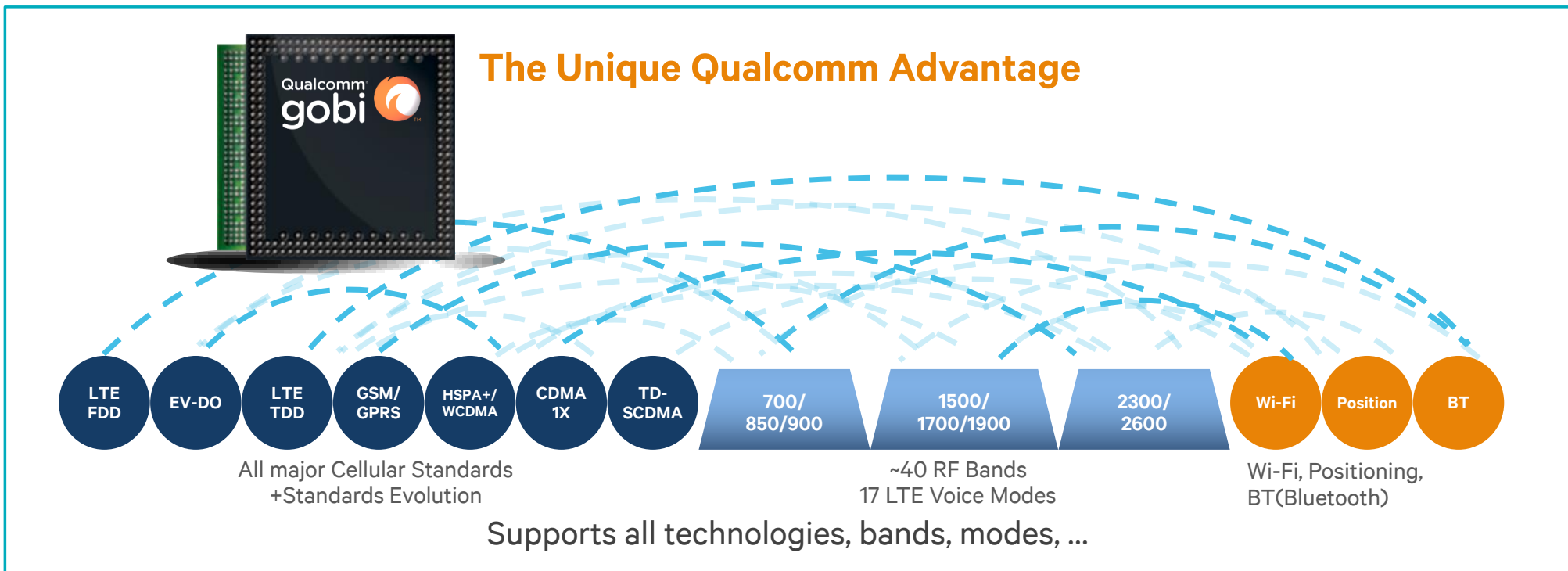
Qualcomm is the leader in Mobile 3G/4G technologies

Each modem generation enhances user experience and provides more capacity



Qualcomm is the leader in Mobile 3G/4G technologies

Hiding the complexity underneath the most seamless mobile connectivity



Evolving mobile technologies deliver great mobile experiences

1



1G established seamless mobile connectivity introducing mobile voice services

3



3G optimized mobile for data enabling mobile broadband services, and is evolving for faster and better connectivity

2



2G digital wireless technologies increased voice capacity delivering mobile to the masses

4



4G LTE delivers more capacity for faster and better mobile broadband experiences, and is also expanding in to new frontiers

5



Qualcomm has been at the forefront of this evolution, pushing wireless boundaries to enable the best mobile experiences

to learn more, go to: www.qualcomm.com/wireless

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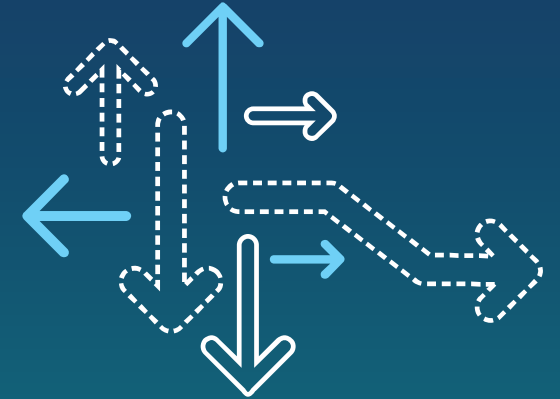
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