

June 2014

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# The Evolution of Mobile Technologies:

1G ⇔ 2G ⇔ 3G ⇔ 4G LTE

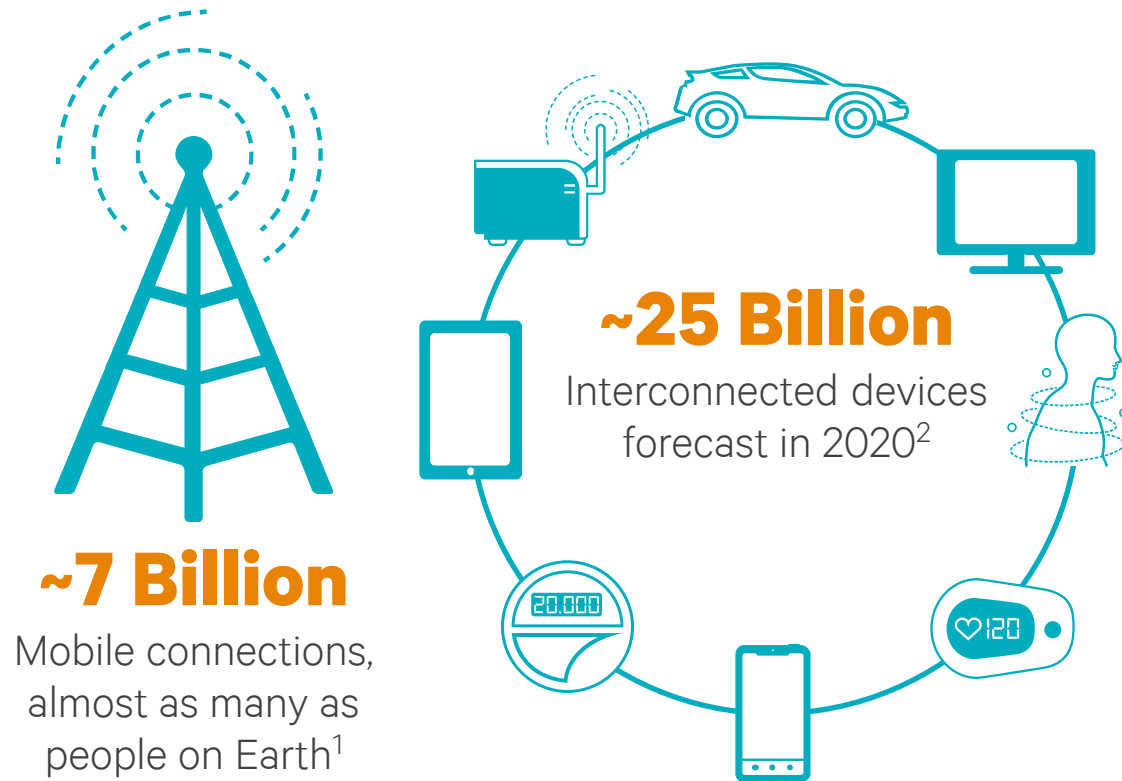
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QUALCOMM®

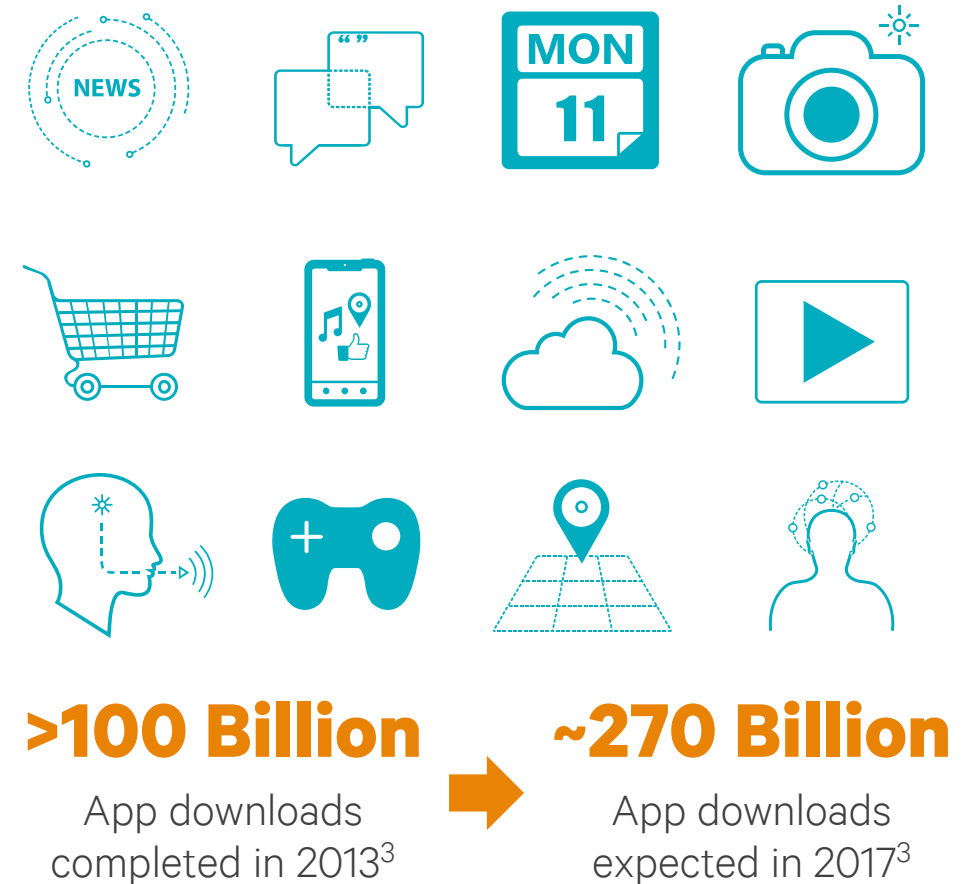


# The mobile experience is expanding everywhere

## Billions of Mobile Connections

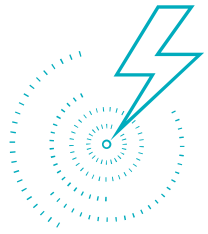


## Billions of Mobile Experiences



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

# Mobile is an amazing technical achievement



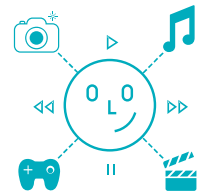
## Mind-blowing Performance

with processing power greater than the most advanced super computers of the early 1990s<sup>1</sup>



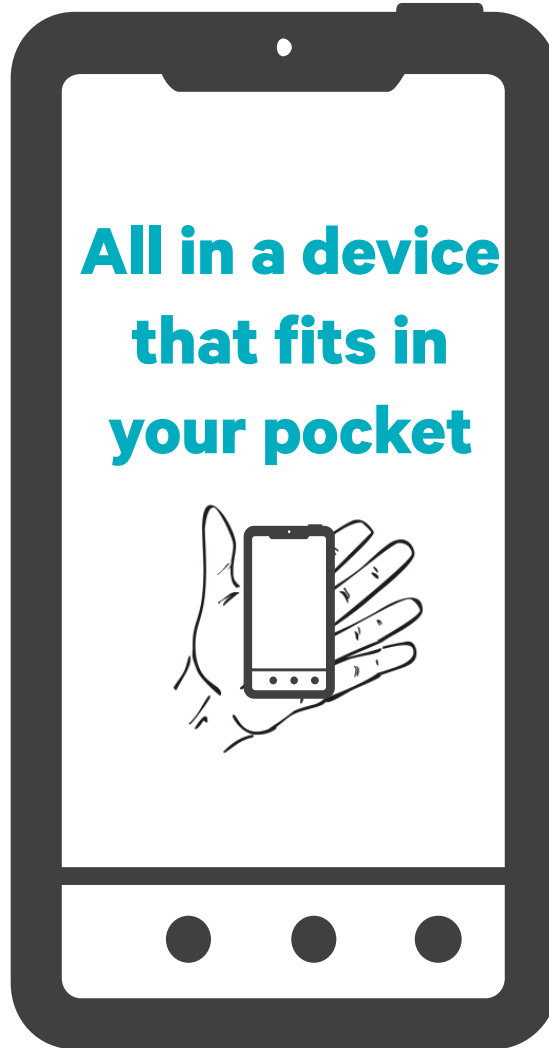
## Jaw-dropping Graphics

with capability to process several thousand megapixels per second<sup>2</sup>



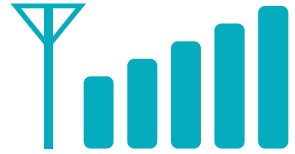
## High Quality Multimedia<sup>2</sup>

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 originated<sup>3</sup>



## Broadband Speeds

with blazing fast data rates capable of 300+ Mbps<sup>4</sup>



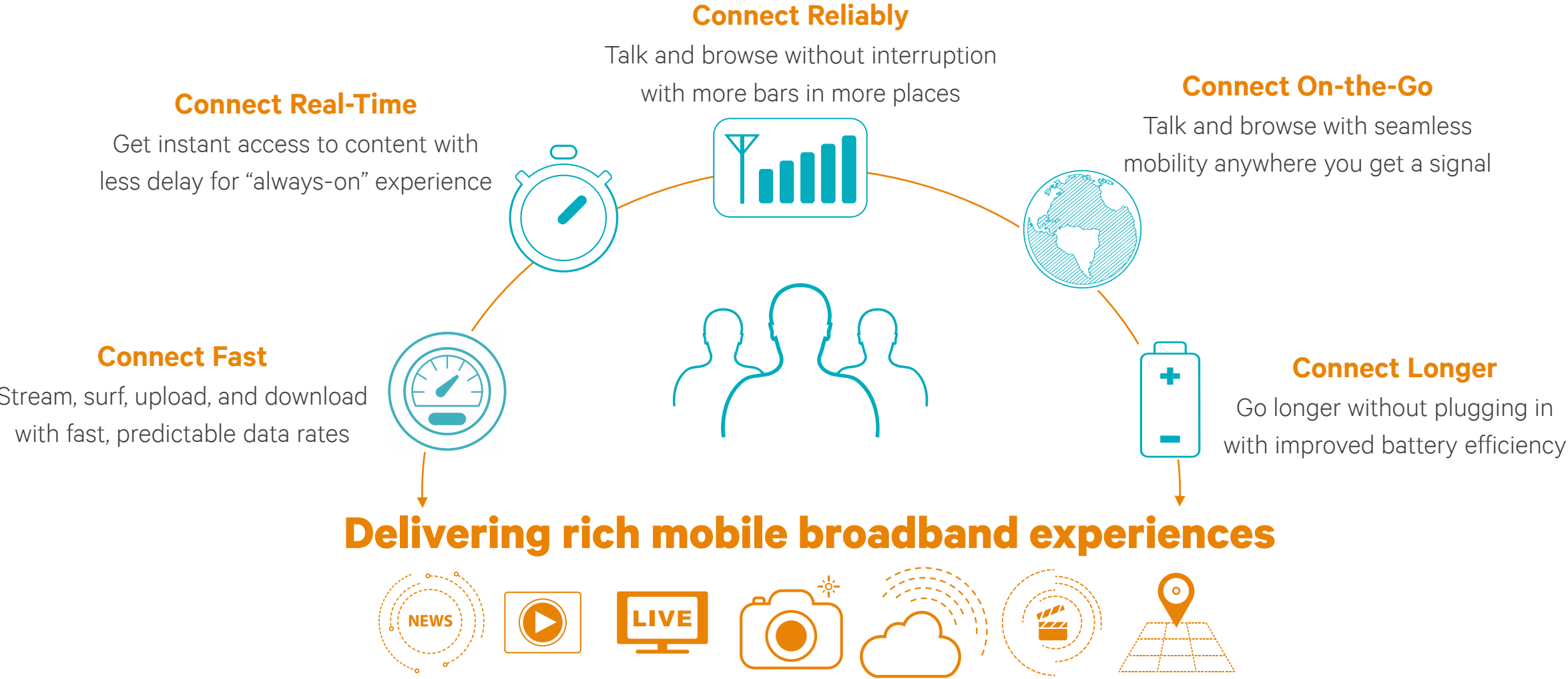
## Long Battery Life

with ability to power all these amazing experiences with less energy than it takes to power a light bulb for 15 minutes<sup>5</sup>



<sup>1</sup> Source: Charlie White, Sep. '13 & giffgaff.com, Sep'13; <sup>2</sup> Based on latest Qualcomm® Snapdragon™ 800 series processors; <sup>3</sup> Based on >140 dB path loss typical in mobile; <sup>4</sup> Based on peak data rates for LTE Advanced; <sup>5</sup> 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



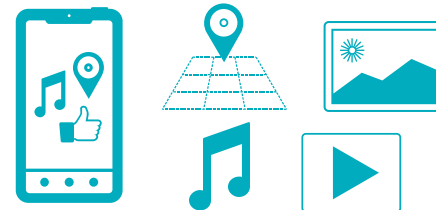
<0.5 Mbps<sup>1</sup>

Digital Voice + Simple Data



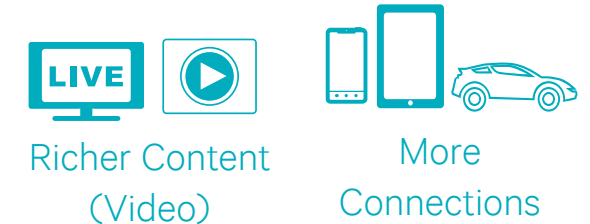
63+ Mbps<sup>2</sup>

Mobile Broadband



300+ Mbps<sup>3</sup>

Faster and Better



<sup>1</sup> Peak data rate for GSM/GPRS, latest Evolved EDGE has peak DL data rates capable of up to 1.2 Mbps; <sup>2</sup> Peak data rate for HSPA+ DL 3-carrier CA; HSPA+ specification includes additional potential CA + use of multiple antennas, but no announcements to date; <sup>3</sup> 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

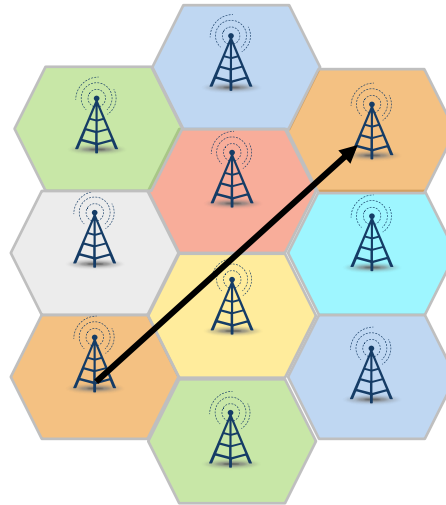


Operator-deployed **base stations** provide access for subscribers

2

## Frequency Reuse

Reusing frequencies without interference through geographical separation

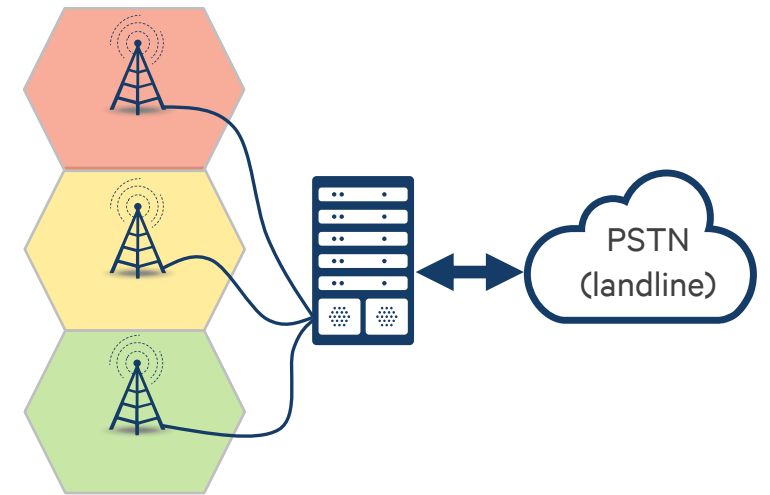


Neighboring **cells** operate on different frequencies to avoid interference

3

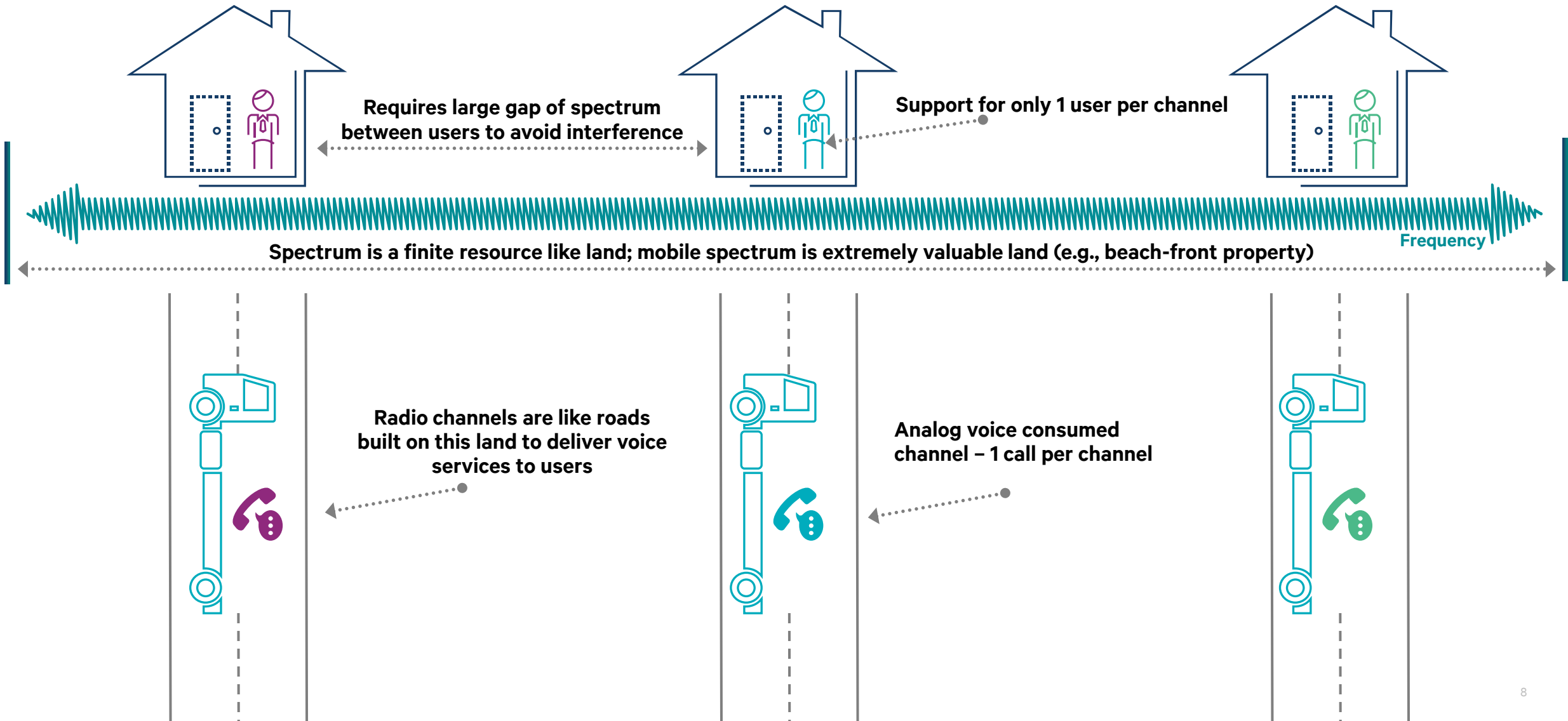
## Mobile Network

Coordinated network for seamless access and seamless mobility



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

# Mobile 1G was amazing, but limited

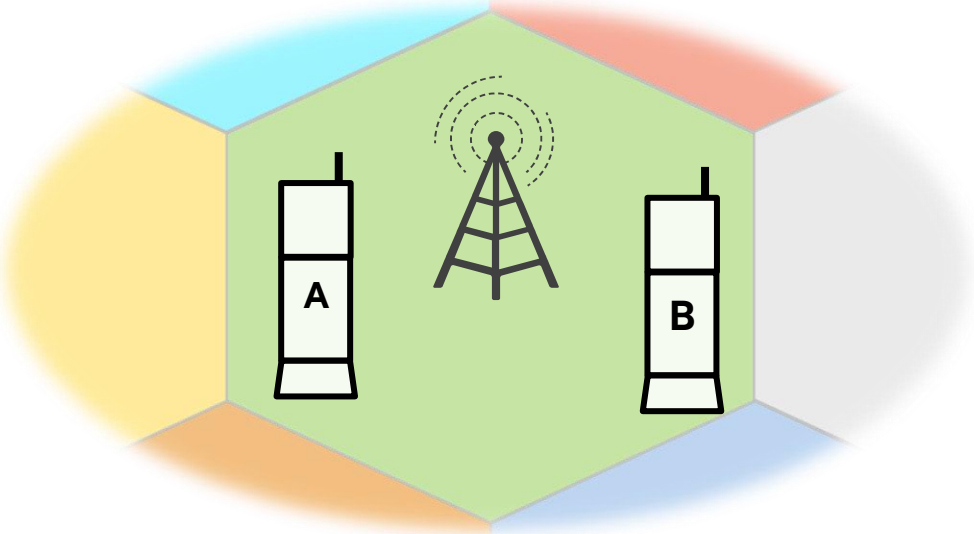




# 1G analog voice was amazing, but limited

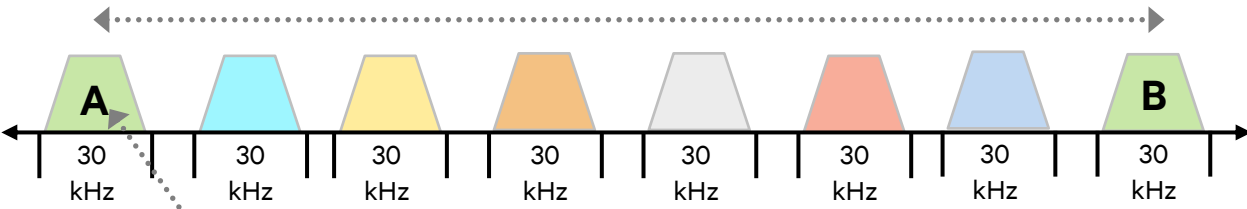
## Limited Capacity

Analog transmissions are inefficient at using limited spectrum



## Frequency Division Multiple Access (FDMA)\*

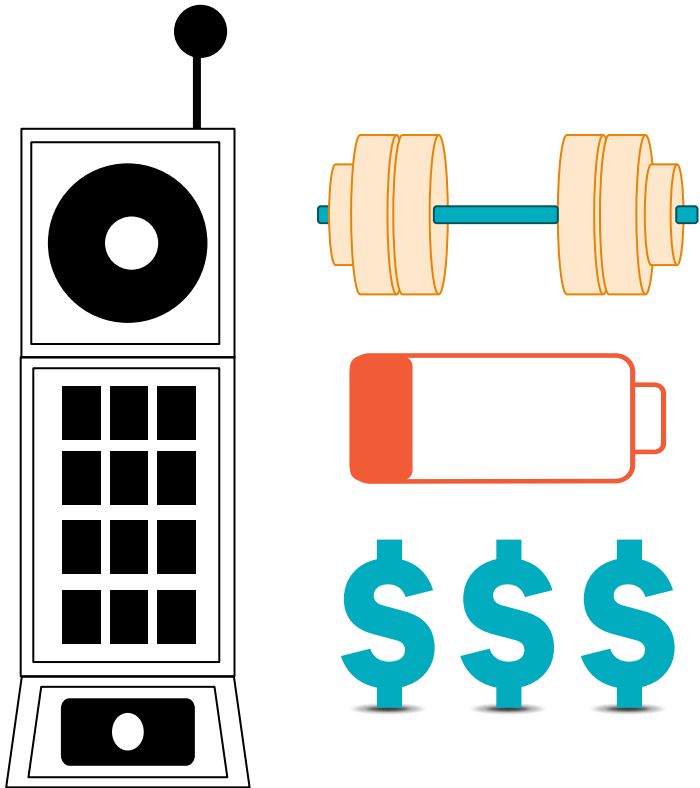
Large frequency gap required between users to avoid interference



Support for only 1 user (analog phone call) per channel

## Limited Scalability

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



\* Example shown based on AMPS 1G technology

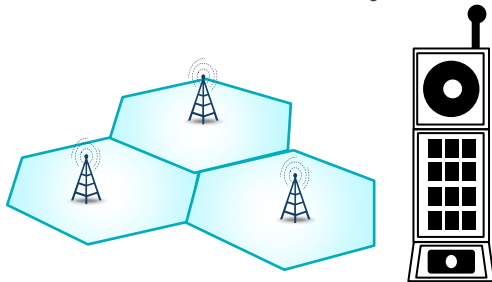
# Mobile 2G digital technologies increased voice capacity

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

## Mobile 1G

AMPS, NMT, TACS

Foundation of Mobile  
Seamless Mobility

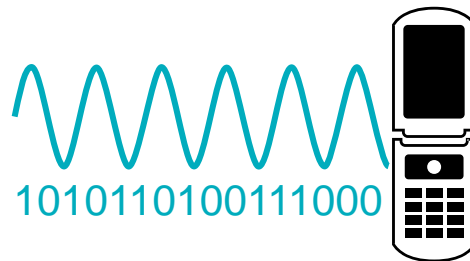


1980s

## Mobile 2G

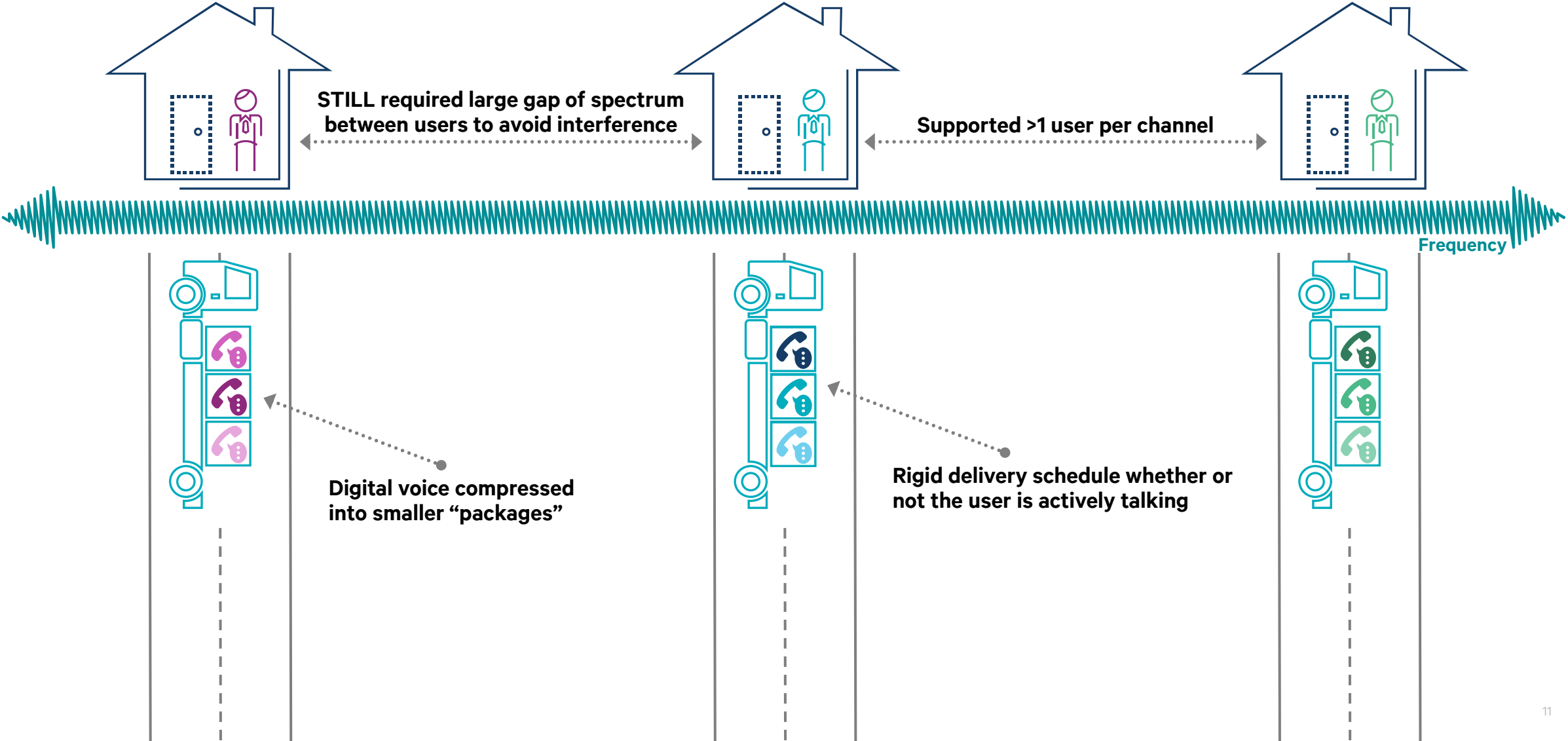
D-AMPS, GSM/GPRS,  
cdmaOne

Mobile for the Masses  
More Voice Capacity



1990s

# Early Mobile 2G technologies enabled more users per channel

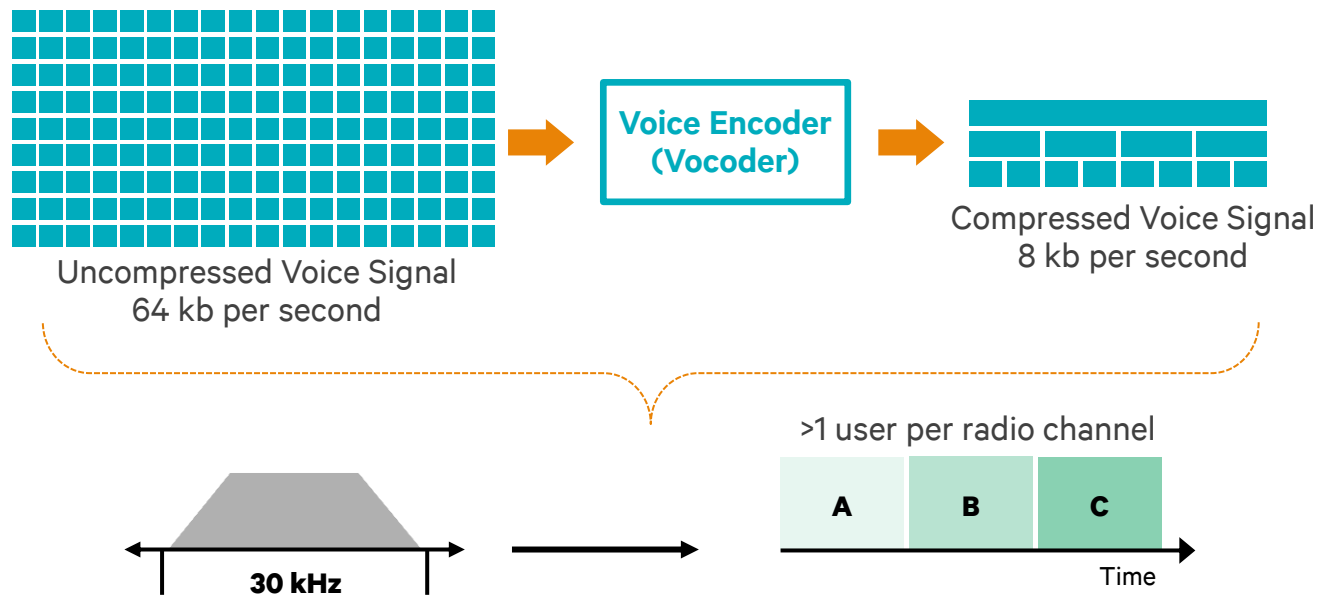


# Mobile 2G digital wireless technologies enabled more users

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

## More Voice Capacity

Digital transmissions enable compressed voice and multiplexing multiple users per channel

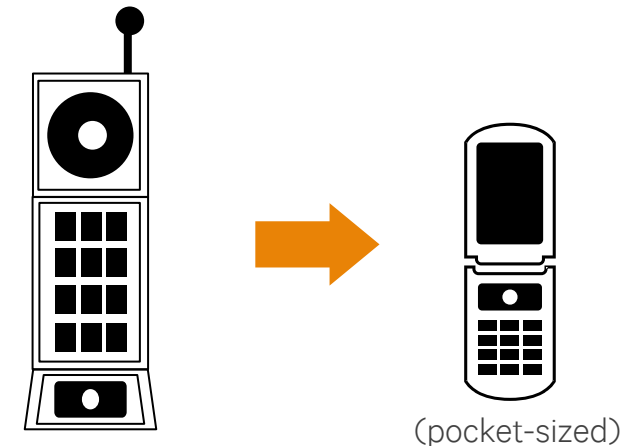


## Time Division Multiple Access (TDMA)

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

## Scalable Technology

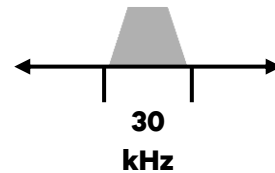
Digital components cost/weight far less plus deliver more secure signal



# Different Mobile 2G TDMA techniques were standardized

## Mobile 1G (Analog)

AMPS, NMT, TACS



Only one user per radio channel



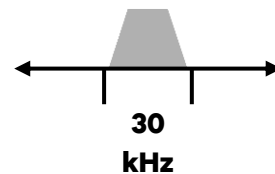
## Mobile 2G (Digital)

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)

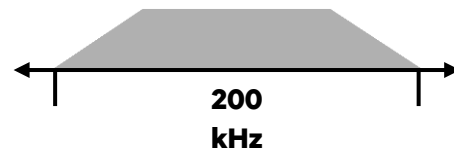
GSM

Standardized by ETSI in 1990 (phase 1)

Initiated in Europe

Still widely used today (>4B connections WW<sup>1</sup>)

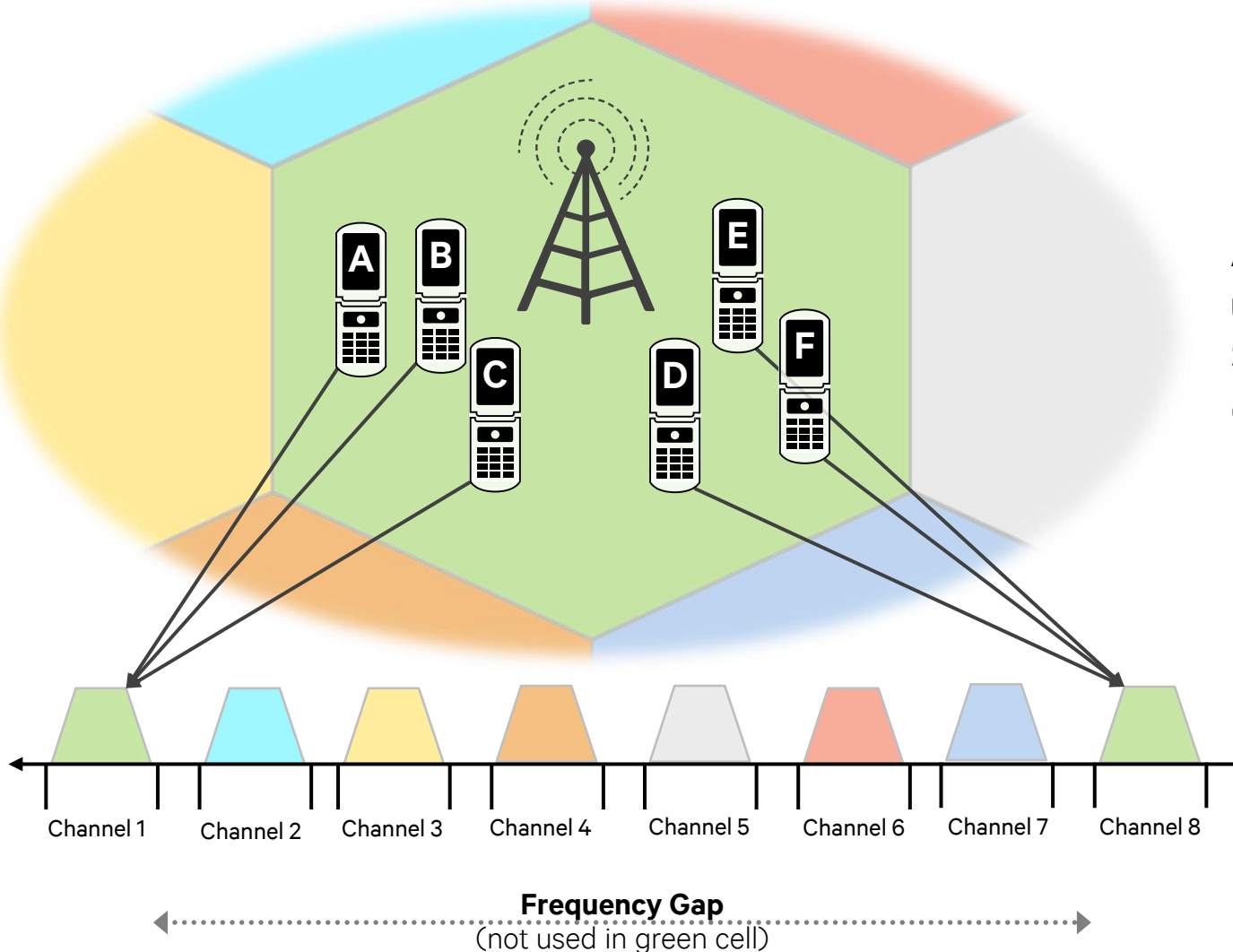
Simple data services with GPRS



Eight users per radio channel



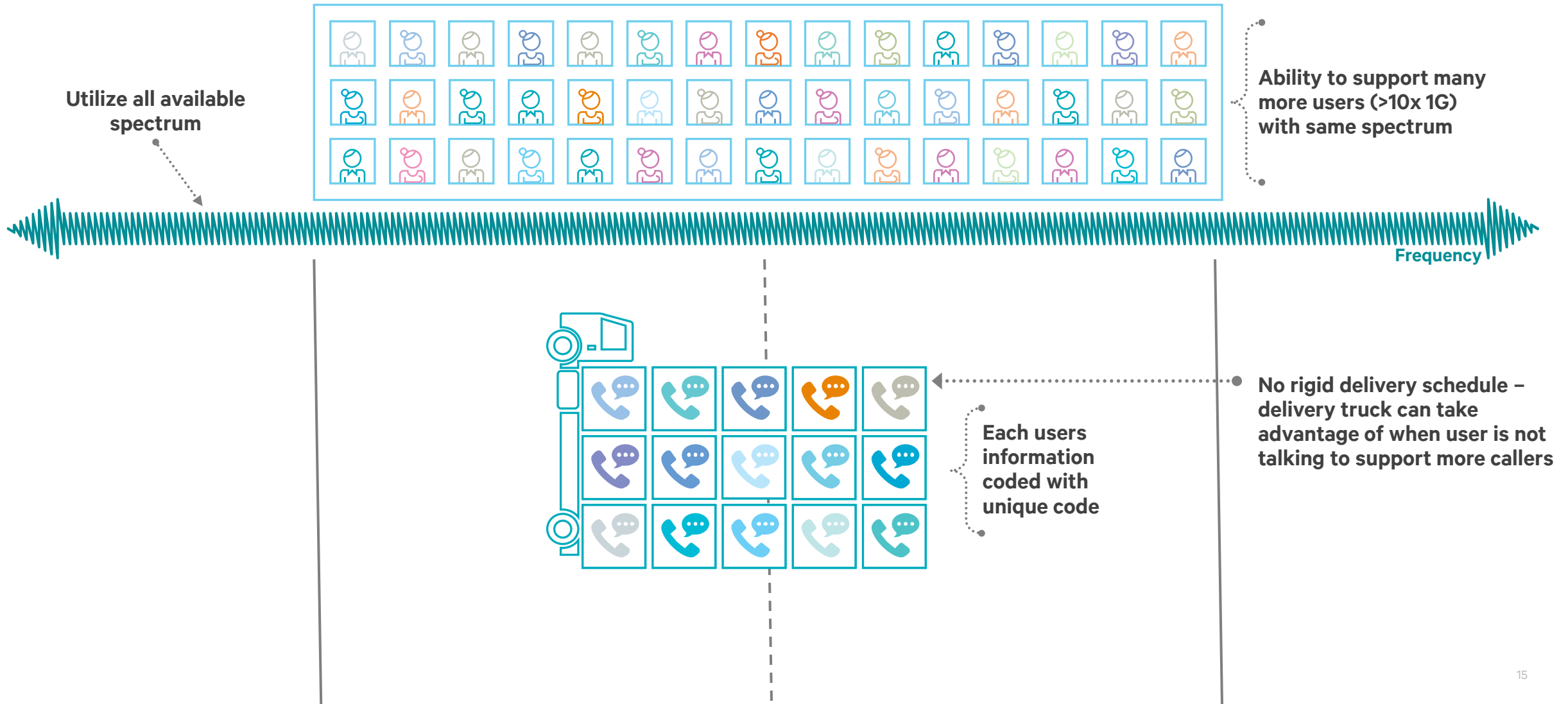
# TDMA still required large frequency gaps to reduce interference



**Also required potentially unreliable “hard” handoffs**

Switch channels between adjacent cells – potential for dropped calls

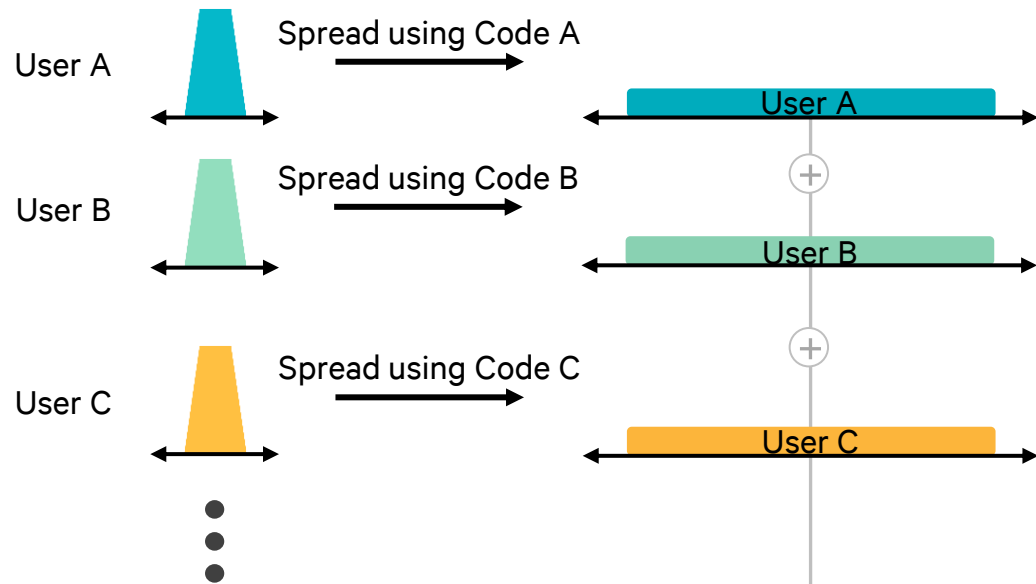
# CDMA utilizes all the available spectrum to support more users



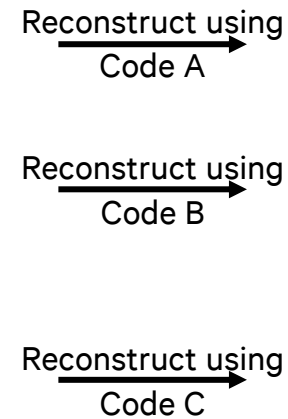
# Qualcomm solved the seemingly impossible wireless challenge

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

## At the Transmitter



## At the Receiver



Other signals look like noise

## Code Division Multiple Access (CDMA)

Multiple users can talk at same time using different languages (“codes”)



1.25 MHz



# Qualcomm solved complex challenges to commercialize CDMA

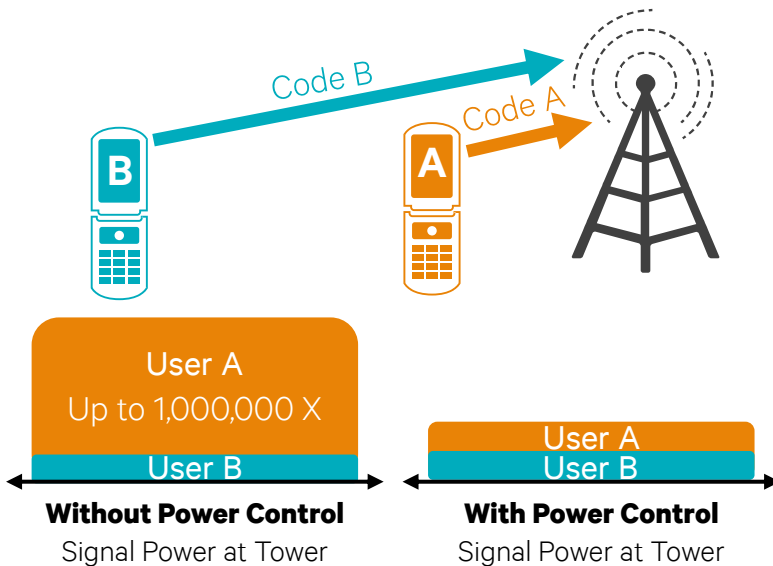
1

## 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



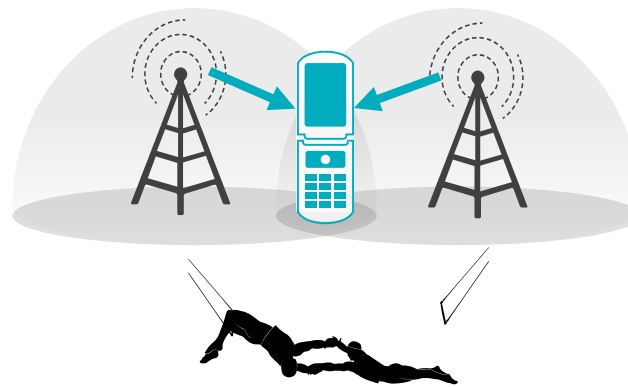
2

## 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

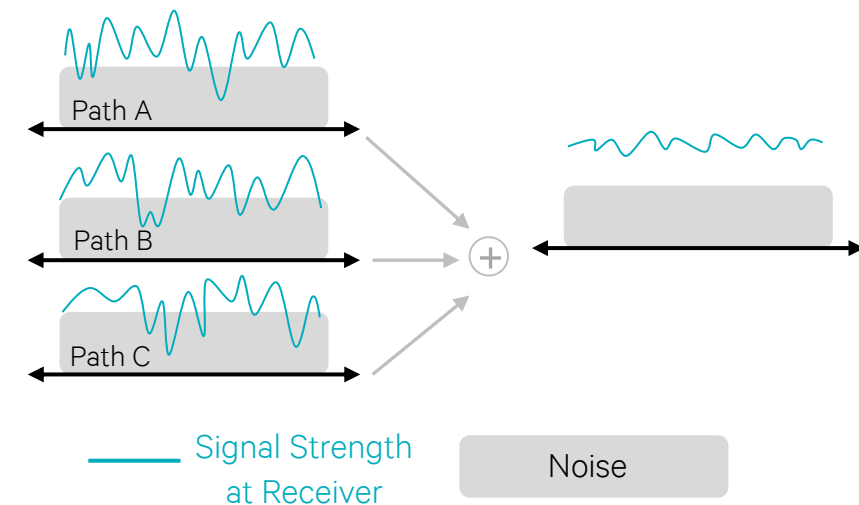
3

## 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

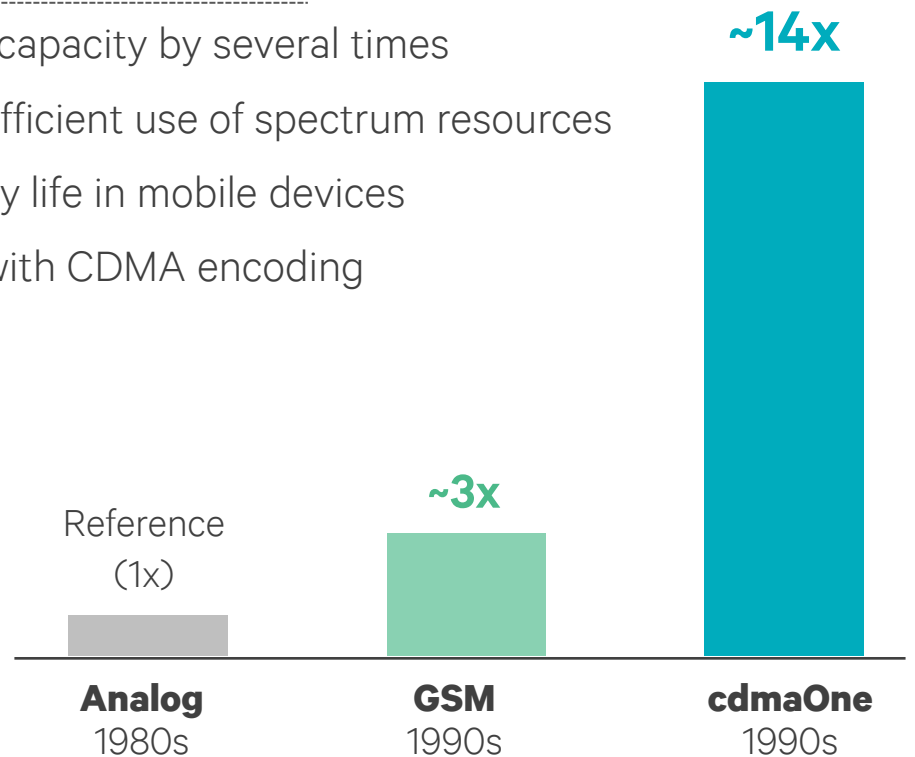


# CDMA delivered unprecedented voice capacity and much more

## 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



**Potential Voice Capacity Improvements<sup>1</sup>**

### CDMA Timeline<sup>2</sup>

**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**

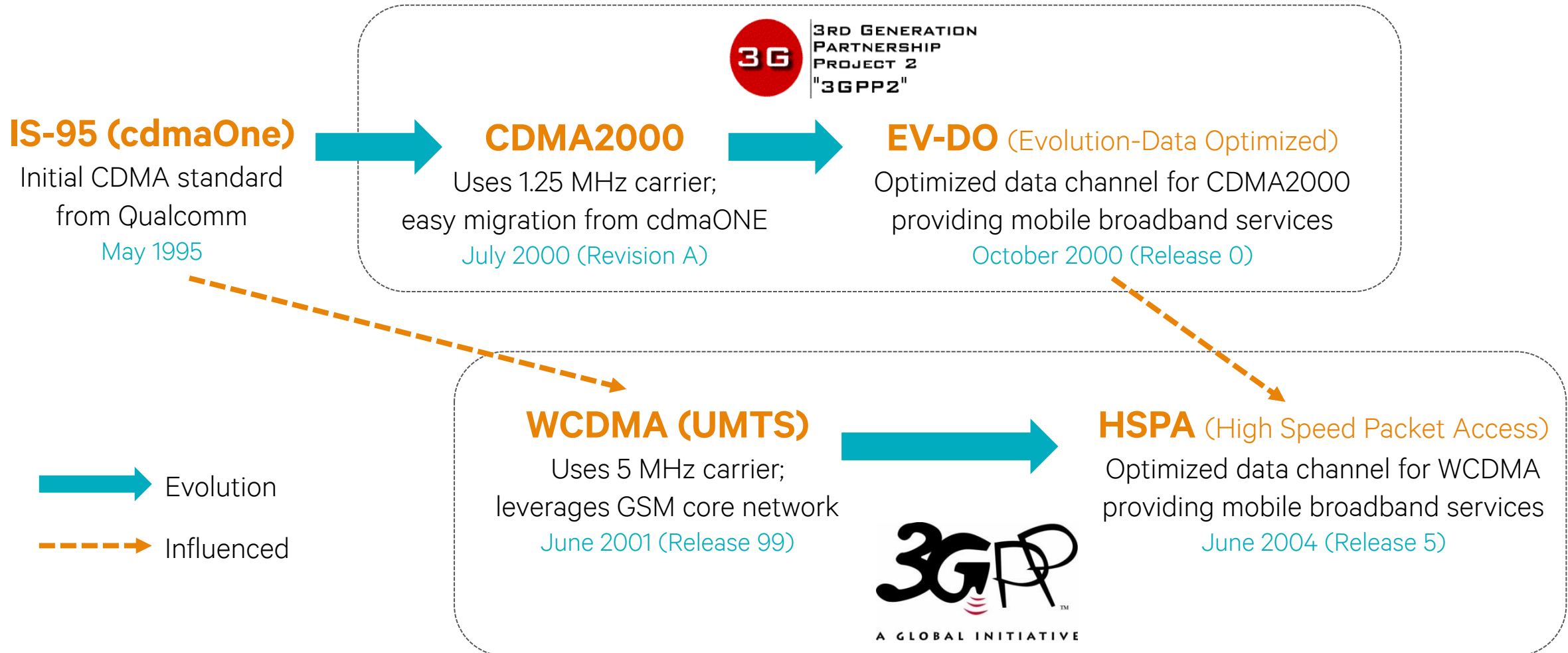
cdmaOne subscribers pass 50 million worldwide (>80 operators in >30 countries)

**CDMA is the foundation for Mobile 3G technologies**

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

# CDMA established the foundation for 3G technologies

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



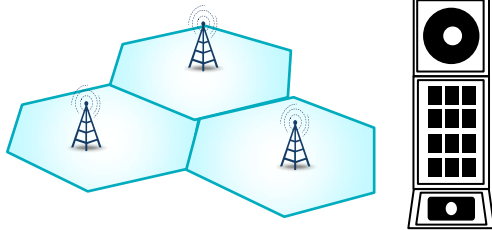
# Mobile 3G evolved mobile for data

Introducing high-speed internet access for the first time

## Mobile 1G

AMPS, NMT, TACS

Foundation of Mobile  
Seamless Mobility

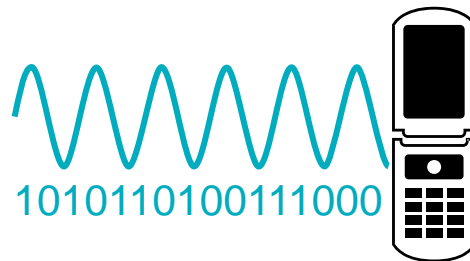


1980s

## Mobile 2G

D-AMPS, GSM/GPRS,  
cdmaOne

Mobile for the Masses  
More Voice Capacity



1990s

## Mobile 3G

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

Mobile Broadband  
Data Optimized



2000s

# Mobile voice was amazing, but consumers wanted more

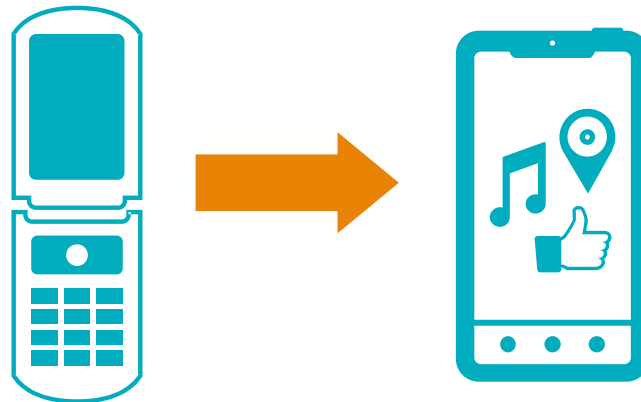
A new, insatiable demand for internet access and data services emerges

## Broadband Internet



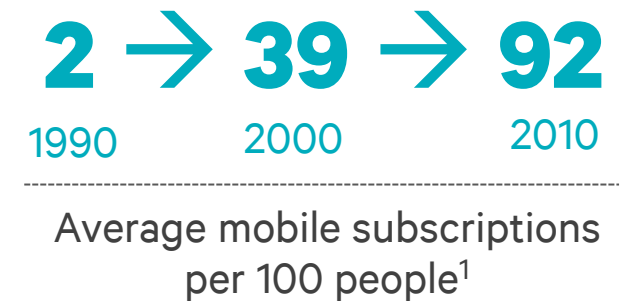
Consumers introduced to broadband internet access in the home/office

## 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

<sup>1</sup> Source: Worldbank.org for United States

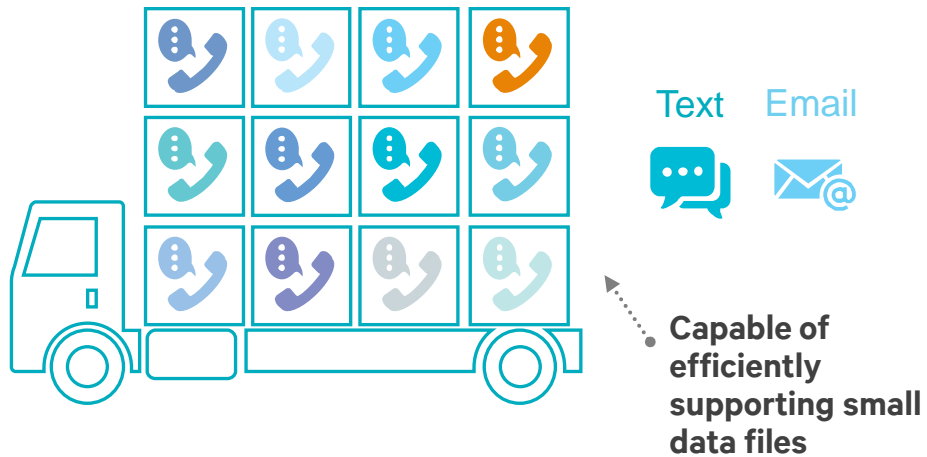
# EV-DO optimized 3G for data enabling mobile broadband

## Data Enabled

Simple Data Services

### Mobile 2G

<0.5 Mbps<sup>1</sup>

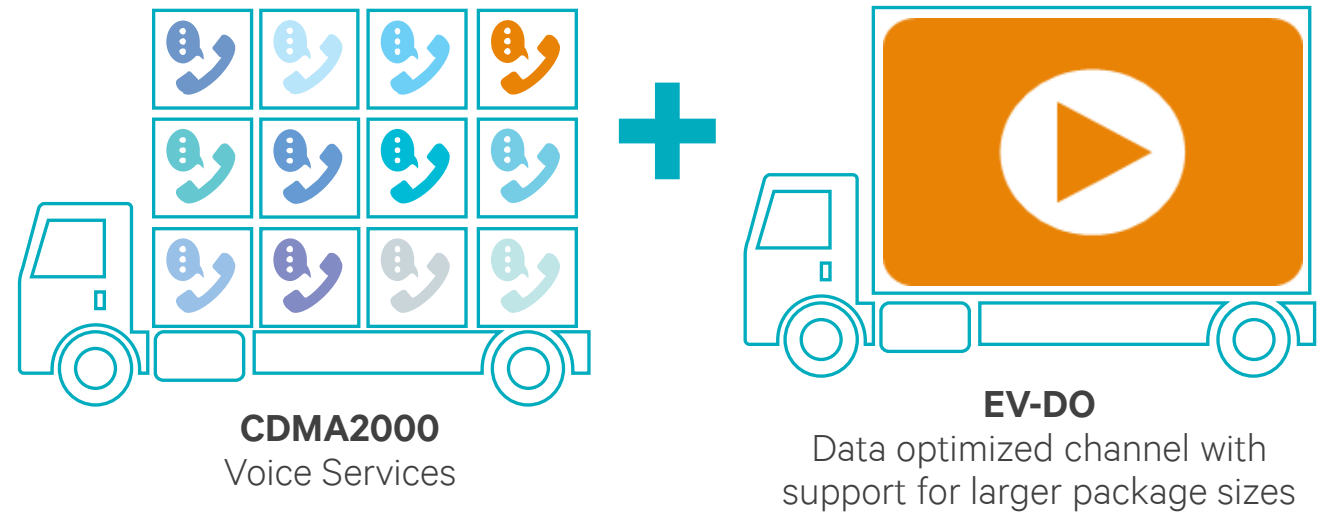


## Data Optimized

Mobile Broadband

### CDMA2000/EV-DO

14.7 Mbps<sup>2</sup>



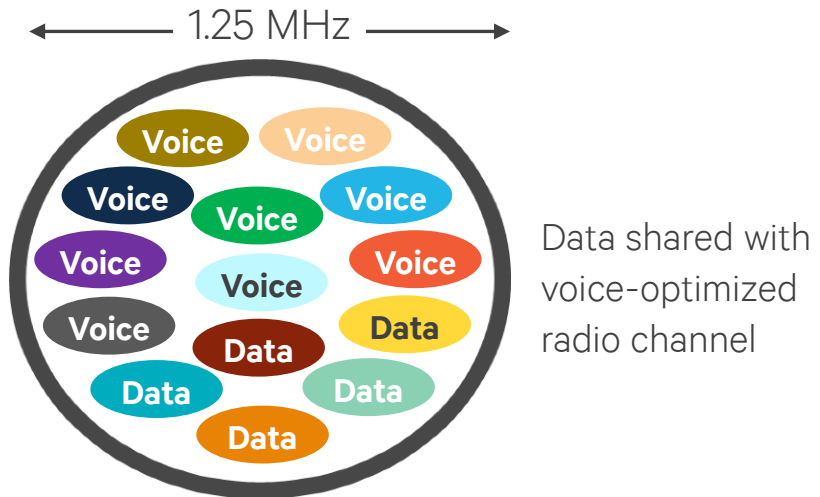
<sup>1</sup> Based on peak data rate – GSM/GPRS

<sup>2</sup> Based on peak data rate for downlink EV-DO Rev. B

# Qualcomm pioneered EV-DO introducing mobile broadband

## Mobile 2G

Data Enabled



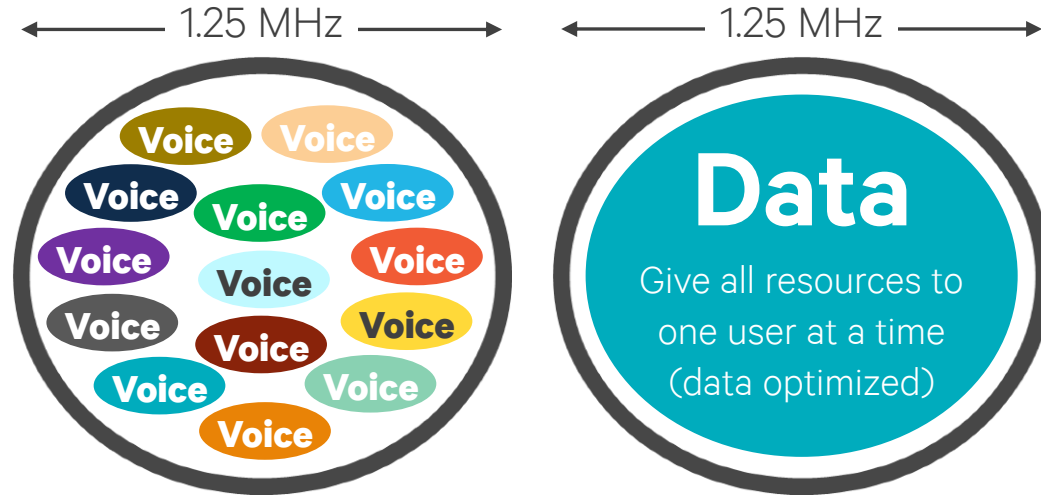
Data shared with voice-optimized radio channel



**Simple Data Services**

## CDMA2000/EV-DO

Data Optimized



Introduction of a data-only, data-optimized channel



**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

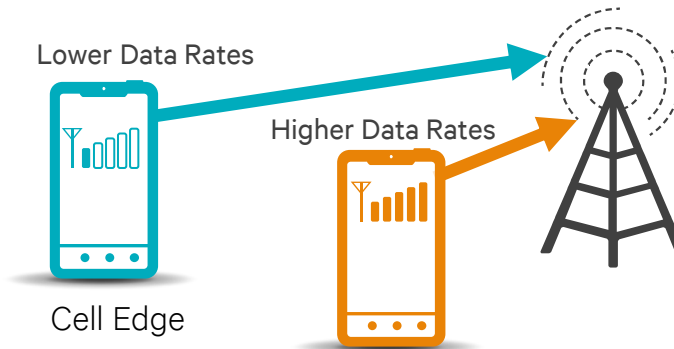


2

## Adaptive Modulation

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

Increases peak data rates

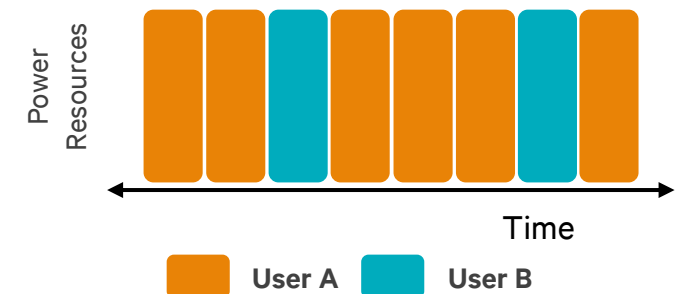


3

## Opportunistic Scheduling

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

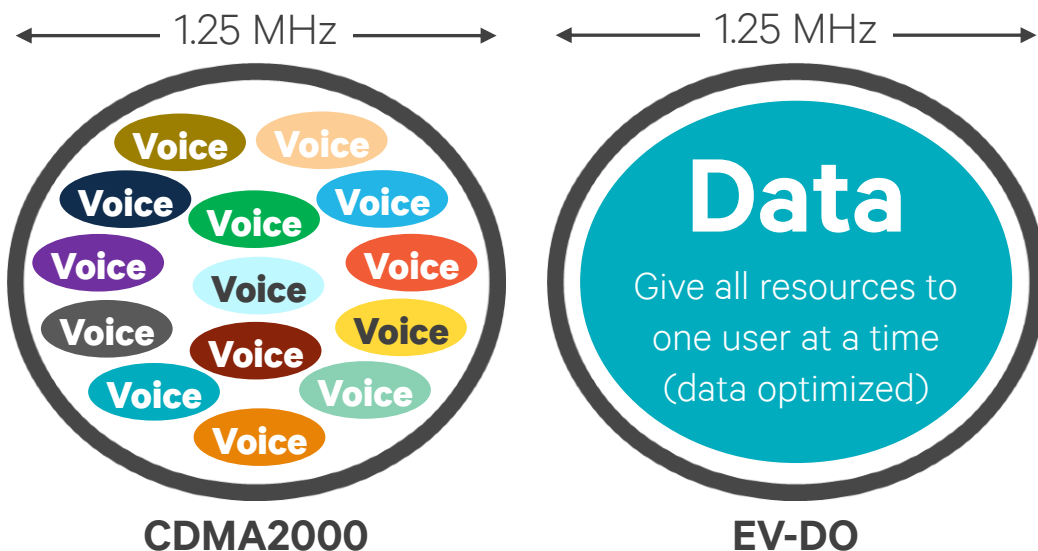
Increases overall capacity



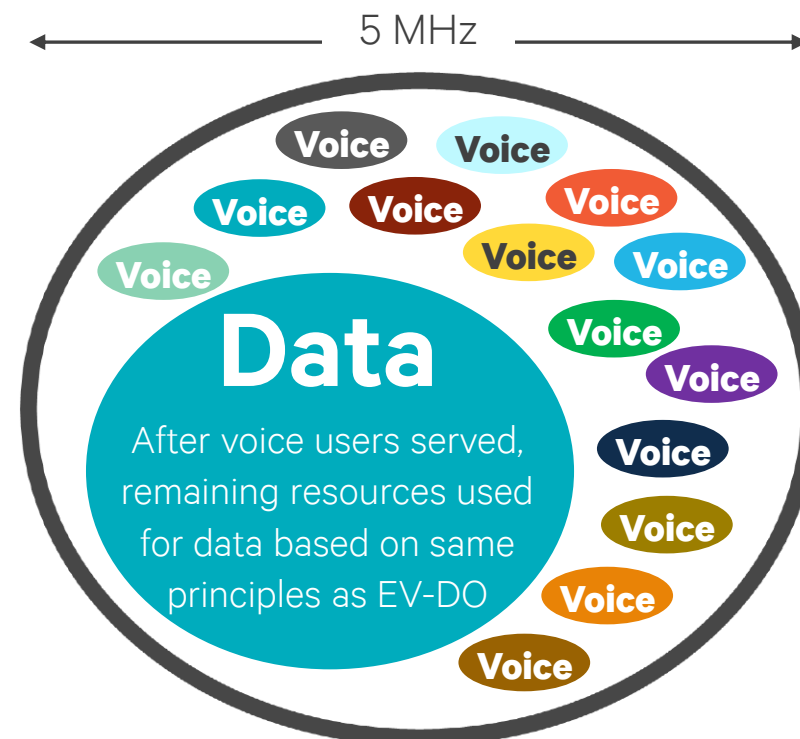


# CDMA2000/EV-DO blazed the trail for WCDMA/HSPA

## CDMA2000/EV-DO



## WCDMA/HSPA



3RD GENERATION  
PARTNERSHIP  
PROJECT 2  
"3GPP2"

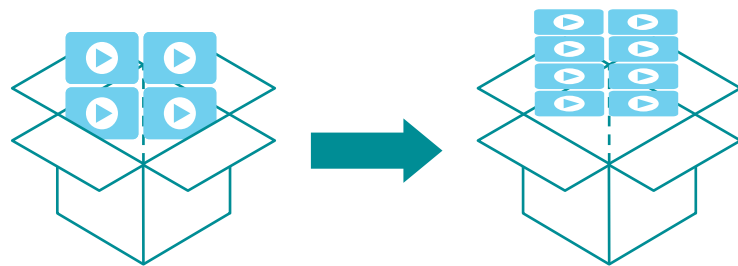
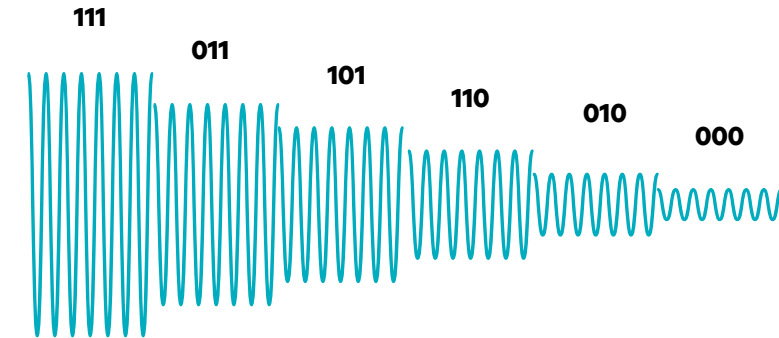


# Mobile 3G evolved to HSPA+ and EV-DO Rev. B

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

## Higher Order Modulation (HOM)

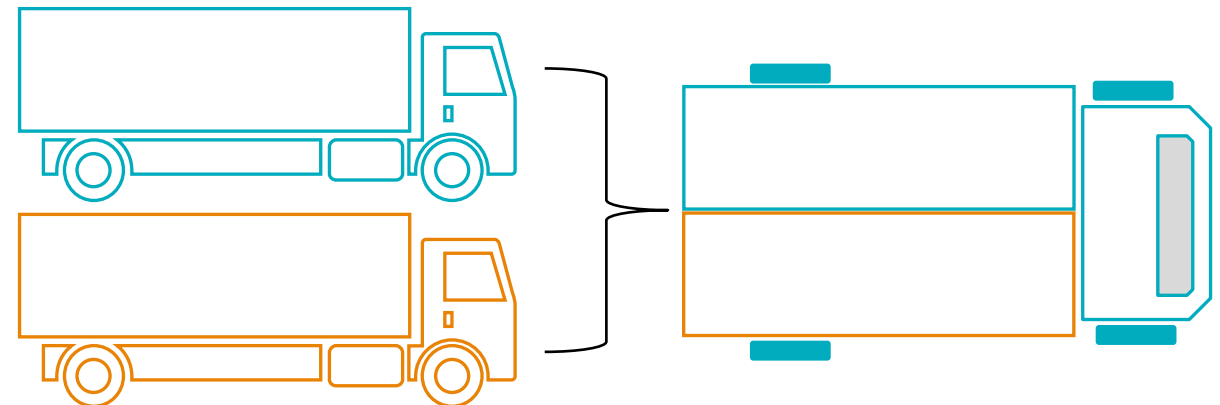
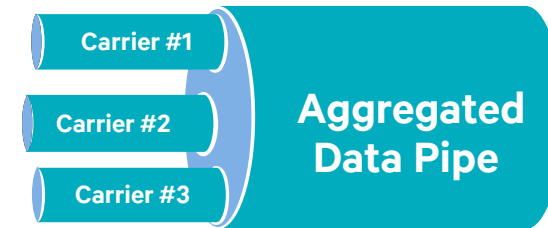
Introduces 64-QAM enabling 50% more bits per second per Hz (bps/Hz)



Enabling packing 50% more data into packages

## Carrier Aggregation

Aggregating spectrum enabling increased user and peak data rates

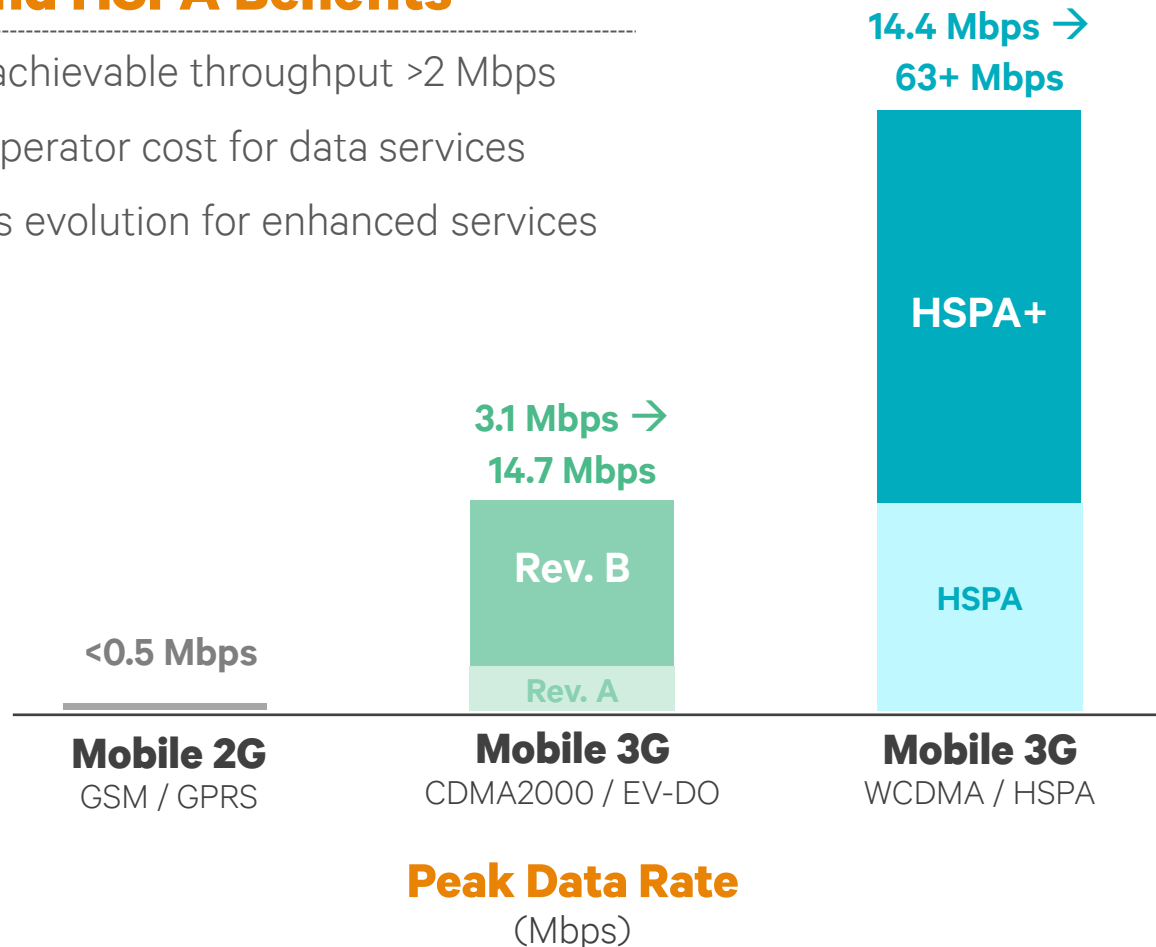


Aggregate channels for higher data rates

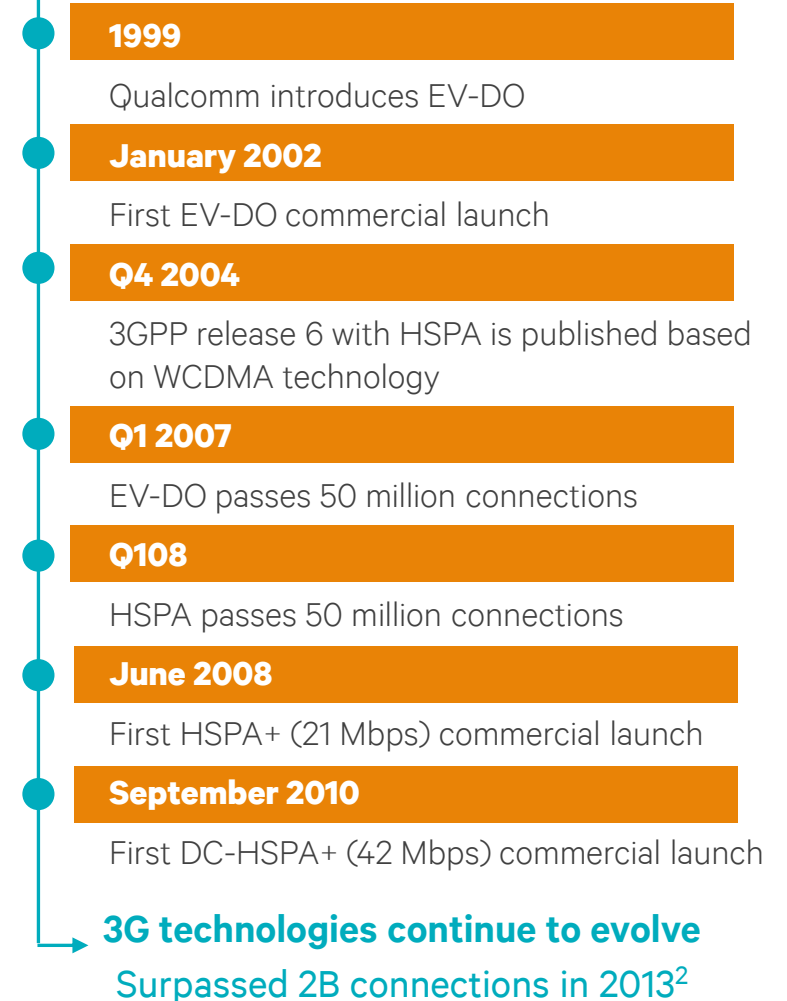
# 3G technologies optimized mobile for data

## EV-DO and HSPA Benefits

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



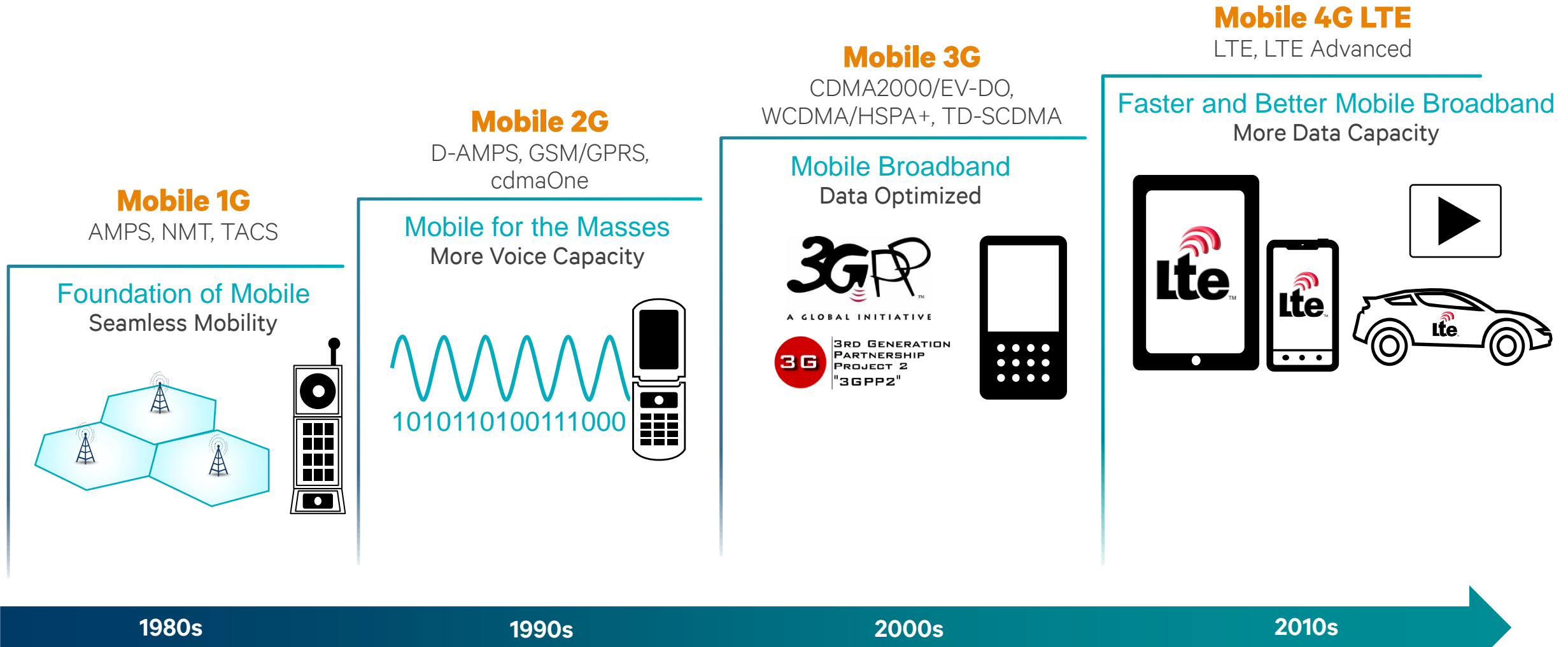
## Mobile Broadband Timeline<sup>1</sup>



<sup>1</sup> Source: CDG ([www.cdg.org](http://www.cdg.org)) and 3GPP ([www.3gpp.org](http://www.3gpp.org)); <sup>2</sup> 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

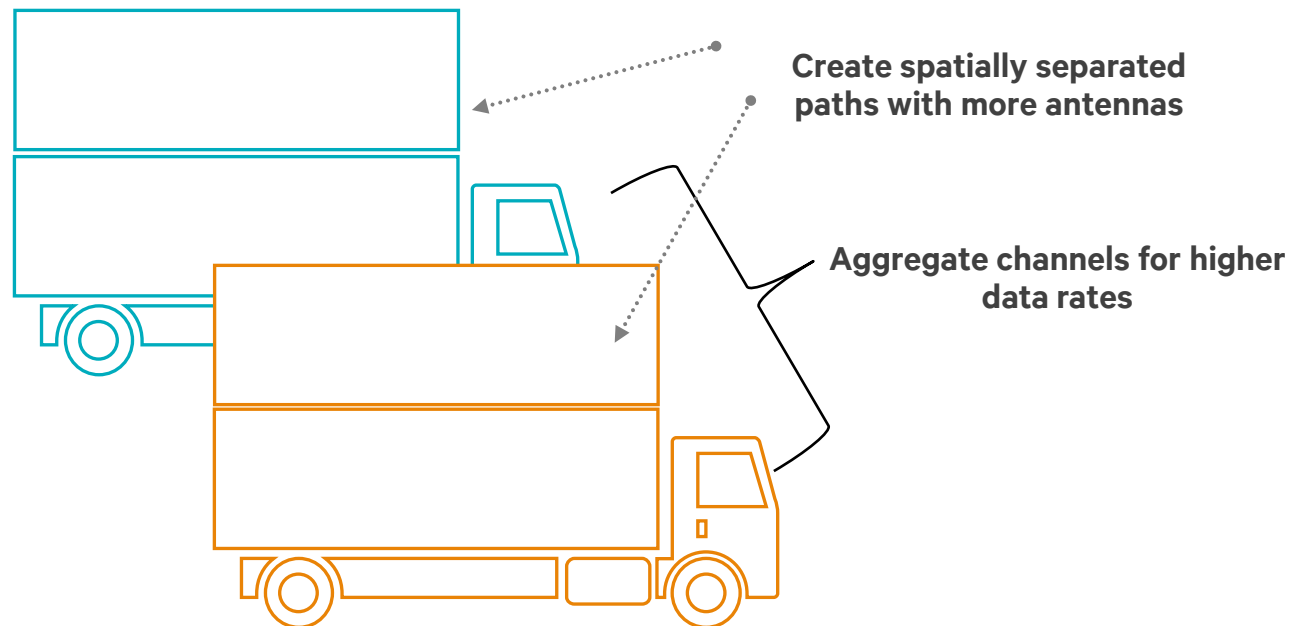
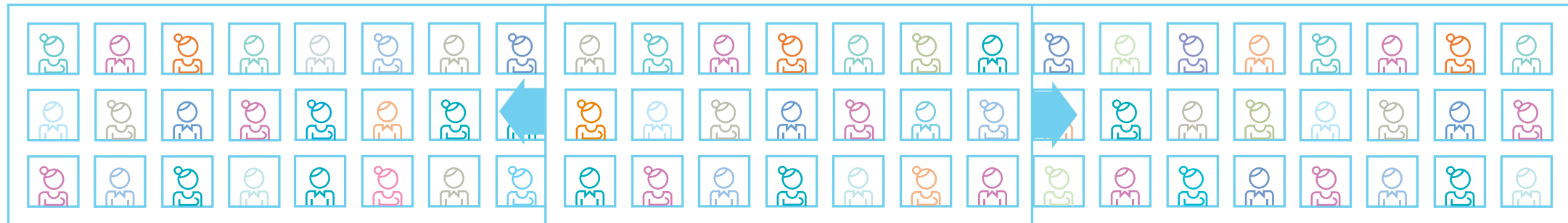
Enabling a consistent broadband experience outside 4G LTE coverage  
Delivering ubiquitous voice services and global roaming

### Multimode

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

# Mobile 4G LTE delivers more data capacity

**Flexible support for wider channels  
supporting more users**



# Mobile 4G LTE delivers more data capacity

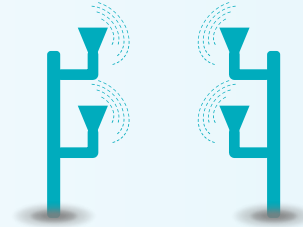
Download, browse, stream, and game faster than ever with faster and better connectivity

## 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

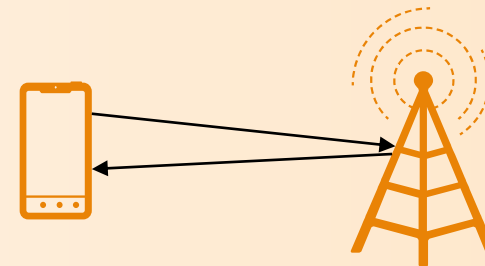
Aggregate up to 100 MHz for higher data rates – 2 carrier (2C) commercial; 3C announced<sup>1</sup>

## 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

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



## Global LTE network launches

**279**

Launches

**101**

Countries

## Large device ecosystem

**1,563**

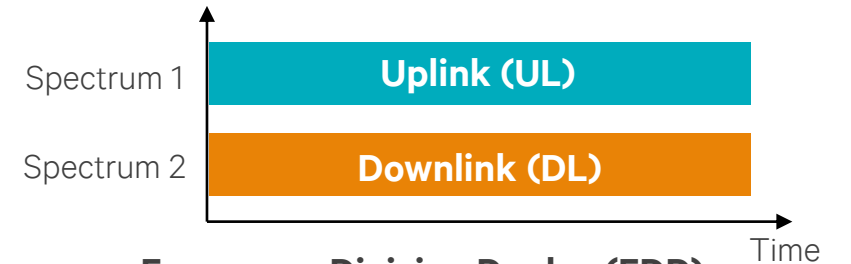
Devices

**>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)

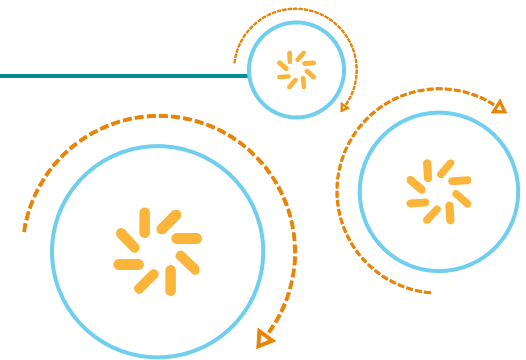
Unpaired spectrum enables asymmetrical DL/UL for more DL capacity





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

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# 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

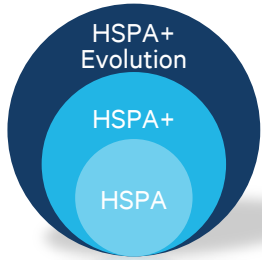


## 3G networks have continued to evolve and improve—so much so some call it 4G

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

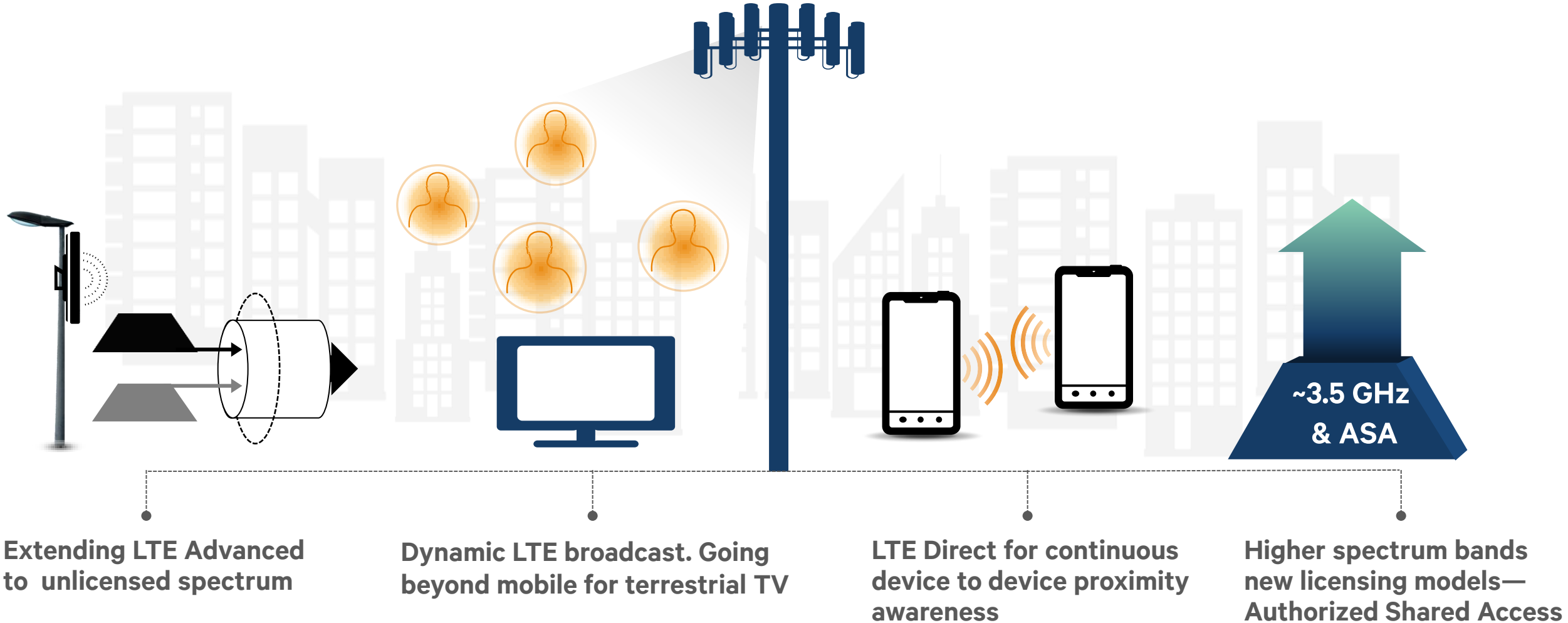
**More Antennas**

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

**Interference Mitigation**

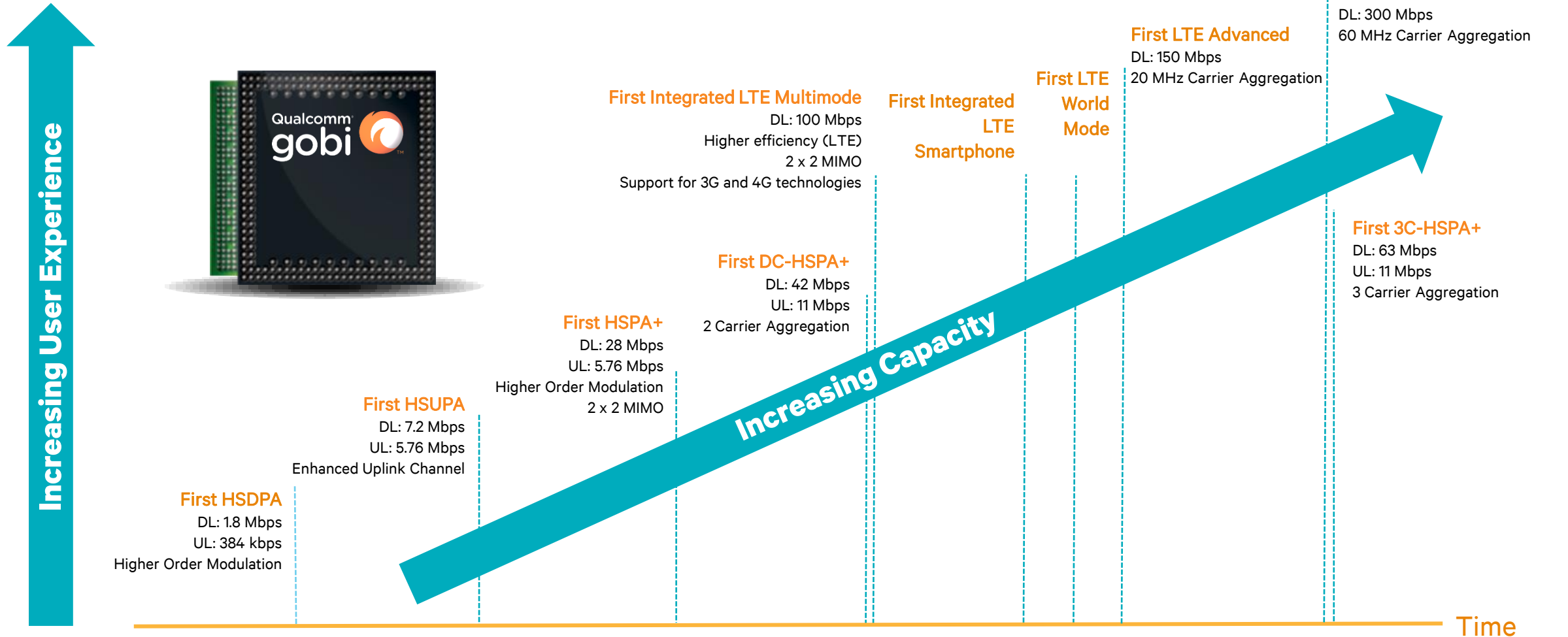
Advanced receivers and antenna techniques, e.g., LTE FeICIC/IC, HSPA+ advanced device receiver

# LTE Advanced is evolving and expanding into new frontiers



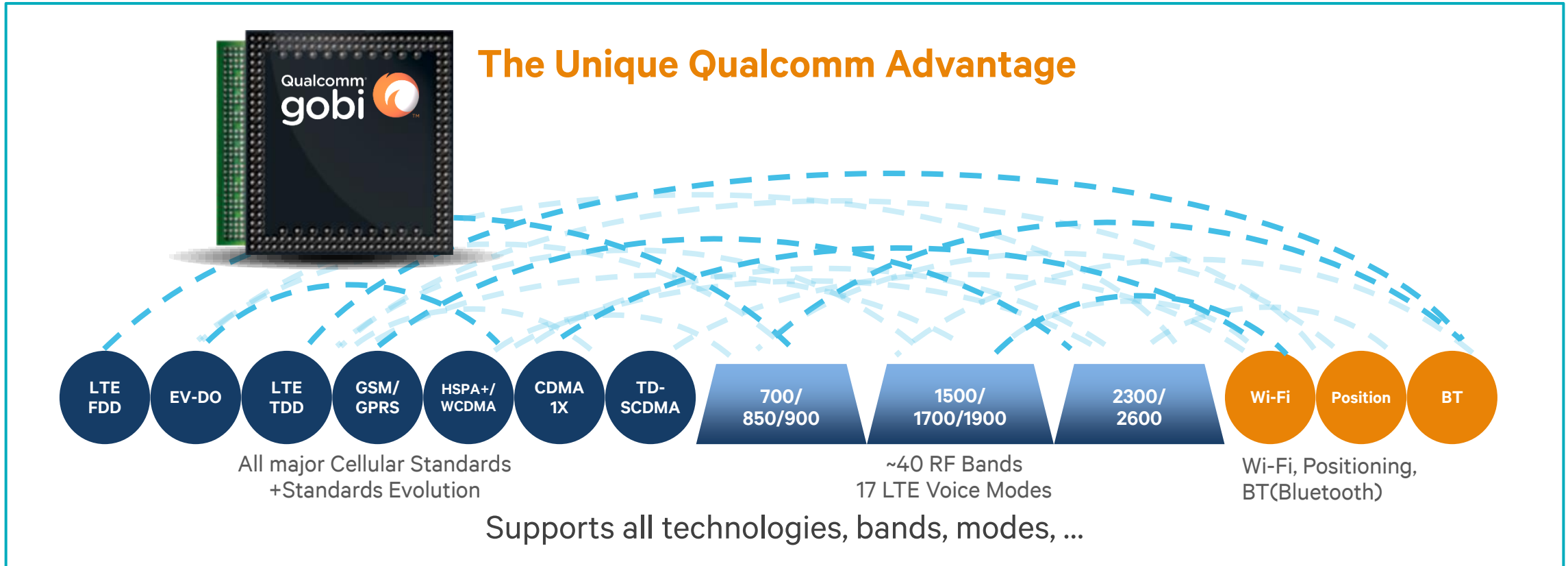
# Qualcomm is the leader in Mobile 3G/4G technologies

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](http://www.qualcomm.com/wireless)

# Questions? - Connect with Us



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BLOG

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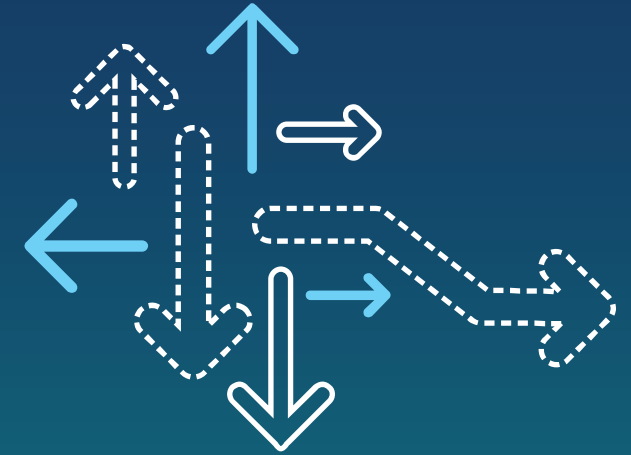
<http://www.youtube.com/playlist?list=PL8AD95E4F585237C1&feature=plcp>



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# Thank you

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