The Magic of Mobile: Wireless Fundamentals

June 2014

QUALCOMM
Wireless is the foundation to mobile

Appreciating the magic of mobile requires understanding the fundamentals of wireless

1. Mobile is the largest technology platform in the world

2. Mobile connectivity is an amazing technical achievement, critical to the mobile experience

3. Wireless fundamentals are the foundation to mobile powered by Mobile 3G/4G technologies

4. Qualcomm is the leader in Mobile 3G/4G, pushing wireless boundaries to enable the best mobile experiences
Mobile is the largest technology platform in the world

- ~7 Billion connections, almost as many as people on Earth\(^1\)
- ~8 Billion smartphones to be shipped 2014-2018\(^2\)
- More prevalent than electricity or running water in some regions

New form factors: tablet/laptop variants, wearables, etc.

Evolving into Internet of Everything: cars, meters, health-devices, etc.

\(^1\) GSMA Intelligence, Apr. ’14
\(^2\) 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

**Jaw-dropping Graphics**
with capability to process several thousand megapixels per second

**High Quality Multimedia**
- 4K Ultra-HD 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

**Broadband Speeds**
with blazing fast data rates capable of 300+ Mbps

**Long Battery Life**
with ability to power all these amazing experiences with less energy than it takes to power a light bulb for 1 hour

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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 >15W light bulb
Connectivity is the foundation of a great mobile experience

**Connect Reliably**
Talk and browse without interruption with more bars in more places

**Connect Real-Time**
Get instant access to content with less delay for “always-on” experience

**Connect Fast**
Stream, surf, upload, and download with fast, predictable data rates

**Connect On-the-Go**
Talk and browse with seamless mobility anywhere you get a signal

**Connect Longer**
Go longer without plugging in with improved battery efficiency

**Delivering rich mobile broadband experiences**

NEWS | LIVE | Camera | Cloud | Location
Coverage

Spectrum

Capacity

Wireless fundamentals are the foundation to mobile
Coverage is delivering a reliable signal to your mobile device despite harsh wireless environments, while on-the-go.

**Key Fundamentals**
- Radio Signal
- Modulation
- Signal-to-Noise Ratio
- Range
- Mobile Cell
- Mobile Network
- Seamless Handoff
- Mobility

**Analogy**
Radio signals are like a ripple in the water.
Radio signals are like ripples in the water

Radio Signal
A form of energy that radiates into space as radio waves.

Amplitude ($A$): Size of the ripple (energy)
Wavelength ($\lambda$): Distance between the ripples (meters)
Frequency ($f$): How often the ripple goes by (hertz)
Radio signals (ripples) are modulated with information

Modulation turns radio signals into information “carriers” creating a radio channel

Amplitude Modulation (AM)
Alternating how big you make the ripples
Radio signals (ripples) transmit in noisy environments

Signal Power

\[ SNR = \frac{Signal \ Power}{Noise + \text{Interference \ Power}} \]

Range

The distance the signal can travel with acceptable SNR to be decoded by receiver
Mobile technologies provide signal quality despite harsh wireless environments

Enabled by Mobile 3G/4G technologies

- Advanced receivers and coding to detect low-power signals from noise
- Multiple antenna techniques to create multiple paths to amplify signal
Mobile technologies provide coverage beyond the cell

Requires **seamless handoff** between transmitters like swinging from a trapeze
Mobile cells are networked to provide mobility

Cells are designed with overlapping coverage to provide **seamless handoffs** across cells

Packet loss required for high priority apps (e.g., video)
Mobile must deliver fast data rates despite finite spectrum, the lifeblood of mobile connectivity

**Key Fundamentals**

<table>
<thead>
<tr>
<th>Radio Frequency Spectrum</th>
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<tbody>
<tr>
<td>Radio Channel</td>
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<tr>
<td>Peak Data Rate</td>
</tr>
<tr>
<td>Licensed Spectrum</td>
</tr>
<tr>
<td>Unlicensed Spectrum</td>
</tr>
<tr>
<td>Time Division Duplex (TDD)</td>
</tr>
<tr>
<td>Frequency Division Duplex (FDD)</td>
</tr>
</tbody>
</table>

**Analogy**

Radio channels are like highways built on finite land
Spectrum is the airwaves that all wireless communications travel

<table>
<thead>
<tr>
<th>Spectrum bands</th>
<th>Maritime navigation signals</th>
<th>Navigational aids (e.g. loran-C)</th>
<th>AM radio, maritime radio</th>
<th>Shortwave radio, radiotelephone</th>
<th>VHF television, FM radio, navigational aids</th>
<th>Mobile, UHF television, GPS</th>
<th>Space and satellite communications</th>
<th>Radio astronomy, radar landing systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>3 kHz</td>
<td>10 kHz</td>
<td>30 kHz</td>
<td>300 kHz</td>
<td>3 MHz</td>
<td>30 MHz</td>
<td>300 MHz</td>
<td>3 GHz</td>
</tr>
<tr>
<td><strong>Wavelength</strong></td>
<td>100 km</td>
<td>10 km</td>
<td>1 km</td>
<td>1 km</td>
<td>10 m</td>
<td>1 m</td>
<td>10 cm</td>
<td>1 cm</td>
</tr>
<tr>
<td><strong>Antennas</strong></td>
<td>Increasing wavelength, larger antennas</td>
<td>Increasing frequency, shorter range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Spectrum is allocated by local governments
Spectrum is divided into frequency ranges (bands) for different types of wireless communication

e.g., 87.5 to 108.0 MHz for FM radio
Spectrum is like land – a finite resource; Radio channels are like highways built on this land

**Radio Frequency Spectrum (land):**
Frequency range for different types of wireless communication

- 100 MHz
- 850 MHz
- 1,500 MHz
- 1,900 MHz
- 2,350 MHz

**Radio Channel (highway):**
Spectrum for specific communication link

- FM Radio
- Mobile band
- GPS
- Mobile band
- Satellite Radio

**Data (vehicles):**
Bits of information carried on Radio channel
Spectrum is the lifeblood of mobile connectivity

Mobile must overcome finite spectrum to deliver fast data rates

More → More → Faster

Spectrum  Capacity  Data Rates

6 GHz
Travels short range

Mobile Licensed Spectrum
Cleared spectrum for exclusive use ensuring quality of service, mobility, and control

Evolving Mobile 3G/4G technologies maximize spectrum efficiency with:
- Advanced receivers and radio link improvements to get more bits per Hz
- Multiple antenna techniques to create multiple paths to carry more data
Mobile uses different spectrum for different types of access

**Licensed Spectrum**
Cleared spectrum for exclusive use
(Mobile 3G/4G technologies)

**Unlicensed Spectrum**
Spectrum shared by multiple technologies
(Wi-Fi, LTE, BT & others)

**Foundation of Mobile Broadband**
- Predictable Performance, Subscription-based
- Ubiquitous Coverage
- Seamless Mobility

**Foundation of Local Area Broadband**
- Simple Deployment
- Short Range, Local Coverage
- Residential, Enterprise, Connected Home
Mobile technologies are a two-way (duplex) radio channel

Frequency Division Duplex (FDD)
Paired spectrum enables better coverage

Time Division Duplex (TDD)
Unpaired spectrum enables asymmetrical DL/UL for more DL capacity
A radio channel has a peak data rate

**Peak Data Rate** \( \approx W \cdot n \cdot M \) – overhead

Theoretical max data rate in ideal conditions measured in bits per second (bps)

- **Spectrum Bandwidth**: The width of the radio channel (highway) built on spectrum (land)
- **Number of Antennas**: The number of spatially separated paths (highway overpasses)
- **Higher Order Modulation**: The number of bits (passengers) transmitted per signal (vehicle)

Note: Overhead is extra bits for each packet beyond the payload containing information necessary to properly transport the packet end-to-end across the network.
Evolving Mobile technologies increase peak data rate

**Peak Data Rate**

\[ W \cdot n \cdot M - \text{overhead} \]

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**Example: LTE Peak Data Rate**

- Spectrum Bandwidth \((W)\) = 20 MHz
- Number of Antennas \((n)\) = 2
- Bits per Symbol \((M)\) = 6
- Overhead = 37.5%
- Peak Data Rate = 150 Mbps

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<table>
<thead>
<tr>
<th>Channel Bandwidth ((W))</th>
<th>200 kHz</th>
<th>5 MHz</th>
<th>20 + 20 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Antennas ((n))</td>
<td>1 x 1 ((n = 1))</td>
<td>1 x 1 ((n = 1))</td>
<td>2 x 2 ((n = 2))</td>
</tr>
<tr>
<td>Modulation ((M))</td>
<td>8-PSK ((M = 3))</td>
<td>16-QAM ((M = 4))</td>
<td>64-QAM ((M = 6))</td>
</tr>
<tr>
<td>Peak Data Rate(^1)</td>
<td>474 Kbps(^2)</td>
<td>14.4 Mbps</td>
<td>300+ Mbps(^3)</td>
</tr>
</tbody>
</table>

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\(^1\) Download peak data rate; \(^2\) Theoretical peak data rate for GSM/EDGE, latest Evolved EDGE has peak DL data rates up to 12 Mbps; \(^3\) Download peak data rate with 2 x 2 MIMO, 64-QAM Modulation, and 2x 20 MHz carrier; 300 Mbps announced as of November 2013
Mobile must deliver fast data rates despite finite spectrum, the lifeblood of mobile connectivity

**Key Fundamentals**
- Capacity
- Multiple Access
- Shannon’s Law
- Spectrum Aggregation
- 1000x Mobile Data Challenge
- Small Cells

**Analogy**
Radio channel has a finite capacity like a pipe
Radio channel capacity is like a pipe’s capacity for water

Capacity

Theoretical max amount of data traffic that can be reliably transmitted over a noisy radio channel at a given time

Radio channel capacity is shared amongst multiple users

- Single user: 100% of capacity
- Multiple users: Share the capacity
A radio channel has a finite capacity

Capacity

Theoretical max amount of data traffic that can be reliably transmitted over a noisy radio channel at a given time

\[ \approx W \cdot n \cdot \log_2(1 + SNR) \]

- More Spectrum
  - Increasing the size of the radio channel (bandwidth)
- Number of Antennas
  - Adding antennas to create spatially separated paths
- Mitigate Interference
  - Improving the quality of the radio signal (SNR)

Shared amongst multiple users
Evolving Mobile 3G/4G technologies increase capacity
Enhancing user experience through faster data rates and lower latencies

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

- **Wider Channels**
  - Flexible support for channels up to 20 MHz enabled with OFDMA

- **Carrier Aggregation**
  - Aggregate more channels up to 100 MHz for higher data rates

- **More Antennas**
  - Advanced MIMO techniques to create spatially separated paths for more data

- **Interference Mitigation**
  - Mitigate interference with advanced receivers and antenna techniques

*Wireless fundamentals are the foundation to this evolution*
Mobile data traffic growth – industry preparing for 1000x

Mobile technology evolutions to increase capacity equation will not be enough

Industry preparing for 1000x data traffic growth¹

Richer content
more video

More devices
everything connected

~25 Billion
Interconnected devices forecast in 2020³

~2/3
Of mobile traffic will be video by 2017²

¹1000x would be reached if mobile data traffic doubled ten times, but Qualcomm does not make predictions when 1000x will happen, Qualcomm works on the solutions to enable 1000x

The biggest gain – reuse Shannon’s Law everywhere!

Scaling Capacity with Small Cells
Reusing Capacity \((C)\) equation everywhere

\[ C \approx n \cdot W \cdot \log_2(1 + SNR) \]
Qualcomm is the leader in seamless mobile connectivity delivering superior performance and technology leadership.
Qualcomm is the leader in Mobile 3G/4G technologies
Each modem generation enhances user experience and provides more capacity

Qualcomm® Gobi™ is a product of Qualcomm Technologies, Inc.

1 November 20, 2013: Qualcomm Technologies Announces Fourth-Generation 3G/LTE Multimode Modem - First Commercial Solution to Offer Global 4G LTE Advanced 40 MHz Carrier Aggregation for CAT6 FDD and TDD
Qualcomm is the leader in Mobile 3G/4G technologies

Hiding the complexity underneath the most seamless mobile connectivity

The Unique Qualcomm Advantage

Supports all technologies, bands, modes, ...

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Thank you

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