5G
Mérouane Debbah
Building a Better Connected World
Huawei

- *Huawei* is the official English transliteration of the firm’s Chinese name 华为
- The origin etymology and character 华 means "flower" (as suggested from its logo). It can also mean "splendid" or "magnificent" or "China/Chinese"
- The character 为 means "action" or "achievement"
- Huawei literally means « China's achievement ». 
Contents

Huawei Overview

Huawei in France

*Taux de change : USD1 = CNY 6.1958 (au 31 décembre 2014)*
Huawei was founded in Shenzhen, China’s Special Economic Zone

1987 - Huawei, a private company, was founded by Ren Zhengfei and several other investors with an investment of US$3,500. At that time, the company was a reseller of PBX switches of Hong Kong Hong Nian Company.

1993 - Huawei developed C&C08 digital switches, which were primarily deployed in rural areas.

1997 - Huawei started engaging global top consulting firms for management transformations.

1999 - Huawei established its first international R&D center in Bangalore, India.

2005 - Huawei became a preferred supplier for top carriers such as British Telecom and Vodafone. Revenue from Asia Pacific, the Americas, and EMEA exceeded domestic market for the first time.

2010 - Huawei transformed itself from a CT company to an ICT company and established three BGs: Carrier BG, Enterprise BG, and Consumer BG.
Today, Huawei is a leading ICT company

**Who is Huawei**
- A leading global ICT solutions provider
- A Fortune Global 500 company, ranking 285 in 2014
- Interbrand Top 100 Best Global Brands

**Employees**
- 170,000+ employees worldwide
- 45% or 76,000+ employees engaged in R&D
- LinkedIn World's 100 Most InDemand Employers

**Market Progress**
- US$46.5B revenue in 2014
- Serving 1/3 of the world's population

**Business Areas**
- Carrier: 77% Huawei's revenue generated from the carrier network business is from world's top 50 carriers
- Enterprise: serving more than 100 global top 500 companies
- Consumer: raising the brand awareness to 65%
Globalized resource deployment and localized business operations

- Operations in 170+ countries and regions; 170,000+ employees comprised of 160+ nationalities worldwide; 30,000+ non-Chinese employees with 75%+ localization rate.
- Huawei’s global value chain allows fluid capability transfer across the globe, develops and retains talent in local countries, and creates jobs and economic opportunities.
Achieve win-win outcomes with global partners through open collaboration

**Joint innovation**
- Set up 28 joint innovation centers with carriers
- Cooperate with top universities in future technologies
- Collaborate with industry partners to develop joint solutions and strengthen cooperation on Industry 4.0 and IoT

**Standards**
- Member of 170+ standards organizations, 185 important positions

**Channel**
- Over 280 tier-1 channel partners globally

**Financing**
- Overseas financial institutions provide 78% of all debt financing

**Suppliers**
- Non-Chinese suppliers account for 82%, which are mainly from the US, Europe, Japan, and Korea
Long-term investment in innovation

- Continue to invest over 10% of revenue into R&D. Total R&D investment in the past decade amounted to US$30.7 billion.
- No. 1 Chinese company with the largest number of patents in China; one of the Top 50 patent holders in the US; one of the Top 10 patent holders in Europe.
- Top 100 Global Innovators 2014 (by Thomson Reuters)
- The Most Innovative Companies 2014 (by BCG)

![Bar chart showing investment over 10 years from 2004 to 2014 in billions of US dollars: $0.6B, $0.7B, $1.1B, $1.4B, $1.8B, $2.3B, $2.9B, $3.9B, $4.9B, $5.1B, $6.6B]

- Strengthen fundamental research
- Open innovation
- Innovation of applications and products
- Innovation in fundamental technologies

HUAWEI
Contents

Huawei Overview

Huawei in France

*Taux de change : USD1 = CNY 6.1958 (au 31 décembre 2014)*
Mr Ren Zhengfei in a meeting with Prime Minister Manuel Valls announced an investment plan for France over 5 years, providing 600 new hires and 1.5 billion euros.

Ren Zhengfei said « **Huawei enhances the competitive advantages of France in the digital economy and is committed to investing in France. Our investments have a significant impact on our overall innovation while sharpening the competitiveness of France in the new technologies and creating jobs for the French talent.** »
INVESTMENT PLAN
2014-2018

RECRUITMENT
- Hiring 600 people including 200 in R&D at the end of 2017
- Creating competence center in the field of French excellence

R&D
Increasing R&D effort with 4 areas of expertise:
- Mathematics
- Design & Aesthetics
- Internet of Things
- Chipset

ECOSYSTEM
- Contribute to the development of French digital economy
- Increase cooperation with SMEs and start-ups

BUSINESS
- Carriers: 4G/LTE, FTTH and 5G
- Enterprise: Fusion range in the Cloud, storage....
- Device: Smartphones, wearable... (P8, Mate 7, Watch)
1.5 billions € investment plan
For the period 2014-2018

+ 700 employees
600 recruitment including 200 in R&D from now until 2018

6 offices in France
Headquarter in Boulogne-Billancourt; offices in Paris, Issy-les-Moulineaux, Bordeaux, Lille, Nantes and Sophia Antipolis

4 R&D centers
Mathematics, Design, Internet of Things and Chipset

13 laureates startups
« IN-Pulse » contest (600 000 € allocation in 2014)

+240M $ procurement in 2014
French suppliers (electronics, software, logistics...)
Huawei French Research Center

- Aesthetic
- Mathematics
- Chipset
- Internet of Things
5G-4G=1G
Mobile Network Technology Lifecycles (North America)

<table>
<thead>
<tr>
<th></th>
<th>Research+Standardization</th>
<th>Time to Peak</th>
<th>Peak to end of Life</th>
<th>Total Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>2G</td>
<td>8</td>
<td>9</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>3G</td>
<td>8</td>
<td>11</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>4G (ESTIMATED)</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>13</td>
</tr>
</tbody>
</table>
International  5G getting Momentum

ITU-R Visions Group
EU
- Framework Program 7, e.g. METIS and 5GNow projects
- 5G PPP in Horizon 2020

UK – 5G Innovation Centre (5GIC) at University of Surrey

US
- Intel Strategic Research Alliance (ISRA)
- NYU Wireless Research Center
- 4G Americas

China
- 863 Research Program
- Future Forum
- IMT-2020 (5G) Promotion Association

Japan – 2020 and Beyond Ad-Hoc Group under ARIB’s Advanced Wireless Communications Study Committee, now transformed to 5G Promotion Forum

Korea – 5G Forum

Russia – 5GRUS by Russia’s Icom-Invest

CJK White Paper

NGMN – White paper on future requirements
- Company internal research

Source: 5G Infrastructure Association.
5G Timeline
Workplan for IMT-2020

2014: Report Technology trends
2015: Report IMT feasibility above 6 GHz
2016: Recommendation Vision of IMT beyond 2020
2017: Modifications of Resolutions 56/57
2018: Technical Performance Requirements
2019: Evaluation Criteria & method
2020: Requirements, Evaluation Criteria, & Submission Templates

Workshop

Proposals “IMT-2020”
Evaluation
Consensus building
Outcome & Decision
“IMT-2020” Specifications
5G From Mobile Internet to Connected World

3G 4G Mobile Internet
(4 Billions@2020)
Mobile Internet replaced PC Internet

5G Connected World
(50-100 Billions@2020)
90% objects are not connected

Voice Smartphone

HD Video Surveillance Augmented Reality Wireless IP TV High Speed Train Meter & Sensor

Stadium 4K 3D HD TV Smartphone Voice Shipping Logistic

Multi-User UHD Telepresence Gaming Wireless Cloud Office Automatic Driving Monitoring

Voice 4K 3D HD TV Stadium Gaming Surveillance Multi-User UHD Telepresence Gaming Wireless Cloud Office Automatic Monitoring

5G
From Mobile Internet to Connected World
(50-100 Billions@2020)
90% objects are not connected
Example: movie projectors tomorrow (lasers)

- 30-50 Mb/s for a single view transmission and Zero-Latency (adaptive) interaction client-server *

*) For luminance (brightness), chrominance (color), resolution, view point, etc. adaptation

2-8K ➞ 30-50 Mb/s/view

Example: The iCub robot platform (www.iit.it)

5,000 sensors!

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Specs</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameras</td>
<td>2x, 640x480, 30fps, 8/24bit</td>
<td>147Mbit/s uncompressed</td>
</tr>
<tr>
<td>Microphones</td>
<td>2x, 44kHz, 16bit</td>
<td>1.4Mbit/s</td>
</tr>
<tr>
<td>F/T sensors</td>
<td>6x, 1kHz, 8bit</td>
<td>48kbit/s</td>
</tr>
<tr>
<td>Gyrosopes</td>
<td>12x, 100Hz, 16bit</td>
<td>19.2kbit/s</td>
</tr>
<tr>
<td>Tactile sensors</td>
<td>4000x, 50Hz, 8bit</td>
<td>1.6Mbit/s</td>
</tr>
<tr>
<td>Control commands</td>
<td>53DoF x 2-4 commands, 100Hz/1kHz, 16bit</td>
<td>3.3Mbit/s (worst case), 170kbit/s (typical)</td>
</tr>
</tbody>
</table>

Force control latency requirement = 1-5 ms

[iit, Genova, Nov 2014]

Example: Future Car Communications

New Antenna Concepts for MIMO, Integration of 11p and LTE/5G, Mobile Edge Computing

Communication requirements

- Better connection than smart phone
- Reliable for future advanced driver assistant systems (ADAS)
- High data volumes (>200MB/s) at low latencies for future cooperative automatic driving functions (V2V)
- Support performance up to maximum speed (500km/h relative)
- Any network operator, regardless of vehicle occupants' contract (safety information)
5G Wireless Requirements For FEC

**Human Centric Communications:**
The user data rate: \(10\text{Gbps}\)
- iPhone, iPad, iGlass, iWatch

The base station data rate: \(1\text{Tbps}\)
- cloud computing blade

**Machine Centric Communications:**
The sensor data size: \(10\sim 100\text{Bytes}\)
- meters, telemetric, RFID, ........

The industry control: \(10^{-4}\) second latency
- Could-drive-car, factory control ....
5G (Beyond Smartphone)

Transform the Industry Verticals

- 400MHz
- 10GHz
- 100GHz
- D2D
- Open OTT
- SDN-RAN
- IoT
- Verticals

- Capacity: 1000X (Capacity/km²)
- Speed: 100X (10Gbps)
- Latency: Less than 1ms
- Links: 100x
- Energy: 1000X Reduce

Auto-drive
Medicare
Robots
Meters Sensors

Beyond Smartphone

Capacity: 1000X
Speed: 100X
Latency: Less than 1ms
Links: 100x
Energy: 1000X Reduce
In the context of 5G activities, a 1000x increase of capacity is targeted.

- New dedicated licensed bands (e.g., spectrum under discussion towards WRC-15)
  - Issue: limited opportunities
- Spectrum Sharing (e.g. Licensed Shared Access in 2.3-2.4 GHz in Europe)
- New mmWave spectrum (10/28-90 GHz, licensed/unlicensed)
- New rules for unlicensed Spectrum for WiFi (5 GHz) or TVWS

<table>
<thead>
<tr>
<th>Company</th>
<th>Spectrum Efficiency</th>
<th>Base Station Densification</th>
<th>Total capacity increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nokia</td>
<td>10</td>
<td>10</td>
<td>1000</td>
</tr>
<tr>
<td>Huawei</td>
<td>4</td>
<td>16-30</td>
<td>640-1200</td>
</tr>
<tr>
<td>NTT DoCoMo</td>
<td>2.8</td>
<td>24</td>
<td>1000</td>
</tr>
<tr>
<td>Ericsson</td>
<td>4</td>
<td>2.5</td>
<td>1000</td>
</tr>
<tr>
<td>RWTH Aachen</td>
<td>3</td>
<td>5</td>
<td>1000</td>
</tr>
</tbody>
</table>

Source: 5G Summit Munich, 10-Feb-2014
5G spectrum – Ofcom position

Ofcom on Monday identified four frequency bands in the 6 GHz-100 GHz range that it believes offer the best potential for use as 5G spectrum.

The U.K. regulator has suggested that the 10 GHz, 32 GHz, 40 GHz, and 66 GHz bands would be appropriate for use for next-generation mobile services (see table). The proposal is based on a combination of in-house analysis, a report by consultancy Quotient Associates, and responses to a consultation that Ofcom launched in January.

“We believe it is desirable to identify specific potential bands above 6 GHz to help focus an agenda item for the World Radio Communication Conference in 2019 (WRC-19) and to maximise the potential for international harmonisation of 5G spectrum,” said Ofcom.

“We have therefore identified a preliminary set of bands in different parts of the 6 GHz-100 GHz range that we currently believe offer the best potential for use in the U.K. and harmonisation of 5G mobile services globally.

“This does not guarantee that these bands will be adopted in the future and we do not rule out consideration of other options” ahead of November’s WRC-15 in Geneva, the watchdog said.

<table>
<thead>
<tr>
<th>Summary of preliminary bands identified</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency range</strong></td>
</tr>
<tr>
<td>Specific bands identified</td>
</tr>
<tr>
<td><strong>Potential bandwidth</strong></td>
</tr>
</tbody>
</table>

Source: Ofcom, April 2015
### Bande 2.6 GHz

<table>
<thead>
<tr>
<th></th>
<th>WiFi</th>
<th>SFR</th>
<th>OF</th>
<th>BYT</th>
<th>Free</th>
<th>TDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>uplink</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TDD</th>
<th>SFR</th>
<th>OF</th>
<th>BYT</th>
<th>Free</th>
<th>radar</th>
</tr>
</thead>
<tbody>
<tr>
<td>downlink</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Largeur (MHz)</th>
<th>15</th>
<th>20</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prix</td>
<td>150 M€</td>
<td>287 M€</td>
<td>228 M€</td>
<td>271 M€</td>
</tr>
</tbody>
</table>

### Bande 800 MHz

<table>
<thead>
<tr>
<th></th>
<th>TNT</th>
<th>BYT</th>
<th>SFR</th>
<th>OF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Largeur (MHz)</th>
<th>10</th>
<th>5+5</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prix</td>
<td>683 M€</td>
<td>1065 M€</td>
<td>891 M€</td>
</tr>
</tbody>
</table>

### Bilan enchères LTE
(somme 2.6 GHz et 800 MHz)

![Graph showing the auction results for different bands]
Today's Long Tail, Tomorrow's New Field

5G will enable new applications, new business models, and even new industries.
5G Will Carry Many Industries and Benefit Stakeholders

Enhance Mobile Internet

- Ubiquitous consistent experience
- New services

Vertical Industries

- Easy access to the common infrastructure of 5G
- Real-time, on-demand service

Empower Internet of Things

- Easy deployment and maintenance
- Network flexibility for multiple industries

Consumers

Operators
Diversified Challenges and Gaps to Reach 5G

- **Latency**: 1 ms E2E Latency
- **Throughput**: 10Gb/s Per Connection
- **Connections**: 1,000K Connections Per km²
- **Mobility**: 500 km/h High-speed Railway
- **Network Architecture**: Slicing
  - Ability Required

**5G**

**GAP**

**LTE**
5G Innovations Will be Applied to 4G to Leverage 4G Investment

- 2014: R12
- 2015: R13
- 2016: R14
- 2017: R15
- 2018: R16
- 2019: ...

5G innovations will be applied to 4G.

4G will stimulate the emergence of new applications for 5G.

5G

Revolution

4G

Evolution

4.5G
How did we get here to 4G and 4.5G => 5G

3.9G
Dec 2008
- Rel-8
- First LTE Release
- Basic LTE functionalities
- OFDM New air interface
- TDD and FDD MIMO
- New System arch

4G
Dec 2009
- Rel-9
- eNB type/service
  - HeNB: hybrid/open access, inbound mobility, inter-HeNB handover
  - Positioning using OTDOA
  - eMBMS
  - VoLTE
- SON
  - Mobility robust optimization (MRO)
  - RACH optimization
  - Mobility load balancing (MLB)
  - Inter-eNB Energy Saving

Mar 2011
- Rel-10
- Carrier Aggregation
- DL/MIMO: 8x8
- UL MIMO: 4x4
- eNB type/service
  - HetNet e/CIC
  - HeNB: mobility enh. SIPTO/LIFA
  - Relay
  - CS Fallback
  - SRVCC
- SON
  - enhanced MRO
  - enhanced MLB
  - Minimization of drive tests (MDT)

June 2013
- Rel-11
- CoMP
- Enhanced PDCCH
- CA enhancements
- eNB type/service
  - HeNB: mobility enh.
  - FelCIC
  - eDDA
  - Network-Based Positioning
  - MTC
  - Service continuity for eMBMS
- SON
  - Network energy saving
  - enhanced MDT
  - Further SON enhancement

Dec 2014
- Rel-12
- SCE PHY
- Dual Connectivity
- FDD/TDD CA
- DL MIMO enh.
- eNB type/service
  - eMT @ RAN
  - Low cost MTC @PHY
  - D2D
  - Positioning
  - LTE-WLAN interwork
  - SCM
- SON
  - LTE-HRPD SON
  - eMBMS MDT

Mar 2016
- Rel-13
- LAA/I-LTE
- 3D/Massive MIMO
- Massive CA (32CC)
- UL 64QAM
- Dual Connectivity enh.
- eNB type/service
  - Ultra Low-cost MTC
  - Single Cell PTM
  - High speed support
  - LTE-WLAN aggregation
  - Latency optimization
  - Flexible bandwidth
- SON
  - AAS SON

4.5G has some key radio features that will form the basis for a 5G system (Massive MIMO, LAA, enhanced MTC, Latency reduction..)
3GPP work areas in 4.5G leading to 5G

Flexible Spectrum Utilization
- Physical layer small cell enhancements
- U-LTE/LAA
- Flexible Bandwidth
- FDD/TDD CA
- Massive CA
- Flexible Duplex

Flexible Service Extension
- FeMTC
- Single Cell PTM
- D2D/V2V
- Positioning enh.
- Latency Optimization
- High Speed Scenario Support

Flexible Network
- Enhanced Multiuser Transmissions
- 3D MIMO
- Uplink Enhancement
- Small Cell Enh./Dual Connectivity
- LTE-WLAN Aggregation
- Multi-RAT Joint Operation
A Global Unified Standard for 5G

Global Unified Standard

Global Roaming | Scale Economics

Other Industries

WLAN

WiMAX

3G

WCDMA
EV-DO
TD-SCDMA

LTE-FDD
LTE-TDD

5G

IEEE
Key Challenges for Reaching 5G

Spectrum
- Aggregate All Available Bands

New Architecture & Operation
- One Physical Network Multiple Industries

New Air Interface
- Flexibility & Spectrum Efficiency
5G Will Aggregate Sub 6GHz and the Bands >6GHz

WRC15
Requirement >500MHz for IMT-2020

WRC19
45GHz available for future Cellular Access and Self-Backhaul

Cellular Bands

Visible Light

5G Primary bands

5G Complementary Bands for Capacity, 45GHz available
LAA is a stepping stone in 4.5G towards 5G

As secondary carriers, LTE carriers at unlicensed bands are integrated to LTE carriers

Non-Standalone

Licensed LTE  
Primary Carrier  
Secondary Carrier  
U-LTE  

Licensed LTE  
Primary Carrier  
Secondary Carrier  
U-LTE  

Coverage & Capacity Guarantee  
Mobility and service continuity  
QoS Guarantee  
Unified OAM, RRM, Billing  

Controlled by Operator Networks

Without Licensed LTE, U-LTE will lose these advantages

Standalone

U-LTE

Carrier Aggregation into LTE networks
A New Architecture & Operation

- Video Industry Network Slice
- Connected Car Network Slice
- IOT Network Slice

Industry defined network slicing

Service oriented cloud-formation

Internet architectural operation

Application Field

Unified Control Plane

Multi-Application User Plane

Telco OS

Developer

Consumer

Partner

Operator

DC
New Air Interface

Mobile Internet

Adaptive Air Interface

Full Duplex

Massive MIMO

SCMA

Polar Code

F-OFDM

Internet of Things

One air interface fits many applications with high flexibility, at least a $3x$ spectrum efficiency improvement.
Consolidated Front haul & Backhaul – *one* Fixed Networks

- Cloud/C-RAN virtualizes all 5G compute resources
- C-RAN requires ultra low delay/jitter ‘front-haul’
- One option is use of dedicated fiber per antenna site
- Allows C-RAN to send I/Q samples at ultra low delay/jitter

- C-RAN communicates with antenna sites and other 5G components over same network.
- Network now has to support ultra low delay/jitter and provide extremely precise clocking.
- Work starting in IEEE but needs CPRI / division changes
SDN/Transport-SDN for back-haul/front-haul/DC/DCI

- Multiple SDN/TSDN controllers
- Allocate B/W connectivity
- Reconfigure optical network
- Reconfigure IP network
- Reconfigure microwave network
- Reconfigure DC network
- Allocate DC resources for EPC
- Allocate resources for C-RAN
- Consolidated view for services.
Optimized NFV/SDN for EPC/TE/C-RAN etc.

- Hybrid CPU/FPGA (Intel 2017)
- Allow massive parallel programming
- Can do LP/ILP/Convex/FFT etc in HW/Software hybrid
- High performance f()=DPI
- High performance packet forwarding
- Problem – very hard to program
Huawei 5G Low Band Test Bed

Cell Throughput@ Sub6G

10  32  Gbps

200MHz BW

System Info. @ 200M BW

<table>
<thead>
<tr>
<th>MCS</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer</td>
<td>12</td>
</tr>
<tr>
<td>TPF</td>
<td>5.3305 Gbps</td>
</tr>
<tr>
<td>SE</td>
<td>5.6224 bps/Hz</td>
</tr>
<tr>
<td>SNR</td>
<td>29.1152 dB</td>
</tr>
</tbody>
</table>
Huawei 5G High Band Test Bed

Breaks World Record

115.20 Gbps

9.6GHz BW
Thank you

www.huawei.com

Copyright©2015 Huawei Technologies Co., Ltd. All Rights Reserved.
The information in this document may contain predictive statements including, without limitation, statements regarding the future financial and operating results, future product portfolio, new technology, etc. There are a number of factors that could cause actual results and developments to differ materially from those expressed or implied in the predictive statements. Therefore, such information is provided for reference purpose only and constitutes neither an offer nor an acceptance. Huawei may change the information at any time without notice.