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# *Lecture 9*

## Mobile Devices


[Source: Nokia]

**Mobile Business I (WS 2022/23)**

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- Introduction
- Categorisation of Mobile Devices
- Components of Mobile Devices
  - Accumulators
  - Processors, Memory, and Storage
  - Display
  - Means for I/O

# Mobile Terminal vs. Mobile Device

- A *Mobile Device* is a small, handheld computing device.

- *Mobile Terminal* emphasises the fact that the mobile device represents the end of a communications link or the edge node of a communications network.

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# Device Manufacturers and Brands

(including some historic ones)

- Alcatel
- Apple
- Audiovox
- Benefon
- BenQ Mobile
- Blackberry
- Bosch
- Ericsson
- Google
- HTC
- Huawei
- LG Electronics
- Microsoft
- Motorola
- NEC
- Nokia
- Panasonic


- Philips
- Sagem
- Samsung
- Sendo
- Siemens
- Sony
- TCL Communication
- Telepong
- Telit
- Telme
- Toshiba
- Trium
- Windhorst
- Xelibri
- Yulong
- ZTE

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# Worldwide Mobile Phone Sales to End Users by Vendor Q1-2017 vs. Q1-2005

| Company | 1Q17 units | 1Q17Market Share (%) | 1Q05 units | 1Q05 Market |
|---|---|---|---|---|
| Samsung | 78,671.4 | ***20.7*** | 24,479.8 | ***13.5*** |
| Apple | 51,992.5 | ***13.7*** | - | |
| Huawei | 34,181.2 | ***9.0*** | - | **-** |
| Oppo | 30,922.3 | ***8.1*** | - | |
| Vivo | 25,842.2 | ***6.8*** | | |
| Nokia | ➲ others | | 76,088.4 | ***30.4*** |
| LG Electronics (former LG) | | | 11,464.2 | ***6.3*** |
| Lenovo*/Motorola | | | 30,143.3 | ***16.7*** |
| Huawei | | | ➲ others | |
| TCL Communication | | | | |
| ZTE | | | | |
| BenQ Mobile | | | 10,209.5 | ***5.7*** |
| Sony Mobile Com. | | | 9,905.8 | ***5.5*** |
| Others | 158,368.7 | ***41.7*** | 39,829.5 | ***21.9*** |
| **TOTAL** | **379,977.3** | **100.0** | **180,992.2** | **100.0** |

Based on [Gartner2017] and [Gartner2006]

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# Worldwide Mobile Phone Sales to End Users by Vendor Q1-2017 vs. Q1-2016

In 1.000 Units

| Company | 1Q17 Units | 1Q17 Market Share (%) | 1Q16 Units | 1Q16 Market Share (%) |
|---|---|---|---|---|
| Samsung | 78,671.4 | ***20.7*** | 81,186.9 | ***23.2*** |
| Apple | 51,992.5 | ***13.7*** | 51,629.5 | ***14.8*** |
| Huawei | 34,181.2 | ***9.0*** | 28,861.0 | ***8.3*** |
| Oppo | 30,922.3 | ***8.1*** | 16,112.6 | ***4.6*** |
| Others | 184,210.9 | ***48.5*** | 171,461.4 | ***49.1*** |
| **Total** | **379,978.3** | **100.0** | **349,251.4** | **100.0** |

Based on [Gartner2017]

# Worldwide Mobile Phone Sales to End Users by Vendor 2012 vs. 2011 – A Decline?

In 1.000 Units

| Company | 2012 Units | 2012 Market Share (%) | 2011 Units | 2011 Market Share (%) |
|---|---|---|---|---|
| Samsung | 384,631.2 | ***22.0*** | 315,052.2 | ***17.7*** |
| Nokia | 333,938.0 | ***19.1*** | 422,478.3 | ***23.8*** |
| Apple | 130,133.2 | ***7.5*** | 89,263.2 | ***5.0*** |
| ZTE | 67,344.4 | ***3.9*** | 56,881.8 | ***3.2*** |
| LG Electronics | 58,015.9 | ***3.3*** | 86,370.9 | ***4.9*** |
| Huawei Technologies | 47,288.3 | ***2.7*** | 40,663.4 | ***2.3*** |
| TCL Communication | 37,176.6 | ***2.1*** | 34,037.5 | ***1.9*** |
| Research In Motion | 34,210.3 | ***2.0*** | 51,541.9 | ***2.9*** |
| Motorola | 33,916.3 | ***1.9*** | 40,269.1 | ***2.3*** |
| HTC | 32,121.8 | ***1.8*** | 43,266.9 | ***2.4*** |
| Others | 587399.6 | ***33.6*** | 595886.9 | ***33.6*** |
| **TOTAL** | **1,746,175.6** | **100.0** | **1,775,712.0** | **100.0** |

Cf. TOTAL Units sold in 2013: 1,820,200.0

[Statista2014] [Gartner2013a]

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# Worldwide Smartphone Sales to End Users by Vendor Q1-2019 vs. Q4-2018

In 1.000 Units

| Company | 1Q19 Units | 1Q19 Market Share (%) | 4Q18 Units | 4Q18 Market Share (%) |
|---|---|---|---|---|
| Samsung | 71,621.1 | ***19.2*** | 70,782.5 | ***17.3*** |
| Huawei | 58,436.2 | ***15.7*** | 60,409.8 | ***14.8*** |
| Apple | 44,568.6 | ***11.9*** | 64,527.8 | ***15.8*** |
| Oppo | 29,602.1 | ***7.9*** | 31,589.9 | ***7.7*** |
| Others | 141,405.2 | ***45.2*** | 153,205.0 | ***44.3*** |
| **Total** | **373,001.4** | 100% | **408,358.5** | 100% |

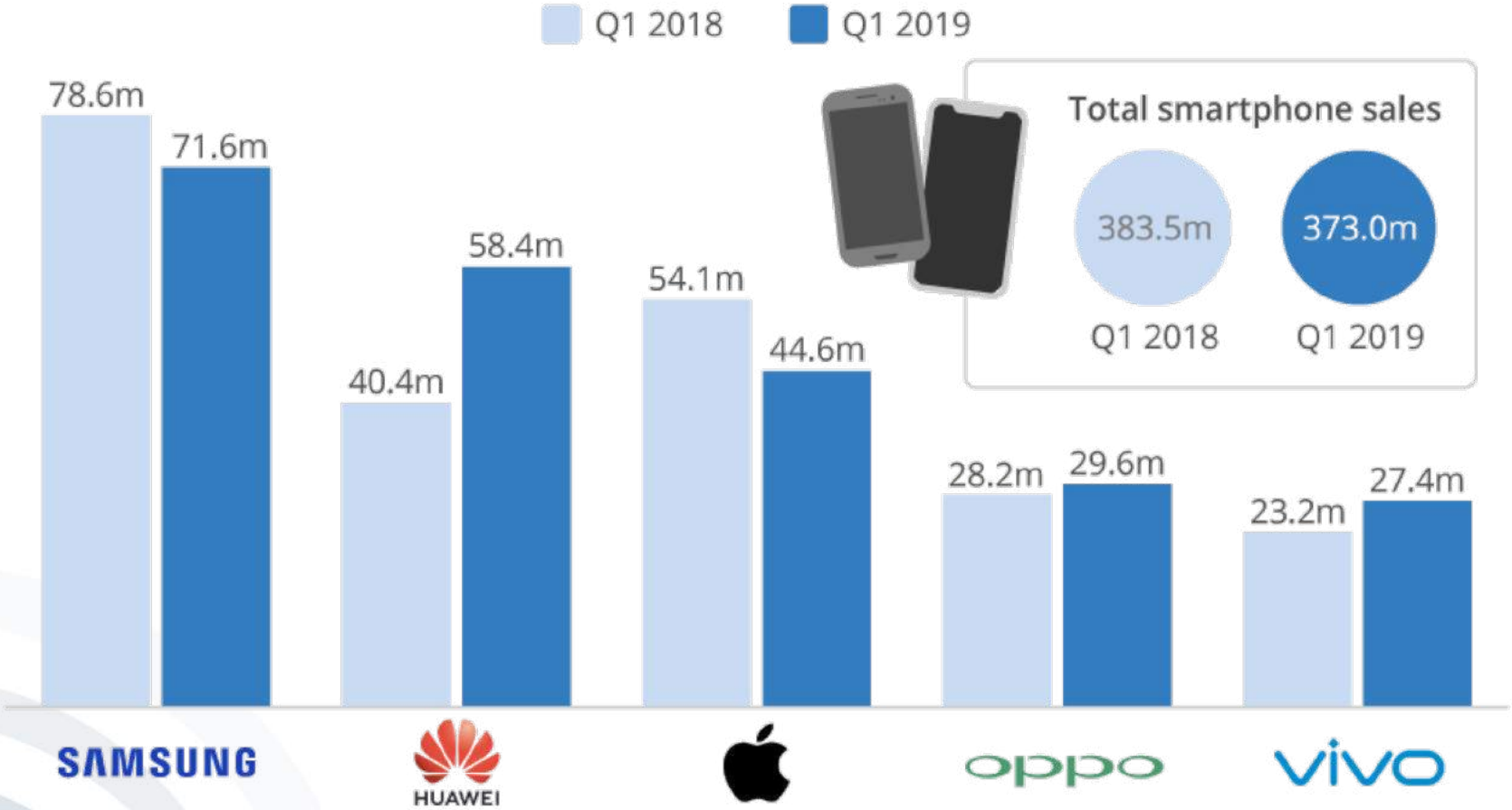
Based on [Gartner2019] and [Gartner2018]

# Worldwide Smartphone Sales in Q2-2013

- “Smartphones accounted for 51.8 percent of mobile phone sales in the second quarter of 2013, resulting in smartphone sales surpassing feature phone sales for the first time.”

[Gartner2013b]

# Worldwide Smartphone Sales to End Users by Vendor Q1-2019 vs. Q1-2018




[Statista2019]

# Worldwide Smartphone Sales to End Users by Vendor Q1-2019 vs. Q1-2018

In 1.000 Units

| Company | 1Q19 Units | 1Q19 Market Share (%) | 1Q18 Units | 1Q18 Market Share (%) |
|---|---|---|---|---|
| Samsung | 71,621.1 | 19.2 | 78,564.8 | 20.5 |
| Huawei | 58,436.2 | 15.7 | 40,426.7 | 10.5 |
| Apple | 44,568.6 | 11.9 | 54,058.9 | 14.1 |
| Oppo | 29,602.1 | 7.9 | 28,173.1 | 7.3 |
| Vivo | 27,368.2 | 7.3 | 23,243.2 | 6.1 |
| Others | 141,405.2 | 37.9 | 159,037.1 | 41.5 |
| **Total** | **373,001.4** | **100.0** | **383,503.9** | **100.0** |

Source: [Gartner2019]

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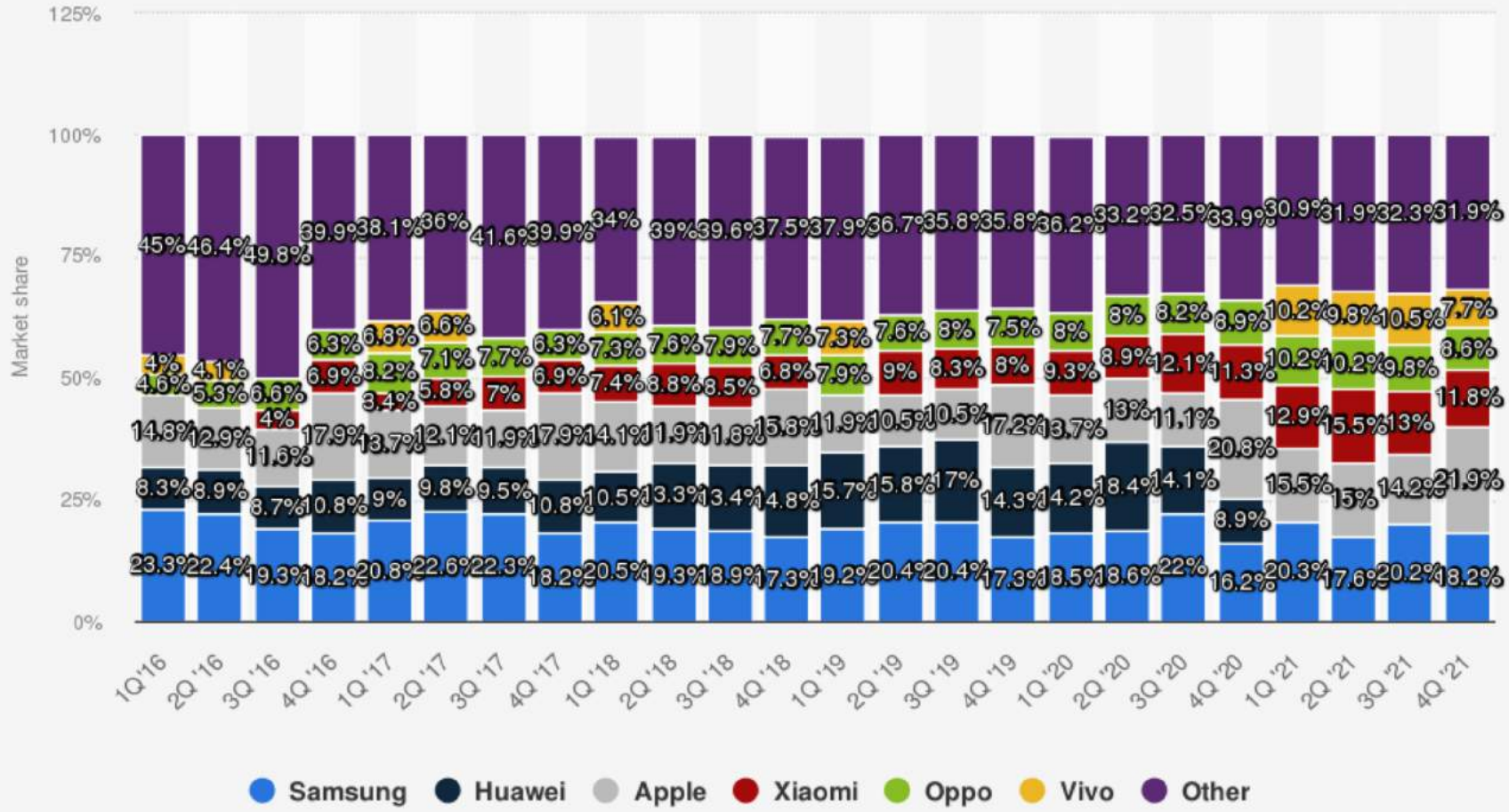
# Worldwide Smartphone Sales to End Users by Vendor from Q1-2016 to Q4-2021




Source
Gartner
© Statista 2022

Additional Information:
Worldwide; 2016 to 2021

[Statista2022]

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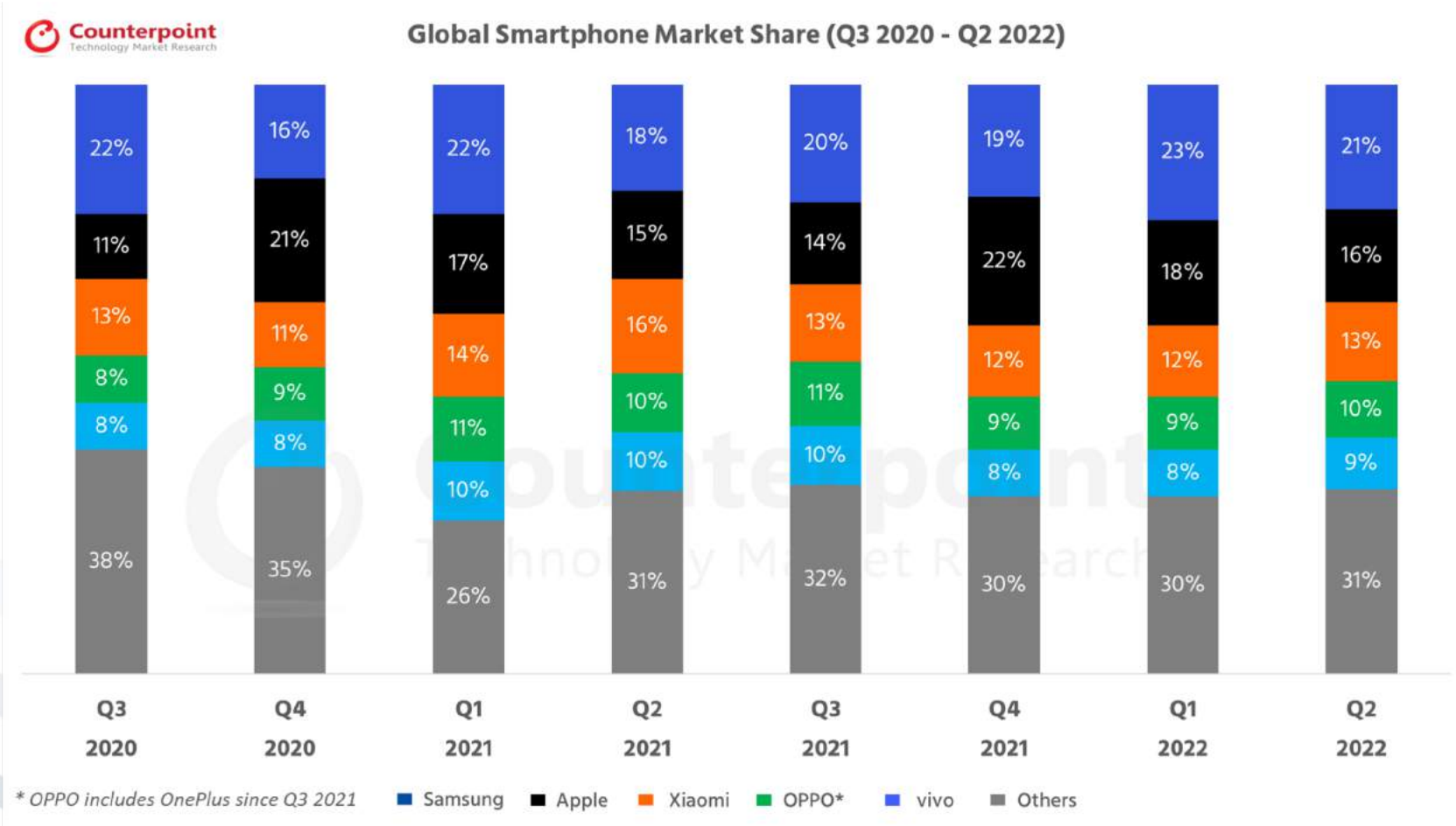
# Worldwide Smartphone Market Share by Vendor from Q3-2020 to Q2-2022




[counterpointresearch2022a]

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# Worldwide Smartphone Market Share % by Vendor from Q3-2020 to Q2-2022

| Brands | Q3 2020 | Q4 2020 | Q1 2021 | Q2 2021 | Q3 2021 | Q4 2021 | Q1 2022 | Q2 2022 |
|---|---|---|---|---|---|---|---|---|
| **Samsung** | 22% | 16% | 22% | 18% | 20% | 19% | 23% | 21% |
| **Apple** | 11% | 21% | 17% | 15% | 14% | 22% | 18% | 16% |
| **Xiaomi** | 13% | 11% | 14% | 16% | 13% | 12% | 12% | 13% |
| **OPPO*** | 8% | 9% | 11% | 10% | 11% | 9% | 9% | 10% |
| **vivo** | 8% | 8% | 10% | 10% | 10% | 8% | 8% | 9% |
| **Others** | 38% | 35% | 26% | 31% | 32% | 30% | 30% | 31% |

[counterpointresearch2022a]

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# Worldwide Smartphone Global Smartphone Shipments by Vendor from Q3-2020 to Q2-2022

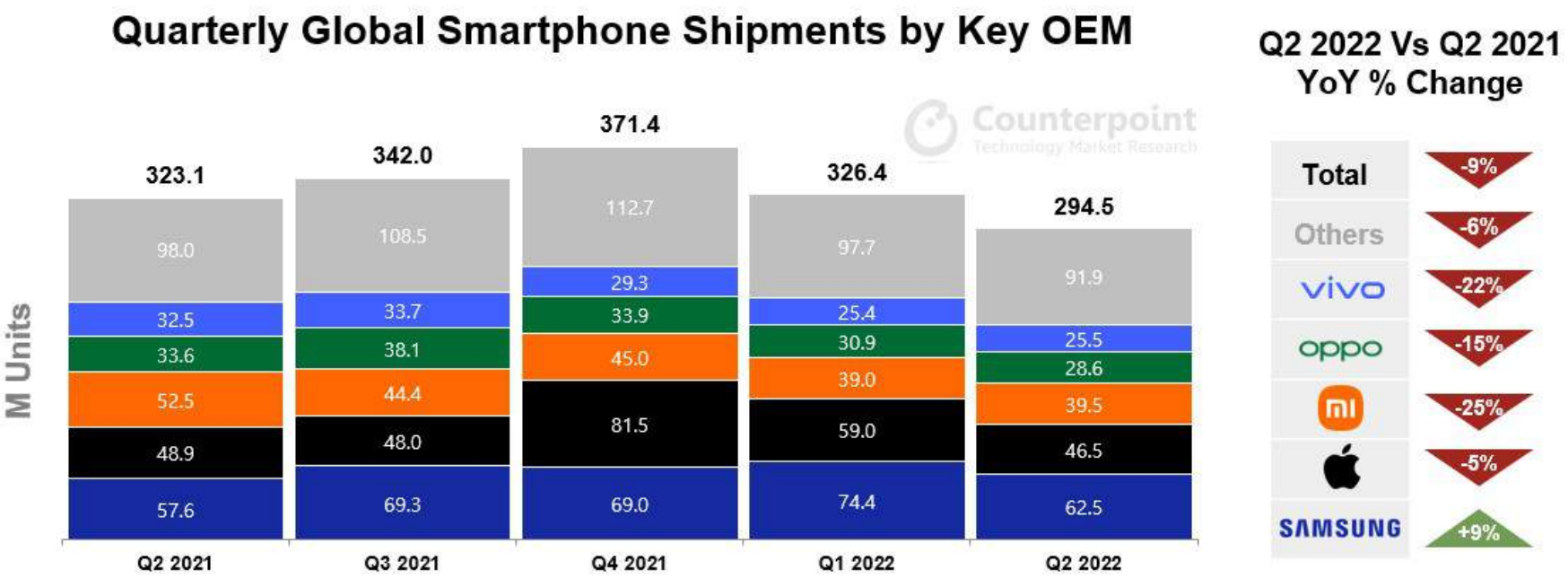
(in Millions)

| Brands | Q3 2020 | Q4 2020 | Q1 2021 | Q2 2021 | Q3 2021 | Q4 2021 | Q1 2022 | Q2 2022 |
|---|---|---|---|---|---|---|---|---|
| **Samsung** | 80.4 | 62.5 | 76.6 | 57.6 | 69.3 | 69.0 | 74.5 | 62.5 |
| **Apple** | 41.7 | 81.9 | 59.5 | 48.9 | 48.0 | 81.5 | 59.0 | 46.5 |
| **Xiaomi** | 46.5 | 43.0 | 48.5 | 52.5 | 44.4 | 45.0 | 39.0 | 39.5 |
| **OPPO*** | 31.0 | 34.0 | 38.0 | 33.6 | 38.1 | 33.9 | 30.9 | 28.2 |
| **vivo** | 31.0 | 33.4 | 35.5 | 32.5 | 33.7 | 29.3 | 24.8 | 25.5 |
| **Others** | 135.0 | 139.8 | 96.8 | 98.0 | 108.5 | 112.7 | 98.2 | 92.3 |
| **Total Market** | 365.6 | 394.6 | 354.9 | 323.1 | 342.0 | 371.4 | 326.4 | 294.5 |

*OPPO includes OnePlus since Q3 2021

[counterpointresearch2022a]

# Worldwide Smartphone Sales to End Users by Vendor from Q2-2021 to Q2-2022




*Source: Counterpoint Research Quarterly Market Monitor, Q2 2022*
*Note: OPPO includes OnePlus since Q3 2021*

[counterpointresearch2022b]

# Evolution of Mobile Devices


Time

- Augmented Reality (AR) capabilities
- Near Field Communication (NFC)
- Sensors (accelerometer, gyroscope, etc.)
- Possibility to execute 3rd party software
- Multimedia applications (MP3, radio, camera, video, TV, etc.)
- Data services (GPRS, UMTS, LTE, Wi-Fi)
- Bluetooth
- Interactive Voice Response (IVR)
- Short Message Service (SMS)
- General telephony capabilities

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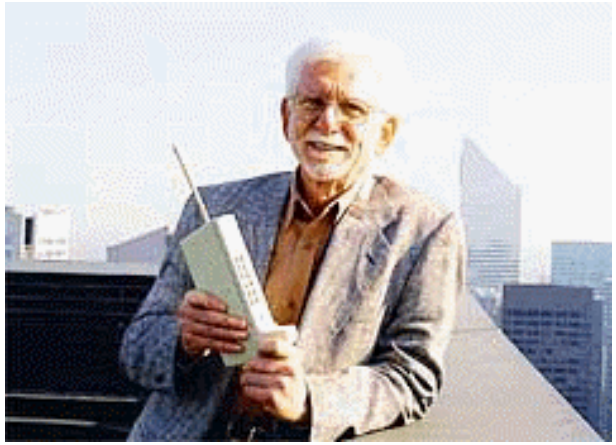
# Evolution of Mobile "Devices"

## Examples



© New York Times

1973



© Microoptical

2001

2019-2022

2016

2013

2017



2005

© IBM

2006

2007

2010

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# Mobile Devices Size

- Everybody wants smaller devices.
- Everybody ? …

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# Worldwide Device Shipments by Segment – 2018 View

- Worldwide device shipments and projections by segment show a shift in consumer preferences:

| Device Type | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|
| *Traditional PCs (Desk-Based and Notebook)* | 220 | 204 | 193 | 187 |
| *Ultramobiles (Premium)* | 50 | 59 | 70 | 80 |
| **PC Market** | **270** | **262** | **264** | **267** |
| *Ultramobiles (Tablets and Clamshells)* | 169 | 160 | 159 | 156 |
| **Computing Devices Market** | **439** | **423** | **423** | **423** |
| *Mobile Phones* | 1,893 | 1,855 | 1,903 | 1,924 |
| **Total Devices Market** | **2,332** | **2,278** | **2,326** | **2,347** |

Note: The *Ultramobile (Premium)* category includes devices such as Microsoft's Windows 8 Intel x86 products and Apple's MacBook Air.
The *Ultramobile (Tablets and Clamshells)* category includes devices such as, iPad, iPad mini, Samsung Galaxy Tab S 10.5, Nexus 7 and Acer Iconia Tab 8.

- The reason may be an increasing focus on energy efficiency and weight.

[Gartner2018a]

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# Worldwide Device Shipments by Segment – 2019 View

In 1.000 Units

| Device Type | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|
| *Traditional PCs (Desk-Based and Notebook)* | 195,317 | 189,472 | 182,823 | 175,058 |
| *Ultramobile (Premium)* | 64,471 | 68,869 | 74,432 | 79,871 |
| **PC Market** | **259,787** | **258,341** | **257,255** | **254,929** |
| *Ultramobiles (Basic and Utility)* | 149,561 | 147,963 | 145,811 | 143,707 |
| **Computing Devices Market** | **409,348** | **406,304** | **403,066** | **398,636** |
| *Mobile Phones* | 1,811,922 | 1,802,628 | 1,824,628 | 1,798,356 |
| **TOTAL** | **2,221,270** | **2,208,697** | **2,227,694** | **2,196,992** |

- Note: The *Ultramobile (Premium)* category includes devices such as Microsoft's Windows 10 Intel x86 products and Apple's MacBook Air.
  The *Ultramobile (Basic and Utility Tablets)* category includes devices such as, iPad, iPad mini, Samsung Galaxy Tab S2, Amazon Fire HD, Lenovo Yoga Tab 3, Acer Iconia One.

[Gartner2019a]

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# Worldwide Device Shipments by Segment – 2022 View

In 1.000 Units

| Device Type | 2020 | 2021 | 2022 |
|---|---|---|---|
| *Traditional PCs (Desk-Based and Notebook)* | 178.279 | 169.891 | 161.672 |
| *Ultramobiles (Premium)* | 72.529 | 76.789 | 80.036 |
| **Total PC Market** | **250.807** | **246.680** | **241.708** |
| *Ultramobiles (Basic and Utility)* | 138.712 | 134.255 | 132.465 |
| **Computing Device Market** | **389.519** | **380.935** | **374.173** |
| *Mobile Phones* | 1, 776.779 | 1, 771.242 | 1, 756.936 |
| Total Market | 2, 166.298 | 2, 152.177 | 2, 131.109 |

- Note: The *Ultramobile (Premium)* category includes devices such as Microsoft's Windows 10 Intel x86 products and Apple's MacBook Air.
  The *Ultramobile (Basic and Utility Tablets)* category includes devices such as, iPad, iPad mini, Samsung Galaxy Tab S2, Amazon Fire HD, Lenovo Yoga Tab 3, Acer Iconia One.

[Gartner2022]

# “Fair” and ecologically friendly Mobile Devices

- Grounded in the idea to develop and market smartphone hardware and software designed and produced with minimal harm to people and planet.

FAIRPHONE

- Strict observation of:
  - Type of raw materials (ecological aspects)
  - Origin of raw materials (political aspects)
  - Lifespan of components and easy repair (durability aspects)
  - Upgradeable through modularization

FAIRPHONE

[Source: news.phonebloks.com]

It is *“not possible to produce a 100% fair phone yet, but by aiming toward this end seeks to raise awareness among consumers and in the mobile industry.”* [Wiki2013]

PHONEBLOKS

Based on [Tage2013, Heise15]

# “Fair” and ecologically friendly Mobile Devices

- **Fairphone 1** out of stock
  - **25,000** from the first batch of Fairphones sold in 2013.
  - **35,000** from the second batch of Fairphones on sale in 2014.
- **Fairphone 2**

[www.fairphone.com/about/]

FAIRPHONE

  - Over **65,310** phones delivered by the end of 2017.
  - More available on the online shop and from some retail partners

[Fairphone2016, Fairphone2017]

| Model | Release Date |
|---|---|
| Fairphone 1 | Dec 2013 |
| Fairphone 2 | Dec 2015 |
| Fairphone 3 | Sep 2019 |
| Fairphone 3+ | Sep 2020 |
| Fairphone 4 | Sep 2021 |

[Wiki2022]
[Fairphone2022]

- Introduction
- Categorisation of Mobile Devices
- Components of Mobile Devices
  - Accumulators
  - Processors, Memory, and Storage
  - Display
  - Means for I/O

- Categorisation is possible by:
  - Technical characteristics
  - Application aspects
    - Lifespan of an application
    - Functional completeness (Is the functionality comparable to a desktop PC/Laptop?)
    - Size of the device
    - Security features

# Categorisation of Mobile Devices

## Technical Characteristics

- Hardware independence
  - Independent devices
  - Devices with external communication
  - Devices with external security modules
  - Devices with external memory
- Operating system – Characteristics
  - Memory security, file security, access control
  - Security module support, secure I/O, program and system integrity

# Categorisation of Mobile Devices

## Application Aspects 1

- Lifespan of an application
  - Battery consumption, amount of data, and size of memory
  - Data integrity, amount of communication, and costs
- Completeness of the functionality for the end-user
  - Information / Reaction
  - Limitations due to device size
  - Feature Sets

# Categorisation of Mobile Devices

## Application Aspects 2

- Device size
  - Small / integrated devices
  - „Pocket-sized“
  - „Tablet-sized”
  - „Laptop-sized“
- Access to the security module
  - Data integrity, encryption
  - Digital signatures
  - Access control, authentication

# Use Cases

- Different requirements for different kinds of devices:

| | Mobile Phone | Tablet | Laptop |
|---|---|---|---|
| *Number of „Switch-ons“ per day* | low | low | variable |
| *Frequency of use cases* | very high | rather low | low |
| *Duration of usage per task* | variable | short/ medium | high |

Based on [Burckhardt2001]

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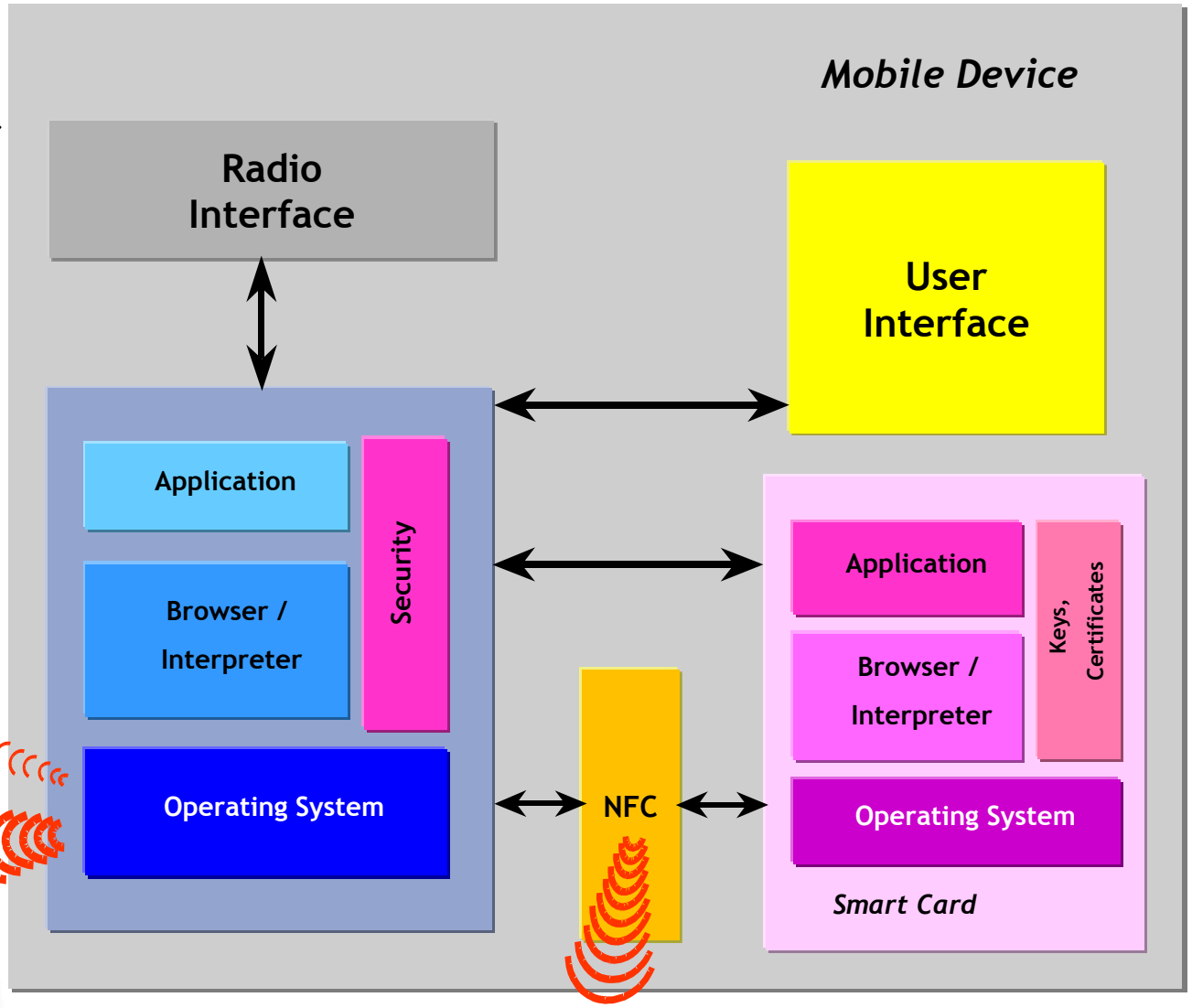
# Functional Architecture




Based on [Posegga2001]

# Size of a Mobile Device

- The size of a mobile device is considerably determined by its:
  - Input Facilities (e.g. keyboard)
  - Output Facilities (e.g. display)

➲ Separation of components (e.g. display in the watch, head-mounted-displays)

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# Accumulators

| Mobile phone | Standby time (in h) | Talk time (in min) | Capacity (in mAh) | Display |
|---|---|---|---|---|
| Nokia 6310 (2001)  | 408 | 360 | Li-Polymer; 1.100 mAh | Graphic 96 x 65 |
| Nokia N-Gage (2004)  | 240 | 120 | Li-Ion; 850 mAh | Color 176 x 208 4.096 colours |
| MDA pro (2005)  | 260 | 480 | Li-Polymer; 1.620 mAh | Touch TFT 640 x 480 65.536 colours |
| T-Mobile Ameo (2007)  | 300 | 240 | Li-Ion; 2200 mAh | Touch TFT 640 x 480 65.536 colours |
| Apple iPhone 4 (2010)  | 300 | 420 (3G) - 840 (2G) | Li-Polymer; 1420 mAh | Touch TFT 960 x 640 16.7m colours |
| Apple iPad Air 2 (2014)  | *Up to 9 hours of surfing the web using 3G data network (10 hours with WiFi)* | | Li-Polymer; 7,340 mAh | Touch TFT 2048 x 1536 16.7m colours |
| Apple iPhone 6S (2015)  | *Talk time: Up to 14 hours on 3G* *Internet use: Up to 10 hours on 3G, up to 10 hours on LTE, up to 11 hours on Wi-Fi* | | Li-Polymer; 1,715 mAh | LED-backlit LCD, capacitive touchscreen, 16m colours |
| Apple iPhone 7 (2016)   | *Talk time: Up to 14 hours on 3G* *Internet use: Up to 12 hours on 3G/LTE, Up to 14 hours on Wi-Fi* | | Li-Ion; 1960 mAh | 4.7-inch (diagonal) LED-backlit widescreen, 1334 x 750 |

# Accumulators

| Mobile phone | Standby time (in h) / Talk time (in min) | Capacity (in mAh) | Display |
|---|---|---|---|
| Apple iPhone 8 (2017)  | *Talk time (wireless): Up to 14 hours*<br>*Internet use: Up to 12 hours* | Li-Ion;<br>1,821 mAh | 4.7-inch (diagonal) widescreen LCD Multi-Touch display with IPS technology<br>1334 x 750 |
| Apple iPhone X (2017)  | *Talk time (wireless): Up to 21 hours*<br>*Internet use: Up to 12 hours* | Li-Ion;<br>2,716 mAh | 5.8-inch (diagonal) all-screen OLED Multi-Touch displayHDR display<br>2436 x 1125 |
| Apple iPhone XR (2018)  | *Talk time (wireless): Up to 25 hours*<br>*Internet use: Up to 15 hours* | Li-Ion;<br>2942 mAh | 6.1-inch (diagonal) all-screen LCD Multi-Touch display with IPS technology<br>1792 x 828 |
| iPhone XS / **XS Max** (2018)  | *Talk time (wireless): Up to 25 hours*<br>*Internet use: Up to 15 hours* | Li-Ion;<br>3174 mAH | 6.5 inch Super Retina HD display<br>2688 x 1242 |

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# Accumulators

| Mobile phone | Video Playback (in h) | Audio Playback (in h) | Capacity (in mAh) | Display |
|---|---|---|---|---|
| iPhone 11 / 11 Pro / **11 Pro Max** (2019)  | *Video playback up to 20 hours, video playback (streamed) up to 12 hours, and audio playback up to 80 hours* | | Li-Ion; 3969 mAH (Fast charge) | 6.5 inch Super Retina XDR OLED display 2688 x 1242 |
| iPhone 12 / 12 Pro **/ 12 Pro Max** (2020)  | *Video playback up to 20 hours, video playback (streamed) up to 12 hours, and audio playback up to 80 hours* | | Li-Ion; 3687 mAH (Fast charge) | 6.7 inch Super Retina XDR OLED display 2778x1284 |
| iPhone 13 / 13 Pro **/ 13 Pro Max** (2021)  | *Video playback up to 28 hours, video playback (streamed) up to 25 hours, and audio playback up to 95 hours* | | Li-Ion; 4352 mAH (Fast charge) | 6.7 inch Super Retina XDR OLED display 2778x1284 |
| iPhone 14 / 14 Pro **/ 14 Pro Max** (2022)  | *Video playback up to 29 hours, video playback (streamed) up to 25 hours, and audio playback up to 95 hours* | | Li-Ion; 3687 mAH (Fast charge) | 6.7 inch LTPO Super Retina XDR OLED 2796x1290 |

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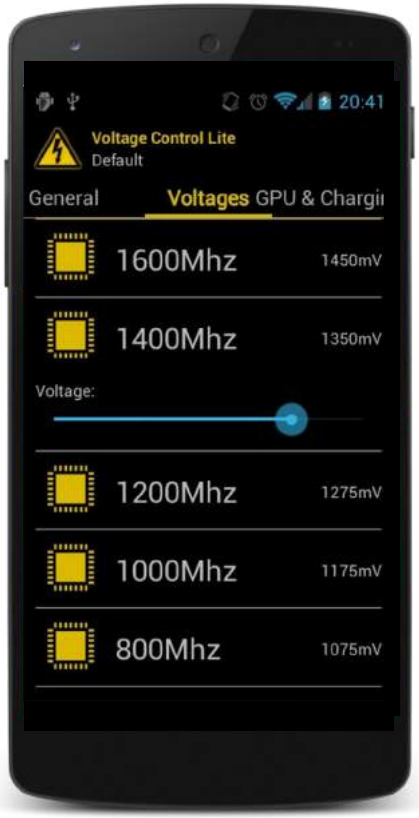
# Processors

- Performance increase
  - Higher clock frequency (but frequency scaling typically comes at the price of higher voltage!)
  - Larger on-die-caches (cache memory) built into the CPU (“on die”) to reduce memory access time
- Power consumption decrease
  - Processor's core voltage (1995: 3.5 V; 2000: 1.35 V; 2013: 1.0 V; 2022: 0.9-1.3V)
    - Lower bound is the voltage needed to switch a transistor
    - Quadratic relationship between voltage and power consumption

➲ Less heat loss

- Power Management
  - triggered by changes of the energy supply




Picture source: “Voltage Control” Application (Google Play Store) by darek.xan

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# Processors

## Overview of Mobile Devices

| Logo | Device | Processor | Mhz | MIPS |
|---|---|---|---|---|
|  | Nokia N-Gage (2004) | ARM7 | 104 | ?? |
|  | HTC/T-Mobile MDA (2002) | Intel StrongARM | 206 | 274 |
|  | Apple iPhone 4, iPad (2010) | Apple A4 | 800 (iPad: 1000) | 2.000 |
|  | Notebook (2006) | Intel CoreDuo Processor | 2.000 | < 14.000 |
|  | Notebook (2010) | Intel Core i7 Quad-Core | 3.600 | > 20.000 |
|  | Apple iPad Air 2 (2014) | Apple A8X | 1.500 (Triple-core) | ?? |
|  | Apple iPhone 6S (2015) | Apple A9 | 1,800 (Dual-core) | ?? |
|   | Apple iPhone 7 (2017) | Apple A10 | 2,300 (Quad-core) | ?? |

# Processors

## Overview of Mobile Devices

| Logo | Device | Processor | Mhz | MIPS |
|---|---|---|---|---|
|  | Apple iPhone 8 (2017) | Apple A11 Bionic | 2,39 (Hexa-core) | ?? |
|  | Apple iPhone X (2017) | Apple A11 Bionic | 2,39 (Hexa-core) | ?? |
|  | Apple iPhone XR (2018) | Apple A4 | 2,49 (Hexa-core) | ?? |

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# Processors

## Overview of Mobile Devices

| Logo | Device | Processor | Mhz | MIPS |
|---|---|---|---|---|
|  | iPhone 11 / 11 Pro / **11 Pro Max** (2019) | Apple A13 Bionic (7 nm+) | Hexa-core (2x2.65 GHz Lightning + 4x1.8 GHz Thunder) | |
|  | iPhone 12 / 12 Pro **/ 12 Pro Max** (2020) | Apple A14 Bionic (5 nm) | Hexa-core (2x3.1 GHz Firestorm + 4x1.8 GHz Icestorm) | |
|  | iPhone 13 / 13 Pro **/ 13 Pro Max** (2021) | Apple A15 Bionic (5 nm) | Hexa-core (2x3.23 GHz Avalanche + 4x1.82 GHz Blizzard) | |
|  | iPhone 14 / 14 Pro **/ 14 Pro Max** (2022) | Apple A16 Bionic (4 nm) | Hexa-core (2x3.46 GHz Everest + 4x2.02 GHz Sawtooth) | |

# Memory

- General trade-off between storage on the server vs. storage on the client
- Storage on the client
  - Subscriber Identity Module (SIM)
  - Random Access Memory (RAM)
  - Memory cards
  - Microdrives



- Introduction
- Categorisation of Mobile Devices
- Components of Mobile Devices
  - Accumulators
  - Processors, Memory, and Storage
  - Display
    - Liquid-Crystal-Displays (LCD)
    - Organic Light Emitting Diodes (OLED)
  - Means for I/O

# Display
## Liquid-Crystal-Displays (LCD)

- The LCD technology is widespread in the market.
- “Consists of an array of tiny segments (called pixels) that can be manipulated to present information“
- Examples:
  - Dual Scan Twisted Nematic (DSTN)
  - Thin-film Transistor (TFT)


Example: Dynasheet (Toshiba)
1cm, 200g, 2005

# Display
## Liquid-Crystal-Displays (LCD)

- DSTN-Display (Dual Scan Twisted Nematic)
  - Passive matrix
  - LCD displays with passive control have a relatively high latency (generally more than 100 ms). This implies a blurred image with frequently changing picture elements.
- TFT-Displays (Thin Film Transistor)
  - Active (transistor for each pixel)

mobile business

# Display
## Resolution

| Logo | Mobile phone | Display | Resolution | Colours |
|---|---|---|---|---|
|  | Nokia 6310 (2001) | Graphic | 96 x 65 | none |
|  | Siemens S55 (2002) | Color | 101 x 80 | 256 |
|  | Nokia N-Gage (2004) | Color | 176 x 208 | 4.096 |
|  | Samsung E700 (2003) | TFT-Color | 160 x 128 | 65.536 |
|  | MDA III (2004) | Touch TFT | 320 x 240 | 65.536 |
|  | MDA Pro (2005) | Touch TFT | 640 x 480 | 65.536 |
|  | T-Mobile Ameo (2007) | Touch TFT | 640 x 480 | 65.536 |
|  | Apple iPhone 4 (2010) | Touch TFT | 960 x 640 | 16.7m |
|  | Apple iPad 2 (2010) | Touch TFT | 1024 x 768 | 16.7m |
|  | Apple iPad 3 (2012) | Touch TFT | 2048 x 1536 | 16.7m |
|  | Apple iPad Pro (2015) | Touch TFT | 2732 x 2048 | 16.7m |
|  | Apple iPad Pro 2 (2017) | Touch TFT | 2732 x 2048 | 16.7m |

mobile business

# Display
## Resolution

| Logo | Mobile phone | Display | Resolution | Colours |
|---|---|---|---|---|
|  | Apple iPhone X (2017) | AMOLED | 2436 x 1125 | ?? |
|  | Samsung Galaxy S10 (2019) | AMOLED | 3040 x 1440 | ?? |
|  | iPhone 11 / 11 Pro / **11 Pro Max** (2019) | Super Retina XDR OLED | 2688 x 1242 | |
|  | iPhone 12 / 12 Pro **/ 12 Pro Max** (2020) | Super Retina XDR OLED | 2778 x 1284 | |
|  | iPhone 13 / 13 Pro **/ 13 Pro Max** (2021) | Super Retina XDR OLED | 2778 x 1284 | |
|  | iPhone 14 / 14 Pro **/ 14 Pro Max** (2022) | LTPO Super Retina XDR OLED | 2796 x 1290 | |

# Display

## Organic Light Emitting Diodes (OLED)

- Polymers can convert electric energy to light.
- Complete layer is thinner than 500 nm (0.5 thousandth part of one mm), luminosity approx. 100W electric bulb.
- 180° viewing angle

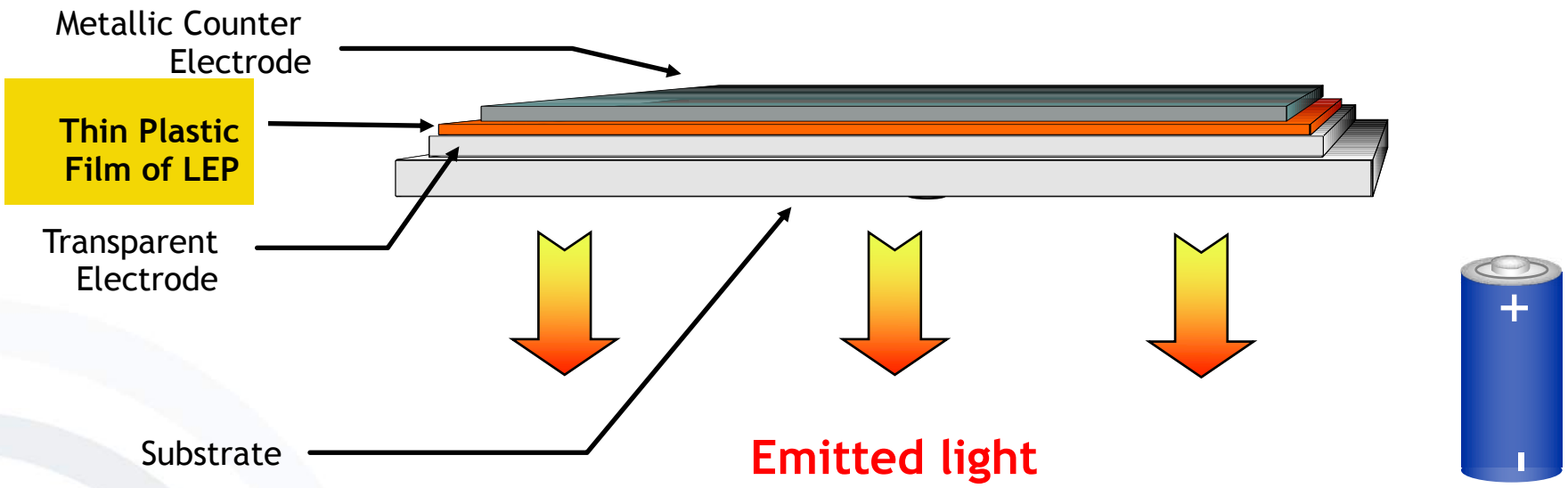
www.opto.com.tw

https://upload.wikimedia.org/wikipedia/commons/0/0b/OEL_right.JPG

# Display
## Advantages of OLED

- OLED consist of self lighting polymer molecules:
  - No background lighting is necessary
  - Electric power consumption decreases and longer usage times become possible.
  - Space for extra components
  - Devices can be thinner and lighter.

# Light Emitting Polymer Device




[Covion2006]

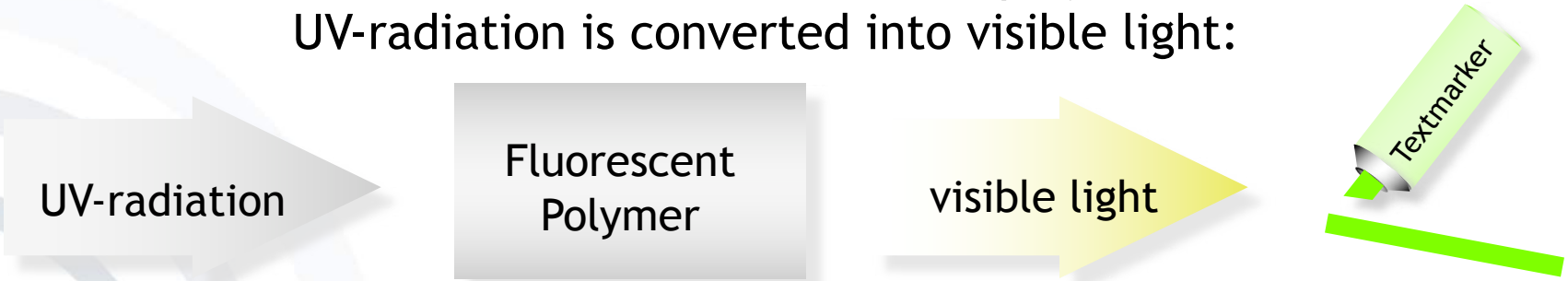
# Display

## Organic Light Emitting Diodes (OLED)

- Polymers are large molecules widely known as plastics.
- *Light Emitting Polymers (LEPs)* are special plastic materials that convert electrical power into visible light.
- A thin film of *Light Emitting Polymer* put between two electrodes will glow ...

***Light Emitting Polymers*** convert electrical power into visible light:

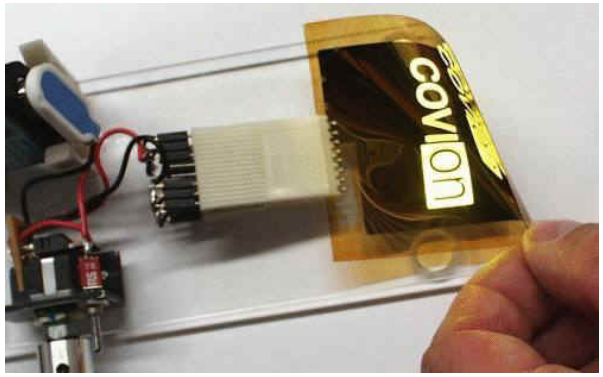

This is related to the fluorescence of polymers where UV-radiation is converted into visible light:




[Covion2006]

# Display
## Organic Light Emitting Diodes (OLED)

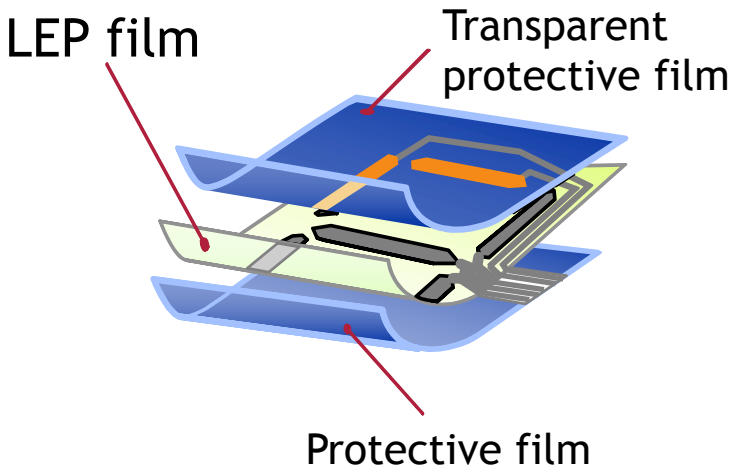
- Because plastic materials are flexible and robust even non-planar displays can be manufactured ...






*Samsung Galaxy Round (2013 in Korea)*

[Samsung2013]




[Covion2006]

# Types of OLED

- Two main types (based on the driving electronics)
  - PMOLED (Passive-Matrix OLED)
    - Simpler electronics, no storage capacitor
    - Lower cost
    - Lower lifetime (due to the higher voltage needed)
    - Limited size and resolution
    - Mostly used for simpler displays, e.g. mp3 players, mobile phone sub-displays, etc.
  - AMOLED (Active-Matrix OLED)
    - Contains storage capacitor to maintain the pixel line state
    - No restrictions on size and resolution
    - More costly
    - Used for higher quality screens, such as mobile phones (Blackberry Priv, HTC One A9, Samsung Z3, Samsung Galaxy S10, Microsoft Lumia 950 XL, Apple iPhone X, etc.)

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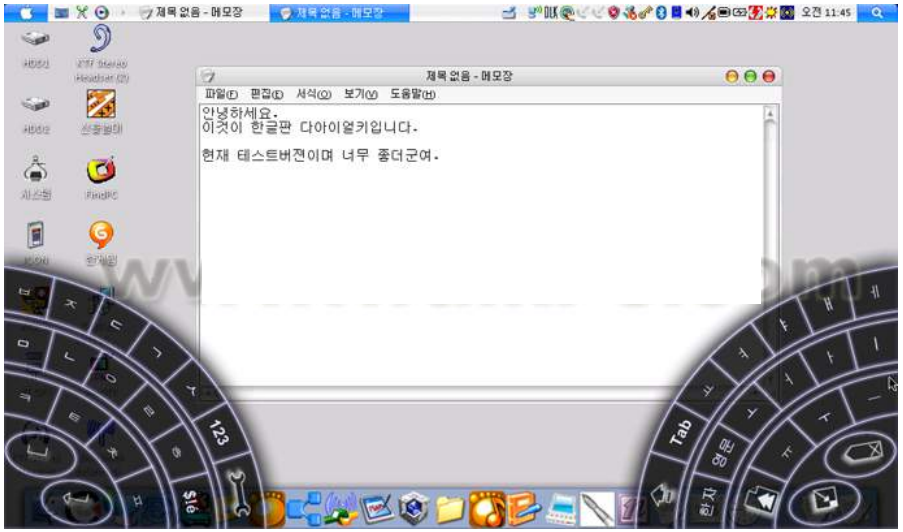
    - Device Input
    - Personal Area Networks (PAN)

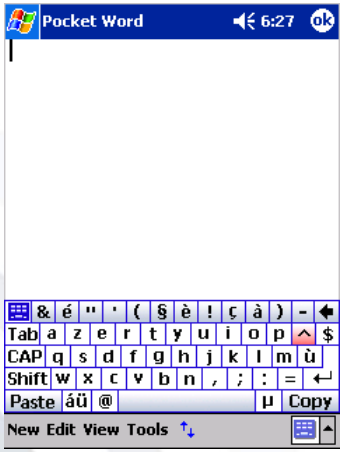
Currently, the following input solutions for mobile devices exist:

- QWERTY-Keyboard
- Palm-Graffiti
- Tegic T9
- Octave
- SWYPE
- Recognition of handwriting
- Speech recognition

mobile business

# Input
## QWERTY-Keyboards


# Input
## PALM Graffiti

- Handwriting recognition software
- Artificial script, based on upper-case characters
- Can be drawn blindly with a stylus on a touch-sensitive panel

# Input

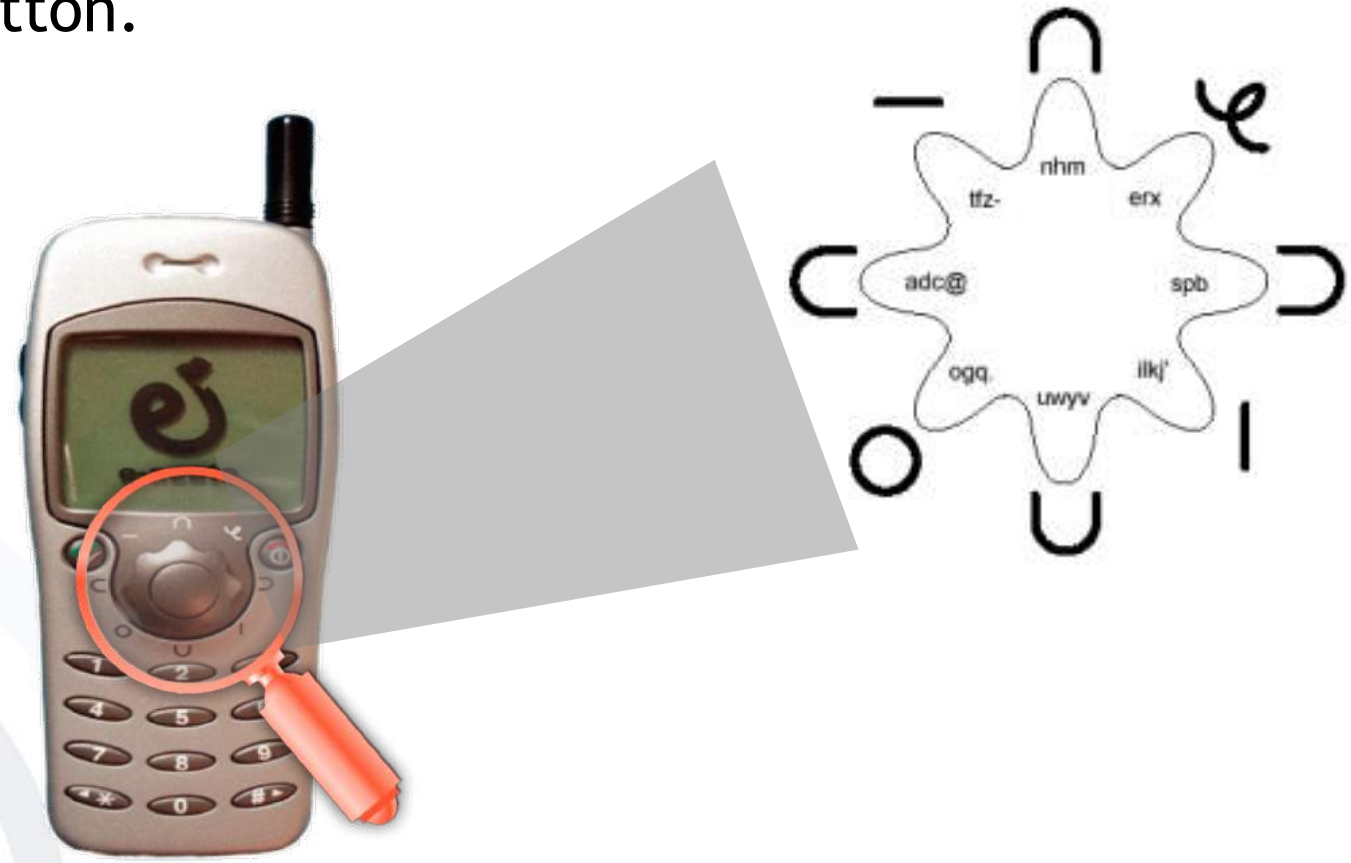
## Tegic Communications T9

- T9 (*Text on **9** keys)* is a predictive text technology developed by Tegic Communications.
- Widely used by: LG, Samsung, Nokia, Siemens, Sony Ericsson, Sanyo
- Uses a dictionary of words, which is used to look up all the possible words, corresponding to the sequence of keypresses.
- Available in 27 languages

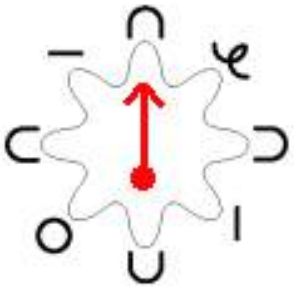

[T92006]

# Input
## Octave

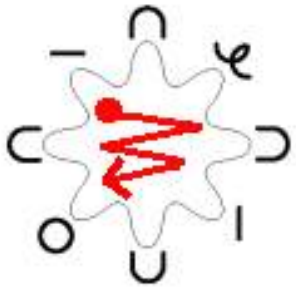
- Characters can be input by either pen or button.



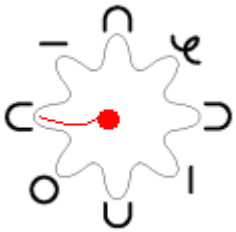
# Input
## Octave



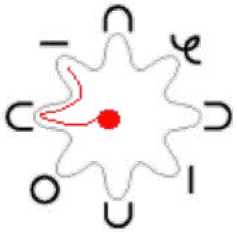
“capital letters”



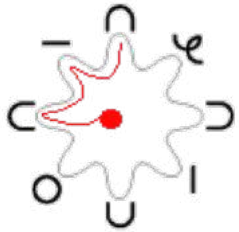
“reset”



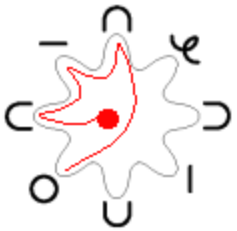
a·



at·



ath·ens



atmo·sphere

# Input
## SWYPE

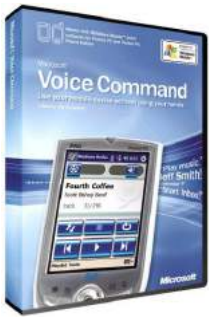

[http://swypeinc.com/product.html]

- Input by sliding a finger or stylus from letter to letter, lifting only between words
- Word is guessed using error-correcting algorithms and language model
- Developed by Swype Inc.
- First commercially available on Samsung Omnia II (on Windows Mobile 6.5), also available for Android

# Input
## Speech Recognition

- Translation of spoken words into text
- Supports various applications, e.g. for
  - initiation of phone calls
  - message composition
  - …
- Originally performed directly on PDAs/smartphones
- Nowadays usually provided as a cloud service
  - Voice is recorded and compressed
  - Sound file is sent to a server where the actual recognition process is performed
  - Text is sent back to smartphone
- Examples
  - Apple Siri
  - Google Now
  - Samsung S-Voice
  - Amazon Alexa
  - Windows Phone Voice Control
  - Blackberry 10 Voice control
  - …
- May become important feature for smart watches
- In contrast, term *voice recognition* refers to *identity* of the speaker, not *what* is said.


[Source: Wikipedia]






[Source: Samsung]

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# Personal Area Network (PAN)

- Personal environment, short range
- ***Purpose***: Connection of devices in short range, for example mobile device and printer.
- Replaces cable-connections:
  - **I**nfra**r**ed **D**ata **A**ssociation (IrDA)
  - Bluetooth
  - Near Field Communication (NFC)

# Personal Area Network (PAN)
## Infrared

- IrDA: Infrared Data Association (1993):
- Standardized infrared-protocols
- Asynchronous, serial connections up to 115 kbit/s (Serial Infrared) or 4 Mbit/s (Fast Infrared)
- Point-to-Point
- Protocol-family for various purposes

- Exemplary applications:
  - Transmission of mobile business cards
  - Sales data extraction from cigarette vending machines
  - Connection between mobile and laptop
  - Wireless printing
  - Remote control for consumer electronics, e.g. TVs

# Personal Area Network (PAN)

## Infrared

- Attributes:
  - Wireless
  - Range of up to 10 meters
  - Illumination-angle 15 – 30 degrees
- Disadvantages:
  - **Sounding:** If the infrared-ray misses the target
  - Optical connection required
  - Short interruptions of the optical connection, e.g. between laptop and mobile phone in trains, lead to complete network-interruption.

# Personal Area Network (PAN)

## Bluetooth

- Frequency range of 2.4 GHz
- Simple and cheap possibility to set up ad-hoc networks of limited range (up to 10 meters)
- No official standard, but de-facto-standard
- Consortium: Ericsson, Intel, IBM, Nokia, Toshiba, etc.
- v5 (2016) improved speed, privacy, and connectivity (support for the Internet of Things)
- Broadly supported by related industries:
  - Computer hardware
  - Software
  - Consumer electronics
  - …

Bluetooth™

# Personal Area Network (PAN)

## Popular Bluetooth Applications

Sound transmission
(to earphones, headphones
or Hi-Fi equipment)

Wireless communications between devices
(Bluetooth-Headset)

# Personal Area Network (PAN)

## Bluetooth Applications

- Connection of periphery-devices (headsets, keyboards, mice, etc.)
- Setting up of ad-hoc networks for spontaneous data exchange
- Ad-hoc connection of different networks (e.g. laptop ⇔ mobile or phone ⇔ GSM ⇔ net)
- Applications similar to applications based on infrared technology
- Weaknesses of infrared technology were overcome
  - Increased bandwidth (up to 865.2KBit/s)
  - No optical connection between devices necessary
  - Expanded range (up to 10m)
  - Allows setting up of ad-hoc networks instead of point-to-point connections

# Personal Area Network (PAN)

## Near Field Communication (NFC)

- Enables radio communication between
  - two NFC compatible devices (two active devices),
  - An (active) NFC device and an (unpowered, passive) tag
- NFC based on existing radio-frequency identification (RFID) standards
- Range: 10 cm or less
- Transfer rates between 106 kbit/s and 424 kbit/s
- Three major modes of NFC
  - Reader/Writer Mode
  - Card Emulation Mode (referred to as "Digital Wallet")
  - Peer-to-Peer Mode


[NFC]

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