Why and what you need to know about 6G in 2022

5G Advanced is establishing our early vision and the technical foundation for 6G in 2030 and beyond.
There is a rich roadmap of 5G technologies coming with the 5G Advanced evolution.

Agenda

6G will be the future wireless innovation platform for 2030 and beyond.

6G will be more than a new radio, expanding AI, sensing in the connected intelligent edge.

We are leading cutting-edge wireless research across six technology vectors on the path to 6G.

Why and what you need to know about 6G in 2022:

5G Advanced is establishing our early vision and the technical foundation for 6G in 2030 and beyond.
Driving digital transformation across industries

5G will enable $13.1 Trillion in global sales activities in 2035

Source: The 5G Economy, an independent study from IHS Markit, commissioned by Qualcomm Technologies, Inc., November 2020
Qualcomm is leading the realization of the connected intelligent edge.

Convergence of:
- Wireless connectivity
- Efficient computing
- Distributed AI

Unleashing massive amount of data to fuel our digital future

To scale efficiently, AI processing is expanding towards the edge.
5G Advanced on the path to 6G

5G Advanced
- A unified platform for innovations
- 2nd wave of 5G innovations

5G Advanced on the path to 6G
- Continued 5G evolution in the 6G era
- Next technology leap for new capabilities and efficiencies

Foundational research → Vision forming → Service requirements → Study Item (proposals) → Work Item Trials → IoDTs

Rel-15 → Rel-16 → Rel-17 → Rel-18 → Rel-19 → Rel-20 → Rel-21

3GPP 6G Workshop

2018 → 2019 → 2020 → 2021 → 2022 → 2023 → 2024 → 2025 → 2026 → 2027 → 2028 → 2029 → 2030+
Driving a balanced 5G Advanced evolution across key technology areas

Mobile broadband evolution and further vertical expansion
Deliver enhanced mobile broadband experiences and extend 5G’s reach into new use cases

Immediate commercial needs and longer-term 5G vision
Drive new value in commercialization efforts and fully realize 5G’s potential with future deployments

New and enhanced devices and network evolution
Focus on the end-to-end technology evolution of the 5G system to bring new levels of performance

Release 18 starts the 5G Advanced evolution and it prepares for new and enhanced features coming in subsequent releases
3GPP Release 18 sets off the 5G Advanced Evolution

Strengthen the end-to-end 5G system foundation

- Advanced DL/UL MIMO
- Mobile IAB, smart repeater
- Evolved duplexing
- AI/ML data-driven designs
- Green networks

Proliferate 5G to virtually all devices and use cases

- Enhanced mobility
- Boundless extended reality
- Expanded sidelink
- Expanded positioning
- Drones & expanded satellites comm.
- Multicast & other enhancements

Learn more about 3GPP Release 18
Key market trends and technology drivers leading the way to 6G

- Core technology advancements
- Environmental and societal sustainability
- Enhanced and new experiences
Key market trends and technology drivers leading the way to 6G

Core technology advancements

- Advanced RF
- Compute topology
- Machine learning and AI
- Silicon / material
- Extreme disaggregation
- Multimedia / display
- Perception / human interface
- Power management
- Others…
Key market trends and technology drivers leading the way to 6G

Environmental and societal sustainability

- Wireless ecosystem reach to fuel sustained global economic growth
- System design to consciously minimize environmental impact
- More accessible networks, devices, services to promote digital equality
Key market trends and technology drivers leading the way to 6G

Enhanced and new experiences

- Fixed and mobile broadband to further evolve bringing next-generation experiences
- Digital twins to more accurately model the physical world continuing to derive new values
- Metaverse to further augment the physical world creating next-level immersivity
Propelling next-level experiences and innovative use cases in the new era of the connected intelligent edge for 2030 and beyond

- Enhanced boundless XR experiences
- Wireless sensor fusion
- Collaborative robots, real-time command and control
- Hologram telepresence
- Human augmentation and digital twins
- Fixed and mobile broadband evolution
- Critical services expansion
- Ultra-wide area to micro connectivity
- Fixed and mobile broadband evolution
- Smarter verticals
- Critical services expansion
- Collaborative robots, real-time command and control
- Hologram telepresence
- Ultra-wide area to micro connectivity
- Fixed and mobile broadband evolution
- Smarter verticals
A smarter wireless platform to support enhanced services and new use cases
A smarter wireless platform with new capabilities that expand beyond communication.
6G will be designed to meet enhanced traditional communication requirements as well as KPIs for new capabilities.
Designing 6G to meet a diverse set of system requirements

Further enhancing foundational wireless performance vectors (e.g., capacity, data rate, latency)

Introducing new dimensions (e.g., user experience, positioning capability, ease of onboarding)
Key longer-term research vectors enabling the path towards 6G
Key longer-term research vectors

enabling the path towards 6G

AI-native E2E communications
Data-driven communication and network design, with joint training, model sharing and distributed inference across networks and devices

Expanding into new spectrum bands
Expanding to THz, wide-area expansion to higher bands, new spectrum sharing paradigm, dynamic coordination with environmental awareness

Merging of worlds
Physical, digital, virtual, immersive interactions taking human augmentation to next level via ubiquitous, low-power joint communication and sensing

Scalable network architecture
Disaggregation and virtualization at the connected intelligent edge, use of advanced topologies to address growing demand

Air interface innovations
Evolution of duplexing schemes, Giga-MIMO, mmWave evolution, reconfigurable intelligent surfaces, non-terrestrial communications, waveform/coding for MHz to THz, system energy efficiency

Communications resiliency
Multifaceted trust and configurable security, post quantum security, robust networks tolerant to failures and attacks
Advancement in AI is making Wireless better:
- Elevated level of performance
- More efficient resource utilization
- Energy reduction for longer battery life
- Personalized security and privacy
- Continuous enhancements over time
- New and enhanced system capabilities

Proliferation of cellular is making AI better:
- Responsive user experiences and services
- Lifelong learning
- Flexibility for distributed functionality across devices
- On-device intelligence assisted by cloud
- Scale intelligence through distributed learning
- Massive data aggregation for improved AI models

5G and AI are working together to accelerate innovations
Evolving towards native wireless AI/ML

Multiple wireless AI/ML training and inference scenarios

**Overlay AI/ML**
- Independently at the device or network
- No collaboration
- Network ML
- On-device ML
- ML operates independently at the device and network as an optimization of existing functions
- Proprietary ML procedures including model development and management
- Proprietary and standardized data collection used as input to training

**Cross-node AI/ML**
- Coordinated between device and network
- Device and cloud APIs work together for best functionality
- ML operates in a coordinated manner between the device and network
- Proprietary and standardized ML procedures including model development and management
- Further data collection used as input to training as well as monitoring

**Native AI/ML**
- At all device and network layers
- Device and network exchange control/input across all layers
- ML operates autonomously between the device and network across all protocols and layers
- Integrated ML procedures across to train performance and adapt to different environments
- Data fusion for integrated dynamic ML lifecycle management
6G system targets all spectrum types and bands

Critical for the success of next-generation wireless systems

**Coverage**

- **Low bands**
  - below 1GHz
- **Mid-bands**
  - 1GHz – 7GHz
- **Upper mid-bands**
  - 7GHz – 24GHz
- **mmWave bands**
  - 24GHz – 100 GHz
- **Sub-THz bands**
  - 100GHz & beyond

**Capacity**

- **Licensed spectrum**
  - Exclusive use of spectrum that remains the industry’s top priority
- **Unlicensed spectrum**
  - Shared use of more available spectrum
- **Shared spectrum**
  - Evolving spectrum sharing that allow fair and more efficient sharing
New upper mid-band brings order of magnitude more wide-area capacity

Larger contiguous bandwidths can bring efficiencies, fuel growing data demand, and enable new applications

- Delivering new capacity for wide-area broadband (e.g., smartphones, smart cities, automotive, verticals)
- Fueling scalable boundless XR user support in wide area through wider bandwidth availability
- Supporting high-resolution RF sensing for new use cases (e.g., environmental monitoring, activity detection)

Upper Mid-Band
7 to 24 GHz

Best of wide-area coverage of sub-7 GHz and wide-band capacity of mmWave
Continuous expansion and enhancement of mobile mmWave technologies

Building on the solid foundation of 5G NR

Coverage
Innovations to overcome significant path loss in mmWave bands

Beam management
Innovations to beam pairing, tracking and recovery

Device size/power
Innovations to optimize mmWave design for smartphone form factor

Robustness
Innovations to overcome blockage from hand, body, walls, foliage, etc.

Topology enhancement
Innovations to efficiently scale and densify the network
Making sub-Terahertz spectrum viable for communications and beyond

Building on our mmWave experience to address key system challenges at higher band spectrum

Use case feasibility
Evaluating diverse use case, form factor requirements and how sub-THz can deliver an effective solution

System design
Building early prototypes to overcome implementation challenges (i.e., device formfactor, power consumption, etc.)

Propagation loss
Advancing intelligent beamforming to overcome indoor path loss, penetration loss, foliage loss, and others
<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlocking new spectrum</td>
<td>that may require non-exclusive licensing and sharing with primary users</td>
</tr>
<tr>
<td>Designing for efficient and coordinated spectrum sensing / sharing</td>
<td>that improves overall system performance</td>
</tr>
<tr>
<td>Leveraging O-RAN architecture</td>
<td>to allow operators to cost-efficiently offer service differentiations (e.g., through RU sharing)</td>
</tr>
<tr>
<td>Utilizing adaptive AI/ML</td>
<td>to address high-mobility scenario and public / private networks coexistence in the same band</td>
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</tbody>
</table>

**Evolution to licensed spectrum sharing for improved efficiency, flexibility, and user experience**
6G XR requirements fueled by digital twins and spatial compute

Digital twins digitize the complex physical world in the metaverse
Spatial compute enables immersive interaction with 3D digital content

100x network capacity
0.1-10 Gbps per user
Use multiple frequency bands
(sub-THz, mmW, sub 7GHz, 7-24GHz, unlicensed, shared spectrum)
6G protocols can natively support distributed compute

- Dynamically distributing workloads
- Delivering low power and low latencies
- Incorporating e2e QoS and session handling

- 6DoF/SLAM
- Hand Tracking
- Facial Expression
- Eye Tracking
- 3D Graphics Rendering
- Scene Understanding
- Objected Rec and Tracking
- Camera Processing

High performance GPU/CPU

<100mW modem+RF
Utilizing existing waveform and other fundamental physical layer designs in existing spectrum (sub-7, mmWave) and new higher-band spectrum (e.g., upper mid-band, THz)

Integrating environmental detection capabilities (e.g., positioning, RF sensing) to enhance quality of service and support emerging applications

Providing cooperative sensing capability across networks (e.g., TRP\(^1\)) and devices, utilizing overall network processing with diverse topology

INTEGRATED TECHNOLOGY PLATFORM THAT CAN
Enable joint communications, positioning, RF sensing, and more
6G technology platform will require a new air interface design
An innovation opportunity to achieve higher capacity, system throughput and efficiency

**Channel Coding**
Advanced channel coding targeting high-throughput, low-power, cost efficient implementation, approaching the theoretical bound on different block length and SNR regimes

**Waveform**
New waveforms and advanced signal processing to deliver higher spectral and power efficiency across a variety of spectrum bands within 6G unified air interface (UAI)

**Multiple Access**
Continuous evolution of scheduled multiple access in conjunction with advanced MIMO, duplexing technologies to support extremely high cell capacity. Development of contention based random access to facilitate scaling up massive large number of devices in cellular system

**Foundational PHY designs are crucial for enabling 6G new features:**

**Advanced RF and baseband joint design**
Supporting wider bandwidth, faster Tx/Rx switching, higher PA efficiency, massive spectrum aggregation across new bands and existing bands

**Efficient modem system implementation**
Modem-RF implementation friendly PHY to facilitate data rate envelope scaling while maintaining superior power efficiency

**Advanced air interface features**
Coevolution of waveform and multiple access with next-gen MIMO, flexible/full duplex

**Extreme energy-efficient devices**
Diverse devices and use cases, ranging from extreme data rate to passive IoT

**Seamless multi-RAT connectivity and spectrum sharing**
Flexibility and efficient multi-RAT (5G/6G) spectrum access and resource sharing over multiple users and multi-RAT connectivity on the same device

**Enabling immersive experience**
Enabling high capacity XR to facilitate immersive metaverse experiences using 6G air interface and new network topology technologies
Driving towards a full duplex wireless system
Lower latency, better coverage, expanded capacity, flexible spectrum deployment and service multiplexing

**Static TDD**
Time aligned to avoid inter-site interference; Time separation to avoid self-interference; Existing 5G systems (i.e., Rel-15) adopt static TDD (and FDD) duplexing

**Subband half duplex (SBHD)**
Frequency aligned to avoid inter-site interference; Time separation to avoid self-interference; Implemented in SD test network (MWC'21)

**Subband full duplex (SBFD)**
Frequency aligned to avoid inter-site interference; Frequency separation + interference cancellation to avoid self-interference; Implemented in SD test network (MWC'22)

**Single frequency full duplex (SFFD)**
Interference cancellation to avoid self-interference; Targeting future simulations, prototyping, and standardization in 6G and beyond

**Self interference mitigation**
Subband half duplex (SBHD) (uplink)
Subband full duplex (SBFD)
Subband half duplex (SBHD) (downlink)
Cross-link interference mitigation

**Duplexing evolution**

**Driving towards a full duplex wireless system**
Lower latency, better coverage, expanded capacity, flexible spectrum deployment and service multiplexing
Giga-MIMO expands network coverage to upper mid-band

Giga MIMO with wide bandwidth and large number of antenna elements (i.e., >2k)
More antenna elements with same aperture, 3-4x wavelength reduction vs. sub-7 GHz
Building on 5G sub-7 GHz and mmWave technologies and approaches

For supporting wide-area use cases in X-band (8–12 GHz) and Ku-band (12–18 GHz)
Global spectrum discussions underway
Experimental licenses e.g., 8.5-9 GHz, 12.75-13.25 GHz
Regional and ITU discussions ongoing for longer term refarming

Best of wide-band mmWave and wide-area sub-7 GHz
GHz bandwidth – 10x more capacity than existing massive MIMO systems
Comparable wide-area coverage to massive MIMO in sub-7 GHz
Higher positioning, radar, and RF sensing resolutions

Note: Part of the spectrum may be studied or supported already in 5G NR Release 19+
Serving more diverse requirements with an evolving topology

Radio access network
- eMBB
- Massive IoT
- V2X
- URLLC
- Boundless XR
- Industrial IoT

Converged Worlds

Regional cloud
- for traditional cloud applications
- Larger service area

Local edge
- for on-prem enterprise and low latency operator services
- Low latency in the local service area

Cell-site edge
- for applications serving converged physical and digital worlds
- Lowest latency

Physical world
- Digital world
- Virtual world

4G

5G

6G
Evolving network architecture towards 6G
Driven by disaggregation and cloudification of tiered services

Cloud-based core network
Core network hosted in public and/or private clouds
Flattening of architecture by moving 5G CU functions to Core in 6G
Applications and Core on same platform crate opportunity for differentiated E2E performance

RAN Intelligent Controller (RIC)
Intelligent optimization via RIC applications from third-parties
Opportunity for network and device side intelligence framework synergy

Virtualized DU and open fronthaul
Virtualized DU with PHY processing in accelerators
Widespread adoption of standards-based fronthaul for interoperable RU
Rapid upgrade cycles on network create opportunity for more upgradable and modular device software

Upgrade for legacy bands
Leverage flexible 5G design to support efficient DSS with 6G
Potential reuse of legacy RU if 6G supports 5G symbol numerology
Easy upgrade of virtualized DU by adding 6G accelerator cards

1 Central unit; 2 Distributed unit; 3 Radio unit
6G will drive diverse deployment topologies and technologies

- Fiber, in-band or out-of-band wireless fronthaul
- Macro cell and small cells co-siting with existing infrastructure (e.g., sub-7 GHz) with Giga-MIMO or mmWave
- Fiber backhaul
- Centralized coordination
- Macro cell and small cells integrated access / backhaul (IAB) and mobile IAB
- In-band or out-of-band wireless
- Simple and smart repeaters
- Intelligent surface (IS) and reconfigurable intelligent surface (RIS)
- Distributed massive MIMO using Radio Units
- Fiber backhaul
- A scalable and distributed network architecture can meet diverse coverage, capacity, and other performance requirements

WLAN integration

RSU
Passive MIMO for coverage extension and improved energy efficiency

Also known as RIS – Reconfigurable Intelligent Surfaces that can support various deployments and use cases

- Providing dynamic control of reflective beam directions with PA-less operations
- Extending coverage for users in challenging locations (e.g., cell-edge, indoors, and with blockage)
- Achieving better network energy efficiency

Expanding the deployment toolbox to efficiently provide broader network coverage

<table>
<thead>
<tr>
<th>Macro cells</th>
<th>Remote radio heads</th>
<th>RF repeaters</th>
<th>Integrated access/backhaul</th>
<th>Smart passive MIMO (IS &amp; RIS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro cells</td>
<td>Small cells</td>
<td>Smart repeaters</td>
<td>Passive MIMO</td>
<td>Other infrastructure options...</td>
</tr>
</tbody>
</table>
Further evolving cellular for non-terrestrial communication

That complements terrestrial communication

5G Rel-15
Study Item focused on deployment scenarios and channel models

5G Rel-17
Work Item focused on supporting satellites and HAPS for eMBB and IoT 1 with enhancements to synchronization, scheduling, HARQ, mobility, and more

6G
Potential focus on delivering an integrated 3D heterogeneous network, where terrestrial infrastructure can be complemented by non-terrestrial ones

5G Rel-16
Study Item focused on solutions for adapting 5G NR to support NTN

5G Rel-18+
Expected to further enhance communications for UAV, HAPS, and satellites

1 eMTC and NB-IoT; 2 Geostationary; 3 Medium Earth Orbit; 4 Low Earth Orbit; 5 Unmanned Aerial Vehicles; 6 High Altitude Platform Station;
Our research focus in 6G security and privacy across all layers

Building on the proven, solid security foundation of 5G

Data security and privacy
Data provenance (e.g., to defeat deep fake)
AI/ML federated learning
Secure multi-party computation
Differential privacy
Homomorphic encryption of secure off device data processing
Zero knowledge proof for data/identity privacy

Secure communication
PHY/MAC security
Ultra secure communication
Network hiding
All encryption (including broadcast / scheduling info.)
Jamming resilience
Post quantum cryptography (resilient against quantum computers)
Quantum security (key generation, key distribution)

Identity and device management
Identity privacy
Multifaceted trust
User / device / subscription authentication
Device onboarding and ownership structure/management
Device / user attestation, multi-factor, continuous authentication
Electronic ID ecosystem (e.g., secure, private, agile root of trust for identity, trusted D2D security bootstrapping

Platform security
Blockchain
Web 3.0
Confidential Computing
Driving the 5G evolution with our advanced R&D demonstrations

- Foundational Air Interface Innovations
- Expansion to New Applications

- Subband Full Duplex
- Upper mid-band with Giga-MIMO
- Sub-THz with lensed MIMO
- Intelligent 5G mmWave deployment
- Boundless augmented reality
- 5G cloud gaming
- mmWave cooperative sensing
- Secure services beyond data

- 5G mmWave mobility enhancements
- Advanced mmWave spectrum sharing
- Cross-node ML for CSF
- 5G NR-Light capacity
- 5G device mesh network for IoT
- Cooperative radar sensing
- Side link positioning with single RSU
- Enhancing safety with smart RSUs

- Cross-node ML for beam management
- Green networks Super-QAM
- 5G mmWave precise positioning
- Narrowband positioning for 5G NR-Light
- 5G Advanced for smart factory
- Innovation platform for new verticals
- Intelligent industrial positioning
- Precise positioning with 5G mmWave

Watch all on YouTube
Driving the 5G Advanced technology evolution into 6G

Strong 5G momentum sets stage for global expansion

Rel-15 eMBB focus
Rel-16 and 17 expanding to new industries
Rel-18, 19, 20 and beyond Continued 5G evolution and proliferation

6G
Next technology leap for new capabilities and efficiencies
Rel-21 and beyond New innovation platform
Historically 10 years between generations
Technology foundation for the next generation

A key enabler of the connected intelligent edge
Thank you