5G: Bringing precise positioning to the connected intelligent edge
Positioning complements the Connected Intelligent Edge

Bringing new value to virtually all devices
Transformation of the connected intelligent edge has begun at scale

Processing data closer to devices at the edge helps to scale more efficiently and derives new system values (e.g., lower latency, enhanced privacy)
In this new era, devices are becoming more intelligent. Based on growing AI processing capabilities and expanded availability of diverse data inputs (e.g., sensors), actionable insights can be generated on-device.
Positioning is a key dimension for the intelligent edge
Using a diverse set of technologies

Precise positioning

Wireless
- Cellular
- Wi-Fi
- Bluetooth
- Ultra-wide band (UWB)

GNSS
- Multiple GNSS constellations
- Multi-frequency GNSS
- Server-assisted GNSS
- Sensor-assisted GNSS

Sensors
- Accelerometer
- Gyroscope
- Compass
- Camera
- Radar
- Lidar

GNSS: Global navigation satellite system
Precise positioning
Can deliver tangible benefits for a diverse set of wireless use-cases

Indoor navigation  Drone tracking  Public safety  Geofencing  Vehicular navigation

Fleet management  XR optimization  User insights  Asset tracking  AGV tracking
Cellular positioning

Expanding capabilities and enhancing user experiences
Cellular positioning
Complements other technologies for reliable precision

- Stationary, pedestrian, and vehicular mobility
- Indoors and outdoors
- Broad range of devices
- Spectrum flexibility
- Diverse use cases
Identifying the opportunities for cellular positioning
Addressing the need to improve overall positioning capability

**GNSS limitations**
- Poor accuracy in dense urban environments
- Long cold start and acquisition times when un-assisted
- Significant power consumption for mobile devices
- Vulnerable to jamming or spoofing

**Sensor limitations**
- Drift from ground truth accumulates over time
- Unsuitable for absolute positioning

**WLAN, Bluetooth, & UWB limitations**
- Local solutions
- Limited mobility
Positioning
Has always been a core part of cellular technology

**1990s**
Digital voice
IS-95 (CDMA)

**2000s**
Wireless internet
CDMA2000/EV-DO
WCDMA/HSPA+

**2010s**
Mobile broadband
LTE, LTE Advanced,
Gigabit LTE

**2020s**
Connected Intelligent
Edge
5G New Radio (NR)

Cell-ID / eCID
EOTD / UTDOA
A-GPS / DGPS
OTDOA-IPDL
gpsOne™ / Wireless-Assisted GPS
OTDOA / UTDOA
Inter-RAT
RSTD
DL-TDOA / UL-RTOA
DL-AoD / UL-AoA
Multi-cell
RTT

AFLT: Advanced forward link trilateration; A-GPS: Assisted GPS; AoA: Angle of arrival; AoD: Angle of departure; DGPS: Differential GPS; eCID: Enhanced cell ID; EOTD: Enhanced observed time difference; IPDL: Idle period down link; RAT: Radio access technology; OTDOA: Observed time difference of arrival; RSTD: Reference signal time difference; RTOA: Relative time of arrival; RTT: Round trip time; TDOA: Time difference of arrival; TOA: Time of arrival; UTDOA: Uplink time difference of arrival.
Reliable emergency positioning requires multiple positioning technologies and sensors for accuracy and robustness.

**Assisted GNSS**
GNSS assistance delivered over cellular or Wi-Fi

**In-building cellular and WLAN location**
On-device altitude sensor for vertical positioning

**LTE and 5G-NR**
Terrestrial positioning
Powering a new wave of precise positioning opportunities with 5G

Breaking technology barriers
5G NR includes key innovations for positioning

**Flexible/scalable bandwidth**
Leveraging wider bandwidths in a variety of spectrum and deployment scenarios for precise time of flight

**Beam selection**
Improving beam selection accuracy by correlating downlink and uplink signals

**Group delay calibration/compensation**
Integrating methods for measuring, reporting, and compensating for processing delays

**Beam-centric PRS design**
Leveraging massive antenna array for 3D location estimation using finer beam widths

**Robust Rx/Tx beam determination**
Positioning using serving and neighboring cells with a purpose-built standard

**Robust time of arrival (ToA) estimation**
Including joint beam direction and ToA estimation to mitigate the effects of multipath

NR: New radio; PRS: Positioning reference signals; Rx: Receive; Tx: Transmit
5G brings multiple positioning techniques

For different deployment scenarios and use-cases

**Cell-ID**
The network reports the location of the cell-site serving the device or the centroid of its coverage.

**MC-RTT**
Time differences between downlink PRS from multiple cells and uplink SRS are reported either by the cell-site or the device.

**DL-TDOA**
The device measures the time difference of arrival (TDOA) of downlink positioning reference signals (PRS) from different cells and cell-sites.

**DL-AoD**
The device measures and reports the strength with which it receives PRS for each beam, where the angle of the beam is known.

**UL-RTOA**
The network measures the relative time of arrival (RTOA) of the device’s sounding (SRS) from different cells and cell-sites.

**UL-AoA**
The network measures the azimuth and zenith of arrival of SRS from the device relative to a reference direction.

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AoA: Angle of arrival; AoD: Angle of departure; DL: Downlink; MC: Multi-cell; PRS: Positioning reference signals; RTT: Round-trip time; SRS: Sounding reference signals; UL: Uplink

Leveraging time of flight and angular resolution to deliver precise positioning.
A joint communication and positioning/sensing technology platform for Industry 4.0

- Private 5G network
- Licensed, shared and unlicensed Spectrum
- Ultra Reliable Low Latency Communication (URLLC) and 5G Sidelink
- Ethernet and Time Sensitive Networking (TSN)
- Precise positioning

Dedicated and reliable networks optimized for local services

Scalable wireless connectivity on a future proof platform

Capabilities for new use-cases e.g., seamless mobility with wireless Industrial Ethernet
5G breaks the technology barrier for centimeter-level industrial precise positioning
5G brings robust positioning to drone use cases

**Inspection**
- Critical infrastructure inspection (e.g., cell towers, bridges)
- Inspection of hard-to-reach assets (e.g., oil & gas, wind turbines)

**Agriculture**
- Crop visual inspections
- Automated planting
- Livestock tracking

**Public safety**
- Emergency services
- Cellular coverage for first responders
- Search and rescue

**Film and Entertainment**
- Consumer flying cameras
- Movies and news media
- Real estate
- Sporting events

**Delivery**
- Package delivery
- Transport of medicines and vaccines
Boundless XR
Contextual photorealism everywhere
Believable photorealism with split-rendering over 5G, high capacity and low latency 5G connectivity, and the freedom of seamless mobility with precise positioning
Pushing forward with the 5G positioning technologies

Release 16
Establishing foundation

Achieving accuracy of 3m/10m (indoor/outdoor) for 80% of time
Supporting RTT\(^1\), AoA/AoD\(^2\), TDOA\(^3\), single-cell positioning
Including new evaluation scenarios, i.e., industrial IoT

Release 17
Enhancing performance

5G Positioning Evolution
Meeting centimeter-level absolute accuracy requirement of down to 0.3m
Reducing positioning latency to as low as 10 ms
Scaling to higher capacity for millions of simultaneous devices (e.g., IoT, automotive)

5G Advanced in Release 18+
Improving performance, expanding to new devices and deployments

Sidelink positioning and ranging
Defining reference signals, measurements, procedures for out-of-range, absolute and relative (e.g., ranging) sidelink positioning

Improved positioning performance
Specifying higher layer solutions for RAT\(^4\) dependent positioning techniques, accuracy improvement based on PRS/SRS\(^5\) bandwidth aggregation, carrier phase measurements, and positioning accuracy in heavy NLOS\(^6\) with AI/ML

NR-Light\(^7\) positioning
Setting performance requirements, evaluating performance for R17 positioning procedures, and identifying potential enhancements

Positioning technology at Qualcomm

Longstanding technology leadership and continued innovation for the future
A long history of innovation in wireless positioning

Pre-GPS fleet management

Two-way data communication with OmniTRACS and Qualcomm two-satellite positioning

Introducing GPS receivers to CDMA mobile phones

Significant progress made in mitigating low satellite signal levels, adjacent channel interference, space and power constraints, long response times, and poor accuracy

Integrated mobile platforms for robust positioning

Multiple radio access technologies, multiple GNSS constellations, multiple sensors, and multiple positioning algorithms for a broad range of precision based on signal quality
Qualcomm Technologies

#1 in location technology across mobile, automotive and IoT

20+ Years in mobile location tech
~10B Devices shipped with our location capabilities
100+ Mobile OEMs
100+ Operator deployments

1. QYResearch, Ranking of Global Top GNSS Chip Manufacturers by Revenue, Apr. ’20
2. Internal data
Meet the positioning requirements for diverse applications with a broad set of location technologies.
Qualcomm flight RB5 5G platform

World’s first 5G and AI drone platform

Autonomy
Visual inertial odometry (VIO)
Path planning
GPS-denied navigation
BVLOS flight
Follow-me flight mode
Obstacle avoidance
Multi-object detection and tracking

BVLOS: Beyond visual line of sight
Qualcomm Flight platform is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.
Setting the bar in 5G positioning at MWC Barcelona 2021

Wide-area 5G positioning
Over-the-air outdoor demo

Release-16 Single-cell and Multi-cell positioning
Round-trip time (RTT) and angle of arrival (AoA) positioning techniques combined for single-digit meter-level precision
Showcasing the benefits of ML and sensor fusion

5G industrial precise positioning
Over-the-air indoor demo

AGV with Uplink TDoA for Release-16 centimeter-level precision
Onboard Inertial sensor and CoMP for robustness against RF blocking
Deployment-friendly 100 MHz carrier in Sub-7 GHz
AI/ML for enhanced 5G positioning performance

- 5G channel multi-path profile
- Sensors
- GNSS information
- 5G positioning measurements (e.g., RTT + AoA)

Neural Network

Intelligent location server

Improved device position estimate
5G Sidelink in 3GPP Rel-18 and beyond

Brings flexibility to positioning in different operational scenarios and with multiple spectrum options

**Operational scenarios**

### In coverage
Uu-only or Uu + SL cooperative positioning when 5G UEs are within network coverage area

### Partial coverage
Uu + SL cooperative positioning when only some UEs are within network coverage area

### Out of coverage
5G Sidelink ranging when network coverage is not available

**Spectrum options for 5G sidelink**

Licensed or unlicensed spectrum

Licensed-assisted positioning on unlicensed spectrum

NR sidelink operation on **licensed** or **unlicensed** spectrum
Advancing 5G positioning with 5G sidelink and RF sensing

3GPP Release 18 and beyond

5G NR positioning
3GPP Release 16

Use positioning reference signals (PRS) over the 5G NR air interface (Uu) to estimate the position of a 5G device

Cooperative positioning with 5G sidelink
3GPP Release 18+

Exploit more line-of-sight opportunities by using 5G sidelink (SL) PRS for ranging between devices, in addition to PRS over the Uu interface to estimate the position of multiple 5G devices simultaneously and cost-effectively

Cooperative sensing with 5G sidelink
3GPP Release 18+

Simultaneously estimate the position of passive device-free objects and 5G devices by using PRS over the Uu and SL interfaces, and by measuring reflected paths
Learn more on location and positioning technology

with the Qualcomm Wireless Academy

Gain a competitive advantage by developing a greater understanding of location and positioning.

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