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# Centimeter positioning accuracy in modern wireless cellular networks – wish or reality?

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**Abstract:** The paper explores the evolution of wireless positioning technologies across cellular network generations, emphasizing the advancements from 2G to the current 5G and anticipating the upcoming 6G around 2030. Positioning methods, such as Theta-Theta, Rho-Rho, and Hyperbolic, are discussed for both two-dimensional and three-dimensional applications, revealing the complexities and improvements in accuracy. The limitations of methods like Theta-Theta are addressed, and enhancements through multi-antenna systems are explored. The role of Ultra-Wideband (UWB) technology in overcoming the limitations of Received Signal Strength Measurement (RSSI) for accurate distance measurements is highlighted. The abstract underscores the continuous strive for precision in location determination, catering to diverse applications from industrial automation to sports and rehabilitation.

**Keywords:** positioning, wireless systems, positioning accuracy, 2G, 4G, 5G, 6G

# Centimetrska natančnost pozicioniranja v sodobnih brezžičnih celičnih omrežjih – želja ali resničnost?

**Izvleček:** Ta članek opisuje metode, ki se uporabljajo v brezžičnih celičnih omrežjih za določanje položaja terminala ali druge brezžične naprave. Članek obravnava metode in njihovo natančnost pri določanju lokacije. Vse generacije celičnih omrežij, od druge generacije (2G) naprej, imajo vgrajene mehanizme za določanje položaja uporabnika. Natančnost se je z razvojem generacij povečevala in se pričakuje, da bo dosegla centimetrsko natančnost v šesti generaciji. Določene industrije, kot so zdravstvo in industrijska proizvodnja, zahtevajo še posebej natančno določitev položaja, zato je za sodobna celična omrežja ključno, da to omogočajo na cenovno ugoden, energetsko učinkovit, zanesljiv in varen način. Pomembno je, da so te storitve zagotovljene predvsem znotraj stavb. Rezultati naše raziskave kažejo, da sta peta (5G) in šesta (6G) generacija zelo blizu izpolnitvi omenjenega merila centimetrske natančnosti pri določanju položaja.

**Ključne besede:** pozicioniranje, brezžični sistemi, centimetrska natančnost, 2G, 4G, 5G, 6G

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## 1 Introduction

The pursuit of highly accurate location systems has become an integral part of modern society, where location-based services are ubiquitous and essential for numerous applications, from navigation and emergency response to asset tracking and virtual reality (VR) / augmented reality (AR) / extended reality (XR). High positioning accuracy is of utmost importance in many of the industries listed in Table 1.

Wireless cellular networks have long been seen as a promising platform for precise location capabilities. Even the second generation (2G) wireless systems enabled identification, which determined the terminal's position according to the coverage of an individual sector of the base station. This worked everywhere, but the accuracy depended on the size of the cell and/or sector. However, achieving centimeter-level accuracy in such networks is not a trivial task, as it involves overcoming

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a variety of technological challenges and reconciling different factors that affect localization accuracy. Better accuracy can already be obtained by measuring the strength of the received power, but we must know the signal losses on the radio path. From this, we can estimate the terminal's distance from nearby base stations and then determine its position using the intersections of the virtual circles formed around the base stations by the calculated distance values. Since the strength of the received power depends on the orientation of the user's device and the environment in which the user is located, the accuracy is good only when the user is in the direct line of sight or near the base station. In modern cellular networks with enough bandwidth (5G and 6G) we can expect to determine the position of any object very precisely, even with centimeter accuracy [1]. Centimeter-level accuracy will be of utmost importance in industries such as healthcare and manufacturing, as well as logistics, sports and gaming.

**Table 1:** Industries and value of accurate positioning.

| Industry | Value of positioning |
|---|---|
| Military and defense | • Locating people<br>• Unmanned aerial vehicle (UAV) navigation<br>• Unmanned underwater vehicles (UUV) navigation<br>• Robot navigation |
| Healthcare management, hospitals, and clinics | • Locating patients and visitors<br>• Tracking medical equipment |
| Warehousing, logistics and distribution | • Product inventory<br>• Collision avoidance and maritime precise docking<br>• Optimizing routes |
| Manufacturing | • Managing inventory<br>• Optimizing workflow<br>• Quality assurance |
| Sports, entertainment, and gaming | • Enhanced analytics<br>• Improving player performance<br>• Location aware apps (VR/AR/XR) |

The remainder of this scientific paper is structured as follows: The next section gives a basic understanding of cellular networks. Then, we dive into the details of how accurately devices can be located within these networks. Here, we explore the current state-of-the-art methodologies, technological advances, and potential ways to bridge the gap between wishful thinking and practical reality. Additionally, we scrutinize the limitations of conventional positioning approaches based on measurements of signal strength, time-of-arrival, and angle-of-arrival. What follows is a discussion on positioning in 5G, driven by the escalating demand for improved accuracy and the significant pressure on the wireless industry to develop innovative solutions that meet these expectations. The fifth section is dedicated to positioning accuracy and the extent of uncertainty, expressed as an area. In conclusion, this scientific inquiry not only illuminates the theoretical aspects of achieving centimeter-level positioning accuracy in wireless cellular networks but also provides valuable insights into the practical feasibility and real-world challenges that lie ahead. By presenting a comprehensive overview of the current situation, this paper aims to foster dialogue and collaboration among researchers, industry representatives, and policymakers to turn the aspiration of centimeter-level positioning in wireless cellular networks into a tangible reality.

## 2 Cellular networks

In the second generation (2G), a simple time measurement method has been used for decades. The principle behind this method is that the base station sends a command to the terminal. Based on the response, it sets the corresponding time delay of the signal. This functionality basically enabled normal communication between the base station and fast-moving terminals, but the position accuracy was inaccurate. Therefore, the extended Cell ID was introduced for the location-based emergency call service [2]. In 2G networks, time was typically measured with a resolution of about 4.615 μs and an uncertainty or margin of error of around ±20 μs.

In the fifth generation (5G), we expect to be able to determine the position of the terminal with an accuracy of better than one metre. New technical solutions are used, e.g. determining the angle of transmission and reception, measuring the signal propagation time across several cells and measuring the time difference when user devices only receive signals. The latter is typical for satellite navigation. It enables the terminal to determine its position without the network knowing about it, as an terminal does not utilise network resources [3], [4]. In addition to broadband mobility [5], increased responsiveness, constant availability, enhanced security and other improvements, 5G, which meets the capacity requirements of modern applications, will also bring more accurate determination of the position of wireless devices. The 5G is unlikely to deliver everything we expect of it, especially when deployed in a non-standalone mode of operation [6].

Much of what is promised in 5G - including position accuracy of a few centimeters - will probably be delivered by the sixth generation (6G). The following enhancements in 6G may contribute to the expected accuracy of around one centimeter:

- Densification of base stations and antennas allows more precise triangulation and localization of devices.
- Technologies such as massive MIMO (Multiple Input Multiple Output) and beamforming improve signal strength and directionality, enhancing the accuracy of location estimation.
- Integration of edge computing capabilities enables faster data processing closer to the source (at the network edge). This facilitates real-time data analysis and decision-making, leading to more accurate localization results.
- 6G networks may use artificial intelligence and machine learning algorithms to analyze large amounts of data and optimize localization algorithms. AI can learn from patterns and improve the accuracy of location estimation over time.

The 6G, designed to be superior to previous generations in all parameters, will be used in the fight against modern challenges facing humanity, such as epidemics and natural disasters, allowing us to monitor people's movements and save lives without violating their privacy. Tracking is one of the most important features of modern wireless cellular networks and opens many use cases in the field of digitalisation. With digitalisation, the industry is also striving for automated production processes and mobile robots with centimeter-accurate positioning, especially indoors where global satellite navigation systems do not work [7]. In sport and rehabilitation, knowledge of posture in combination with biomechanical feedback [8] helps to promote the athlete's motor skills and monitor their training.

## 3 Positioning methods

Modern localisation methods use electronic devices, which are an example of complex and sophisticated high-frequency technology in engineering. These procedures are essentially based on a system of high-frequency electromagnetic beacons distributed in space. By processing signals from these beacons and knowing their positions, the receiving device can determine its position with a certain degree of accuracy. In doing so, it employs two-dimensional positioning through one of the following geometric methods [9]:

- Theta-Theta (with two azimuths),
- Rho-Rho (with two distances),
- Rho-Theta (with distance and azimuth),
- Hyperbolic (with distance differences of up to three beacons).

The methods mentioned above are applicable for determining the position of an object in two dimensions. For three-dimensional positioning, a minimum of four beacons must be available.

The 3rd Generation Partnership Project (3GPP) committee identified positioning methods in 3GPP Releases 15, 16, and 17, all related to power, angular, or time measurements. 5G indoor positioning in offices, shops, etc., is specified in 3GPP Release 16, with certain enhancements for industrial applications (e.g., manufacturing, logistics) in 3GPP Release 17. Combining 5G and the Satellite Navigation System (GNSS) can achieve a positioning accuracy of ten meters outdoors or in rural and urban clear sky areas.

Positioning methods in 4G (3GPP Release 15) use the following mechanisms:

- Observed Time Difference of Arrival (OTDoA),
- Uplink Time Difference of Arrival (UL-TDoA),
- Positioning methods based on power measurements (RSS).

In 5G, the list of aforementioned mechanisms is expanded by two more (3GPP Release 16 and 17), namely:

- Round trip time (RTT),
- Angle of Arrival/Angle of Departure (AoA/AoD).

### 3.1 Theta-Theta Method

In the Theta-Theta system (positioning with two azimuths), as illustrated in Figure 1, a terminal at an unknown location measures the angle between the reference direction determined by north and the orientation towards two or more base stations with known locations. By utilizing the measured angles, the termi-

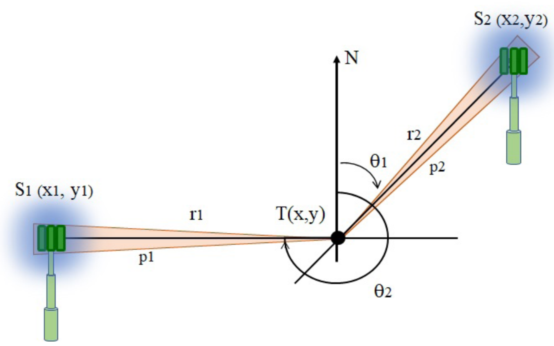


**Figure 1:** Positioning with the Theta-Theta system: the terminal measures the azimuth angle θ - between the reference direction determined by north - and the orientation to two or more base stations at an unknown location.

nal determines its position at the intersection of the lines.

The terminal position T (x, y) is calculated from equation (1):

$$y = \frac{y_2 \cdot \tan(\theta_2) - x_2}{\tan(\theta_2) - \tan(\theta_1)},\ x = y \cdot \tan(\theta_1) \quad (1)$$

This system is not very accurate due to the imprecision in angle measurements. The error is proportional to the distance between the terminal and the beacon, which can be calculated using equation (2):

$$\Delta P = r \cdot \sin(\Delta\alpha) = r \cdot \Delta\alpha \quad (2)$$

where ΔP is the positioning error, r is the distance between the terminal and the base station (beacon), and Δα is the angle measurement uncertainty. If lines p1 and p2 in Figure 1 intersect perpendicularly, the error area is the smallest. Therefore, it makes sense to choose base stations that are perpendicular to each other in relation to the user's position. As already mentioned, the positioning error of the Theta-Theta system increases proportionally to the distance of the terminal from the base station(s). For example, with an angular uncertainty of ±1 degree at a 100 m distance from the base station, using equation (2), the positioning error is 1.7 meters. If the distance of the terminal from the base station increases by a factor of ten, the error also increases by a factor of ten, reaching 17 meters.

To determine the angle at which the terminal receives the beacon signals, i.e. the angle of arrival, a system with several antennas is used, where multiple antennas can be on the receiving side (Figure 2) or on the transmitting side (Figure 3).

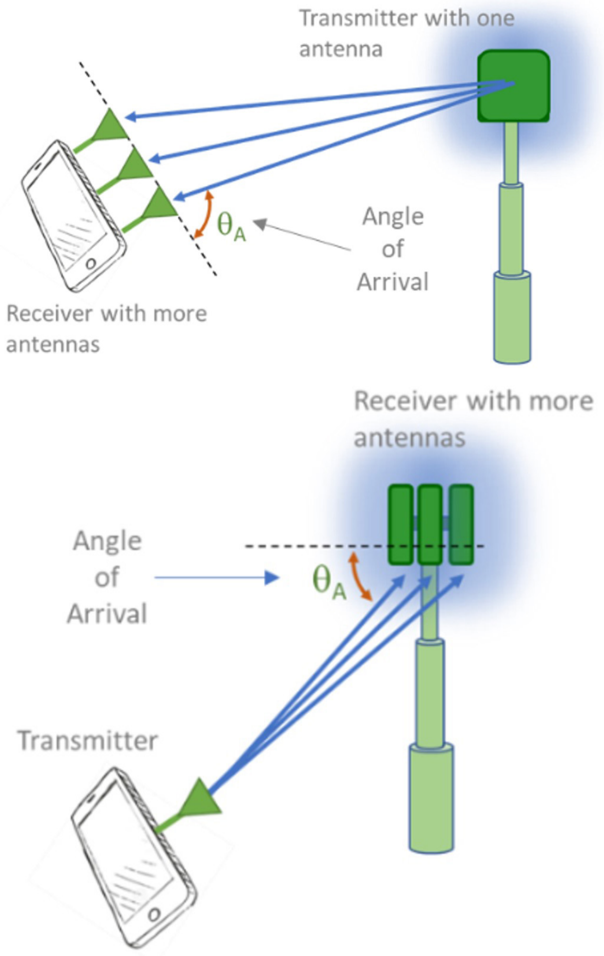


**Figure 2:** Multiple antennas on the receiver side enable AoA measurements.

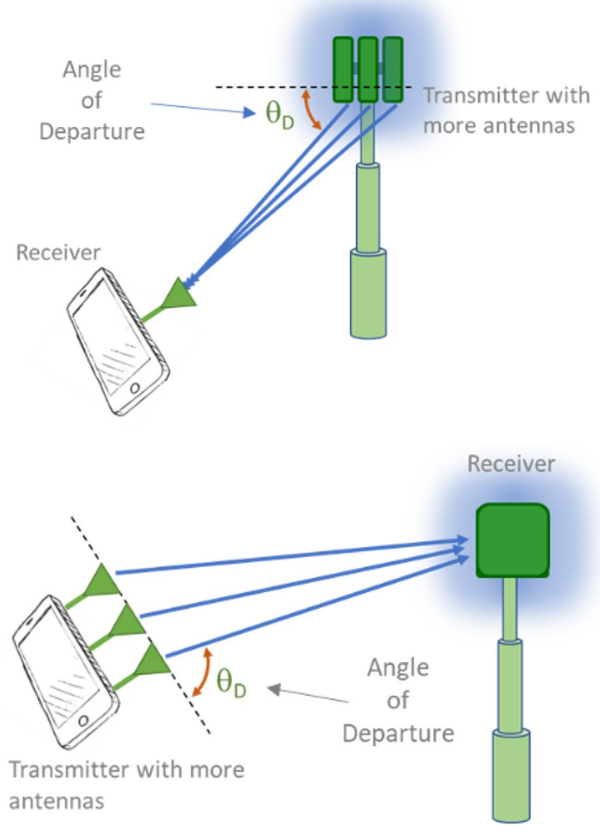


**Figure 3:** Multiple antennas on the transmitter side enable AoD measurements.

In a multi-antenna system on the receiving side (Figure 2), the angles of arrival (AoA) are measured. Each antenna receives a signal with a different phase, allowing the calculation of the antenna's direction. In the case of a system with several antennas on the transmitting side (Figure 3), the angles of departure (AoD) are measured. Each antenna transmits at its own time, and the receiver receives signals with different phases, enabling the calculation of the transmission angle. In both cases, AoA and AoD, the angle can be calculated from the measured phase difference of the signals arriving at the pair of receiving antennas, as illustrated in Figure 4.

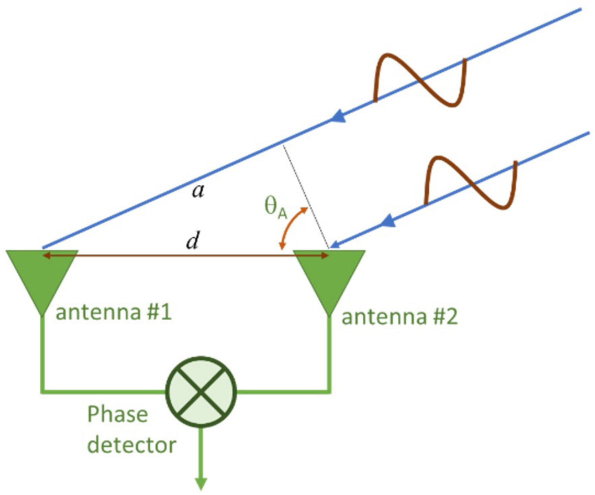


**Figure 4:** Positioning with the Theta-Theta system.

The phase difference φ is calculated according to equation (3):

$$\varphi = \frac{a}{\lambda} \cdot 2\pi = \frac{d}{\lambda} \cdot 2\pi \cdot \sin\theta_A \quad (3)$$

The angle of arrival $\theta_A$, at which the signals arrive, depends on the distance d between the receiving antennas, the wavelength λ of the signal, and the measured phase difference ϕ. The angle of arrival is calculated according to equation (4):

$$\theta_A = arc\sin\frac{\phi\lambda}{2\pi d} \quad (4)$$

Beam shaping by adjusting the phase difference between the antennas [7] is more effective in the millimeter wave part of the spectrum, where optical technologies are used for better accuracy [8].

The Theta-Theta method is rarely used in its version based only on basic geometrical laws and phase measurements. However, with the use of additional mechanisms enabled by modern cellular networks, this method becomes very accurate.

### *3.2 Rho-Rho Method*

In the Rho-Rho system (positioning of the terminal with two known distances), the terminal at an unknown location measures the distance between it and two or more base stations with known locations (Figure 5). The terminal position T (x, y) is calculated from equation (5):

$$\begin{aligned}\rho_1^2 &= x^2 + y^2 \\ \rho_2^2 &= (x - x_2)^2 + (y - y_2)^2\end{aligned} \quad (5)$$

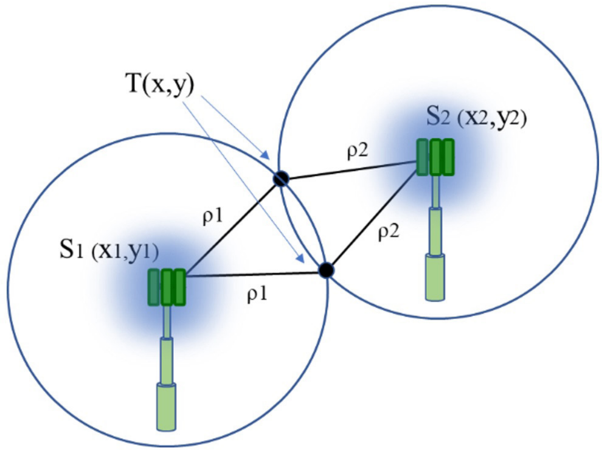


**Figure 5:** Positioning the terminal with the Rho-Rho system: the distance between the terminal at an unknown location and two or more base stations at known locations is measured.

The terminal determines its location using the trilateration process, based on the intersections of virtual circles formed by the distance, calculated from the travel time measurements from the base station to the terminal. The terminal's position is defined as the intersection of two circles, each with a base station at the center. The uncertainty of the travelling time refers to non-ideal measurements, so the distance from the terminal represents a ring and not a circle, and the result is that the intersection of the rings in Figure 6 is a green uncertainty region.

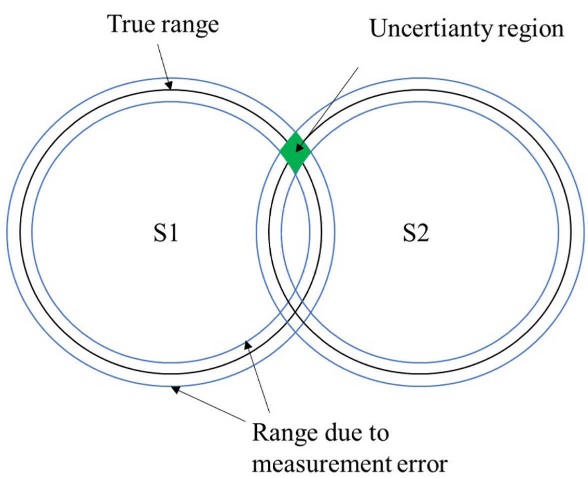


**Figure 6:** Uncertainty region (depicted by the green patch) in the Rho-Rho positioning system.

The size and shape of the uncertainty region depends on the distance between the centres of the rings and their thicknesses. Another weakness is that the intersection of two rings results two solutions, introducing ambiguity. This can be resolved by measuring the distance from a third base station (e.g. from RSSI data, see section 3.5) or by knowing the previous position of terminal, which is likely close to the current position.

### 3.3 Rho-Theta Method

In the Rho-Theta system (positioning of the terminal with a known distance and angle), the terminal measures the distance to the base station and its azimuth (Figure 7). The terminal position T (x, y) is calculated from equation (6):

$$x = \rho \cdot sin(\theta)$$
$$y = \rho \cdot cos(\theta). \quad (6)$$

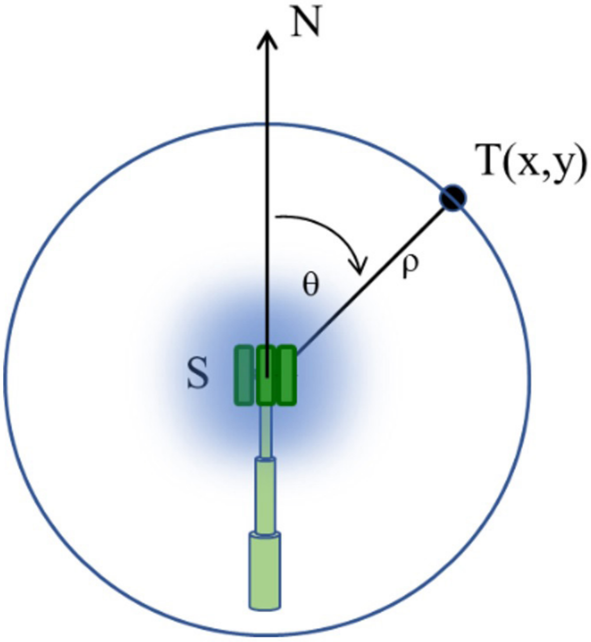


**Figure 7:** Positioning with the Rho-Theta system involves the terminal at position T(x, y) measuring the distance to the base station and its azimuth.

### 3.4 Hyperbolic Method

In the Hyperbolic system, a terminal at an unknown location measures the time differences between itself and two base stations at known locations. A 5G receiver only computes its position based on the relative time of the individual base stations, which is known as the Downlink Time Difference of Arrival (DLTDOA). In 4G, this function is referred to as observed time difference of arrival (OTDOA) [12], described in the 3GPP Release 15 specifications. In both cases, the time difference of the base stations is measured, but they must all be ynchronized. The user terminal, in this case, functions similarly to a satellite navigation signal receiver. For this purpose, base stations transmit a positioning reference signal (PRS). The accuracy of the calculation of the terminal's position depends on the synchronization and measurement of time differences. The hyperbolic method for determining position has been used for years by maritime systems (e.g. LORAN, now e-LORAN) and satellite navigation systems such as GPS, GLONASS, Galileo, Beidou and others.

### 3.5 Received Signal Strength Measurement

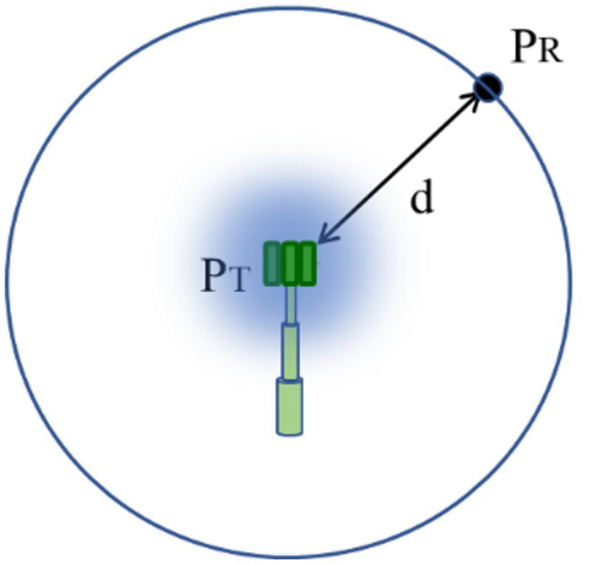


**Figure 8:** Received Signal Strength measurements. The terminal calculates the distance to the base station from the RSSI indicator.

Ideally, we can determine the power of the received signal using equation (7):

$$P_R = \frac{P_T \cdot G_T \cdot G_R \lambda^2}{(4\pi d)^2} \quad (7)$$

d is the distance between the transmitter ($P_T$, $G_T$) and receiver ($P_R$, $G_R$), and $\lambda$ is the wavelength of the signal.

Using the Received Signal Strength Indicator (RSSI) to determine position is simple and requires only negligible additional costs. The measurement is independent of the modulation process and data transfer rate and does not require synchronization between devices. It works best near the base station, as accuracy depends on distance and environment, as shown in Figure 9.

Since it is not possible to know signal losses on the radio path in a dynamic mobile environment, and the measurement result is also affected by the orientation of the user device, a comparison with a pre-made learning da-

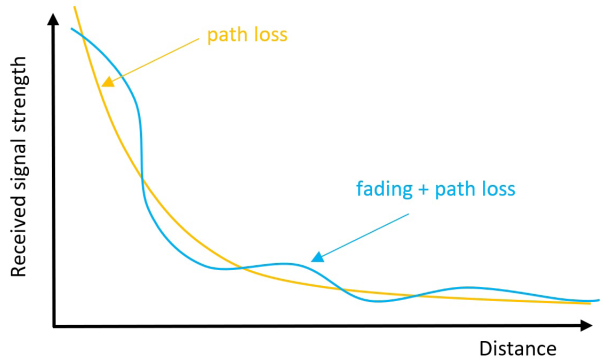


**Figure 9:** The problem of positioning from the measured received power depends on the distance from the base station and the environment.

tabase is useful [13]. The RSSI at a distance d from the transmitter is calculated according to equation (8):

$$RSSI_d = -10 \cdot n \cdot \log_{10}(d) + RSSI_0 \tag{8}$$

$RSSI_0$ is constant, index n represents losses in space and depends on environment (Table 2).

**Table 2:** Index *n* in different environments [10].

| Environment | Environment index (n) |
|---|---|
| Free space | 2 |
| Metropolitan area | 3 – 5 |
| Office building | 4 – 6 |
| Factory | 2 – 3 |

Distance measurement is enhanced through indirect means, particularly by measuring time. 3GPP Release 8 introduced cell identification, present in all cellular network generations, with accuracy dependent on cell or sector size. In 4G, Timing Advance improved cell identification by adjusting the expected time delay for receiving the terminal's signal. 5G introduced a multi-cell Round-Trip Time (RTT) measurement function, enabling the terminal to determine distances without time synchronization. The RTT value, representing the time each frame travels from the transmitter to the receiver and back, is used to calculate distances to individual 5G base stations (gNBs). Taking into account signal processing time, the distance (d) between the transmitter and the receiver is calculated using the speed of light (c) in equation (9):

$$d = \frac{RTT}{2} \cdot c \tag{9}$$

However, due to factors affecting the accuracy of RSSI determination, such as antenna patterns, reflections, and obstacles, RSSI alone is rarely used for precise distance measurements and positioning.

For more accurate time measurements, a signal with the largest possible bandwidth is required. This is an advantage of ultra-wideband radio communication systems (UWB). Modern mobile networks provide sufficient radio spectrum, facilitating more precise time measurements and, consequently, more accurate positioning.

## 4 Positioning in 5G

The positioning method in 5G, defined in 3GPP Release 15, is known as Observed Time Difference of Arrival (OTDOA). Certain conditions must be met for this method: The base stations (gNBs) must be synchronised, the positions of the gNBs must be known, and at least three beacons are required. The position is calculated by the receivers of the gNBs. In this scenario, 5G terminals are passive, as they only receive signals, similar to satellite navigation terminals.

As far as time and angle-based positioning methods are concerned, 5G introduces several improved parameters for better accuracy. The delay error variance decreases in the order of the square of the bandwidth as the bandwidth increases. Angle variance remains completely independent of the bandwidth. 5G offers a significant improvement in bandwidth compared to LTE (20 MHz for 4G compared to 100 to 400 MHz for 5G). Received power is inversely proportional to all estimation variances and can be increased by beamforming. 5G provides five different choices for subcarrier spacing (15 kHz, 30 kHz, 60 kHz, 120 kHz, and 240 kHz). The subcarrier spacing linearly increases the angle variance and simultaneously linearly decreases the delay variance. To counteract this effect, increasing the receiving power is a natural solution.

Different antenna patterns (varied spacings and the number of polarisations in the antenna array) do not affect the delay variance but rather the total number of antenna elements in the array. The number of rows and columns of the antenna array results in a cubic decrease in the angle variances.

In the 5G architecture (3GPP Release 16), specific elements are dedicated to positioning:
The Location Management Function (LMF) receives results of measurements and assistance information from the gNB and the terminal, via the Access and Mobility Management Function (AMF), to compute the position of the terminal.

A new NR Positioning Protocol (NRPPa) is introduced between the radio network and the core network, which carries positioning information between the radio network and the LMF via the Next Generation Control plane (NG-C) interface. The LMF configures the 5G terminal using the LTE Positioning Protocol (LPP).

5G utilizes two reference signals for positioning: the Positioning Reference Signal (PRS) in the downlink and the Sounding Reference Signal (SRS) in the uplink.

Beamforming can be used for more precise positioning, which improves the signal-to-noise ratio by increasing the gain of the beamforming. The terminal position is provided in terms of the Angle of Departure (AoD), while multiple antennas at the gNB in the uplink enable precise Angle of Arrival (AoA) measurements.

Table 3 presents a comparison of the estimated average positioning accuracy of various technologies [7].

**Table 3:** Positioning accuracy of different technologies.

| Technology | Accuracy (m) |
|---|---|
| 4G | 20 – 50 |
| 5G on cmWaves | 10 – 20 |
| 5G on mmWaves | <1 |

## 5 Positioning accuracy and area of uncertainty

As an illustration of position accuracy determination, we consider the AoA method, which is closely linked to the area of uncertainty. This scenario is depicted in Figure 10 with two base stations (Tx1, Tx2) and a mobile user (Rx).

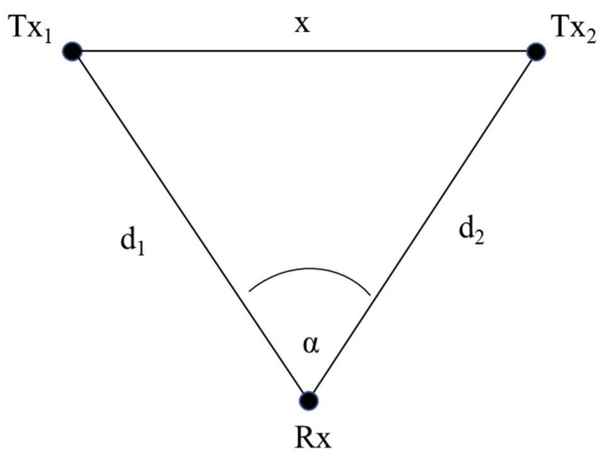


**Figure 10:** Geometry for determining the position and uncertainty area of the terminal (receiver).

The two stations are separated by a distance x, and the user sees the transmitters at an angle α. We also consider the angle measurement error, denoted by Δ. By changing the angle α, we can observe changes in the size of the uncertainty area. In our example we assume that the distance between the receiver and each transmitter is the same (d1 = d2 = d).

To calculate the distance of the receiver from the transmitters, equation (10) is used. It is consistent with the basic geometry of an isosceles triangle.

$$d = \frac{\frac{x}{2}}{\sin\left(\frac{\alpha}{2}\right)} \tag{10}$$

where d is the distance between the receiver and each transmitter, x is the fixed distance between the transmitters, and α is the angle at which the receiver sees both transmitters. The position error δp is determined by equation (11). The expression can be simplified due to the small value of the error:

$$\delta p = d \cdot \sin(2\Delta) = d \cdot 2\Delta \tag{11}$$

Finally, we come to the equation (12) for calculation the area of uncertainty.

$$A = \frac{(d \cdot 2\Delta)^2}{\sin \alpha} \tag{12}$$

The input data for calculating the uncertainty area are as follows: distance between transmitters (x) is 500 m, measurement error (Δ) is ±10 milliradians, and angle (α) is between 1 and 178 degrees. We use the Matlab tool for the calculation. The Figures 11 and 12 show how the uncertainty area varies with angle and distance [16].

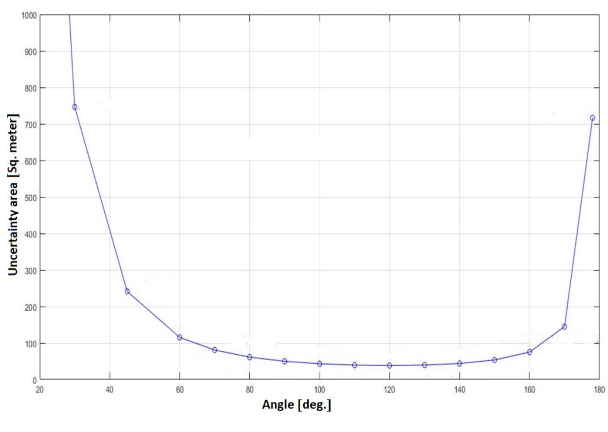


**Figure 11:** Uncertainty area as a function of angle.

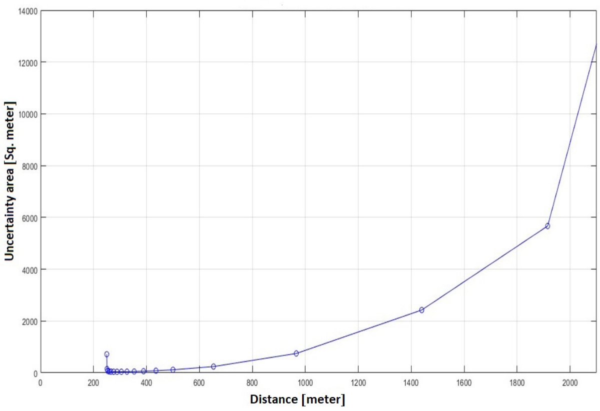


**Figure 12:** Uncertainty area as a function of distance.

Figure 11 shows that the uncertainty area decreases as the angle increases. In this case, the smallest area of uncertainty is when the angle of arrival is 120 degrees, and the user is at 289 meters. At that point the area of uncertainty is 38.5 $m^2$ and consequently the most precisely determined location. If the angle approaches zero or 180 degrees, the area increases greatly due to the geometry of the angle and the trigonometric functions, so that these extreme angles are not taken into account in the calculation. We can logically conclude that the measurements become less accurate as the distance between the user and the base stations increases, as it is shown in Figure 12.

## 6 Results and discussion

We can conclude that centimeter positioning accuracy with cellular technologies is possible inside buildings under certain conditions. This is possible on mmWave frequencies using mechanisms built into modern cellular networks as: Downlink Observed Time Difference of Arrival (DL-TDOA, assisted by the terminal), Uplink Time Difference of Arrival (UL-TDoA, assisted by the base station), and RTT.

Methods used for positioning outside buildings, however, allow the positioning with a few meters' accuracy on cmWave frequencies, which is sufficient for most smart outdoor applications, e.g. smart agriculture, outdoor asset tracking, environment monitoring, smart city infrastructure, outdoor events, and the like. In outdoor cases, for less precise measurements, we can use other previously mentioned methods. In many outdoor cases, a combination of cellular and satellite technologies is very useful, e.g., combination of 5G and GPS.

Finally, the design of the antenna (MIMO or single-beam antenna) and the antenna pattern have a great influence on the accuracy of the position determination. Narrower beamwidth means a higher gain of the antenna, which results in higher received power and higher accuracy in determining the distance. Narrow beamwidth also improves user positioning resolution, reduces the susceptibility to more reflections from the environment and reduces interference. Therefore, MIMO antenna with beamforming [17], [18], offers the positioning accuracy down to sub-meter level, which is much better than a standard single-beam antenna.

## 7 Conclusions

This paper discusses positioning methods in modern cellular networks that may be suitable for the new challenges brought by the smart industry. When using several base stations, the position can be determined by different signal measurement methods: (a) by measuring the Angle of Arrival (AoA), (b) by measuring the Angle of Departure (AoD), (c) by measuring the Round-Trip Time (RTT), and (d) by measuring the Observed Time Difference of the received signal (OTDoA).

As seen from the example in Chapter 5, the accuracy of position determination is closely related to the size of the uncertainty area. This depends on the angle at which the user sees the base stations and the distance from the base stations. The uncertainty area strongly depends on the triangle geometry of the base stations and the user.

If a single base station is available, we can use the Rho-Theta method, which identifies the distance between the terminal and the base station by measuring the Round-Trip Time (RTT) and the angle by measuring the Angle of Arrival (AoA).

The combination of different methods for determining the position of the terminal and adding new ones to the standards allows for better position accuracy.

We can summarize the findings in a few observations:
- (a) the 5G system can perform positioning without user intervention,
- (b) all devices receive a positioning service,
- (c) the advantage of the large computing capacity is available in the network,
- (d) there is low battery consumption of the terminals, and finally
- (e) positioning accuracy in 5G can be of the order of centimeters.

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## 9 Conflict of Interest

The authors of this document have no conflicts of interest (COI) in this paper.

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