5G VS WI-FI INDOOR POSITIONING: A COMPARATIVE STUDY

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ABSTRACT

Sensing location information in indoor scenes requires a high accuracy and is a challenging task, mainly because of multipath and NLoS (non-line-of-sight) propagation. GNSS signals cannot penetrate well in indoor environment. Satellite-based navigation and positioning systems cannot therefore be used for indoor positioning.. Other technologies have been suggested for indoor usage, among them, Wi-Fi (802.11) and 5G NR (New Radio). The primary aim of this study is to discuss the advantages and drawbacks of 5G and Wi-Fi positioning techniques for indoor localization.

KEYWORDS

5G Networks, Wi-Fi, Indoor Positioning, Localization

1. INTRODUCTION

Since GSM, the focus of the mobile radio users's location has shifted from basically outdoors to indoors. According to statistics, people spend 90% of their time indoors [1]. The position marked and tracking of people and connected devices in an indoor environment is more and more needed. The rise of indoor location-based services (ILBS) has motivated further research in indoor positioning techniques. The commercial interest is growing with new applications for indoor localization, like smart factories and IoT (Internet of Thing).

Indoor scenes are often complex with non-line-of-sight (NLoS) conditions in the process of signal propagation. There are obstacles and the environment changes quickly, causing signal fluctuation. Despite these difficulties, high localization accuracy is a goal to achieve in order to provide reliable ILBS [2]. As Global Navigation Satellite Systems (GNSS) signals cannot penetrate well in indoor environments, traditional satellite-based localization systems, such as Global Positioning System (GPS) from U.S., BeiDou from China and Galileo from Europe, are not sufficient for indoor positioning. Since telecom signals are often present in indoor environments, their use for indoor localization makes sense. However, according to technology companies reports on indoor localization systems, mobile phones are not always covered by cellular networks in many indoor environments, which makes cellular-based indoor positioning currently impossible in some cases [1]. However, in a near future, 5G picocell base stations, also known as gNodeBs, will be densely deployed for indoor coverage and thus, 5G signals will reach indoor environments [3].

Most of the cellular networks, i.e. GSM, UMTS and LTE networks, only provide simple and rudimental localization techniques, as it is mentioned in [4]. Most of the time, mobile network operators do not deploy advanced cellular-based location methods because of additional implementation costs. However, 5G networks standardization evolves to satisfy the needs of

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industrial use cases, often refered as Industry 4.0. In a near future, centimeter accuracy positioning will probably be needed in fully automated factories to track the location of moving assets and machinery or product storage [5]. Consequently, smart factories remain the most important segment for accurate positioning and advanced cellular-based positioning techniques will be deployed for this segment. 3GPP has defined a use case called indoor factory (InF) environment with specific positioning precision expectation for 5G NR release 17.

Another technology that has drawn attention for indoor positioning research is Wi-Fi. With public Wi-Fi hotspots widely available, Wi-Fi is probably the most popular wireless technologies today [6]. This WLAN technology is also attractive because most mobile phones and connected objects (monitoring tools, security cameras, smart watches, …) are compatible with it.

Wi-Fi coverage is about 1 km and it can be enhanced with additional hotspots deployement. Although Wi-Fi was originally designed for computer-to-computer communication, it can provide Internet connectivity and compete with cellar networks. Wi-Fi is based on the IEEE 802.11 standard and uses the carrier sense multiple access protocol with collision avoidance (CSMA/CA). 2.4 GHz and 5 GHz are the most widely used frequency bands for Wi-Fi. They belong to unlicensed ISM bands. New versions, like 802.11 g and 802.11 n, can use different frequency bands, and provide better bandwidth and transmission rates [7].

The deployment of Wi-Fi positioning systems is cost-effective because additional positioning equipment is not needed. Positioning algorithms based on Wi-Fi wireless networks have become popular because of the wide coverage of Wi-Fi signals and low positioning error [8]. The latest Wi-Fi standard called Wi-Fi 6, also known as 802.11ax, improves wall penetration, which reaffirms the idea that WiFi is a suitable technology for indoor positioning. Although Wi-Fi allows reliable data transmission in NLoS and poor lighting conditions, it shows relatively highpower consumption when compared to cellular and Bluetooth [9].

This brief view on Wi-Fi and 5G technologies allows to infer that they are major candidates for indoor positioning systems deployement. This paper further studies the advantages and drawbacks of these two technologies with respect to the indoor localization problem.

2. Research Method

Wireless network positioning methods can be classified in several categories:

- Time-based : This category relies on measuring the time of signal propagation. One example is the time of arrival (ToA) algorithm, where the propagation time between the transmitter and receiver is used to calculate the object location. A time synchronization process between the transmitter and the receiver is needed [5]. Another example is the time difference of arrival (TDoA) algorithm, where the arrival-time in at least three anchor nodes is used to calculate the object position. Unlike ToA, this technique needs time synchronization among anchors only [5]. LoS condition is needed. A last example is RTT (Round trip time of flight). This ranging technique is based on round-trip signal propagation time. In this method, a node transmits a packet to another one and waits for a response. The duration of this operation can be used to compute the distance between the nodes. RTT is calculated using only one clock. Consequently, this algorithm does not need time synchronization. A disadvantage of RTT-based ranging is the necessity of averaging the estimates obtained form many measurements to get a better estimation of the position [10]. This increases the distance estimation latency.

- RSS-based : Many Wi-Fi indoor positioning algorithms use the RSSI (Received Signal Strength Indicator). This signal represents the received power level taking into account the attenuation at the receiver antenna [1]. For cellular systems, another RSS value is frequently used: the RSRP (reference signal received power). This parametercan provide better power information related to different locations [11]. In 5G networks, the path loss value between the gNodeB and the UE (user equipement) can be calculated with RSRP and reference signal transmit power parameters. Then a path loss model can be used to estimate the distance between the gNodeB and the UE.

Remarks: In the trilateration process, distance measurements between the transmitter and receiver terminal are used to compute the intersection between geometric forms, like circles and hyperbolas, which gives the position estimation. Several types of measurements can be employed, such as ToA, TDoA and RSSI [11]. Hence, trilateration can be implemented with time-based or RSSI-based algorithms.

- Angulation/direction-based techniques: The mobile device location is estimated with the angle or direction of arrival (AoA or DoA) of the received signals. If at least two directions of the incoming signal are known, the intersection of these directions allow to estimate the position. LoS condition is required [11]. The term Angle of Departure (AoD) is also employed depending on the reference terminal (the anchor node or the mobile device) [5]. We will see that in both Wi-Fi and 5G, angulation methods are often combined with the previously mentioned methods.

- Location fingerprinting (also known as pattern matching) consists in finding the best match for a signal, such as RSS signal, measured by the mobile device, from a fingerprint map, which is stored in a cloud server. Each location in the room has its own unique signal pattern in a fingerprint map, and when the received signal pattern from measured signal matches one unique signal pattern of the fingerprint map, the device location is detected [12].

For each wireless network positioning methods, 5G and Wi-Fi implementations are compared. To the best of our knowledge, such a comparative study has never been done so far. The task is not easy because these two technologies have different positioning frameworks and procedures. It is important to note that the implementation of a given positioning method can be very different from a wireless technology to another. The considered comparison criteria are, among others, indoor positioning accuracy, difficulty in deploying the equipment and global availability of the indoor positioning solutions.

3. Comparative Analysis

3.1. Time- Based Solutions

In both cellular and Wi-Fi networks, the round trip time (RTT) can be used to estimate the distance between the mobile station and base station as argued in [13] and [14]. In consequence of the effects of shadow fading and path loss, the accuracy of this method can be limited and is not sufficient for indoor localization [14]. According to authors in [15], measuring RSS is a very common approach for Wi-Fi-based localization. In contrast, time-based measurements, such as RTT, ToA and TDoA, are not commonly employed because measuring the time delays is a complex process.

Besides, some Wi-Fi amendments, such as IEEE 802.11mc, feature the FTM (fine-time measurement) protocol, which provides more accurate time measurements, so time-based positioning techniques can be used. For instance, the trilateration method and FTM-based range measurements are used in [16]. Although the system was able to give meter-level precision, it was very sensitive to NLoS conditions. Besides, Wi-Fi FTM is still not widely available. Consequently, Wi-Fi time-based trilateration is still under developing and not commercialized yet.

Although general purpose 5G networks are optimized for reliable voice communication and data transfer, reference signals dedicated for positioning and sensing are available. The SRS (sounding reference signal) is related to the positioning in the uplink and the PRS (positioning reference signal) is related to the positioning in the downlink [17]. In 5G NR, two important indoor localization techniques are DL-TDOA (downlink time-difference-of-arrival), based on the PRS and uplink TDOA (UL-TDOA) based on the SRS [5]. Comparing with DL-TDOA, one of the biggest disadvantage of the UL-TDOA is that it is difficult for different base stations to receive UEs signals because the number of mobile devices requiring a location service is important and the transmit power is limited. This is especially the case when thousands of IoT devices are transmitting SRS. On the other hand, DL-TDOA positioning signal can easily allocate more bandwidth using a CA (carrier aggregation) scheme, giving more bandwidth to the downlink channel, which is an advantage [18]. Indeed, one current limit of positioning technology is the time stamping resolution, which depends on the system bandwidth. The bandwidth allocated for the localization service should be at least 100 MHz to enable submeter accuracy [19].

Another limit of positioning technology is precise and accurate synchronization. Relative synchronization of the base stations should be on the order of nanoseconds to enable submeter accuracy [19]. In practice, not all 5G fronthaul equipments support phase/time synchronization [20]. Consequently, 5G trilateration does not always meet the performance that the standard specifications promise. It is difficult to synchronize gNBs to an ideal distant clock (GNSS) in subnanoseconds accuracy because of atmospheric fluctuations, temperature fluctuations and imperfections in the RF transceiver of the devices. Consequently, a positioning accuracy of less than 1 meter cannot be guaranteed [21]. Current GNSS based synchronization solutions have 100 ns timing accuracy, which is satisfactory for 5G gNBs synchronization. However, GNSS signals cannot penetrate correctly in indoor environments due to signal attenuation. Many 5G small cell base stations will be deployed indoor and thus, GNSS based synchronization will not be possible. Fortunately, another positioning technique called Multi-RTT (Multi-cell round-trip-time) relaxes requirements on time synchronization. This technique involves Rx-Tx time difference measurements from multiple gNBs and a UE, using PRS and SRS signaling, for the signal of each cell. Basically, RTT values of each cell are used to estimate the location. In addition, Multi-RTT gives higher location precision than TDoA-based methods [17].

In 5G rel-16 and rel-17, new types of time measurements are available for localization methods based on time or power estimates by using large antenna arrays [22]. The high received power of 5G signals also benefit the positioning parameter estimation [23]. Rel-17 proposes better signaling and procedures than rel-16 by allowing wider bandwidth, which increases timing measurements resolution [24].

3.2. RSS and Angle-Based Solutions

Wi-Fi indoor positioning methods can be RSSI-based. A high RSSI value represents a strong signal. RSSI is logarithmic and thus, if the RSSI increases by 6 dB that means that the signal strength increases twofold. The strength of the signal is stronger at a short distance and weaker at a long distance. Moreover, the radio signal is sensitive to the presence of objects. If there are obstacles between the transmitter and receiver terminals, it will have a negative impact on the signal power level and thus, the location precision. Hence, the authors in [1] believe that localization method employing a RSSI algorithm cannot be improved that much in theory. However authors in [25] stated that one advantage of RSS-based methods is that LoS path is not required.

Using the Channel state information (CSI) is a promising approach to replace RSSI-based methods [26]. The communication channel experiences various effects such as fading, scattering and power decay with the distance. The CSI represents the quality of the RF signals propagation from the transmitter terminal to the receiver terminal. It is generally more robust than conventional RSSI information but it is more prone to smaller-scale multipath fading [11]. Angulation methods are not commonly used in Wi-Fi but Yang et al. combined an AoA (angle of arrival) approach with a Wi-Fi CSI to achieve sub-meter level localization accuracy [27]. AoA is a common angulation method. The acquisition of angular parameters is a complex task and AoA requires multiple antenna system to estimate the angle. The position accuracy is low for longer distances from the reference anchor due to the quantization and multipath errors of the estimated angle [19]. AoA deployment is more costly, due to multi-antenna systems. Hence, it is not widely available in daily life. Yang et al. research work pioneers the usage of CSI because current Wi-Fi interfaces on mobile phones do not support CSI measurement. Indeed, CSI is extracted using customized firmware, which is more expensive and less flexible for large deployement [11].

Cell identification (CID) positioning is a network based techique that can also be employed to estimate the location of mobile devices but the precision is poor. The simplest example is when the position of the mobile phone is approximated as the position of the base station [28]. This method is not precise in GSM networks because only one cell is connected to the device [29]. Experiments with Cell-ID location techniques were conducted in [30] and the authors concluded that the accuracy of Cell-ID is not sufficient, even for non-industrial use cases. As of LTE rel-9, the successor of cell ID is available under the name enhanced cell ID (E-CID). This localization technique improves the positioning performance by taking into account additional network characteristics [11]. Enhanced Cell-ID combines the location of the base station serving the UE with additional measurements, such as the power related parameters (RSRP), the angle of arrival of a signal from the mobile device and time related parameters (ToA or RTT). In UMTS networks, Cell-ID was an angle-based technique, but as of LTE, E-CID can be considered as a combination of RSS-based and angulation method because the process relies on both the RSRP and the angle parameters. As RSRP-based approaches require a precise propagation model to obtain good signal energy estimation, it is difficult to produce accurate measurements in complicated dynamic environments and thus, AoA/AoD-based methods are not the best methods for LTE networks [5]. However, the recent 5G releases can use higher frequency bands or mmWave (millimeter wave) communication, which enhance the directionality and allow very high precision range and angle measurement. MmWave-based systems are less sensitive to interference than the sub-6 GHz counterparts. However, they suffer from path loss. Deploying dense picocells can mitigate this problem [25].

In the case of dense deployment of indoor small cells, the E-CID method can achieve horizontal location accuracy within 50 meters and vertical location accuracy within 10 meters [11]. A drawback of E-CID is that additional equipement is required, which increases the costs. In 5G rel-16, regular use-cases require a positioning accuracy of 50 meter and a latency of 30 seconds [5], while commercial indoor use-cases require a location accuracy of 3 meter and a latency of 1 second. Such an accurate positioning will be allowed by 5G picocell gNBs deployment. However, this localization accuracy is currently only achieved in simulation [25]. The deployement of 5G systems that meet this accuracy requirement is still a work in progress.

The rel-17 amendment will also increase 5G location precision to sub-meter level [31] by combining various measurements and improving the bandwidth, the power, and the number of antennas. The idea of combining RSS, time and angle measurements was already present in Enhanced Cell-ID and it will be applied to other 5G techniques to come. Furthermore, 5G NR rel17 considers that joint processing of time-and angular-based techniques could solve the dense multipath problem present in the InF (indoor factory) case [32]. Rel-17 also proposes to combine E-CID with Multi-RTT.

Authors in [33] claimed that the directional information obtained from the AoA method with multiple antenna technology, also known as MIMO (multiple-input/multiple-output), can improve the accuracy in rural areas covered by LTE networks. In 5G rel-16, a new positioning technique based on AoA was standardized and integrated in the 5G protocol: UL-AoA (uplink AoA). This method involves gNB measurement of the azimuth and zenith of arrival of UE's SRS relative to a reference direction. Another technique called DL-AoD (downlink AoD) was also standardized. In this process, a UE measures the beam RSRP of gNB using PRS [5].

Employing large antenna arrays for 5G transmission and reception points gives more angle information and thus, can optimize the localization parameter estimation [23]. Furthermore, 5G rel-17 states that larger antenna array apertures in massive MIMO gives narrower directional beams and increases angular resolution when implementing UL-AoA [32].

3.3. Location Fingerprinting

In the last years, Wi-Fi-based positioning based on RSSI fingerprinting has become more popular than traditional triangulation mainly because this method is simpler to implement [34, 8]. As already mentioned, RSS-based techniques do not need LoS. This is also the case of radio frequency signal fingerprint-based methods [35] and thus these methods are suitable for indoor positioning. The operation of fingerprinting-based localization requires two steps. In the first step, often called offline phase, site surveys or path loss predictions are used to create a database of RSSI. In the second step, also called online phase, the mobile device measures RSSI values and reports them to a cloud server, where the data are proccessed and the device location is estimated by finding the best match for the measured signal pattern [7]. For example, the RADAR system [36] is a RSSI fingerprint-based indoor localization system that uses Wi-Fi signals. It can achieve a localization accuracy of 3 meter. Moreover, the "WiNar" system [37] combines RTT-based and RSS-based fingerprinting to tackle indoor environment problems like multipath, NLoS conditions and interferences.

The advantage of Wi-Fi-based indoor localization using fingerprint algorithms, is that knowing the location of all APs (anchor points) in advance is not required. The fingerprint process can adapt itself to AP location changes because the mobile device can send new information about the surrounding APs to the cloud server in real time [38]. However, the techniques based on RSSI perform better than fingerprinting when the APs location is known. To be able to replace fingerprint-based with more accurate RSSI-based methods, some researchers are working on new methods to improve APs location estimation [39].

On the cellular side, implementing a radio frequency signal fingerprint-based method has the advantage of not requiring additional hardware in the network infrastructure. Such a method was discussed in a 3GPP meeting under the name radio frequency pattern matching (RFPM) to be standardized in LTE release 12 [40], but no further work was done later. Cellular-based location fingerprinting is still not part of the 3GPP standard, but it is currently coming back to the table in 5G rel-18. Wi-Fi-based fingerprint algorithms are more popular in research labs because the 5Grelated information required for positioning is not accessible by everyone: a license is needed to use closed-source 5G tools. In [41], RSSI, RSRP, reference signal receiving quality (RSRQ) and signal to interference plus noise ratio (SINR) are used together in a fingerprint algorithm that uses 5G signals.

4. CONCLUSIONS

Wi-Fi indoor localization is mostly based on fingerprinting methods, while angulation and trilateration techniques are not commonly used and are not enough accurate for indoor localization. Despite sporadic research articles about integrating fingerprinting methods in 5G systems, cellular-based location fingerprinting is not standardized yet. However, 5G NR offers concepts that could be used to increase positioning accuracy, like broader bandwidth with mmWave frequencies and dense deployement of picocells with more LoS conditions. 5G NR is showing the most impressive indoor positioning techniques. In industrial use-cases, the latest 5G rel-17 can fulfill the localization precision requirement, while Wi-Fi standards need improvement regarding indoor positioning. However, there is a lack of field measurements to confirm the theoretical localization performances promised by the 3GPP standard, while Wi-Fi positioning systems are more common and detailed analysis of their performance are regularly published by many researchers. Besides, mobile network operators will not implement the advanced techiques presented in this paper at large scale for cost reason. They will be deployed for specific industrial needs.

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