УДК 004.4: 004.4 DOi 10.30837/ bi.2022.1(98).10

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WIRELESS METHODS FOR THE LOCAL POSITIONING WITHOUT ACCESS TO THE INTERNET AND GPS SERVICE

Local positioning in buildings without access to the Internet is a crucial requirement in many scenarios, such as large corporate offices, hospitals, universities, and shopping malls. However, this need for local positioning also presents certain challenges and problems that must be addressed. One of the most significant challenges of local positioning in buildings without internet access is the lack of reliable and up-to-date indoor map data. Without accurate map data, it can be difficult to navigate through complex indoor environments or locate specific rooms or facilities within a building. Another challenge is the absence of GPS signals in indoor environments, which makes it challenging to obtain accurate location information. This is especially problematic when attempting to track the movement of people or objects within a building. Additionally, the lack of internet access can make it difficult to implement location-based services that rely on data transfer between devices. This includes applications like indoor navigation, asset tracking, and location-based marketing, which all require internet connectivity to function correctly. Despite these challenges, there is a growing need for local positioning in buildings without internet access. This is especially true for large organizations and institutions that rely on efficient and effective operations within their indoor environments. Some technologies can provide accurate location information and help to mitigate some of the challenges associated with local positioning in buildings without internet access. They allows to obtain the accurate location information without relying on GPS signals or internet connectivity. The need for local positioning in buildings without internet access is becoming increasingly important, especially for large organizations and institutions that require efficient and effective operations within their indoor environments.

LOCAL POSITIONING METHODS, WIRELES TECHNOLOGIES, WI-FI, BLE, IPS

І.А. Ревенчук, В.Є. Валуйський, М.І. Темнохуд. Бездротові методи локального позиціонування без доступу до Інтернету та служби GPS. Локальне позиціонування в будівлях без доступу до Інтернету є важливою вимогою в багатьох сценаріях, наприклад у великих корпоративних офісах, лікарнях, університетах і торгових центрах. Однак ця потреба в локальному позиціонуванні також створює певні виклики та проблеми, які необхідно вирішити. Однією з найбільш важливих проблем локального позиціонування в будівлях без доступу до Інтернету є відсутність надійних і актуальних даних карт приміщень. Без точних картографічних даних може бути складно орієнтуватися в складних приміщеннях або визначати місцезнаходження окремих приміщень чи об'єктів у будівлі. Іншою проблемою є відсутність сигналів GPS усередині приміщень, що ускладнює отримання точної інформації про місцезнаходження. Це особливо проблематично під час спроби відстежити рух людей або об'єктів усередині будівлі. Крім того, відсутність доступу до Інтернету може ускладнити впровадження служб на основі визначення місцезнаходження, які покладаються на передачу даних між пристроями. Сюди входять такі додатки, як навігація в приміщенні, відстеження ресурсів і маркетинг на основі місцезнаходження, для належної роботи яких потрібне підключення до Інтернету. Незважаючи на ці проблеми, зростає потреба в локальному позиціонуванні в будівлях без доступу до Інтернету. Це особливо вірно для великих організацій та установ, які покладаються на ефективну та результативну роботу всередині своїх приміщень. Деякі технології можуть надати точну інформацію про місцезнаходження та допомогти пом'якшити деякі проблеми, пов'язані з локальним позиціонуванням у будівлях без доступу до Інтернету. Вони дозволяють отримати точну інформацію про місцезнаходження, не покладаючись на сигнали GPS або підключення до Інтернету. Потреба в локальному позиціонуванні в будівлях без доступу до Інтернету стає все більш важливою, особливо для великих організацій та установ, які потребують ефективної та результативної роботи всередині своїх приміщень.

МЕТОДИ ЛОКАЛЬНОГО ПОЗИЦІОНУВАННЯ, БЕЗДРОТОВІ ТЕХНОЛОГІЇ, WI-FI, BLE, IPS

Introduction

Wireless local positioning without access to the internet and GPS service has become an essential requirement for many industries such as logistics, healthcare, manufacturing, and retail. With the increasing demand for location-based services, there is a growing need for reliable and accurate wireless local positioning methods that can work even in environments where GPS signals and internet connectivity are not available.

Traditional GPS-based systems cannot provide accurate location information in indoor environments, such as shopping malls, hospitals, and airports, where signals are often blocked or degraded by walls and other obstacles. In addition, many remote areas or developing countries still lack reliable internet connectivity, making it challenging to provide location-based services that rely on internet access.

To overcome these challenges, new wireless methods have been developed for local positioning without access to the internet and GPS service. These methods use wireless technologies such as Bluetooth Low Energy (BLE) beacons, Wi-Fi-based positioning, and indoor positioning systems (IPS) to provide accurate location information. The use of these technologies can be highly beneficial for industries such as logistics, where accurate location information can improve efficiency and reduce costs.

1. Wi-Fi network positioning general description

Nowadays, Wi-Fi networks are so common that with their help you can easily create a network that will consist of a large number of devices that are not tied to a specific location and can change their position in space. At the moment, almost any corporate client has Wi-Fi coverage, so the infrastructure of such a wireless network can be used to perform a number of specific tasks. One of them can be local positioning in the organization. The accuracy of such systems directly depends on the density of access points that are tied to specific points on the plan of a building, structure or a certain area.

Indoor Wi-Fi solutions use existing Wi-Fi access points or special Wi-Fi enabled sensors to detect and locate Wi-Fi transmitting devices such as smartphones and indoor tracking tags[1].

Location data collected by sensors or access points or sent from access points to client devices is fed into various location programs and converted into statistical data, which in the future can provide numerous cases of use of user location data.

Wi-Fi-based positioning systems can use different methods to determine the location of devices. Most of them rely on methods that are based on the Received Signal Strength Indicator (RSSI). However, some apps may use more advanced Wi-Fi positioning methods[2].

1.1. Wi-Fi positioning using access points

Wi-Fi positioning using access points directly depends on the existing Wi-Fi infrastructure installed indoors to determine the location of the desired devices[2].

This technology allows large organizations to use their existing infrastructure to run their location-based applications without the need to install new hardware.

Access points in a building can detect data transmissions from surrounding Wi-Fi devices, both on and off the local network. This data about the user's location is then sent to the server and used to calculate the position of the device in the space of the building.

1.2. Wi-Fi positioning using sensors

Sensor-assisted Wi-Fi positioning primarily uses Wi-Fi-enabled sensors that are deployed at fixed positions within the interior of a building.

These sensors can passively detect and locate data transmissions from smartphones, asset tracking tags, beacons, personnel badges, portable devices and other Wi-Fi devices.

The location data collected by the sensor is then sent to the server and received by the central Indoor Positioning System (IPS) or Real-Time Location System (RTLS). The location engine analyzes the data to determine the location of the device transmitting the data[3]. These coordinates can be used to visualize the location of a device or object on a spatial map of a particular space or be used for other purposes depending on the specific application that needs to recognize the location.

2. Wi-Fi positioning methods

The most common methods of Wi-Fi positioning determine the location of an object using an indicator called the Received Signal Strength Indicator (RSSI), mainly for device multilateration or fingerprint calculation. These approaches, which were based on signal strength, are very simple to implement and cost-effective, but cannot provide high accuracy because the signal strength can be affected by the environment.

RSSI solutions are also susceptible to errors that can be caused by the movement of objects in the environment, such as people.

Adding other less common and more advanced methods can lead to more accurate Wi-Fi positioning results. These include Angle of Arrival (AoA) and Time of Flight (ToF)

2.1. RSSI multilateration

In RSSI-based applications, multiple existing Wi-Fi access points or fixed-position Wi-Fi-enabled sensors will detect Wi-Fi devices that are transmitting data and the received signal strength from the device.

This location data collected by access points or sensors will be sent to a central Indoor Positioning System (IPS) or Real-Time Location System (RTLS)[4].

The RSSI multilateration scheme is shown in fig. 1.

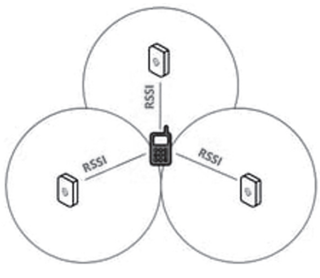

Fig. 1. RSSI scheme

The exact location engine analyzes the data and uses multilateration algorithms to estimate the location of the devices transmitting the data. In addition, you can use the signal strength of the nearest access points relative to the wireless device to determine the location of the device.

Using an RSSI-based method with multilateration is the simplest and cheapest option for Wi-Fi positioning. However, it cannot provide a high degree of positional accuracy because it is subject to signal attenuation, signal absorption, signal reflection and various interferences.

2.2. RSSI fingerprinting

Fingerprinting is also an RSSI-based method. Wi-Fi fingerprint positioning primarily involves the use of a database that will record the location and signal strength of surrounding Wi-Fi access points, as well as the Wi-Fi coordinates of a device such as a smartphone or tracking tag in an inactive phase[5].

Creating a fingerprint database requires a long and time-consuming calibration process that may need to be repeated multiple times. During active device tracking, the RSSI value is compared to these footprints in the database to estimate the location of the pre-trained device.

The RSSI fingerprinting cheme is shown in fig. 2.

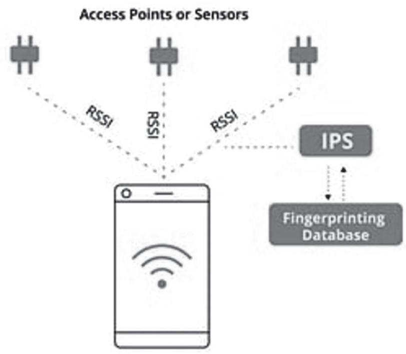

Fig. 2. RSSI fingerprinting scheme

Similar to signal strength and multilateration positioning, fingerprinting does not provide high positioning accuracy unless the system is constantly calibrated to environmental changes. This is a low-cost Wi-Fi positioning method, but it requires constant updating of the trained patterns in the database.

Fingerprinting approaches are also affected by signal attenuation (the biggest influence), signal absorption, signal reflection, and random interference in the signal path.

2.3. Time of Flight (ToF) method

Time of Flight – it is a highly accurate positioning method used by precision technologies such as UWB. This advanced technique can accurately measure the distance between Wi-Fi devices by calculating the time it takes for a signal to travel between devices.

ToF can be used to determine the exact location of a Wi-Fi device using multiple sensors or access points. This requires an integrated deployment of access points or sensors to detect Wi-Fi devices such as a smartphone or tracking tag.

To work properly, sensors or Wi-Fi access points must be precisely synchronized to the same master clock. The device's Wi-Fi signals will be received by access points or sensors in range and time-stamped.

The scheme of ToF method is shown in fig. 3.

All time-stamped data is then sent to a central ISP or RTLS. The location system will analyze the data from each anchor and the difference in arrival time at each anchor, and then use multilateration to accurately calculate the coordinates of the mark.

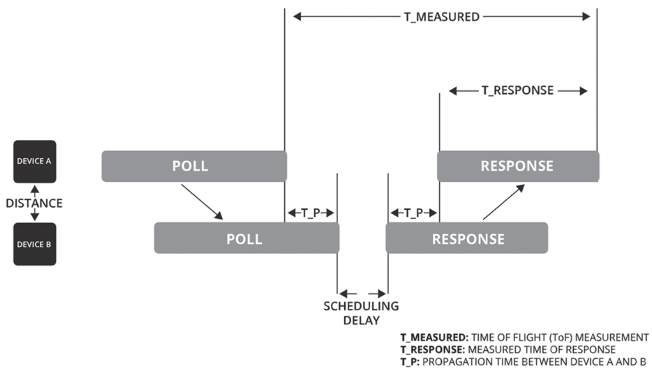

Fig. 3. Time of Flight scheme

Although ToF provides more accurate Wi-Fi positioning, the deployment of this approach involves a higher level of complexity and may not be cost-effective in scenarios where high accuracy is not required. Wi-Fi Round-Trip-Time (Wi-Fi RTT) is a new method of locating Wi-Fi devices that uses ToF. Specified in the IEEE 802.11-2016 standard, Wi-Fi RTT allows devices to measure the distance between devices using the signal transit time between devices.

This calculation is based on the path traveled by the signal and is determined using the speed of the electromagnetic wave and the speed of light. This can be used for ranging between two devices or for indoor positioning with multiple access points or multi-lateration sensors.

2.4. Angle-of-Arrival (AoA) method

The angle-of-arrival method is an advanced method that can provide Wi-Fi positioning with increased accuracy compared to more traditional methods such as fingerprinting and RSSI.

This is made possible thanks to the Wi-Fi interface Multiple Input Multiple Output (MIMO). To be able to determine direction, a mobile device such as a tag or beacon with a single antenna transmits data to a fixed Wi-Fi sensor with a multi-antenna system.

The phase shift of multiple antennas as a result of signal reception is measured and calculated to determine the angle of the transmitting mobile device and create a zone of certainty of the object to be found.

One advantage of the angle of arrival method is that it reduces the number of reference points required. Instead of the minimum three sensors required for any multilateration method, you only need two to determine position unambiguously.

The scheme of AoA is shown in fig. 4.

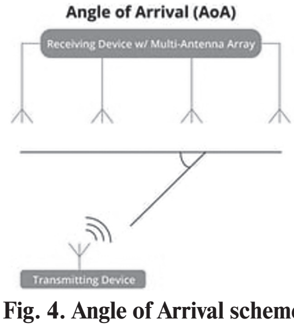

Fig. 4. Angle of Arrival scheme

Additional reference points increase the accuracy and reliability of calculated positions. Although angle-of-arrival indoor positioning is more accurate than other methods up to signal strength, solutions using this technique are just entering the market.

3. Wi-Fi positioning accuracy, range and frequency of work

So how accurate can Wi-Fi positioning be? Wi-Fi 5 and below are typically less accurate than other RF technologies such as Ultra Wideband Beacons (UWB) and Bluetooth Low Energy (BLE) and achieve Wi-Fi location accuracies typically less than 10 meters (under optimal conditions and deployment).

The current Wi-Fi 6 technology standard promises accuracy in the meter range, but since this is a new technology, this has not yet been demonstrated and tested in the field. The last update to the 802.11az standard in March 2021, also called Next Generation Positioning (NGP), promises improved Wi-Fi positioning accuracy.

Wi-Fi positioning accuracy is significantly lower when using single access points, but Wi-Fi-enabled sensors can be added to enhance the tracking of traditional access points, or even as separate sensors for more accurate positioning in the vicinity.

Different Wi-Fi positioning methods can also provide different degrees of accuracy. Traditional approaches such as RSSI multilateration and fingerprinting provide accuracies that are significantly lower than more advanced methods such as angle of arrival, time-of-flight, and Wi-Fi RTT.

The Wi-Fi positioning range may vary depending on factors such as the use of Wi-Fi access points or sensors or the nature of the indoor space. Wi-Fi operating at 2.4 GHz typically works up to 100 meters (under optimal conditions and deployment) and can be used even outside of premises where the appropriate infrastructure is in place.

However, Wi-Fi operating at 5 GHz reduces the range due to the higher frequency, operating at about 50% of the achievable range of 2.4 GHz. Also, at 5 GHz, higher signal attenuation should be expected if signals must pass through environmental obstructions such as doors, walls, or metalized windows.

Wi-Fi technology, like other RF standards, offers unique characteristics and benefits that can make it an accepted option depending on individual needs, project budget, facility, and specific location-based use cases.

The most important differences between Wi-Fi and other technologies are its ability to use existing Wi-Fi infrastructure and its flexibility for use in many applications that use location. Wi-Fi is present in devices almost everywhere, is used by many location tracking systems, and can be extended for indoor positioning in a whole range of industries and use cases.

4. Bluetooth Low Energy technology overview

Bluetooth Low Energy (BLE) is a wireless communication technology that was introduced as a part of the Bluetooth 4.0 specification. It is designed to provide low-power wireless connectivity to devices with low data rates over a short range. BLE operates on the same 2.4GHz ISM band as traditional Bluetooth, but it uses a different modulation scheme and has a lower power consumption than traditional Bluetooth[6].

This tecnologe was developed to address the limitations of traditional Bluetooth, which required high power consumption and was not suitable for applications that required long battery life. BLE provides a low-power alternative to traditional Bluetooth, allowing devices to run on batteries for months or even years, making it an ideal solution for devices such as sensors, wearables, and IoT devices.

BLE uses a master-slave architecture in which a master device controls the communication with one or more slave devices. The master device is responsible for initiating and managing the communication, while the slave device responds to the master's requests. The communication between the master and slave devices is carried out using packets of data that are transmitted over the airwaves.

One of the key features of BLE is its ability to operate in a low-power mode, also known as sleep mode. In sleep mode, the device consumes very little power and wakes up only when there is data to be transmitted or received. This allows devices to conserve battery life and operate for long periods without the need for frequent recharging.

It is also designed to be highly secure, with features such as encryption and authentication built into the protocol. This makes it suitable for applications that require a high level of security, such as healthcare, finance, and government.

This technology is widely used for applications that require low power consumption and short-range wireless connectivity, such as wireless sensors, wearables, and IoT devices[7]. BLE enables devices to connect and communicate with each other over a range of up to 100 meters in open space. However, the range can be reduced by walls and other obstacles.

BLE is often used in combination with other wireless technologies, such as Wi-Fi and GPS, to provide more accurate location information in indoor environments or areas where GPS signals are not available. BLE beacons, for example, are small battery-powered devices that emit a signal that can be received by BLE-enabled devices, allowing them to determine their proximity to the beacon and calculate their location.

It is also widely used in healthcare applications, where it can be used to monitor patients' vital signs, track their medication usage, and provide remote patient monitoring. In addition, BLE-enabled wearables can be used to track fitness and exercise activities, such as steps taken, distance traveled, and calories burned.

So, BLE technology offers low power consumption, short-range wireless connectivity, and a wide range of applications in various industries, including healthcare, fitness, automotive, and industrial automation. Its ability to provide location-based services makes it a valuable tool for many applications, and its low power consumption makes it an ideal solution for IoT devices and other battery-powered applications[8].

5. BLE advantages and disadvantages

Every technology has its strong and weak sides. For the BLE tecnology it is possible to specify the next advantages:

Low Power Consumption: One of the biggest advantages of BLE is its low power consumption. BLE devices can operate for years on a single coin cell battery, making them ideal for small, low-power devices such as wearables, sensors, and other IoT devices.

Low Cost: BLE technology is low-cost, making it an affordable solution for manufacturers and consumers. It has lower hardware costs compared to traditional Bluetooth technology and other wireless technologies.

Easy Integration: BLE technology can easily integrate with other wireless technologies, such as Wi-Fi and NFC. This makes it easier for devices to communicate with each other and with the internet[9].

Robustness: BLE technology is designed to operate in noisy radio frequency environments, making it robust and reliable even in the presence of interference from other wireless devices.

Security: BLE technology has several layers of security built into it, including data encryption, user authentication, and secure pairing. This makes it a safe and secure technology for transmitting sensitive data.

However the Bluetooth Low Energy techology has some disadvantages that needs to be solved or taken to the account while using it:

Limited Range: The range of BLE devices is limited to around 10-30 meters, depending on the environment. This is a disadvantage when compared to other wireless technologies such as Wi-Fi, which can cover larger distances.

Limited Bandwidth: BLE technology has a limited bandwidth, which means it can only transmit small amounts of data at a time. This makes it unsuitable for applications that require high-speed data transfer[10].

Compatibility Issues: BLE technology is not compatible with older devices that use traditional Bluetooth technology. This can be a disadvantage if older devices need to communicate with newer BLE devices.

Complexity: BLE technology is more complex to set up and configure compared to traditional Bluetooth technology. This can be a disadvantage for non-technical users who may find it difficult to use.

6. Ultra-Wide Band technology overview

Ultra-wideband (UWB) technology is a wireless communication protocol that utilizes very short-duration pulses of electromagnetic waves to transmit data over a wide frequency spectrum. UWB signals occupy a frequency bandwidth that is typically several GHz wide, compared to the narrowband signals used in traditional wireless communication systems, such as Wi-Fi and Bluetooth[11].

UWB technology is designed to enable high-speed wireless data transfer, accurate location tracking, and other applications that require high bandwidth and low power consumption. UWB technology was originally developed for military and scientific applications in the 1960s, and it was later used in commercial applications such as radar systems and ground-penetrating radars. In the early 2000s, UWB technology was standardized by the Federal Communications Commission (FCC) in the United States, which opened the door for its use in commercial applications.

One of the key advantages of UWB technology is its ability to accurately measure the distance between two UWB-enabled devices. This is made possible by the short duration of the UWB pulses, which allows for precise time-of-flight measurements of the signal. UWB distance measurement is highly accurate, with a typical error of only a few centimeters, making it ideal for applications such as indoor location tracking and asset tracking[12].

Another advantage of UWB technology is its high data transfer rates. UWB can achieve data transfer rates of up to 480 Mbps, which is significantly higher than Wi-Fi and other wireless communication protocols. This makes UWB ideal for high-bandwidth applications such as streaming video and audio. UWB technology also offers low power consumption, making it suitable for battery-powered devices such as smartphones, wearables, and Internet of Things (IoT) devices. UWB devices can operate in a low-power mode when not transmitting data, which helps to conserve battery life.

One of the main challenges of UWB technology is its limited range. UWB signals have a shorter range than Wi-Fi and other wireless communication protocols, typically only a few meters. This makes UWB ideal for short-range applications such as indoor location tracking and asset tracking, but less suitable for long-range applications such as outdoor communication[13].

Another challenge of UWB technology is its susceptibility to interference from other wireless devices. UWB signals can be affected by other wireless signals operating in the same frequency band, which can lead to reduced signal quality and data transfer rates.

Despite these challenges, UWB technology has gained traction in recent years, particularly in the areas of indoor location tracking and asset tracking. UWB-enabled devices are becoming increasingly common in smartphones, wearables, and other consumer electronics, and the technology is being adopted in various industrial and commercial applications, such as automotive and logistics.

7. UWB Advantages and disadvantages

Ultra-Wide Band is the good positioning technology that has the next strong sides:

High Precision: Ultra-Wide Band (UWB) technology offers high precision location accuracy, which makes it an ideal choice for applications such as indoor navigation, asset tracking, and industrial automation. UWB can achieve sub-centimeter accuracy, which is much better than other wireless technologies such as Wi-Fi or Bluetooth.

Immunity to Interference: UWB operates on a wide frequency band, which allows it to avoid interference from other wireless signals such as Wi-Fi or Bluetooth. This makes UWB a reliable and robust technology for use in harsh and noisy environments[14].

High Data Rates: UWB technology can achieve very high data rates of up to 10 Gbps, which is much faster than other wireless technologies such as Wi-Fi or Bluetooth. This makes UWB an ideal choice for high-bandwidth applications such as streaming video or audio.

Low Power Consumption: UWB devices require minimal power, which makes them ideal for use in battery-operated devices such as smartphones, smartwatches, and IoT sensors. This enables UWB devices to operate for longer periods of time without needing a battery recharge.

Security: UWB technology provides a high level of security through its use of short duration pulses, which makes it difficult for unauthorized users to intercept or decode the transmitted data.

In order to these strong sides UWB has some challenges and weak sides that need to be mentioned:

Cost: UWB technology is still relatively expensive compared to other wireless technologies such as Wi-Fi or Bluetooth. This can make it challenging for businesses to justify the cost of implementing UWB technology in their operations.

Limited Range: UWB technology has a limited range of typically around 10-20 meters, which makes it unsuitable for applications that require longer range communication such as outdoor navigation[15].

Line-of-Sight Requirement: UWB signals are highly directional and require a clear line-of-sight between the transmitter and receiver for optimal performance. This can limit the practical applications of UWB technology, especially in environments where obstacles such as walls or furniture may interfere with the signal.

Limited Availability: UWB technology is not yet widely adopted, which can limit its availability and interoperability with other devices and systems.

Regulatory Restrictions: UWB technology is subject to regulatory restrictions in some countries, which can limit its adoption and deployment in certain regions.

Conclusion

In conclusion, each wireless technology - Wi-Fi, BLE, and UWB - has its own strengths and weaknesses, making it suitable for specific applications. Wi-Fi offers a wide range and high data rates, making it ideal for applications such as internet connectivity and large-scale asset tracking. BLE is a low-power technology with good range and is well-suited for applications such as indoor navigation and proximity sensing. UWB technology offers high precision location accuracy, low power consumption, and immunity to interference, making it an ideal choice for applications such as indoor asset tracking, industrial automation, and secure communication.

The continued evolution and development of wireless technologies hold tremendous potential for transforming industries and enabling new applications. As the demand for wireless connectivity and location services continues to grow, it is likely that these technologies will continue to evolve and improve, offering new opportunities and solutions for a wide range of industries and applications.

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The article was delivered to editorial stuff on the 18.10.2022