BlueDAT - A conceptual framework for smart asset tracking using Bluetooth 5 in industrial enviroment

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Abstract— **In course of digitization of production facilities, tracking of assets in the supply chain becomes increasingly relevant for the manufacturing industry. Asset tracking refers to the method of tracking physical production orders, either by scanning bar code labels on production bins or by using tags with UWB, GPS, BLE or RFID technology attached to the bins that transmit their location to a suitable system. Current research and development projects use the Bluetooth (BT) standard 4.2. Although BT 4.2 is very energy-efficient and good results are achieved and considering the test results of current BT 4.2 AT systems, this paper describes the structure and prototypical implementation of a low-cost BT 5 Asset Tracking System. This open system is characterized by the reduction of unnecessary data transmission, greater configurability (e.g. transmission interval) and a generally higher intelligence of the individual receiving stations. Therefore, we expect a higher accuracy and reliability due to the collaboration of the receiving stations. The objective is to create a system that can be used economically for industrial companies while still providing adequate results in the area recognition of assets. The proposed solution is expected to reduce the costs associated with tracking and managing assets and improve asset utilization and operational efficiency.**

Keywords— Asset Tracking, Bluetooth Low Energy (BLE), Supply Chain Management, Industry 4.0, Internet of Things

I. Introduction

In the course of the digitization of production facilities, asset tracking (AT), i.e. the tracking of assets in the supply chain, is gaining increasing relevance in the manufacturing industry [1]. Modern production companies are required to track each individual production step and to be able to determine the current location of the respective order in real-time. This happens on the one hand to meet the required quality and warranty claims of the processing companies and on the other hand, the own better predictability of production processes. Especially suppliers in the automotive industry are subject to strict specifications [2].

Another important point in the digitization of production is the so-called paperless production. Previously, the order papers had to be printed for each order. In paperless manufacturing, job-relevant data is provided through digital media. This provides more up-to-date information, and thus reduces printing costs [3]. One component to achieve this goal is AT, as the (intermediate-)products or transportation boxes/bins can be uniquely identified by the mounted transmitter. AT refers to the method of tracking physical production orders, either by scanning bar code labels on production bins or by using tags with Ultra Wide Band (UWB), Global Positioning System(GPS), Bluetooth Low Energy (BLE) or Radio-Frequency Identification (RFID) technology [4] attached to the bins and transmit their location to a receiver. Basically, there are two different approaches to AT, on the one hand the determination of the exact position on the basis of x/y coordinates achieved by triangulation of an object or on the other hand, the area detection, also called location tracking or zone detection, the observed area is divided into different zones and you try as accurate as possible to determine in which area the asset is currently located [5]. In this paper, we focus only on the area detection approach to AT:

From a technical point of view, the UWB radio standard is regarded as the "Golden Standard" when tracking objects. UWB calculates the position of the monitored object with the propagation time of the signal, resulting in significantly more accurate results than Bluetooth (BT) based systems that use the received field strength indicator (RSSI) to estimate the distance [6]. However, AT systems based on UWB technology are far more expensive than BT systems and thus not economically viable for use with a high number of tracked objects and large areas for businesses. Current research and development projects use the standard BT 4.2 [7]–[11]. Although BT 4.2 is very energy-efficient and good results are achieved, the RSSI value loses its significance if the distance between asset and receiver is five meters or more [5]. The eightfold increase in broadcasting capacity combined with longer range enables now BT 5 to have a better communication channel between IoT devices than BT 4.2 [12].

Therefore, this paper describes the structure and prototypical implementation of an AT system based on the BT 5 radio standard. BT 5 was developed especially for the Internet of Things - quadrupling the range, twice the transmission speed and eight times the capacity of broadcast packages compared to B 4.2 with the same energy consumption are the key features of this new standard. It can be assumed that with an AT system based on BT 5.0 a more accurate position determination or better area recognition can be made than with conventional BT 4.2 systems. The aim is to create a low-cost system that can be used economically for industrial companies, while still providing adequate results in the area recognition of assets. The proposed solution is expected to reduce the costs associated with tracking and managing assets and improve asset utilization and operational efficiency. In addition, algorithms will be developed that reduce the network load in the company compared to conventional systems and do not absorb any additional data, such as data from the mobile devices of the employees. Subsequently, the developed prototypical AT system will be evaluated in industrial environments.

The remainder of this paper is structured as follows: chapter 2 summarizes related work on radio technologies for AT and BT 5, chapter 3 introduced the BT 5 standard and its properties, chapter 4 presents the results of field tests conducted with conventional commercial AT systems using BT 4.2, chapter 5 presents the concepts and development of technologies and algorithms to improve the detected problems, and subsequently chapter 6 concludes and presents further work.

II. Related Work

The localization of assets is an issue that can be important for many different companies all with divergent use-cases and scenarios. These use-cases also come with different focal points and restraints depending on the systems objectives and environment. This causes a lot of research to be conducted for the individual scenarios with multiple radio technologies in use.

Alvarez and Las Heras describe how to setup a AT-System using a ZigBee-based sensor network [13]. Their use of relative field level-based algorithms avoids the need of system calibration due to signal strength fluctuation.

Some AT-Systems combine two radio technologies in order to compensate the drawbacks of one technology with the strengths of the other.

Kao et al. evaluated a method that combines Wi-Fi fingerprinting and BLE trilateration positioning methods [8]. The Wi-Fi fingerprinting method estimates the rough position of asset in a large building, provided by mobile device user, and when the user approaches the asset, the exact position of asset is estimated by the BLE trilateration method. The experimental result showed that the BLE trilateration positioning achieved 90% accuracy within 1.21 meters.

Bluetooth 5 can be used in three different Data Transfer Modes, which vary on the way data is transferred. These modes have been evaluated by Di Marco et al. to give a more detailed insight into the performance of each separate mode, and under which circumstances they are best used [14]. In Advertisement mode the data is simply broadcasted on all of the different (random access) advertisement channels. This requires only little data overhead for transmission, but therefore an increase of lost packets might apply. Also, no link layer encryption is standardized for advertising packets.

In connection mode the data is transferred on a dedicated connection channel in case a high transmission-bandwidth and -reliability or encryption is required. The extended advertising mode has been introduced in Bluetooth 5 to exploit the advantages of advertising and the use of additional channels for data transmissions.

In terms of service ratio advertising mode performs better than extended advertising for short packets, but both advertising and extended advertising mode suffer high losses compared to connection mode. However, as traffic increases, the performance of connection mode degrades due to the high number of connection timeouts, and extended advertising mode is preferable.

In general, various aspects must be considered and different data transfer modes may be chosen depending on the case at hand.

III. Bluetooth 5

According to the Bluetooth SIG, the new radio standard BT 5 is expected to bring about some significant improvements in terms of IoT. Thus, the transmission speed of 1MBit/s to 2MBit/s increases, without significant impact on energy consumption. Furthermore, the 4-fold range compared to BT 4.2 is to be achieved. However, to reach the full range it is necessary to use the Physical Layer LE Coded, which is limited to a data rate of 125kbit/s. 4-fold the range and same time using the double data rate is still not possible. But the 125 kbit/s data rate is sufficient for asset tracking [15]. In any case, BT 5 is ideal for asset tracking due to its long range, low energy consumption and the extended advertise mode.

A) Longer range

As said BT 5 has a 4-fold range than the BT 4.2 standard in the LE Coded Layer. This means a reach of about 200m, in addition, the penetration of obstacles such as walls and doors will be much better. For tests with Bluetooth 5, Espen Wium achieved a range of 1.6 km outdoor in visual contact [16]. This is possible with BT 5 long range mode, that is a coded physical layer with 125kbps data rate, which is 8 times less than the standard 1Mbps Bluetooth low energy RF format [15]. According to AT a long range is important, otherwise the assets can get lost [17]

B) Low power consumption

The new BT 5 standard consumes half the power of its previous version no matter if operating in long range- or in double speed mode. For AT systems this is very important, cause the beacon battery should last a very long time. Current beacons have a battery life of 6 months up to 5 years [12]. This long runtime can be achieved with special beacons by only starting the advertising-mode and giving signals when they are getting moved.

C) Low cost hardware

AT systems that are used in industry normally have to cover large areas and track a large number of assets. That's why these systems usually consist of a large number of gateways and beacons.

An advantage of the BT technology is that the components are low cost compared to other wireless standards such as UWB.

Thus, systems with more than 1000 beacons also can be an interesting investment for a company.

In addition to the advantages, there are some characteristics of BT that can have a negative impact on AT systems and their functionality.

A) Signal fluctuation
The Bluetooth signal has a high signal fluctuation. The reasons for this is the low transmission power, especially in BLE mode [18].

B) Environment influences
Industrial environments are none static areas. Vehicles and production containers are constantly changing their position. This causes signal fluctuations, that makes it impossible to use the fingerprint methodology to support accuracy as done in other papers [19] [20]. In order to obtain accurate results in location tracking, it is necessary to use more gateways than in optimal areas.

C) Power consumption
An advantage of RFID tags is the fact that they don't require batteries and can be operated in passive mode. Current BT beacons always need a battery to operate. Of course, beacons have a much higher range than RFID tags, but in terms of maintenance, each operator costs are also important.

IV. FIELD TESTS OF AVAILABLE SYSTEMS

A series of tests were conducted to evaluate the effectiveness of BT asset tracking systems in an industrial environment. The tests were setup in a section of the production in a foundry where the products remained within the same containers, as shown in Figure , which are also identified by a barcode. The gateways were placed so that smaller zones (up to about 5m radius depending on the surrounding) would be monitored by a single gateway, bigger zones by multiple gateways (2-4) and a zone outside the building by monitoring two exits each with a gateway approximately 3m from the beacons path. The Bluetooth beacons were set to a moderate power level (0dB) and an advertising interval of one second.

Figure 1. Production container with mounted beacon and barcode.

The system was tested for its ability to detect beacons in every stage of the production, with an additional focus on how well it could detect passing beacons leaving the building through the monitored exits, and on how well the beacons could be recognized in the correct storage area.
The signal range of a beacon in a production environment and the influence of the product containers on the signal were also evaluated.
The tests showed that beacons were well detected when they passed the gateways near the exits, but they could not always be recognized in the correct production zone, especially when a container was placed near the border of a zone. A zone with a higher density of gateways could locate a beacon more reliably. This is due to a relatively high fluctuation of a Bluetooth signal in a manufacturing hall with a lot of machines, metal containers and people caused by the signal being absorbed or reflected. The range of a beacon depends heavily on its surrounding and chipset. Ranging from 13m when the signal needs to transmit through multiple containers and about 50m in line of sight within the production area compared to 100-150m range when outside within line of sight. Through the tests of current AT-systems, we have found the following weak points for industrial use:

- Most systems only work with a cloud storage solution, which might not be in favor when the company has its own data servers.
- The integration of gateways into the local network is not always trivial, depending on the company's IT structure.
- The Gateways produce a high amount of traffic on the local network because the gateways transmit every result that gets detected in a regular interval. This also causes a high amount of required storage to save the data.
- Beacon integration from different suppliers is not always fully possible.

V. CONCEPTS AND DEVELOPMENT OF TECHNOLOGIES AND ALGORITHMS TO IMPROVE THE DETECTED PROBLEMS

As the test results showed, a lot of issues occurred, because all the detected signals were just sent unfiltered and unprocessed to one central station (the cloud server). The data has then been regathered and has finally been collectively processed on a local server. Processing this data that late in the system chain, led to substantial problems:

- All continuously gathered RSSI values of all BT devices (from each gateway) resulted in a big data pool, where only around 40% of the detected devices have been devices of interest. Devices of interest means the BT beacons that actually should be tracked. The other 60% have been other BT devices, which were nearby (for example smartphones of the employees).
- In the test results, occasionally noticed big statistical outliers in the signal strength in form of positive and negative peaks have been noticed. These were caused by the always occurring changes in the production environment. For example, when forklifts interfere with the signal or when employees were

working just at the container, where a specific beacon was installed.

- The scan. interval of gateways was not configurable on a appropriate, flexible level. It was either possible to set the sending interval to a relatively small value (one minute) or a rather high value. Choosing the one-minute interval led to the outcome, that the cloud server received these unfiltered data mixed with all the statistical outliers (as mentioned above). As a result, it was necessary to regather a big amount of data from the cloud, to finally process it again on a server on the local network and to finally also store it there. Choosing a higher interval (like 15 minutes, which was the next option after one minute) resulted in a loss of possible important tracking-data.

- The gateways had no logical information about their location or the location of other gateways in the production hall. They didn't even have any information about the existence of other gateways at all. Each gateway gathered and forwarded data from all the beacons it got signals from. The gateways didn't communicate with each other (for example to determine, where a certain beacon maybe is at nearest at a specific time).

The source of these (and other) problems seemed always to be the gateways and their rigid behaviour. There was almost no possibility to configure the gateways, so they would act more specific on the conditions and needs of the setting/environment. In addition to that, it was not possible to specify a target host to which the gateways should send their data. There was no other option than sending the data to the cloud service and regather them later on via multiple REST-API calls. The more data was stored on the cloud and the more data the API-Client wanted to receive, the more single HTTP-requests were necessary.

In some points, the lack of configuration possibilities made it even harder to integrate the gateways into the company's IT infrastructure. This was needed after all, since the gateways needed a persistent connection to the internet in order to work. Finally, the internal infrastructure even had to be adopted, due the lack of configuration possibilities of the gateways..

The setup also showed potential security issues, by sending all the tracking data to a cloud. First, from the view of the company, it couldn't fully be guaranteed who would get access to their tracking data. One who gets access to the tracking data, might be able to conclude important information about the production processes of the company. So in the worst case, competitors (who might get access to the data somehow) could learn about the companies production strategies. Second, since the gateways were not only forwarding the IDs and signals from beacons, but also from all other BT devices in the environment, the privacy of the employees could be influenced. Whenever an employee had a smartphone with activated BT, his signal data were transferred permanently to the cloud too.

The setup of gateways follows a closed-system concept: There is no possibility to modify or even program their basic functionalities. So there have been no possibilities to extend them or even implement further logic or algorithms to make the gateways functionality better suitable for the requirements of the setting.

As a result, we started to develop our own gateways, with the goal to make them more open, more flexible, smarter as well as easily extendable and adaptable for many different use cases and environments. Also, we wanted to use BT5 for that gateways because of its longer range and the extended advertising mode, where it's possibly to send more data without connecting to the central. A big focus in this system is, that the gateways should not only receive and forward signals of BT devices to a server. They should already have architectural concepts implemented, which allow them, to process and analyze tracking data, as soon as it is received. To achieve this, we designed three core features:

A. *Multiple node system*

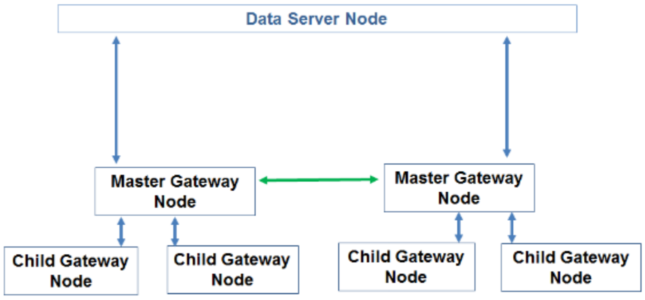

Figure 2. Concept of the Master-Child-communication.

The basic concept of the system is, that it is a Multiple Node System. The intent of this concept is to give each of the gateways - and also the server(s) they are communicating with - its very own dedication within a network of devices. Each device is a node in this network and has its specific role, as shown in Figure 2. The purpose of this network as a whole, is to receive and to process data from all the assets within its range. The range of this network should be the whole production area of a company, where certain assets need to be tracked.

Each area of the production hall has exactly one master gateway node (MGN) and a freely definable number of child gateway nodes (CGN). The more CGNs an area has, the more accurate is the localization of a beacon within that area. The MGNs among themselves exchange data about the beacons, which they receive from their respective CGNs.

Of course, it's not only possible, but even very likely that a single beacon is visible to gateways in more than only one area at the same time. By exchanging information, the MGNs should be able to determine very exactly in which area a beacon is located at a certain time, without having statistical outliers anymore. After the determination, the respective gateway sends the data of the beacon to a data server node (DSN). The purpose of this node is to store the data in a database and make it available for statistical queries for the users (like: „show the tracking history of beacon XY in the time from 01.01.2018 until 07.07.2018").

B. *Configuration Service Node*

In this network of nodes, where each node has its own dedicated role, each gateway node needs to rely on different settings to fulfill its purpose. For example:

- The location it belongs to.
- If it is an CGN or an MGN. When it's an CGN: the MGN it belongs to.

- Its sending interval

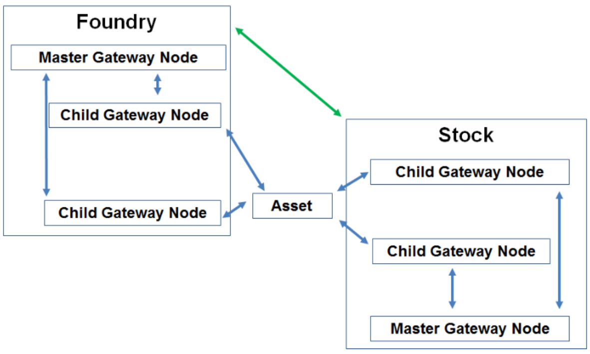

Figure 3. Concept of Master-Child Gateways.

To make this work, there's one additional node required in the network: The configuration server node (CSN), as shown in Figure 3. This is the very first node each gateway contacts, after it boots. The CSN serves the gateways with the information about their role in the network (and their general settings). Along with some essential information (see the list), the CSN sends device whitelists to the gateway nodes. These whitelists tell the gateways exactly which BT devices they should monitor. This list can be the same for all gateways - or different for various production areas or even for different single gateways.

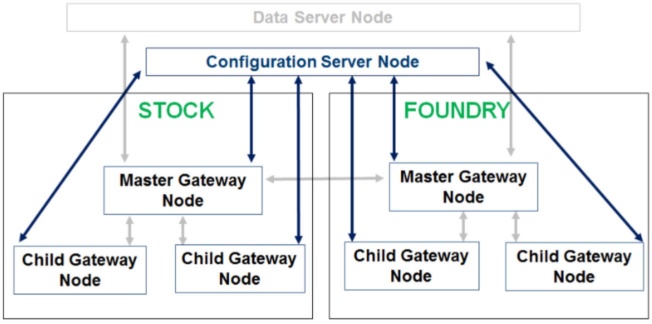

Figure 4. Concept of configuration server node

C. Weighted Signal Detection

One problem that sometimes occurred, during the tests of the commercial asset tracking system, were temporary outlier signals. Sometimes the signal strength of some gateways massively varied for a certain amount of time, even if the position of the tracked asset has not changed a bit. This was mostly caused by environmental influences/changes. Because of this, the gateway nodes are not only forwarding each signal, they get from a beacon. Instead of that, each gateway stores a history of received signals per beacon. They are observing this list for some time and regularly check if the signal either:

- is constant
- is constant, but sometimes has a few outliers, which are just there for a short amount of time
- has changed constantly at a certain point in time, in a remarkable way

Additionally, the MGNs are constantly exchanging these lists, so each MGN also knows about the monitored signals of the beacons from all other MGNs. The monitored changes of the signals are then finally processed by a weighting-algorithm. By the weighted outcomes of this algorithm, it should be possible to get certain recognitions about the state of an asset. For example:

- As long a signal is constant on all MGNs, it's very likely that the asset hasn't moved.
- If the signal of a certain beacon changes for a short amount of time at one gateway, but stays constantly at other ones, it's very likely that some temporary change in the environment has influenced the signal.
- If the signal gets constantly lower/higher at one gateway and also constantly changes on other gateways at the same time, it's very likely that the beacon/asset is moved.

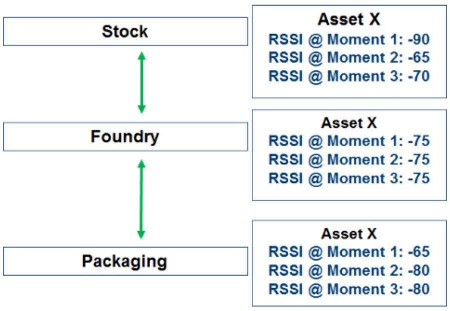

Figure 5. Weighted signal monitoring.

VI. CONCLUSION AND FUTURE WORK

The objective is to create a system that can be used economically for industrial companies while still providing adequate results in the area recognition of assets. The proposed solution is expected to reduce the costs associated with tracking and managing assets and improve asset utilization and operational efficiency.

BT 5 can help to improve AT-systems in the future cause of it's low power consumption and longe range. Also, the use of mesh networks that is only available since BT 5 could help to improve AT-systems, because only one Gateway has to be connected to the WIFI to send data to the application server.

The improvements of the BT standard will greatly impact and enhance future IoT applications such as AT systems. The next steps are the evaluation of the system in the industrial environment as well as a quantitative comparison of BT4 and BT5 in the use of AT systems.

A well-integrated AT system can provide a company with valuable Information about its products within production and internal logistics. This can prove to be useful for employees in the production, as the time to search for a specific asset can be drastically reduced, and for management and planning, as it can give a easy overview of the products within the production flow. Therefor it is for example possible to give estimates on the remaining time that a product needs to be shipable. An AT-system can also be helpful for internal optimization.

If a company already possesses a more trivial system for tracking its assets, this could be used to create trainings-data for a machine learning algorithm that could improve accuracy as well as decrease faulty position data due to signal fluctuations.

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