

## IS BLUETOOTH LOW ENERGY AN ALTERNATIVE TO NEAR FIELD COMMUNICATION?

WOLFGANG NARZT, LUKAS FURTMÜLLER, MATTHIAS ROSENTHALER

*Johannes Kepler University Linz, Austria*

*wolfgang.narzt@jku.at, luk.furtmueller@gmail.com, roenthalermatthias@gmail.com*

While the Bluetooth Low Energy (BLE) standard is commonly being used for energy-efficient mid-range data transmission and localization where distances of several meters are to be covered, its signal characteristics also reveals stable and deterministic behavior in the ultra-short range with significant higher signal strengths compared to distant placements, which potentially qualifies BLE as a substitute technology for Near Field Communication (NFC) for the purpose of identifying objects at very short distances. This paper investigates the signal strength behavior of BLE at a few centimeters distance between transmitter and receiver, points out strengths and weaknesses in terms of antenna alignments, shielding issues and interfering signals and presents potential application areas for ultra-short range object identification with a transmission technology that is not designed for that purpose.

*Key words:* Bluetooth Low Energy, Near Field Communication, Signal Strength Measurement, Object Identification

### 1 Introduction

The operating ranges of different wireless radio transmission technologies are typically marked off [9]: NFC and passive Radio Frequency Identification (RFID) are close proximity wireless technologies whose coverage footprint is measured in centimeters. Bluetooth and active RFID are wireless personal area network technologies operating within a few meters. WiFi is a wireless local area network technology serving the mid-range within a hundred meters. And finally, cellular communications, i.e., 3G, 4G and Long Term Evolution (LTE), are wireless wide area network technologies used for farther distances (just to name a few exemplary representatives).

Each technology has its range-specific area of application (e.g., identification of objects, localization or data transfer) and is usually tied to its designated section of operation. Whenever an application requires overlapping range-specific radio functions (e.g., unambiguous identification of objects in the near field and data transmission in the surrounding area) more than one transmission technology must be involved (e.g., NFC or passive RFID in combination with WiFi or Bluetooth). This instance forms an obstacle in some cases as NFC or RFID is unavailable for a majority of smartphones. In this connection, BLE could be a potential solution, enabling smartphone users to simultaneously identify close objects and to transfer data in the vicinity with the same technology, for, we have experienced that BLE produces significant signal characteristics at ultra-short ranges and therefore started investigating whether BLE could be used as a substitute for NFC.

To be precise, we do not intend to replace NFC by BLE, which would not be possible, because both technologies are designed for different purposes and also work differently. NFC is a passive one-way identification technology for very short distances requiring no batteries for its tags as power is electromagnetically induced with an NFC reader in range. BLE, on the other hand, is an active, battery-empowered two-way communication technology where its transmitters continually broadcast discovery signals that can be received by listening smartphones. In that sense, these technologies cannot be compared to each other.

However, as BLE is capable of identifying the in-venue presence of smartphone-equipped consumers and to subsequently deliver localized information (i.e., it recognizes BLE-equipped devices within the wireless coverage zone of a transmitter), it could potentially be used to also determine devices within an ultra-short range (equally to NFC) and therefore accomplish near-field object identification (even if technically different to NFC) and mid-range data transfer using just one technology.

## 2 State-of-the-Art

With the BLE standard (based on Bluetooth classic) defined in 2010, a new technology evolved in the field of low-power mid-range data transfer up to 50 meters [1]. Chipsets implementing the BLE standard are integrated in a large number of modern devices (i.e., smartphones, tablets, notebooks, beacons, etc.) [5] enabling BLE to serve various domains like health care, consumer electronics, smart energy, public transportation or security (to name just a few) [9, 14].

BLE has initiated a technology shift in the area of indoor positioning systems [4, 13, 22, 23], where it gradually replaces active RFID- and WiFi-based systems [2, 4, 21]. BLE provides the convenience to place autonomous beacons (even though battery-driven) to arbitrary locations having the additional advantage to determine an approximate position with state-of-the-art smartphones (featuring Bluetooth 4.0 or higher) in a decentralized way. Given that all recent smartphone generations have BLE onboard while comparable RFID systems in smartphones are rare, we conclude that BLE-based localization systems are highly attractive both from a practical and commercial standpoint. Infrastructural measures and processing costs are minimal. For more information on RFID- and BLE-based localization systems, we refer to [1, 2, 5, 24].

BLE splits the ISM band at 2.4 GHz into 79 channels á 1MHz and implements frequency hopping for avoiding collisions. The data transmission rate is at 1Mbit/s with a configurable transmitting power up to +4dBm (which correlates to a maximum coverage of 50 meters). Signal expansion in BLE networks is unsteady, though, which has already been investigated in numerous publications [1, 6, 12, 25]. They confirm fluctuating signal strengths within a range between 1 and 5 meters, observe differences for indoor and outdoor measurements and affirm significant shielding effects of obstacles (i.e., primarily the human body) in line of sight. However, they also reveal that there is no received signal strength indication (RSSI) above -45dBm (approximate) for measurements with a minimum distance of 50 centimeters (note that there were no measurements below this bound). Due to this fact (and also because WiFi networks show an equivalent behavior [20]) we consider BLE an enabling technology for identifying objects in the short range, as well. At close proximity of sender and receiver we observe significantly higher signal strengths compared to all larger distances such that we are not only able to imitate NFC with BLE, moreover we are capable of specifying several distinguishable proximity zones telling us whether an object is 2, 5, 10, or 30 cm away, as the following measurements will prove:

### 3 Measurements

For our measurements we have used 2 types of beacons: the nRF51822 Bluetooth Smart Beacon Kit and the Kontakt.io Smart Beacon (see Figure 1), both using the Nordic Semiconductor Bluetooth chip-set nRF51822 with a 32-bit ARM Cortex M0 CPU, 16KB RAM and a transmission power of +4dBm every 20ms (i.e., for the advertising signals). For the reading device we have used different standard smartphones (a Samsung Galaxy S5 with Android v4.4.2, a Samsung Galaxy S4 with Android v5.0 and an iPhone 6 with iOS 9.1) logging detected MAC-addresses and corresponding RSSI values using the standard BLE APIs.

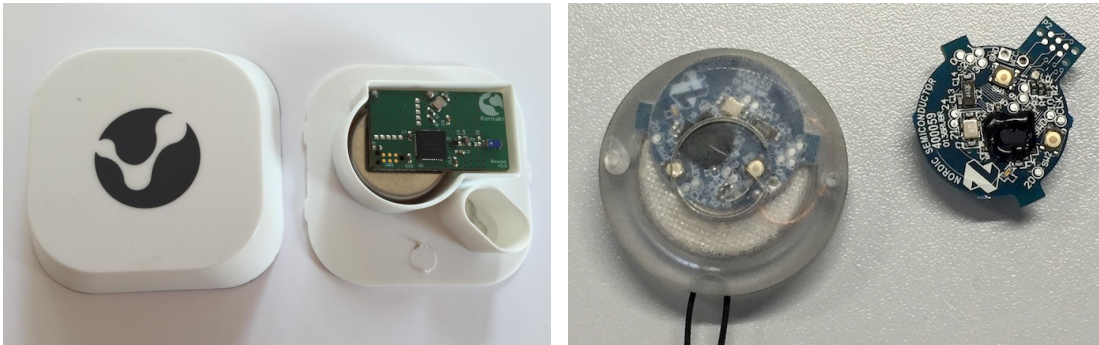


Figure 1 Nordic Semiconductor nRF51822 (left: Kontakt.io Smart Beacon, right: Bluetooth Smart Beacon Kit).

All tests were performed in flight-mode (but with the Bluetooth radio switched on) in order to avoid influencing factors like disruptive WiFi signals. No interfering Bluetooth devices were in range (within a closed room of 3x4x2.5 meters). We also repeated selected tests with LTE, WiFi and Bluetooth switched on and included Access Points and WLAN streaming traffic into our test scenarios in order to gain knowledge about the impact of interfering signals in the 2.4 GHz frequency band.

We conducted five different types of tests for measuring the signal behavior of BLE at close distances:

1. *Rotation Test*: for investigating the impact of different antenna alignments.
2. *Placement Test*: for investigating the impact of shielding hardware of the phone (e.g., batteries).
3. *Distance Test*: for investigating signal strengths in various zones from 0 to 100 cm.
4. *Interference Test*: for investigating the impact of interfering WiFi or other Bluetooth signals.
5. *Shielding Test*: for investigating the impact of shielding obstacles in line of sight

#### 3.1 Rotation Test

For the *Rotation Test* the beacon has been placed at striking distance to the BLE antenna of the smartphone (at the top of the device) and rotated in 90-degree steps (see Figure 2).

For each alignment we took 10 consecutive RSSI measurements in order to record the impact of a distorted antenna arrangement. The chart at the right of Figure 2 reveals the results: The four curves (alignments *a1* to *a4*) show considerable differences from  $-34\text{dBm}$  to  $-28\text{dBm}$  (i.e., a delta of  $6\text{dBm}$ ). Thus, we conclude that the orientation of the beacon in relation to the antenna of the smartphone matters and must be considered. We also recognize stable values for each orientation (fluctuating  $\pm 1\text{dBm}$ ) attesting applicability for the near contact range (opposing major fluctuations at larger distances [1]).

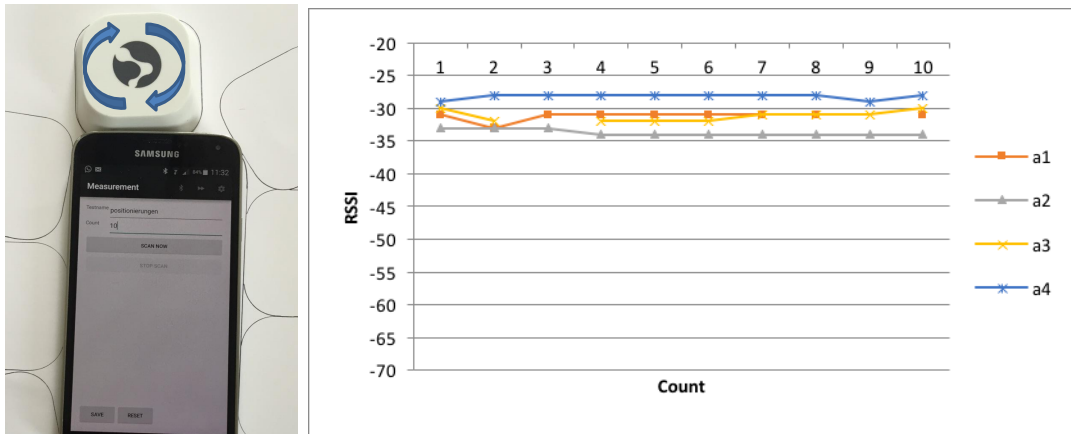


Figure 2 Rotation Test.

### 3.2 Placement Test

For the *Placement Test* we have successively arranged the beacon around the smartphone with again 10 RSSI measurements for each position (see Figure 3). Hereby, we have taken the beacon alignment that produced the best results in the *Rotation Test* (i.e., arrangement *a4*) and used it all through the *Placement Test*. The positions *p1* to *p9* are assigned clockwise starting at the top of the smartphone (so, *p6* is at the opposite side at the bottom).

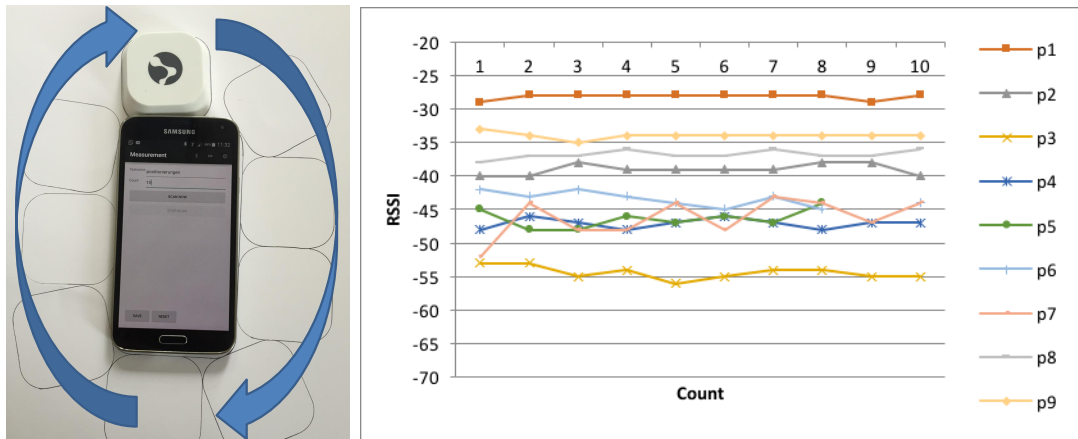


Figure 3 Placement Test.

We observe a wide RSSI range from  $-56\text{dBm}$  to  $-28\text{dBm}$  (a delta of  $28\text{dBm}$ , see Figure 5), which at the first glance seems fatal, because  $-56\text{dBm}$  could also be half a meter or a meter away (with the beacon tangent to the smartphone, though). A slight position change to *p2* noticeably worsens the results with RSSI values from  $-38\text{dBm}$  to  $-40\text{dBm}$ , which is confirmed by position *p3* (sideward on the right) with the worst results. At the bottom of the device (positions *p5* to *p7*) signal fluctuations rise, indicating asymmetric behavior regarding the measurements at the left and right hand side of the smartphone.

While we are not yet able to identify the reasons for these differences we assume that the metal contained in the smartphone’s batteries disrupts the dilatation of the Bluetooth signal. However, the measurements confirm the position of the BLE antenna at the top of the smartphone (to be more precise: at the top left, explaining the asymmetric results).

The assumed shielding impact of the batteries is confirmed in an extended test where we put the beacon right under the smartphone close to the batteries. This test produced the absolute worst results with RSSI values down to  $-63\text{dBm}$  and fluctuations within a range of  $10\text{dBm}$  (see Figure 4).

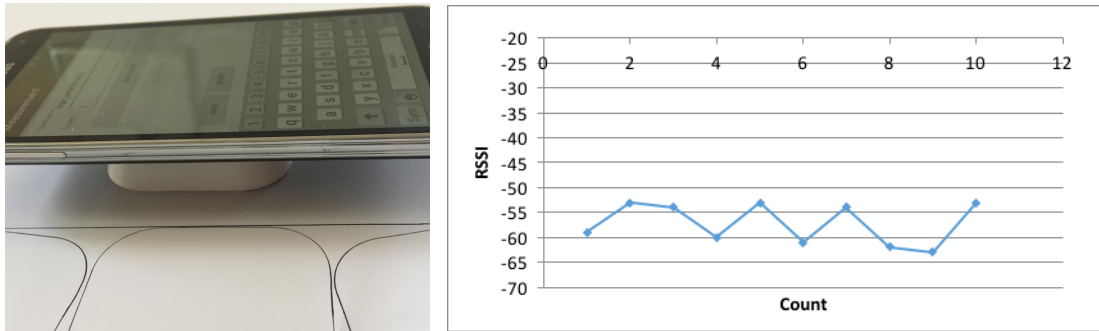


Figure 4 Extended Placement Test (Beacon under Batteries).

Contrary, the best results were measured with the beacon behind the antenna at the top of the smartphone. We observe RSSI values within an average range of  $-25\text{dBm}$  (again confirming the position of the antenna at the top of the smartphone, see Figure 5).

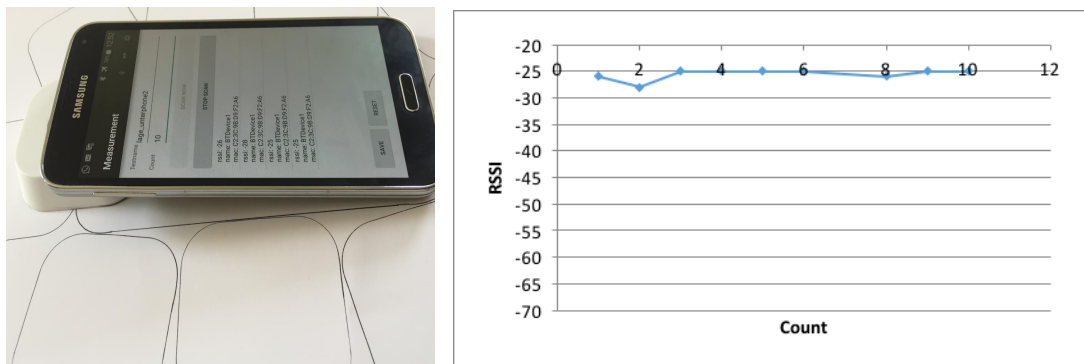


Figure 5 Extended Placement Test (Beacon under Antenna).

The interpretation of the results of the *Placement Test* is ambivalent: On the one hand, we are unable to make any statement about the relative position of the beacon as all tests produced different results (meaning that a beacon could either be in direct contact to the smartphone or more than a meter away). On the other hand, we recognize distinct strong signals when we are aware of the mounting position of the antenna in the smartphone. In that case, we can clearly distinguish near and far located beacons (i.e., we would postulate a designated way for holding the device). With that in mind, we conducted a third test series (i.e., the *Distance Test*) with varying distances utilizing our knowledge about the antenna.

### 3.3 Distance Test

For this test we measured RSSI values with the beacon placed in five discrete distances (2, 5, 10, 20, and 30cm) relative to the top of the smartphone (where the antenna is located, see Figure 6). The orientation of the beacon was derived from the rotation test: We have used alignment *a4* (see Figure 2), which produced the strongest RSSI values, throughout the distance test. Figure 6 presents the results in detail with 50 consecutive measurements for each distance:

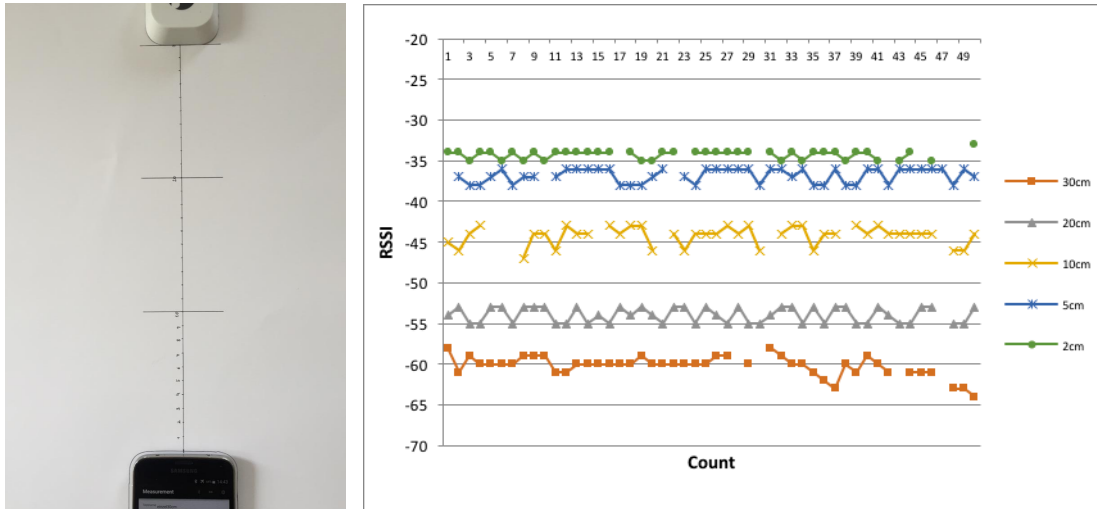


Figure 6 Distance Test.

We recognize separated curves within non-overlapping signal strength ranges for each distance and declining span widths of RSSI values with decreasing distances. Figure 7 underlines these findings by depicting the extreme values for each distance. No maximum value for any distance is above the minimum value of its adjacent shorter distance (with a quite stable variance of extreme values).

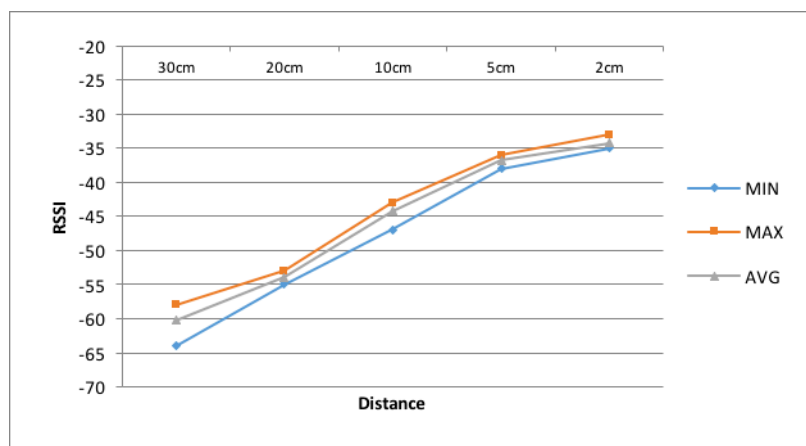


Figure 7 Extreme Values for Distance Test.

These results facilitate the specification of distinct threshold values for distinguishing various near zones and indicate that BLE is capable of differentiating various discrete sections in the near field below 30cm (provided that the mounting position of the BLE antenna in the smartphone in relation to the beacon is considered).

In order to gain a more general statement about the signal behavior of BLE at short distances we repeated parts of the *Distance Test* and modified the parameters of the test. We changed the reading device (from Samsung Galaxy S5 to S4), the operating system version (from v4.4.2 to 5.0), switched on all transmission radios (LTE, WiFi and Bluetooth) and moved to an office with 3 WiFi networks and at least 1 other Bluetooth device in range (average values, because not manipulable). In addition, we directly transferred the measured RSSI values to corresponding distance data following the conversion formula:

$$distance = 10^{\left(\frac{TxPower-RSSI}{10n}\right)}$$

where *TxPower* is the transmission power of the Bluetooth beacon (i.e. +4dBm) and *n* is a signal propagation constant (which is set to 2 in free space). As a result, we can calculate the distance between beacon and reading device at ideal transmission alignment.

At 0.5 cm real distance the measured RSSI values are significantly high resulting in an average calculated distance of 0.53 cm (see Figure 8), which is indeed an excellent result and confirms the constant signal behavior of BLE at very close proximity between sender and receiver (compare Figures 2, 6, and 7). Fluctuations are low, as well, within extreme values of 0.63 and 0.45 cm (i.e., 1.8 mm maximum range and 1.3 mm maximum deviation).

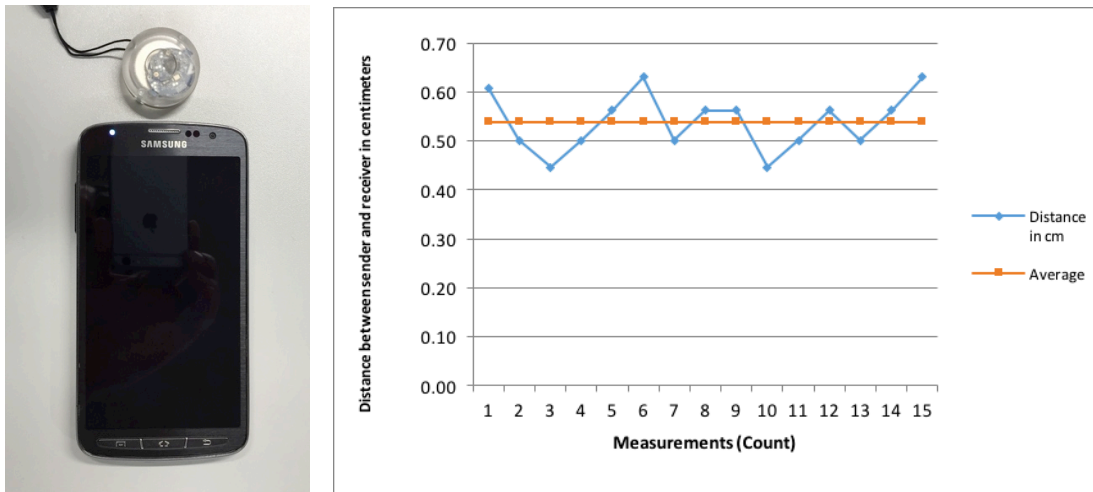


Figure 8 Distance Calculations at 0.5 cm.

At 30 cm real distance the average calculated distance is 32 cm (see Figure 9). While the result is still good (6 % average deviation), we again experience that the performance of the signal decreases with increasing distance (compare Figures 6 and 7). Fluctuations range between 40 and 22.5 cm, thus revealing a maximum deviation of 10 cm.

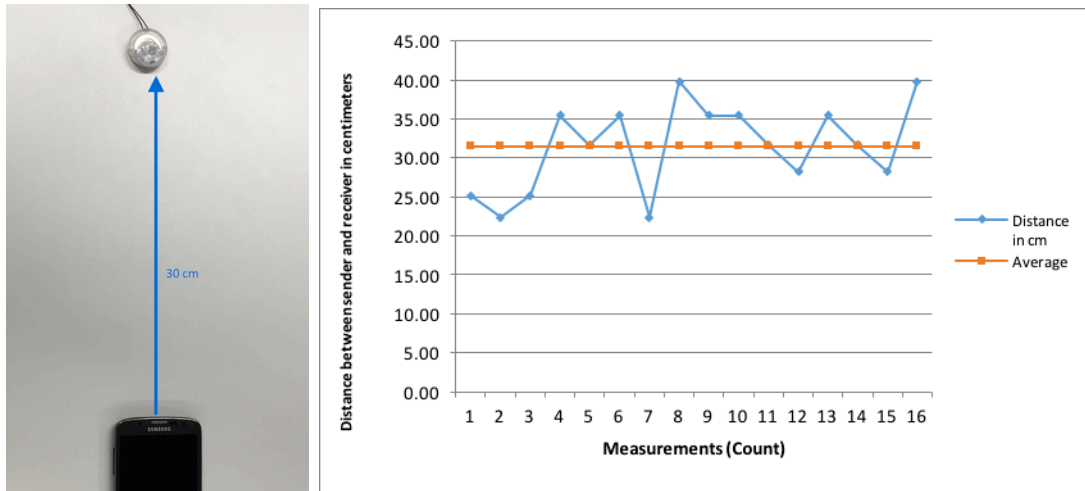


Figure 9 Distance Calculations at 30 cm.

We added another test zone at 1 m in order to complete the picture of rising fluctuation with increasing distance. While at 1 m real distance the average calculated distance is also 1m (see Figure 10), we clearly observe deviations from the origin. The lowest calculated distance was at 70 cm, the highest at 123 cm, which is 30 cm maximum deviation (30%).

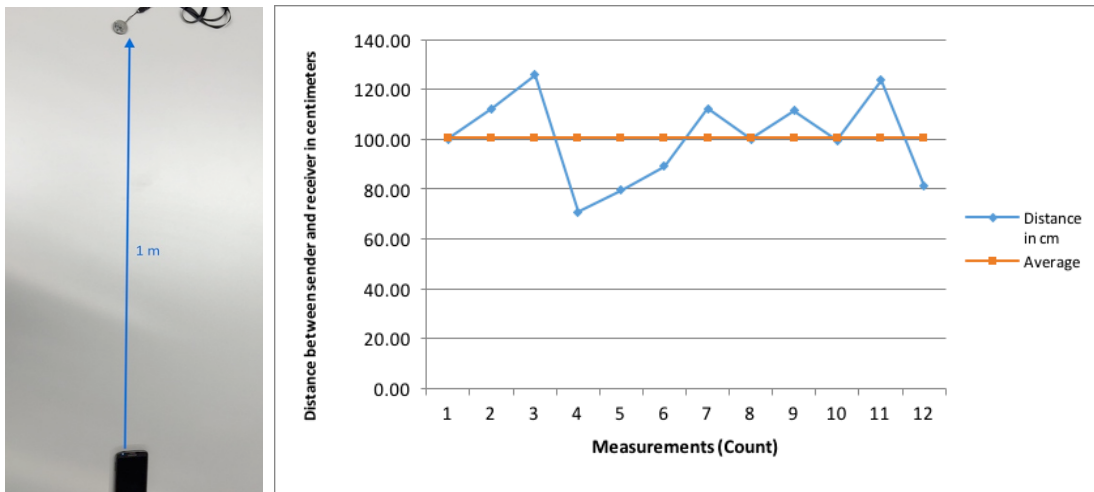


Figure 10 Distance Calculations at 1 m.

### 3.4 Interference Test

With the *Interference Test* we want to investigate the impact of additional transmission signals in the near range within a few centimeters at 2.4 GHz. We want to find out how multiple Bluetooth signals at low distances interfere, if WiFi networks disrupt BLE signals and what consequences these near field transmissions in the same frequency band have in terms of distance calculations.



For the first test we tried to recreate a typical NFC reading scenario with multiple devices in range. In our case we have used a Nordic Semiconductor Bluetooth Smart Beacon Kit and an iPhone 6 as transmitting BLE devices (both sending at +4 dBm). A Samsung Galaxy S4 with Android v5.0 served as the reading device. Beacons and reader were placed as shown in Figure 11 (with the BLE antennas of the smartphones at 2.5 cm distance and the beacon at 25 cm). Expected result: The Android reading device should clearly distinguish between the close iPhone and the distant beacon.

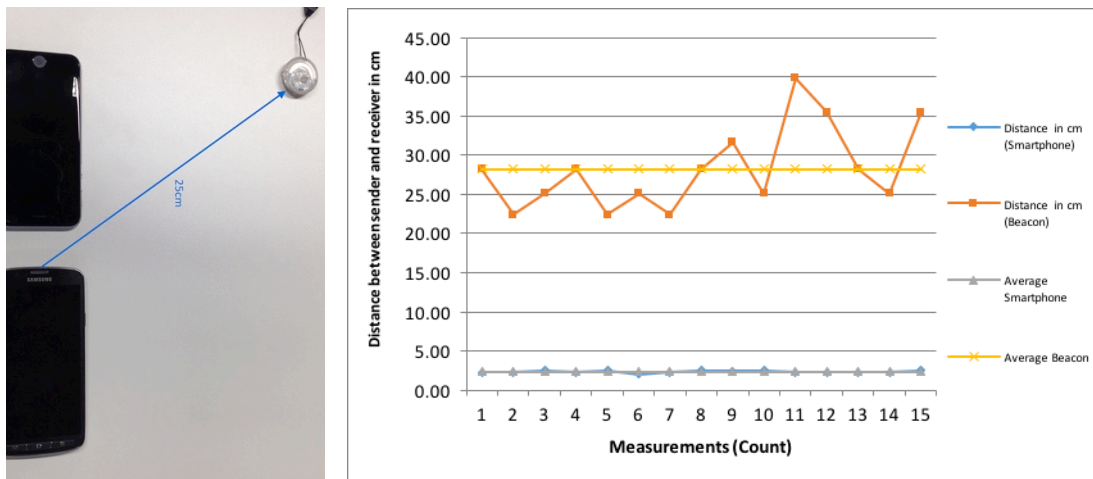


Figure 11 Interference Test (Ideal Antenna Alignment).

The measured results are clear: The average calculated distance between the iPhone and the Samsung Galaxy correlates to the real distance of 2.5 cm and reveals no significant fluctuations. The average calculated distance to the beacon (i.e., 28 cm) slightly deviates to the real distance (i.e., 25 cm), with a minimum calculated value of 22.5 and a maximum value of 40 cm. However, even if the fluctuations to the beacon were significant (due to an additional misalignment to the beacon antenna) Figure 11 clearly shows that there is no overlap between the curves of the two broadcasting devices, thus unambiguously identifying the iPhone as the near device.

For the second test we changed the position and orientation of the iPhone. While it is still at 2.5 cm distance to the Samsung Galaxy we chose the worst antenna alignment and place as identified in the *Rotation* and the *Placement Tests* (see Figure 12). This test should show whether the closest device can still be detected as such even when the alignment to the reading device is not ideal (as it has been in the test before). Distance and orientation of the reference beacon are unchanged.

Figure 12 has the results: We recognize a completely different picture in comparison to Figure 11. The average calculated distance between the two smartphones has increased to 16 cm (while it is 2.5 cm in reality). The fluctuations are even more significant with a minimum calculated value of 6 cm and a maximum of 35.5 cm (i.e., 33 cm maximum deviation). We now observe overlapping curves when we also consider the distance calculations for the beacon. The graph shows that the beacon's calculated distance is closer than the one of the iPhone, meaning that the alignment of sending and reading devices definitely impacts the measuring results and must be considered in a designated way for holding the devices when creating an application)

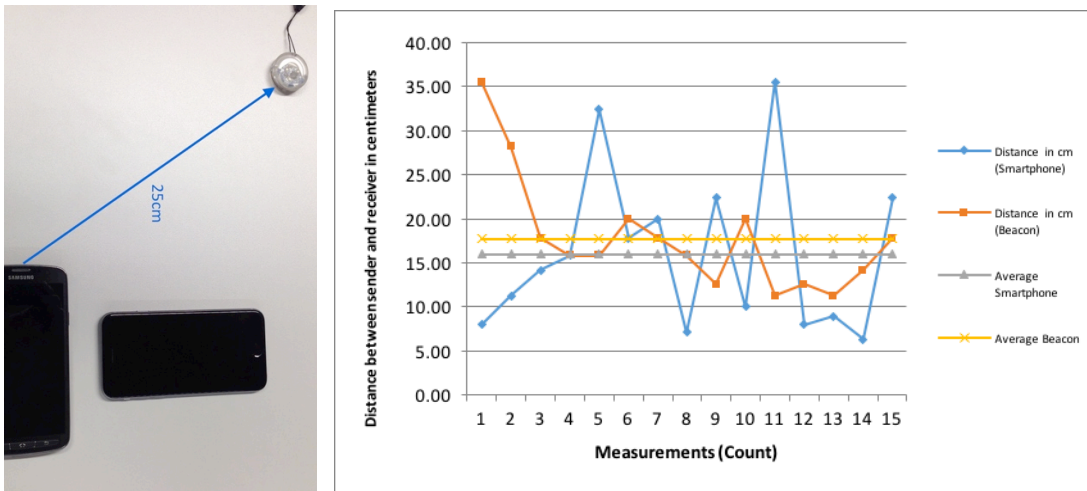


Figure 12 Interference Test (Misaligned Antenna and unideal Position).

The next *Interference Test* considered multiple sending devices in line-of-sight as depicted in Figure 13. The reading device is at the very bottom of the picture, the broadcasting iPhone is at striking distance to it (1 cm, antenna to antenna, ideally aligned) and the beacon is right behind the iPhone.

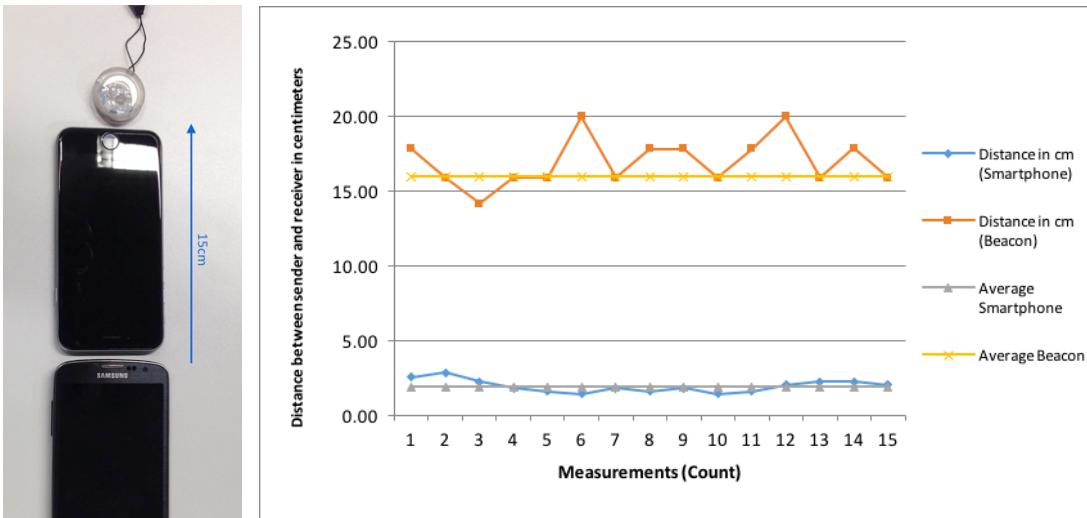


Figure 13 Interference Test (2 Devices in Line of Sight).

The average calculated distance between iPhone and Samsung Galaxy is 2 cm with fluctuations  $\pm 1$  cm, which is quite accurate. Also the calculated average distance to the beacon (i.e., 16 cm) is close to the real distance of 15 cm. Fluctuations range from 14 cm to 20 cm, which is as expected according to the preceding tests at those distances. Thus, several sending devices in line of sight do not significantly impact their signal behavior in relation to the reading device. The iPhone could be clearly determined as the nearest device without any overlaps.

Apart from multiple BLE sending devices we also investigated the impact of other radio transmission technologies, in particular WiFi, as it operates in the same ISM frequency band of 2.4 GHz (up to 2.485 GHz). Simultaneous usage of both technologies may cause collisions [5] and therefore potentially influences the behavior of BLE. Whereas BLE uses 1 MHz bandwidth per frequency step (and therefore accesses 79 channels between it can switch 1.600 times per second – which makes BLE quite resistant to disturbances), WiFi splits the frequency band to 13 channels with 5 MHz each (whereby only 3 channels can be used simultaneously as 1 channel uses 22 MHz bandwidth). As a consequence, a collision of BLE signals within a WiFi network is likely to occur by  $22/79 = 28\%$ . Modern chipsets try to avoid collisions by synchronizing sender and receiver slots, however, we are unaware of its effective impact and therefore try to examine it in the following test setup:

We have used a state-of-the-art WiFi access point (Cisco Aironet 1250) and placed it right next to the BLE receiving smartphone (see Figure 14). A WiFi connection between smartphone and access point had been established and used to create an interfering signal by streaming a video. The BLE broadcasting beacon had been placed in 2.5 cm distance to the antenna of the smartphone.

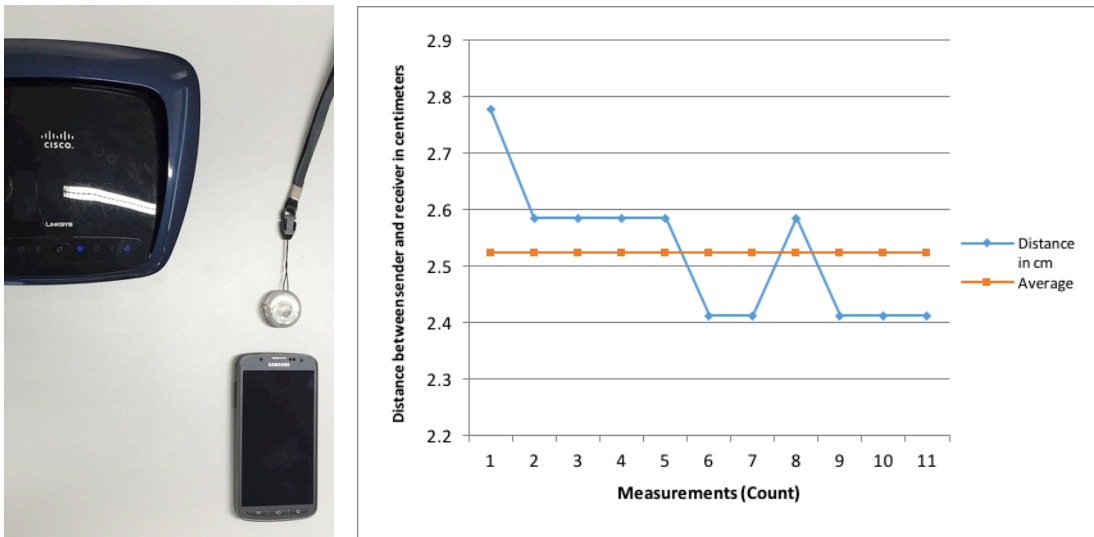


Figure 14 Interference Test (disruptive WiFi signal at close distance).

We observed that we received all BLE broadcasting signals on the smartphone without a single loss and within the time slots of the sending interval of 300ms. Also the distance calculations were accurate with an average calculated distance of nearly 2.5 cm (conform to the actual distance) and minimal fluctuations between 2.8 and 2.4 cm, i.e., 3 mm maximum deviation. Thus, we conclude that simultaneous Wi-Fi data transfer has no effect in terms of signal strength and data loss of BLE.

### 3.5 Shielding Test

As earlier tests have shown, obstacles in line-of-sight between sender and receiver (in particular the human body) significantly weaken radio signals [18, 19]. So, we additionally conducted a series of tests examining the shielding impact of various materials to the signal expansion of BLE.

To start with, we put a human body (approximately 20 cm wide) in line-of-sight between beacon and smartphone with a distance of 40 cm (see Figure 15). To put it casually, the signal still has a chance to find its way around the body.

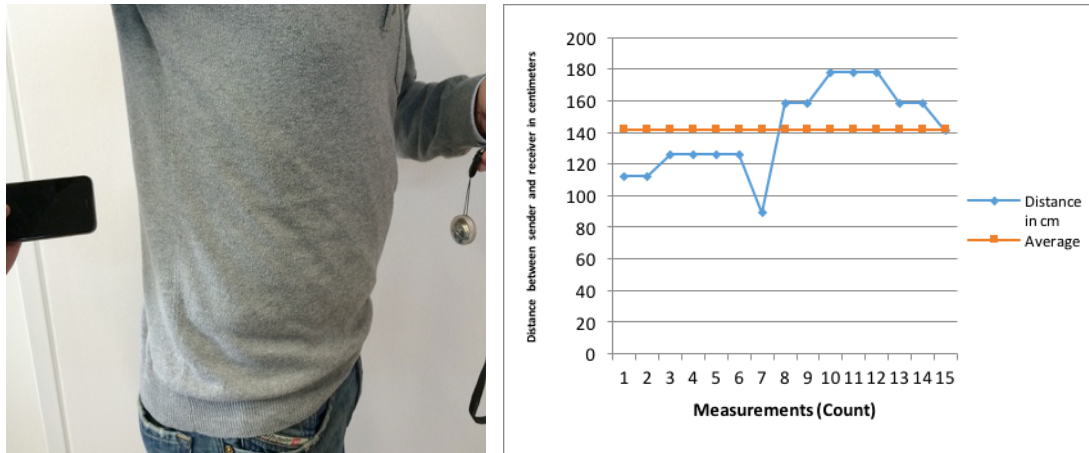


Figure 15 Shielding Test (body 40 cm).

Figure 15 clearly shows that the calculated distance values do not correlate to the real situation. The average calculated distance is 140 cm (i.e., 1 m deviation) having major fluctuations between 90 and 180 cm. This test confirms that the human body significantly shields BLE signals.

However, it still goes worse: If we omit any free space between body and devices (i.e., we minimize the space for the signal to evade) with beacon and smartphone in 20 cm distance, we calculate an average distance of 25 meters (see Figure 16) and a fluctuation width of more than 21 meters (with a minimum value of 1.412 cm and a maximum of 3.548 cm). Indeed, the signal is shielded by the human body such that we occasionally lose connection up to 5 seconds (using a 300 ms broadcasting interval).

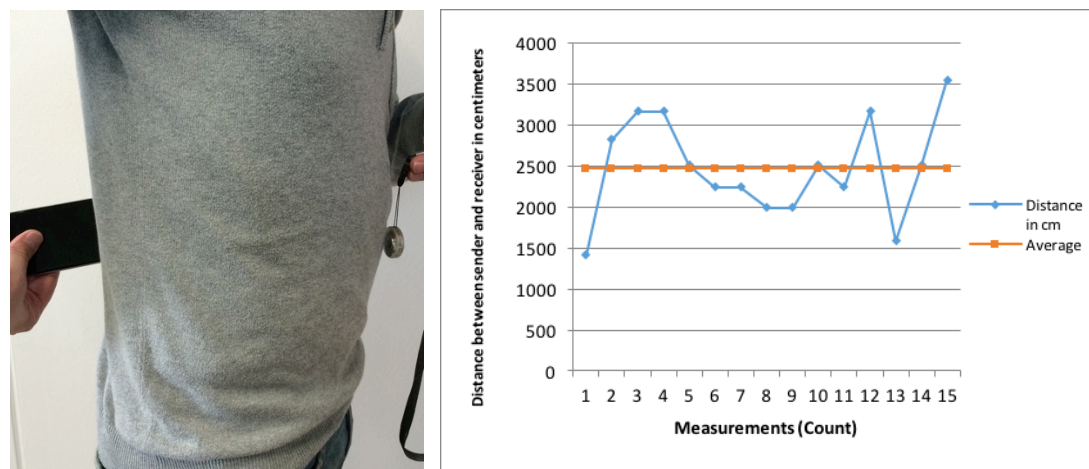


Figure 16 Shielding Test (body 20 cm).

Hence, the human body in between sender and receiver is definitely preventing BLE from being used for distance calculations. This finding is fatal in general, but of minor importance for our goal of imitating Near Field Communication with BLE, as NFC does not work in such a scenario, either.

We complete our *Shielding Tests* with metal and wood as the obstacles in line-of-sight. For both tests we have used boxes in which we put the beacon. The metal box was 3.5 cm high with the beacon lying at the bottom inside the box. The receiving smartphone has been placed on top of the box with the antenna ideally aligned to the beacon (i.e., we held the smartphone upside down, see Figure 17).

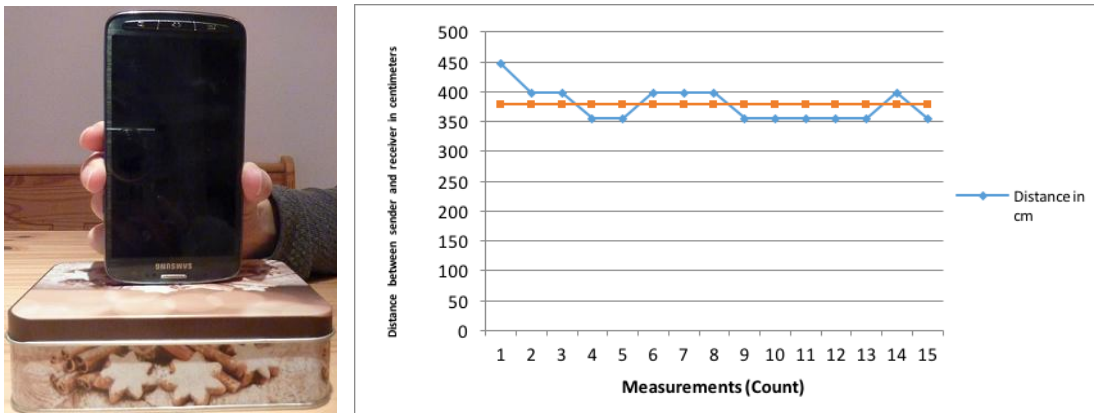


Figure 17 Shielding Test (Metal).

The results reveal that metal has a significant shielding effect for BLE signals, as well. While beacon and smartphone have a real distance of 3.5 cm, our measurements calculate an average distance of 3.8 meters. Minimum and maximum values are 354 and 446 cm, which is a fluctuation width of nearly 1 m.

Wood, on the other hand, has a minimal shielding effect on BLE signals, as Figure 18 shows. The wooden box was 10 cm high and we used the same parameters as with the metal box. The average calculated distance was 13 cm (compared to 10 cm in reality) with extremes between 18 and 10 cm.

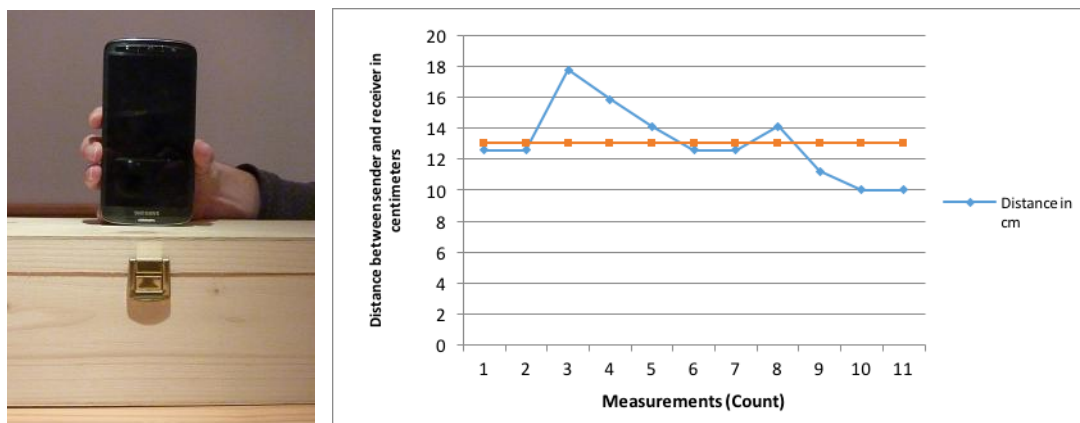


Figure 18 Shielding Test (Wood).

## 4 Application

These tests have been conducted in the course of a national research project Mobility of the Future within the framework of the strategic initiative IV2Splus (Intelligent Traffic Systems and Services, from 2014 to 2016) funded by the Austrian government with cooperating universities, major national public transportation companies and NGOs.

The general aim of this project was to develop new paradigms and technical systems for user guidance and to conceive an emancipated mobility approach, serving people with physical disabilities as well as children, elderly people or humans with cognitive impairments. Our ambition was to simplify and accelerate usage of public transportation for all users by new ideas, concepts and technological solutions.

In that course, we have conceived a so-called Be-In/Be-Out (BIBO) ticketing system [18, 19], enabling passengers to obtain their (virtual) tickets just by “being” inside a vehicle. Infrastructural appliances detect their presence (i.e., their smartphone or a BLE beacon) and initiate services unnoticed in the background. The detection process in a BIBO system requires a transmission technology capable of covering the space in a bus. On the other hand, conductors need to distinctly identify a passenger’s beacon within a few centimeters range just by holding the beacon close to the conductor’s device (e.g., a BLE-enabled phone). For these scenarios we consider BLE an appropriate technology managing both collective registration and dedicated identification all at once.

## 5 Conclusion

Due to the results we conclude that BLE is potentially eligible of imitating NFC with a few constraints: (1) The reading device (i.e., in our case a smartphone) must be adequately arranged such that the antenna of the device is brought to the sending beacon as close as possible. Batteries and other metallic covers in line of sight and particularly the human body significantly worsen the results. (2) The antenna of the beacon additionally impacts the RSSI values measured by the smartphone and potentially impacts a clear separation of near zones (not investigated here).

Due to the manifold of BLE devices available, the results presented here cannot be considered confirmed, yet, as further investigations regarding various BLE beacons, smartphones, or BLE antennas have to be conducted. Nevertheless, our tests at least included a slight variation of both receiving and transmitting BLE device (and of surrounding impact factors) and therefore represent a pretty good starting point, as the number of producers of BLE beacons is very limited.

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