Application of Bluetooth Low Energy Beacons and Fog Computing for Smarter Environments in Emerging Economies

Mingxu Sun[1#], Kondwani Michael Kamoto[0000-0002-0794-8852] [2#*], Qi Liu [3], Xiaodong Liu[4] and Lianyong Qi[5]

[1] School of Electrical Engineering University of Jinan, Jinan, China

[2] Jiangsu Collaborative Innovation Center of Atmospheric Environment and Equipment Technology (CICAEET), Nanjing University of Information Science and Technology, Nanjing, China

[3] Shandong Beiming Medical Technology Ltd., Jinan, China.

[4] School of Computing Edinburgh Napier University Edinburgh, UK

[5] School of Information Science and Engineering, Qufu Normal University, China

[*]Corresponding Author: k_kamoto@yahoo.co.uk

Abstract. The Internet of Things (IoT) has already begun to drastically alter the way people operate in various industries across the world, as well as how we interact with our environment. There is a lot of progress being made toward achieving the envisioned goals of IoT, however there are still numerous challenges to be addressed. Bluetooth low energy (BLE) and its beacons protocol have pushed forward innovations in the field of microlocation, which is a key area of IoT. The emergence of fog computing architecture has also lead to reduced dependence on cloud architecture by shifting resources towards users and local applications. Together these two innovations provide ideal conditions for adoption of IoT in emerging economies, which are known to be both financially and technically constrained. In this paper we provide an overview of the key innovations that are suitable for adoption in emerging economies based on BLE and fog computing. We further present three reference models for indoor navigation systems which can help further the research work in the application of BLE and fog computing.

Keywords: Bluetooth Low Energy, Internet of Things, Emerging Economies.

1 Introduction

The Internet of Things (IoT) [1] has ushered in a new connected approach to our everyday activities. The promise of connectivity with not just people but ‘things’ we come across within our respective environments, living or otherwise, opens up a lot of avenues for smarter world interactions which take into account context (environment and personal preferences). IoT spans across many Cyber-Physical Systems (CPSs) creating

[#] Both authors are the first author due to equal contribution to this paper.

an integrated grouping of systems that provide various services to society. Achieving the vision of IoT is a complicated task due to the current state of systems and the amount of work that needs to be done to turn current systems into their connected and autonomous forms. Current challenges span both the technical and non-technical, however experimental and real world implementations of some of the enabling technologies have shown great promise.

When viewing the promise of a smarter environment from the viewpoint of emerging economies, the implementation of IoT can seem to be a challenging task to accomplish. Successful real world implementations of innovations for IoT and its enabling technologies to date have required a considerable amount of resources, both financial and technical, as well as a favorable economic environment. Given the ongoing challenges that emerging economies face, sourcing the necessary financial and technical investment in order to implement IoT-based systems is typically hard to achieve. However, the improvements that such systems can bring to people and activities of daily life (ADLs) are undeniable.

One of most promising enabling technologies for a number of recent IoT innovations is Bluetooth low energy (BLE), which is commonly applied through the use of BLE beacons. BLE is an energy efficient low data rate technology suitable for power constrained IoT applications [2], [3], and the high availability of Bluetooth-enabled devices has resulted in high rate of adoption by both industry and academia. Other known benefits of BLE are that it doesn't interfere with other wireless infrastructure, and beacons are small in size, low in cost, and platform independent, Some of the well-known applications of BLE beacons include improving shopping experiences [4], navigating museums [5], indoor localization and tracking [6], and helping the blind or disabled [7].

The emergence of the fog computing architecture has also helped to overcome challenges faced along the path to the realization of IoT, which include stringent latency requirements, network bandwidth constraints, resource-constrained devices, and the need for uninterrupted services with intermittent connectivity to the cloud. Fog computing is said to distribute computing, control, storage, and networking functions closer to end user devices, and complements the centralized cloud [8]. Such an architecture alleviates the burden on the cloud to handle all IoT functions and more importantly enables the provision of the required services to enable IoT with little or no dependence on the cloud.

BLE and fog computing provide ideal conditions for technological advancements to me be made within emerging economies, mainly owing to the low cost of setup and maintenance of BLE-based applications, and the ability to only consider cloud-based resources if absolutely necessary to a given system's architecture. This means that IoT innovations can be implemented locally, and then expanded into a fully integrated network when conditions are more ideal. Furthermore, people in said economies generally have access to mobile phone services, with Bluetooth 4.0 enabled smartphones prevalent across the population, making the use of BLE-based IoT applications suitable in those places.

The main purpose of this work is to highlight IoT applications that can be adopted within emerging economies taking into consideration the financial and technical constraints in such environments. In Section 2 we discuss BLE, and some of the recent IoT innovations based on this technology that can be adopted for emerging economies. Section 3 presents our proposed reference models for indoor navigation systems which blend together BLE beacons, augmented reality, fog computing, and natural language processing according to the required level of system complexity. The final section, Section 4, provides a summary of the research work we conducted and de-tails the plans for our future work.

2 Bluetooth Low Energy

The complexity of IoT has motivated the design and provision of low power communication technologies. These demands have resulted in the provisioning of radio-frequency identification (RFID), ZigBee, 6LoPan, amongst others, and now BLE. This section examines the BLE technology and some of its compelling applications with regards to IoT.

2.1 Protocol and Beacons

The BLE protocol operates on the 2.4-GHz ISM spectrum, which it divides into 40 channels, with three channels (channels 37–39) dedicated to advertisement purposes and the rest for data exchange. BLE beacons are devices that are only responsible for advertising. These devices are connectionless and broadcast their signals periodically [9]. These advertising signals contain small data payloads, referred to as advertising protocol data units (PDUs), which typically include a packet header, MAC address, device's unique identifier, and manufacturer-specific data. A device with receiver capabilities typically processing the signals and performs actions based on the received payload. This can range from a simple notification on a smartphone application to more advanced actions such as displaying indoor navigation routes.

2.2 Beacon Protocols

The most well-known beacon protocols are iBeacon [10] developed by Apple, and Eddystone [11] developed by Google. The main difference between these two profiles lies in their definition of the advertising PDU. Eddystone allows developers to switch between URL and TLM frames for the advertising PDU, whereas iBeacon only provides the ability to specify identification information for a beacon. The definitions for each of these profiles is shown in Fig. 1. There are also two open-source alternatives which are AltBeacon [12] by Radius Networks and GeoBeacon [13] by Tecno-World, which are both compatible with any mobile operating platform. AltBeacon provides the same capabilities as iBeacon but is not company specific, and GeoBeacon is geared towards geocaching applications.

(a)

Adv PDU				Payload defined by iBeacon Standard				
1 byte	4 bytes	2 bytes	6 bytes	9 bytes	16 bytes	2 bytes	2 bytes	1 byte
Preamble	Access Address	Header	MAC	iBeacon Prefix	Universally Unique Identifier (UUID)	Major	Minor	Tx Power

(b)

<table>
<tr><th colspan="4">Adv PDU</th><th colspan="7">Payload defined by Eddystone Standard</th></tr>
<tr><td>1 byte</td><td>4 bytes</td><td>2 bytes</td><td>6 bytes</td><td rowspan="2">UID</td><td>1 byte</td><td>1 byte</td><td colspan="2">16 bytes</td><td colspan="2">2 bytes</td></tr>
<tr><td rowspan="5">Preamble</td><td rowspan="5">Access Address</td><td rowspan="5">Header</td><td rowspan="5">MAC</td><td>Frame Type</td><td>Ranging</td><td colspan="2">UID</td><td colspan="2">Reserve</td></tr>
<tr><td rowspan="2">URL</td><td>1 byte</td><td>1 byte</td><td colspan="4">18 bytes</td></tr>
<tr><td>Frame Type</td><td>Ranging</td><td colspan="4">URL</td></tr>
<tr><td rowspan="2">TLM</td><td>1 byte</td><td>1 byte</td><td>2 bytes</td><td>2 bytes</td><td>4 bytes</td><td>4 bytes</td></tr>
<tr><td>Frame Type</td><td>TLM Version</td><td>Battery Level</td><td>Temperature</td><td>ADV_CNT</td><td>SEC_CNT</td></tr>
</table>

Fig. 1. Definitions for advertising PDU of (a) iBeacon and (b) Eddystone BLE profiles

2.3 Beacon-Based Applications

Since the initial demonstration of the capabilities of BLE beacons via the introduction of iBeacon, there has been much interest in making use of this technology to achieve longstanding problems with regards to localization, proximity detection and interaction, and activity sensing. Jeon et al. [9] who presented a detailed study of BLE beacon technology and its relationship with IoT provided a concise summary of the state-of-the-art research on BLE beacon-based applications. They further enumerated some of the outstanding work to be done with regards to BLE beacons, which include interoperability between different beacon protocols, managing and monitoring battery life, and the need for enhanced security features to better support IoT. Faragher and Harle [12] investigated the feasibility of BLE beacon-based indoor localization systems using given deployment configurations and operation parameters. They set up 19 beacons in an office area, and their findings showed that a beacon-based approach achieved less than 2.6m error ninety-five percent of the time when beacons were deployed every 30m^2, outperforming the 8.5m error margin of existing Wi-Fi networks. This increased accuracy greatly assists with the task of activity sensing. Proximity detection and interaction up until the introduction of BLE beacons was usually achieved via the use of QR codes and near-field communication (NFC). However, QR codes need to be installed or printed in a large size to reach a large audience, and NPC have very short interaction distance of 10–20cm, making interactions for large audiences problematic. The use of BLE beacons addresses these shortcomings for such proximity-related tasks.

Three of the most promising applications of BLE beacons which are easily replicated in emerging economies are vehicle-based indoor navigation, building-based indoor navigation, and indoor navigation coupled with mobile augmented reality.

Vehicle-Based Indoor Navigation

Rodrıguez et al. [14] presented their work on an indoor positioning and guidance system for drivers which addressed the challenges faced with indoor parking. They made use of a combination of the inertial sensor data of a mobile phone located inside a vehicle, radio signals coming from a network of BLE beacons, an occupancy grid of the car park, and Bayesian estimation in order to identify the position of a vehicle. Their proposed system further incorporated real-time visual, textual, and auditory instructions to the driver. Their experimental evaluation showed that the proposed system reported the correct position of the vehicle 88% of the time on average, and highlighted the feasibility of implementing vehicle-based indoor navigation, with a significant reduction of the resources for set up and maintenance that are typically required for such an endeavor.

As emerging economies continue to develop and people's living standards improve, more people will have access to vehicles and infrastructure will be improved to cater for the increasing demands of the population. The adoption of such a system which embodies the vision of IoT can greatly simplify people's lives and management of parking structures.

Building-Based Indoor Navigation

Building-based indoor navigation includes landmarks [15], museums [5], airports [16], etc. While there have been a number of applications with regards to museums, airports and schools are areas of great interest for providing smart environments which can assist people and guide them through buildings if need be. One of well-known implementations of such a system is that of Gatwick Airport in the UK [17]. The airport installed 2,000 battery-powered beacons across its two terminals in order to guide airline passengers within the building. These beacons were coupled together with an augmented reality wayfinding tool (see Fig. 2) which enabled passenger navigation within a positioning error margin of 3m. The capabilities of these beacons were made available to airlines which could use the information to send push notifications to warn passengers if they're running late, or even make a decision on whether or not to wait or offload luggage so that an aircraft can take off on time.

The ability to have meaningful interactions with buildings is a key component of IoT, and BLE beacons can greatly simplify the process that makes this possible, regardless of shortage of resources available. As the beacons are typically low cost, an adequate amount can be purchased depending on the required area of coverage. Furthermore as these devices enable indoor positioning and a vast number of services can be built upon knowledge of user location, there is room for growth in innovative solutions.

Indoor Navigation Coupled with Mobile Augmented Reality

Coupling navigation capabilities with augmented reality can greatly aid in contextualizing information, as shown in Fig. 2. Shao et al. [18] investigated whether BLE beacons were capable of enabling provisioning a seamless mobile augmented reality (AR) experience to the users. The authors proposed a self-contained system consisting of a cluster of BLE beacons that are connected to embedded micro-controllers and low-cost stereo cameras. Self-contained here refers to the system being able to function without requiring internet access, external power supply, or other external resources as part of its operations. Unique sets of visual features and a subset of captured 3D point time series data were embedded in the advertising PDUs for each beacon, with a smartphone serving as the receiver for the advertising signals. The received advertising PDUs were merged with a smartphone's inertial data, and the location data and 3D object data were then used to render a 3D object on a smartphone in real-time. The authors modelled two scenarios where they attempted to recognize five basic hand gestures, and two multi-person interactions which were gestures of two people shaking hands, followed by one person waving a hand to another person. Motions were sampled at five different rates 3Hz, 6Hz, 9Hz, 12Hz and 15Hz, and their findings showed that 9Hz sampling frequency is good enough to capture the meaning of a motion that lasts about a second. Low-speed gestures were recognized accurately at 6Hz with the performance dropping to around 75% for slightly more difficult gestures like two-hand waves.

This work showcased that BLE beacon-based systems which incorporate augmented reality can be designed and implemented with minimal resources. Given the enormous benefits of augmented reality systems from health, to education, and manufacturing, utilizing beacons can greatly enhance the capacity of those different industry sectors within emerging economies. Furthermore with the next generation BLE 5.0 beacons expected to have an increase in broadcasting capacity of up to around 256 bytes, more complex applications utilizing beacons and augmented reality can be put into operation.

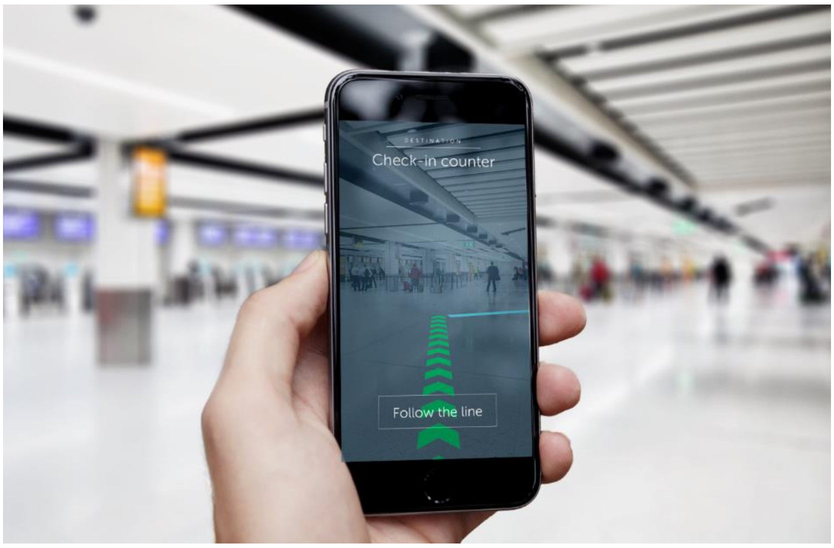

Fig. 2. Gatwick Airport wayfinding tool using augmented reality

3 Proposed Reference Models for Indoor Navigation Systems

The research work presented in Section 2 shows promising results for BLE beacon-based approaches for indoor navigation. This section introduces our proposed reference models for BLE beacon-based indoor navigation systems.

The typical beacon-based architecture is comprised of beacons and a mobile application that receives advertised PDUs and acts upon them. The mobile application can take action solely using local resources, make use of external resources, or a combination of the two. In general the architecture of BLE beacon-based navigation systems is limited by the complexity brought on by the tasks it needs to fulfil. In this section we discuss three reference models ranging from basic navigation, to enhanced navigation, to the ideal IoT navigation.

3.1 Basic Navigation

Base services of a navigation system include providing current location, route paths, and providing details on nearby points of interest (POI). Two of the commonly used indoor positioning techniques are proximity and fingerprinting, with received signal strength indications (RSSIs) being among the main signal features that are used for localization. Proximity looks at positioning using the closeness relative to a known location based on detected RSSIs. Fingerprinting on the other hand involves a two-step process: 1) record known coordinates and the RSSIs from beacons within close proximity to each coordinate and store them, and then 2) detect RSSIs currently being received by a device and attempt to match these to the stored fingerprints. Proximity at a minimum only requires beacon identification information and additional descriptors if need be, whereas fingerprinting requires storage of the fingerprint vectors. As RSSI measurements tend to fluctuate due to environmental changes, signal processing techniques are usually employed in order to improve accuracy. Commonly used processing techniques include Particle Filter [19] and Kalman Filter [20].

The most basic setup for user location is making use of local resources of the mobile application and either the proximity or fingerprinting approach for positioning. The proximity approach would result in the mobile application receiving broadcast messages, selecting the strongest signal detected, and then comparing the related beacon identification information to the locally stored data. The descriptor tied to the matching beacon would then be presented to the user as their approximate location. The fingerprinting approach would involve a vector of RSSIs received by the mobile application being compared to the locally stored fingerprints. The descriptor tied to the matching fingerprint would then be presented to the user as their approximate location. A more complex version of this form of user location would involve making use of an external service to handle the matching processes.

In order to derive an optimal route from the current location to the chosen destination a weighted graph needs to be modeled and made available (locally or remotely) to the mobile application. The provision of a map of the physical space is usually ideal in this scenario which can be used to present the navigation information on the mobile application in a more meaningful manner. POIs within a building are typically tied to a beacon, whether they are at the actual location of it or in close proximity. The process therefore is to identify the beacon that the mobile application is currently closest to and then determine the shortest path to the POI i.e. the target beacon. Given a weighted graph, Dijkstra's algorithm can be used to determine the shortest path [21] between the two beacons. The path can then be presented in the form of step by step text instructions or visual representations on the map of the physical space. It should be noted that the instructions/map will need to be updated as the mobile application moves towards the destination. This can be achieved by the mobile application actively reacting to the new RSSIs that are received by beacons along the path.

The final basic service is to provide details on nearby POIs. This can be achieved by selecting the closest N POIs nearby, or defining a maximum radius (r) from the current location and selecting the POIs that fall within this radius. These nearby POIs can then be displayed on the mobile application with either textual information or a visualized map.

3.2 Enhanced Navigation

Enhanced navigation provides additional services on top of those described in the previous section. This architecture provides additional context to the user, and this is achieved via augmented reality. Mobile augmented reality based on BLE-beacons is a more complex yet achievable architecture. The main challenges are how best to store the required visual features and how to later reassemble them in an augmented view on the mobile application. As showcased by Shao et al. [18], the required visual features can be distributed across a set of beacons. The mobile application then uses the advertising PDUs for the beacons that are in close proximity to reassemble the visual features, and display the augmented view based on the direction and angle of the mobile device. The bottleneck of this approach lies in how best to store the visual features as the beacons have limited payload size. If the size of the visual features exceeds distribution across a set of beacons with either the payload size of the Blue-tooth 4.0 or 5.0 specifications then an alternative method would be to establish a fog node at the premises to handle storage while minimizing the latency.

3.3 Ideal IoT Navigation

The IoT aims to bring context to our everyday living. In a navigation system this means taking into consideration our preferences or other personal factors and customizing the experience. In our opinion the ideal navigation system would take into consideration each person’s culture especially in multi-lingual environments such as airports, universities, or museums, where use of standard languages such as English or French to provide general information is not adequate to all who make use of services within said environment.

Given the tremendous progress in natural language processing techniques in recent years, it has become much easier to develop language models for specific and to some extent general purposes. These language models can be built using various methods and then deployed for use as part of various language services such as translation, part-of-speech tagging, chatbots, etc.

We therefore propose an integrated BLE beacon fog computing architecture. In this architecture BLE beacon can provide services up to those of the Enhanced Navigation approach. However, the language preference set on the mobile application would determine the language in which they view the navigation information. The proposed approach would better contextualize the navigation experience for those with language challenges while still minimizing the infrastructure and computation required.

4 Conclusion

This paper provided a look into Bluetooth low energy and how this technology is helping to bridge gaps along the path to the full realization of IoT. The introduction of BLE beacons and the related protocols has redefined microlocation techniques and also advanced innovations within this subject area.

IoT provides enormous benefits to society, but it and its related systems can be challenging to implement especially in emerging economies which have a considerable number of financial and technical constraints. This research work provided in-sights into what can be achieved by emerging economies with regards to the IoT de-spite these constraints. We additional enumerated three reference models based on increasingly complexity which can be adopted according to the needs of the required indoor navigation system.

Our future work will involve developing a system prototype in order to verify the real world feasibility of the proposed Ideal IoT Navigation reference model. This will give us a better reference point on the capacity of BLE beacons to achieve such a contextualized scenario.

Acknowledgement

This work has received funding from 5150 Spring Specialists (05492018012), the European Union Horizon 2020 research and innovation program under the Marie Sklodowska Curie grant agreement no.701697, Major Program of the National Social Science Fund of China (Grant No.17ZDA092), Royal Society of Edinburgh, UK and China Natural Science Foundation Council (RSE Reference: 62967_Liu_2018_2) under their Joint International Projects funding scheme and 333 High-Level Talent Cultivation Project of Jiangsu Province (BRA2018332).

References

1. Ashton, K.: That internet of things' thing. RFiD Journal 22(7), 97–114 (2009).
2. Gubbi J., Buyya R., Marusic S., Palaniswami M.: Internet of things (iot): a vision, architectural elements, and future directions. future generation computer systems. 29(7), 1645–1660 (2013).
3. Miorandi D., Sicari S., De Pellegrini, F., Chlamtac, I.: Internet of things: vision, applications and research challenges. Ad Hoc Networks 10(7), 1497–1516 (2012).
4. Zaim D., Bellafkih M.: Bluetooth low energy (BLE) based geomarketing system. In: Proceedings of 11th International Conference on Intelligent Systems: Theories and Applications (SITA), pp. 1–6. IEEE, Mohammedia, Morocco (2016).
5. Alletto S., Cucchiara, R., Del Fiore, G., Mainetti, L., Mighali, V., Patrono, L., Serra G.: An indoor location-aware system for an IoT-based smart museum. IEEE Internet Things Journal 3(2), 244–253 (2016).
6. Gast, M. S.: Building applications with ibeacon: proximity and location services with bluetooth low energy. O'Reilly Media, Sebastopol, CA, USA (2014).

7. Cheraghi, S. A., Namboodiri, V., Walker, L.: Guidebeacon: beaconbased indoor wayfinding for the blind, visually impaired, and disoriented. In: Proceedings of IEEE International Conference Pervasive Computing Commun. (PerCom), pp. 121–130. IEEE, Kailua, HI, USA (2017).
8. Chiang, M., Zhang, T.: Fog and IoT: an overview of research opportunities. IEEE Internet of Things Journal, 3(6), 854-864 (2016).
9. Jeon, K. E., She, J., Soonsawad, P., Ng, P. C.: BLE beacons for internet of things applications: survey, challenges, and opportunities. IEEE Internet of Things Journal 5(2), 811-828 (2018). doi: 10.1109/JIOT.2017.2788449
10. Apple -. iBeacon, https://developer.apple.com/ibeacon/, last accessed 2019/06/21.
11. Google - Mark up the world using beacons. https://developers.google.com/beacons/, last accessed 2019/06/21.
12. AltBeacon. https://github.com/AltBeacon, last accessed 2019/06/24
13. GeoBeacon. https://github.com/Tecno-World/GeoBeacon, last accessed 2019/06/24
14. Faragher, R., Harle, R.: Location fingerprinting with Bluetooth low energy beacons. IEEE Journal on Selected Areas in Communications 33(11), 2418–2428 (2015).
15. Rodríguez, G., Canedo-Rodríguez, A., Iglesias, R., Nieto A.: Indoor positioning and guiding for drivers. IEEE Sensors Journal 19(14), 5923-5935 (2019). doi: 10.1109/JSEN.2019.2907473
16. Ito A., Hatano H., Fujii, M., Sato, M., Watanabe, Y., Hiramatsu, Y., Sato, F., Sasaki, A.: A trial of navigation system using BLE beacon for sightseeing in traditional area of Nikko. In: Proceedings of IEEE International Conference on Vehicular Electronics and Safety (ICVES), pp. 170–175. IEEE, Yokohama, Japan (2015).
17. TechCrunch - Gatwick Airport Now Has 2,000 Beacons for Indoor Navigation, https://techcrunch.com/2017/05/25/gatwick-airport-now-has-2000-beacons-for-indoor-navigation/, last accessed 2019/06/21.
18. Shao, C., Islam, B., Nirjon, S.: MARBLE: Mobile Augmented Reality Using a Distributed BLE Beacon Infrastructure. In: Proceedings of 2018 IEEE/ACM Third International Conference on Internet-of-Things Design and Implementation, pp. 60-71. IEEE, Orlando, FL, USA (2018).
19. Djuric, P. M., Kotecha, J. H., Zhang, J., Huang, Y., Ghirmai, T., Bugallo, M. F., Miguez, J.: Particle filtering. IEEE Signal Processing Magazine 20(5), 19–38 (2003).
20. Guvenc, I., Abdallah, C., Jordan, R., Dedoglu, O.: Enhancements to RSS based indoor tracking systems using Kalman filters. In: Proceedings of International Signal Processing Conference (ISPC) and Global Signal Processing Expo (GSPx). Dallas, TX, USA (2003).
21. Edsger W Dijkstra. A note on two problems in connexion with graphs. Numerische mathematik 1(1), 269–271 (1959).