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Digital Places: Location-based Digital Practices in Higher Education using Bluetooth Beacons

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Abstract: The physical campus is a shared space that enables staff and students, industry and the public, to collaborate in the acquisition, construction and consolidation of knowledge. However, its position as the primary place for learning is being challenged by blended modes of study that range from learning experiences from fully online to more traditional campus-based approaches. Bluetooth beacons offer the potential to combine the strengths of both the digital world and the traditional university campus by augmenting physical spaces to enhance learning opportunities, and the student experience more generally. This simple technology offers new possibilities to extend and enrich opportunities for learning by exploiting the near-ubiquitous nature of personal technology. This paper provides a high-level overview of Bluetooth beacon technology, along with an indication of some of the ways in which it is developing, and ways that it could be used to support learning in higher education.

Since their inception, universities have been characterised by the co-location of scholars and learners in a shared physical environment, however recent trends towards the increasing use of technology in education have seen this begin to change. Digital technologies have enabled learners to have high-quality learning experiences, with large amounts of peer interaction, without ever needing to attend a physical campus. However, while digital distance education continues to grow, the benefits of students and lecturers sharing a physical space have not diminished. In particular, there are disciplines that require the use of specialist equipment or other resources that are very difficult to conduct entirely online, while, more generally, the potential for unexpected learning encounters and inspiration as a result of physically being in a collegial learning institution cannot be underestimated.

Therefore, a way to combine the benefits of digital technology, such as ability to share and interact both synchronously and asynchronously, with those of physical co-location, such as access to expertise and inspiration, would greatly benefit many learning spaces. Such a 'Phygital' (Bazzanella, Roccasalva, & Valenti, 2014) learning experience that harnesses the best aspects of the physical and the digital would empower students while also helping to ensure the continued relevance of the university as a physical place. This paper discusses some ways in which a simple, low-cost technology, Bluetooth beacons, could provide the starting point for the 'Phygital University'.

Bluetooth Beacons: Technical Overview

Beacons are unobtrusive transmitters that push a small amount of information to Bluetooth enabled devices within a relatively small, definable area. The beacon devices are small, cheap and can be installed both indoors and outdoors. Currently, there are two major beacon technologies, Apple's iBeacon (introduced in 2013) and Google's Eddystone (introduced in 2015); however, while they are incompatible with each other, for the most part they work in a similar way. Both technologies send out a small piece of data, a unique identification number for iBeacon and either a similar identification number or a short URL for Eddystone, over Bluetooth to any devices within range. This data is then received by nearby mobile devices, processed by associated software and an appropriate action taken according to the data received.

This means that, in the most basic usage, beacons can be used to trigger an associated action on any devices with the appropriate software within range of their signal, such as a smartphone or tablet. However, an additional layer of information can also be created by analysing the strength of the signal to determine the distance from it. In this way, a single beacon could trigger different actions when a device is in its immediate proximity and when it is at the limit of its range. In common with the lighthouse metaphor for which they are named, the beacons transmit only their presence and do not perform any active monitoring of devices within their range meaning that they are not in themselves capable of tracking devices and, by extension, people.

The complexity of action that the beacons can perform depends partially on the type of signal being used and partially on the logic within the app that is being triggered by that signal. Eddystone URL signals, the underpinning technology of Google's 'Physical Web' concept (https://google.github.io/physical-web/), offer a very simple way for objects and locations to transmit a web link to all devices within a defined proximity, whereas iBeacon and the equivalent mode in Eddystone can enable highly specific actions to be performed. This is possible through combining data available to the relevant app, such that a user in a specific location at a specific time might have a particular action triggered while the same user in the same place at a different time would have a different one triggered. For example, at the start of a lecture, the signal from the beacon triggers the app to download and open the slides and other materials that are going to be used in the session, while a few minutes later the same signal triggers the opening of a voting app. Likewise, the same information could be used to trigger different actions for people in the same place at the same time, such as by automatically directing students into different virtual collaboration spaces based on the group to which they are assigned.

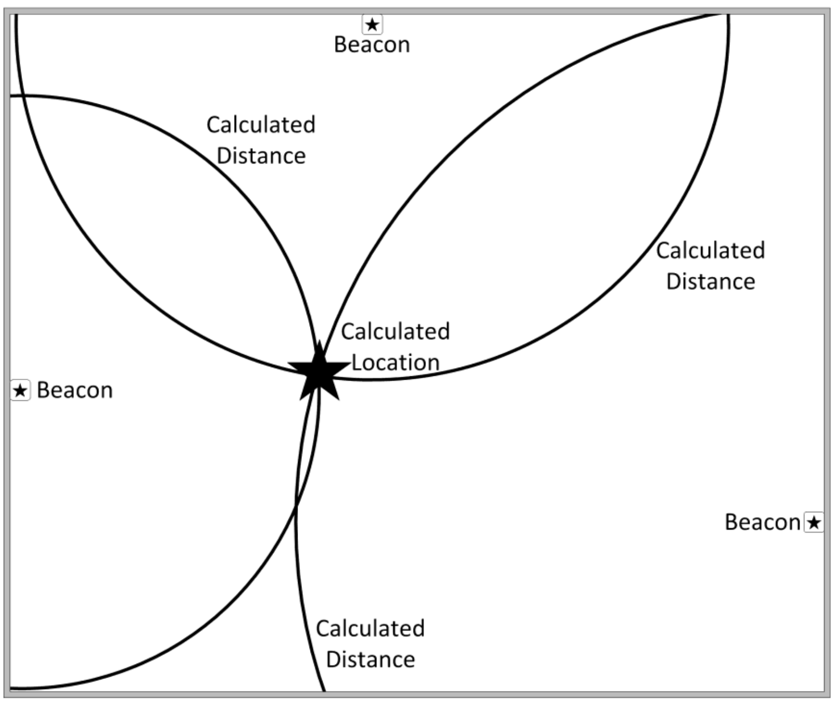

Figure 1: Trilateration techniques used to calculate location within a room.

In addition to treating beacons as single, discrete transmitters, apps can use multiple beacons and a similar technique to the Global Positioning System (GPS) to calculate location. This technique, called trilateration, works on the principle of measuring distance from several known points, using time data to work it out in the case of GPS and signal strength in the case of Bluetooth beacons. An app with the locations of several beacons within a space, ideally three or more, can therefore use this information with the signal strength data from the beacons to work out the area in which the signals intersect, and so identify the device's position to that area (Figure 1). The greater the number of beacons, the more accurate this calculation can become - though interference from furniture and people and objects moving through the space can reduce this theoretical accuracy in the real world. This location data can then be used to place a person on an interactive map, or to trigger actions based on specific locations within a space rather than just distance from a single beacon.

Emerging Beacon Developments

At the time of writing there are several extensions to the basic beacon functionality being investigated, both by the organisations behind the specification and by individual manufacturers of beacons seeking to develop a competitive advantage. These extensions generally require hardware changes to the beacons to support new ways of interacting.

HDMI\Video Beacon

While most beacon applications make use of static beacons that trigger actions on mobile devices as they move around a space, one beacon producer has been developing a product that inverts this relationship. Estimote's Mirror beacons are essentially a small, USB-powered computer and HDMI interface that plug into television screens and digital signage with a Bluetooth chip to detect beacons coming into close proximity (Estimote, 2016). The mirror beacons can then detect an identifier from a nearby device and use that to present personalised information on the screen. So, at an open day, for example, information specific to the courses an individual is interested in can be displayed as they approach the screen, while for a student or conference delegate the screen could display information about their next session and directions to get there.

GPIO (General Purpose Input/Output)

In addition to developing their Mirror beacons, Estimote have also developed beacons that feature GPIO connections. GPIO enables electronic devices to be physically connected to, and communicate with, each other. In the case of Estimote's beacons, the GPIO functionality can be used to either broadcast status information about the connected device, or to send data to the device. For example, an app could store data about the person's preferences for lighting levels or temperature and, by connecting a GPIO beacon to a light or thermostat, this could be used to control these environmental conditions when the individual enters a room (Figure 2).

FatBeacon

One, currently experimental, extension to the Eddystone specification is FatBeacon, which adds a single-page web server to the beacon (Jenson, 2016). The purpose of this is to enable beacons to transmit a small amount of data to be displayed on a device even when the device has no network access. This would be particularly useful for locations where it is desirable to make information available to people but where network access cannot be guaranteed because of the nature of the person, such as a foreign tourist at a museum, or because data signals are slow, difficult to install or unreliable, such as in very remote parts of large national parks or underground.

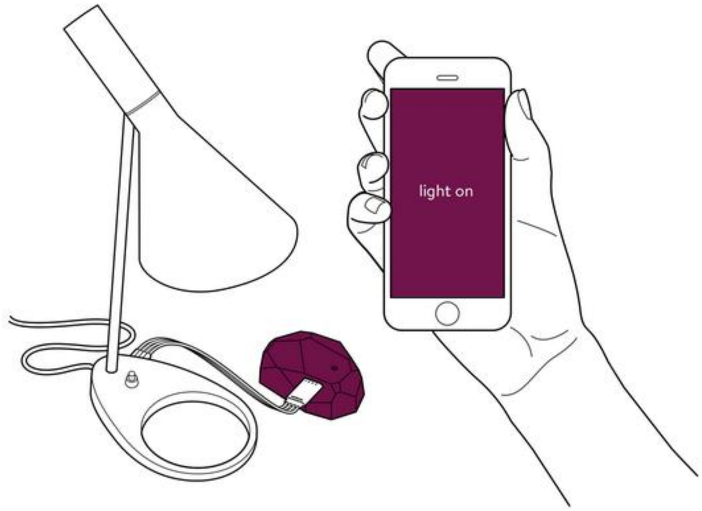

Figure 2: GPIO beacon controlling a lamp

(Reproduced with permission from Estimote)

Existing uses of beacons

This section provides a small sample of some of the ways in which beacons are currently used, both within education and in other domains. As the use of beacons is developing quickly, this is necessarily a snapshot of a few key areas rather than an exhaustive survey.

Outside Education

One of the earliest proposed uses of beacons was to support indoor wayfinding around individual buildings or the wider urban environment. Initially these developments were aimed at people who may struggle when navigating unfamiliar environments due to physical impairments, such as blindness (Bohonos, Lee, Malik, Thai & Manduchi, 2007), or cognitive ones (Chang, Chu, Chen & Wang, 2008). These wayfinding systems have now expanded out to a variety of other situations, including in places as diverse as airports and large sports and entertainment arenas where apps make use of personal information, such as flight details or allocated ticket, to direct people to their required location by the most efficient route (Reed, 2015).

Bluetooth beacons for wayfinding have also found a place in retail, where they assist customers in finding specific products within the store (Thamm, Anke, Haugk & Radic, 2016). However, a further use of beacons in this domain has been in notifying customers of discounts on products as they pass by. As many retailers, particularly supermarkets, have loyalty schemes that track purchases, this data, plus data recorded by the retailer's app, means there is a large amount of data available about a customer's purchasing habits that can be used to make decisions regarding whether to notify particular customers about an offer, such as only notifying customers who fit a certain demographic or those who have frequently purchased a competing product (Allurwar, Nawale & Patel, 2016).

The use of QR codes to provide easy access to additional information about exhibits has become commonplace in museums and art galleries, however some of these organisations have begun to investigate whether beacons can complement or replace these visual markers by providing the same facilities in a less obtrusive way or by allowing new ways to experience the exhibits (New Media Consortium, 2015). A significant difference between this and methods such as QR codes is that rather than being a passive technology that requires active participation from the museum visitor to initiate the interaction, beacon technology can actively trigger notifications and actions on the visitor's device so offering the potential for increased engagement with the electronic resources (He, Cui, Zhou & Yokoi, 2015). With Physical Web technology, a visitor need not even download and install a dedicated app to be able to receive notifications about the exhibits and access additional information, further increasing the potential for engagement from visitors.

Within Higher Education

While the use of beacons within education has so far been limited, the main areas of interest within education has been in supporting administrative tasks, rather than learning, with perhaps the most visible use for the technology has been in monitoring attendance in formal teaching sessions, particularly large lectures. By using the trilateration techniques described above, a smart device can identify its location as being within a room and then, by cross-referencing with a timetabling system and class list data, present an interface that allows the owner of the device to register their attendance or record it entirely automatically (Bae & Cho, 2015; Noguchi, Niibori, Zhou & Kamada, 2015). This facility is already being offered by companies that create apps to support general academic life, such as Ombiel's CampusM (http://www.campusm.com); however, a further enhancement of this concept can be envisioned that would integrate with other institutional systems such as the Virtual Learning Environment and online voting systems to allow session content to be pushed to enrolled students' devices as they arrive in the room, or by automatically presenting the voting interface at the appropriate points during the session.

A similar idea to beacons for attendance monitoring, in that it would use much the same techniques, is the use of beacons to support the presentation of personalised information during open days. The University of Bradford has used beacons to help provide visitors with information specific to their interests around the campus, with the data recorded by the app allowing the university to gain a better understanding of the ways in which people move around the campus during open days (Gibbons, 2015). This additional information could be analysed to assist in refining the open day experience, such as by directing people to points of interest or better planning the amount and placement of people to assist visitors in the future. A pair of smaller scale versions of this campus tour concept have been piloted by the University of Edinburgh's Library Labs, one linking with Google Glass to provide information on exhibition exhibits through augmented reality, and the other to provide self-guided user tours of their library and exhibition space (Willshaw, 2015).

Beacons have also been proposed as a method of restricting the features of smart devices in particular places or at particular times, such as by disabling the camera features during a confidential lecture or class presentation (Thompson, 2013). While there are several issues regarding the practicality of such an approach, not least the issue that simply disabling Bluetooth would prevent the restrictions from being applied in the first place, it could offer a method for providing more control over the ways in which learners are able to use their devices. Though this level of control is unlikely to be desirable as a general facility within higher education, there are still likely to be situations where it would be useful, such as examinations and assessed practical activities where restricted access to materials on a smartphone or tablet would be desirable.

One example of where beacons have been used to support student learning involved the creation of digital 'zones' within a graphic design studio that reflected the different ways in which the physical space was designed to be used (McDonald & Glover, 2016). The placing of this 'digital layer' over the physical space helped to reinforce the expected uses of different parts of the studio, yet also served as focal points for the fairly organic development of a community of practice that included students, tutors, and external professionals. The following section expands on these existing uses within higher education by outlining further ways that beacons could be used to enhance teaching and learning.

Potential beacon use cases in higher education

The implementation of beacon technology has already begun in the retail sector and is typically used to engage their customers with information about products and offers while they move around the store, or walk past it. The transposition of this technology to an educational setting may at first seem novel. However, when looking to the foundation of this development, the focus is user experience and the delivery of context specific, personalised information. With the growing expectations of students for their studies to be linked with and to the professions to which they aspire, and the ability to be able to make use of their own tools and technology, beacons offer a method to add contextual experience and real-world interaction back into the campus experience.

Beacon technology offers academic staff many possibilities to design learning experiences that can facilitate, augment or complement existing approaches. The potential of beacon technology to integrate across the campus to help support, augment and redefine learning, could potentially happen in a range of scenarios. The examples below, drawn from both learning and teaching contexts and wider institutional contexts, have the potential to be transferred to a range of disciplines and organisations

Information Discovery

One of the simplest ways to use beacons is at information points or in situations that showcase work across the campus. This can provide students with information that relates to where they are and what is important for them in that time and place. Different content can be shown depending on proximity to the beacon, whether they've been there before and if they're are moving into or out of a location. This can be used to foster the serendipitous discovery of inspirational information for students, such as alumni profiles, student networking events or personal development opportunities, and also to promote staff and student work to visitors and prospective students at open days.

Example - A student visits a new installation in a gallery space on campus. Through augmentation by the beacons, the student can access information regarding the construction, creator and how to connect with the maker and other viewers of each piece of work. Multiple beacons can be used simultaneously by the mobile app to create a connected user experience that encourages movement through, and exploration of, the gallery space to create a rich and structured learning experience.

Adapting Behaviours

Through use as part of a wayfinding app, beacons could be used to influence behaviour of individuals as they move around the campus. By providing information about the most efficient routes between their current location and where they need to be, an individual's movement around the campus can be altered to reduce congestion. This could be achieved by the app communicating the device's current location with a centralised system that aggregates the data and uses it to dynamically suggest alternate routes. In a similar way, the app could make use of information about the amount of free space and number of free computers in the library and direct the student to a less crowded alternative.

Example - A prospective student comes to an open day and uses an app that has been configured with their interests. The app directs the individual on a personal tour of points around the campus related to their stated preferences and provides information on the courses, profiles of students, alumni and the academic staff, etc. while they are waiting to speak to staff members. This would enable the institution to direct the attention of people on open days and help ensure that the prospective students are well informed about the courses prior to speaking to a staff member, while also reducing overcrowding at bottlenecks around the campus.

Learning Communities in Borderless Spaces

Beacons are a means to facilitate the development of student-led, self-discovery learning zones across different learning spaces. By enabling students to create, adapt, explore and extend these digital spaces using their mobile devices, self-sustaining, mutually beneficial informal learning communities can be encouraged across the formal and informal spaces of a campus and beyond. In addition, the integration of these communities with online collaboration and publishing platforms enables students engaged in these communities to develop digital capability by gaining experience with tools used within their intended profession. The use of beacons would also make these contextual learning communities more readily discoverable by interested third parties, such as researchers and professionals, who would not otherwise be aware of these communities and how they can work with them. As a result, the beacons could offer an opportunity for the learning community to be less insular by enabling outside perspectives into it, while also enabling non-learners to develop their own work through access to motivated groups of learners with whom they share physical and digital spaces.

Example - Postgraduate students use beacons throughout the informal spaces of a campus building as a virtual poster exhibition of their work. By linking to an external publishing platform, the posters can be viewed by people both within the space and outside. By enabling discussion features on the publishing platform, a community of learners, both within the institution and externally, can coalesce in a way that is controlled by the students themselves.

Highly Contextual Information

Beacons only provide very simple pieces of data to devices within range; however, they can also be used to support activities that involve complex micro-location based interactions provided in a timely and situated manner. This infrastructure is relatively low-cost and low-maintenance for the affordances they offer, particularly their potential to create a smart, connected university. If managed, integrated and considered appropriately, this adds value and enhances the holistic learning experience of students on campus by supporting and promoting a more active approach to learning and teaching by academic staff.

Example - During induction week, the beacons are used to notify incoming students about points of interest, such as specialist support areas and faculty offices, in the vicinity as they move around the campus, while for returning students, the same beacons simply provide their usual information.

Creative Subversion of Spaces

While any deployed beacon infrastructure is likely to have been installed for a purpose or a set of purposes, the nature of the technology means that it effectively becomes a public good that can be used by others for their own purposes. Encouraging this use by students for their own purposes offers a method by which they can be encouraged to ‘own’ aspects of the campus and create their own personalised learning experiences. This could be for informal purposes, such as promoting student run events or sharing projects they are working on outside their studies, but could also an opportunity for students to showcase or gain feedback on their in-progress work from other people from the university or members of the public, or to provide wider reach for research surveys.

Example - A university introduced beacons as part of a project to improve way-finding around the campus. However, some software engineering and interaction design students, develop an app that uses the beacons as part of a campus-wide geocaching game where individuals ‘hide’ interesting electronic resources for each other by ‘attaching’ them to specific beacons and posting treasure hunt clues for others to follow.

Serendipitous Learning

An app could be created that is used to promote the portfolios, research work, etc. of people in the immediate vicinity by temporarily ‘attaching’ links to beacons in informal areas in the immediate area, which would naturally become a highly dynamic resource and source of inspiration. This would help build a sense of collegiality as a diverse community of learners, researchers and practitioners by increasing the visibility of scholarly activity from all disciplines across the institution.

Example - A product design student is presenting work in their university’s final year show, a large event that allows friends, family, other students, potential employers and the public to view work from graduating students. As each student is only allocated a small amount of space within a very busy event, they decide to use beacons to extend the reach of their work across the space by allowing attendees to engage with information about their project from much further away than would have otherwise have been possible. The beacons also enable additional information about their work to be available when they are not personally present at the show, or are talking to a visitor to their exhibit. This ability to complement a physical submission or augment the physical space has the potential to be transformative in the way that such students promote their work and the information that they collate about it.

Transdisciplinary Working

Opportunities for students and staff to collaborate within disciplines are an important, and relatively easy, method of developing new approaches and innovative responses to problems. However, there has also been growing recognition within education and industry that even greater benefits can be obtained from the formation of teams of opposing mind-sets, different backgrounds and broader ranges of skills sets. Looking outside of subject silos for interesting conflicts or happenings on the boundaries between disciplines can potentially breed new knowledge creation. Higher education institutions house and facilitate a range of subjects in any one day. Often subjects sit shoulder to shoulder in a shared space at different times, but rarely interact or influence each other. Due to this use of shared spaces, beacons offer the ability to support and facilitate transdisciplinary interaction, through 'breadcrumbs of engagement', that can incubate new ideas or help pull together different people around a common goal, and so offer exciting possibilities for higher education.

Example - a student is working on a project set by a faculty department where there is an explicit requirement to work with peers inside and outside their discipline. Beacons provide a way for them to connect to, and stimulate interaction from, interested people who may have attributes needed to complete the project. The beacons can effectively provide a 'recruitment board' for potential collaborators, something that becomes more powerful by being able to target the physical spaces those with the necessary specialist skills are likely to use, such as engineering labs, product design studios, marketing departments, etc. In this way, the beacons provide a method of reaching across the campus and across disciplines to access peers with based on their skills, talents and experience.

Potential Issues and Mitigating Actions

Equity of Experience

The reliance of beacons on smartphones and tablets raises the problem of equity and the possibility of disadvantaging students who can't afford or otherwise don't have access to these devices. These potential issues can be mitigated against in a couple of ways: the beacons can be used primarily as a convenience - providing easier access to information that is already available - rather than being the sole way to access particular pieces of information or services; or appropriate devices can be made available to students who require but don't have them, such as through a loan scheme. While these help address the problem of equity, they raise further issues of their own, such as the underlying value of using beacons if they are just exposing existing information and how students who have bought their own devices will respond to their peers being given them without payment. However, these issues are beyond the scope of this paper.

Privacy

While beacons themselves tend only to transmit data, not receive it, and therefore are unable to log information about devices in their proximity, apps on the smart devices could be created to do this instead. An app designed to send location data back to a central server in response to being triggered by a beacon could result in real-time information about an individual's whereabouts being logged and analysed, with the potential that both specific activity and more general patterns of activity could be inferred. This issue isn't something that can be addressed from a purely technical point of view as it is the app developer that ultimately controls the level of privacy that their app affords. However, a code of conduct with regards to data used by the app, or a clear explanation of how collected data is used and the privacy implications is recommended to enable potential users of the app to make an informed decision about whether to install and use the app.

Security

The initial implementations of both iBeacon and Eddystone featured little in the way of security, meaning that it was extremely easy to spoof a beacon and use it to trigger any related actions in a place or time other than that which was intended or to interfere with positioning systems. However, later developments of the Eddystone specification have introduced additional features to prevent spoofing and make beacons more secure against being subverted by malicious third parties. These range from simple measures, such as password protecting individual beacons to prevent configuration changes, through to the Eddystone Ephemeral IDentifier (EID) specification that uses cryptographic techniques to change the Eddystone ID number for a beacon over time while still it to trigger actions on devices.

Over-reliance

A potential problem could be encountered should the use of beacons become well integrated into both an institution and its culture. In this case problems may occur when individuals come to rely completely on receiving timely, personalised notifications and therefore may miss important information if this system is not working correctly or their device is misconfigured, and could be further compounded by individuals no longer knowing how to access the equivalent information manually. As this is fundamentally a behavioural issue, the main method by which it can be addressed is by preventing the problem behaviour developing in the first place. Therefore, standard messages in specific locations should be minimised to reduce complacency and information and interactions made available via the beacon and its related apps should ideally also be accessible through other methods, though these will necessarily be less convenient.

Intrusiveness

As one of the primary uses for beacons is to provide location specific notifications, there is the potential that individuals will be so ‘bombarded’ by notifications, particularly in areas with a concentration of beacons, that they will come to see the notifications as spam and disable Bluetooth on their devices to prevent themselves from being overloaded with alerts and other notifications. This issue could be further complicated by this ‘notification fatigue’ being caused by other organisations, such as retailers, but creating a negative perception of the use of Bluetooth beacons within education. There is little technically that can be done to mitigate this issue, particularly in situations where it is the result of actions outside of an organisation’s control, though there are a few methods that may encourage individuals to use the technology on campus even if they switch it off elsewhere. The first is to have a clear code of conduct regarding the types of information that people will receive and allow them to customise their preferences, for example safety-related notifications are always enabled, but individuals can choose whether to receive course- or facilities-related ones. A further method would be to have multiple apps that are used by the beacons in the institution, each focused on a purpose, which would limit the potential for receiving unwanted notifications - though it would mean that more apps need to be created, maintained and downloaded.

Maintenance

Most currently available beacons are sealed units, with non-rechargeable, non-replaceable batteries. While this typically means that the beacons are weatherproof and so suitable for use both indoors and outdoors, it means that when the battery in a beacon becomes fully discharged, it must be completely replaced and disposed of. In addition, as beacons transmit only within a finite radius, it is necessary to visit them to check their charge level and to update the data being transmitted. Together, these mean that maintaining large deployments of beacons can become significantly more challenging, costly and time-consuming than smaller ones and that beacons as less environmentally sustainable than they could be. As these issues are the direct result of the design choices of the beacon manufacturer, there is little that can be done directly to address them as a user, other than by carefully selecting products that minimise the issues and by encouraging manufacturers to develop solutions. Some manufacturers have already begun to address some of these issues, such as Estimote with their ‘Mesh Network’ update feature that enables configuration data to be transmitted beacon-to-beacon without needing to physically visit each one, while other manufacturers are beginning to produce low-maintenance beacons for remote locations that feature solar panels to keep their batteries charged.

Conclusion

With the rapid growth in the use of smartphones and tablets within higher education a large part of the necessary infrastructure for using Bluetooth beacons is already in place. While beacons are beginning to become more widely used outside education, there are clear opportunities within higher education and in the support of learning and teaching, in particular. By providing a mechanism to integrate digital resources and communities with physical spaces, the potential for educationally-enriching interaction between different communities that normally simply co-exist within an online or physical environment is increased. In addition, Bluetooth beacons can enable a more personalised experience for learners and educators, which has the potential to be less frustrating and more welcoming, particularly to new students on a campus, so improving the 'stickiness' of the physical spaces by integrating technology that supports the individual interests and needs of learners within the physical space. These phygital experiences may also provide another way of highlighting the benefits of shared spaces and direct interaction with other learners and educators at a time when the dialogue around education, particularly higher education, is increasingly becoming one about purely distance and online learning models.

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