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A Classification Framework for Beacon Applications

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Abstract

Beacons have received considerable attention in recent years, which is partially due to the fact that they serve as a flexible and versatile replacement for RFIDs in many applications. However, beacons are mostly considered from a purely technical perspective. This paper provides a conceptual view on application scenarios for beacons and introduces a novel framework for characterizing these. The framework consists of four dimensions: device movement, action trigger, purpose type, and connectivity requirements. Based on these, three archetypical scenarios are described. Finally, event-condition-action rules and online algorithms are used to formalize the backend of a beacon architecture.

Type of Paper and Keywords

Short communication: *Beacons, IoT, classification, indoor applications, navigation devices, location-based services, location-based technologies, wireless technologies*

1 Introduction

Location-based technologies present organizations with a wealth of new opportunities for developing a unique customer experience as well as novel location-based services suitable for indoor applications [9]. Indeed, such technologies and the Internet of Things have the potential to radically disrupt major business functions and achieve efficiencies in the likes of marketing, manufacturing, distribution, and sales across many industries. Among the various enablers for this development are *beacons*, an assistive, low-cost technology that helps to connect physical objects or spaces to mobile devices, by employing low-energy Bluetooth connections to transmit messages or prompts to a smartphone or a tablet that have a corresponding app installed. While beacons are typically considered from a purely technical perspective, this paper introduces a conceptual view of beacons that shows which models and methods from computer science are applicable and which insights they allow for respective applications.

The term *beacon* has been in use for centuries to describe any sort of device used to attract attention to a specific location, especially for nautical navigation[1], all of which are only usable outdoors. For example, global positioning system (GPS) technology offers numerous satellite-based applications including vehicle navigation and localization of lost persons, vessels, aircrafts etc.

[1] https://en.wiktionary.org/wiki/beacon

Table 1: A comparison of indoor wireless positioning technologies (based on [17])

	Wi-Fi	RFID	NFC	iBeacon
Range	50m	10m	0.1m	Up to 50m
Cost	High	Low	Low	Medium
Power Consumption	High	Low	Low	Low
Bandwidth	1.5 Gbit/s	Up to 848 Kbit/s	Up to 424 Kbit/s	1Mbit/s
Positioning Accuracy	2-3m	1-2m	Close proximity	1-2m

The focus of this paper is the most recent development in navigation devices called *beacons*, which are based on a convergence of smart devices and micro-location technology, in particular the Bluetooth Low Energy (BLE) communications infrastructure.

Indicative of its emerging status, real-world applications of beacon technology are still in their infancy and there remains a degree of conjecture as to the true value it may offer. Documented applications of beacon technology include occupancy detection in smart building management [3] [4], recycling [5], hospital navigation [17], reminder notifications [1] and location-aware shopping navigation [2].

While Bluetooth Low Energy Beacons are the latest development, other wireless technologies have been used to achieve similar goals. Amongst others, these are wireless LAN (Wi-Fi), Near-Field Communication (NFC), and Radio-Frequency Identification (RFID). Beacon technology has a number of advantages, in particular with regard to its comparatively low energy usage and enhanced range. Apple was the first company to release a contemporary beacon technology with iBeacon [8], which was described as "…nothing more than super-small computers with Bluetooth radios…" [8, p. 222]. Table 1 provides a comparison between iBeacon technology and Wi-Fi, NFC as well as RFID.

As noted above, possible beacon applications are still being explored. However, it is the retail sector that appears to be receiving the greatest amount of early attention (e.g., [15]). As a typical application scenario, consider a coffee shop equipped with a beacon near its entrance. When a customer enters the shop, her/his smartphone can receive the beacon's signal, and trigger a specific action, e.g., the transmission of special promotions, coupons, recommendations or similar.

The goal of this paper is to study various issues regarding beacon applications. To this end, we first report on common scenarios for beacon application in everyday life (Section 2). Then, we present our novel classification framework in Section 3 that lists and differentiates the most important attributes of such scenarios. These dimensions are used to highlight the various archetypes that have emerged so far in Section 4. In Section 5 we elaborate on models and algorithmic concepts that can help understanding beacon applications in greater detail. In particular, we look at event-condition-action (ECA) rules as known, for example, from the domain of active databases and online algorithms. Section 6 concludes this paper.

2 Categories of Beacon Application Scenarios

With the emergence of beacons, people have come up with various potential use cases and scenarios for many different business domains. In a blog post[2], Alexandru Beleau discusses 100 application scenarios and groups them into 14 categories, which we will briefly repeat here:

1. Regarding the **Retail Industry,** he describes scenarios in which the retailer wants to know something (location, past orders) about their customers, who in turn receive some benefit from disclosing their information, for example, entertainment during waiting time, or coupons and discounts for selected products.
2. Next up is the **Hospitality Industry**, which includes applications like queue management and automated check-ins, information provisioning as well as virtual concierges.
3. In the **Tourism** sector, applications are conceivable with regard to information provision about exhibits in museums, or information about the weather at beaches or in ski resorts. Furthermore, virtual billboards could be built that can be attached to exhibits using beacons.

[2] http://blog.mowowstudios.com/2015/02/100-use-cases-examples-ibeacon-technology/

4. In **Education,** beacon technologies allow for information broadcasting to an entire class as well as tracking attendance in courses.
5. For **Healthcare,** scenarios focus on indoor navigation in hospitals as well as promoting health check-ups.
6. Regarding the **Entertainment Industry**, one could envision location-based recommendations, augmented laser tag games, and promotions in sport stadiums.
7. In the domain of **Travel**, indoor navigation and queue management at airports or train stations, personalized offers by travel agencies and letting subway trains know about passengers running to catch offer potential.
8. Regarding **Corporate Scenarios**, helping employees find each other, find rooms or equipment ought to be mentioned.
9. **Automotive** is a further domain in which beacons can be applied, for instance to lock or unlock cars based on proximity to their owner, as well as for smart traffic management.
10. In **Real Estate**, properties on sale may be equipped with beacons to notify passers-by that it is on offer.
11. Using similar ideas, there are ample scenarios for using beacon technology in **Advertising**, with personalized advertising, interactive ads, and the possibility to interact with billboards being promising examples.
12. In the context of **Personal Use,** sample applications include reminders for household duties such as emptying the rubbish, home automation or as a reminder of where a car was parked.
13. In a **General Group**, the author mentions speeding up payment processes, tracking personal items of all sorts and assistance for disabled or visually impaired people.
14. Last, Beleau mentions some of his **Personal Favorites**. Among them are finding themed characters at Comic-Con, enhancing children's toys so that similar toys can be traced in the neighborhood to connect children with similar interests, or monitoring your own bike in case it moves without your consent. Comic-Con, short for Comic Convention, begun in 1970 in San Diego. It brings together comics, movie, and science fiction fans along with hundreds of associated exhibitors. It is now replicated in cities all over the world.

3 A CLASSIFICATION FRAMEWORK FOR BEACON APPLICATION SCENARIOS

Looking at this plethora of different application scenarios, we can recognize many similarities and shared characteristics. Roughly speaking, a scenario addresses one of two main purposes: sensing and locating an object of interest, or disseminating information within a physical space. Achieving these purposes can be done in many different ways, and we now present our novel beacon application characterization framework, which lists four dimensions and their typical manifestations.

The goals of this framework are to establish a common understanding of beacon applications, simplify discussions by suggesting a vocabulary, and allow analysis and comparisons of existing and future scenarios. This enables practitioners that are interested in implementing a beacon scenario to characterize their requirements by going through the various dimensions. Additionally, archetypical solutions are highlighted, such that users can employ these as blueprints to sketch their own ones. The framework is shown in Figure 1, and the remainder of this section will explain the four dimensions in detail.

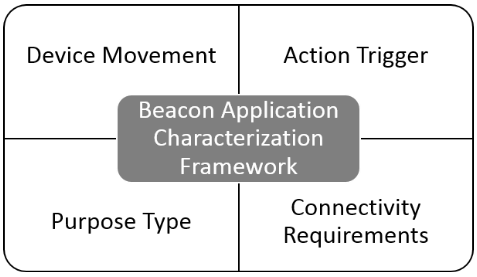

Figure 1: The characterization framework of beacon applications and its dimensions

		Beacon	
		Mobile	Stationary
Receiver	Mobile	*Not observed*	"Retail case"
	Stationary	"Object tracker"	*n/a*

Figure 2: Mobile and stationary beacons and receivers

3.1 Device Movement

Within a beacon application scenario, there are at least two types of devices present: beacons and Bluetooth receivers, with the receivers usually being smartphones. In terms of their physical location, each of these devices can be either mobile (movable), or fixed to a stationary place for an indefinite amount of time. This distinction gives rise to the two-by-two matrix shown in Figure 2.

The stationary-stationary case obviously does not make much sense, so we mark it as non-applicable (*n/a*), because for a location-based service to create any kind of value, at least one of its components needs to be capable of changing its location. The other symmetric case (mobile/mobile) has both receivers and beacons mobile and not fixed to one position. This case has not been observed anywhere, and we cannot think of a reasonable scenario for which this setup would make sense. However, it is still theoretically conceivable, and thus, we are content with proclaiming its theoretical existence for now.

The most interesting cases are those with asymmetric device movement, i.e., either the beacon or receiver is mobile, while the other is stationary. This allows the implementation of systems that use known locations of the stationary devices to give information to, or infer information about, the mobile devices. The case of the mobile receiver / stationary beacon is the traditional setup, which also applies to our introductory retail example. Here, the receivers are usually users with mobile devices running a specific application that receives and interprets beacon signals. The beacons are tied to specific points-of-interest, making them stationary.

On the other hand, the device mobility could also be switched around, such that receivers are stationary and the beacons are mobile. In this case, the receivers do not have to be smart devices and can be replaced by dedicated hardware, like Bluetooth dongles. The beacons as the moving parts of the system need to be in a portable form, like a wristband or a keychain, or need to be capable of being easily attachable to a movable object. To illustrate this, take for example a hospital with many different people in different roles (patient, staff, doctors) walking around and finding their way.

Furthermore, there are many expensive and movable assets, like hospital beds and other medical machinery and equipment. Tracking these assets and their location history has the potential to save time and money, by preventing theft and facilitating finding these assets when they are needed. As an example, patients with Alzheimer's disease could get a beacon-enabled wristband, which sets off an alarm as soon as it moves out of a predefined area. The infrastructure to make this scenario work requires that every room of the hospital is equipped with Bluetooth receivers, which are connected to a central server.

3.2 Action Trigger

This dimension determines what kind of event is necessary to trigger an action by the system. There are two general classes of events, *push* and *pull*. Push means that an event has occurred, which causes the system to automatically perform an action and "push" a result to the user, e.g., a notification. For this kind of setup, a set of rules is usually predefined. These rules typically have the form of event-condition-action (see Section 5). For example, an event could be that a customer enters a shop. The condition is that the customer is loyal, e.g., they entered the shop at least twice in one month. The action then could be to offer a special coupon to this customer, and notify her/him of that through a push notification to her/his smartphone.

Pull actions trigger work differently, in that they are not triggered automatically by the system. Instead, the user has to specify manually her/his desire to perform a certain action. As an example, consider a museum where every exhibit is equipped with a Bluetooth beacon. A visitor of such a museum can install the corresponding app on her/his smart device, and use it to retrieve further information about selected exhibits in the immediate vicinity.

3.3 Purpose Type

The dimension "purpose type" states to what end a beacon scenario has been set up. For now, the two main types of this dimension are *localization* and *information dissemination*. Note that further development of beacon hardware and software could enable many more purpose types in the future.

Localization denotes the identification of the physical position of a specified object in a given space. Depending on what kind of object needs to be localized, we further differentiate three sub-types of localization:

1. **Self-localization:** A user needs their own position in order to orient himself and get directions. This is a common goal in indoor navigation scenarios.
2. **Object tracking:** The positions of multiple objects within a given space (e.g., a building) need to be monitored and be available on demand.
3. **Information collection:** Stored location information can be used to trace the whereabouts and paths of users or objects within a monitored space. This applies for example in malls to identify hotspots and optimize placement of signs or advertisements.

The other main type of purpose of a beacon application is information dissemination, i.e., distribute relevant information to a user based on her/his location. The prime example here is again the museum, which uses beacons to provide more details about its exhibits. Note that these different purpose types may overlap. The museum might do both, i.e., disseminate information whilst also tracking its visitors. However, in such hybrid cases there is usually one main purpose type, which is used to advertise the usage of the system. The second purpose might not be obvious to the users at all times, and privacy concerns may apply.

3.4 Connectivity requirements

It is common that a beacon scenario requires an active Internet connection in order to use the respective system. However, this is not always the case, and so it makes sense to further discuss the different connectivity requirements. An application with a connection to a backend server has the capability to download up-to-date information in real-time, which opens up a plethora of interesting possibilities. Furthermore, a connection is per default bidirectional, so uploads are also possible, which allows the backend to receive information about the current status of the users.

However, using these online functionalities obviously requires that the involved devices are connected to the Internet. The typical connection methods are either mobile data or Wi-Fi, which depending on the environment may not be available. Designing a beacon scenario around the potential non-availability of an Internet connection eliminates this issue. Back in the museum example, it makes sense to have no connectivity requirements, because the network coverage could be bad inside a large building. An application that still provides useful information in an offline fashion then needs to have all the information prepackaged and installed locally on the user's device. Another advantage of an offline app is that privacy concerns are mitigated, because a user's location cannot be tracked, at least not in real-time.

4 ARCHETYPES AND SCENARIOS

Looking at the dimensions described in the previous section it is clear that some combinations do not make much sense, e.g., having both the beacon and the receiver stationary, or having a push action trigger without connectivity requirements. Therefore, it is reasonable to think about realistic dimension combinations and their manifestations. We call such manifestations *archetypes* and discuss three archetypes that we have identified so far.

4.1 Coupon Pusher

The "Coupon Pusher" is the canonical retail case (see Figure 3). The service provider configures a number of beacons, provides an app for mobile devices, and operates a backend. Beacons are stationary and affixed to certain points of interest within a shop, e.g., the entrance, the cash register, or the area where special offers are placed. Beacon signals are received by mobile devices running the app, which are moving through the shop. If any device comes close enough to a beacon, an event is triggered, which transfers the user's information to the backend, which then decides if a coupon should be pushed to the user. This setup allows the service provider to dynamically hand out coupons to specifically targeted users based on pre-defined conditions, e.g., a user has entered the shop `X` times, or spent `Y` minutes there.

Another example may look like this: A small town wishing to foster the local economy founds a reward-points platform on which all local shops are registered. Additionally the shops as well as some local attractions are equipped with beacons, and an app is provided for visitors to the town. If visitors come into the vicinity of these beacons, they are awarded with reward points on the platform, which can then be used for discounted product offerings or other purposes. This idea can be expanded into virtual scavenger hunts with people being lured to specific points of interest. Such an application of gamification to local marketing brings strong incentives to the customers, while being comparably cheap to implement for the service provider.

4.2 Offline Museum App

The second archetype is the "Offline Museum App" (see Figure 4). The main difference here is that there is no backend, which is omitted because all relevant information is pre-downloaded with the application. The typical case is a museum with beacons affixed to each individual exhibit. A visitor that comes close to an exhibit with the app running can then choose to display additional information about that specific exhibit, an idea that we have previously studied based on RFID technology [13] [14]. This provides a location-aware and context-sensitive guide through the museum, which requires no further external connectivity after the initial app download.

4.3 Asset Tracker

The third archetype is the "Asset Tracker" (see Figure 5). The most striking difference is that the movements of beacons and receivers are reversed:

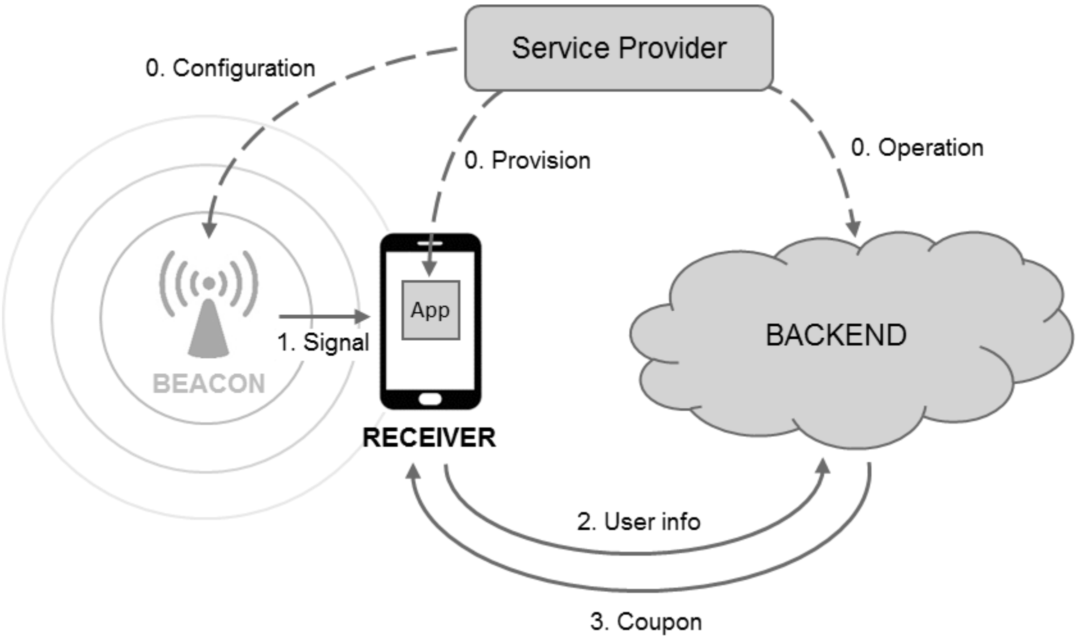

Figure 3: Coupon pusher archetype

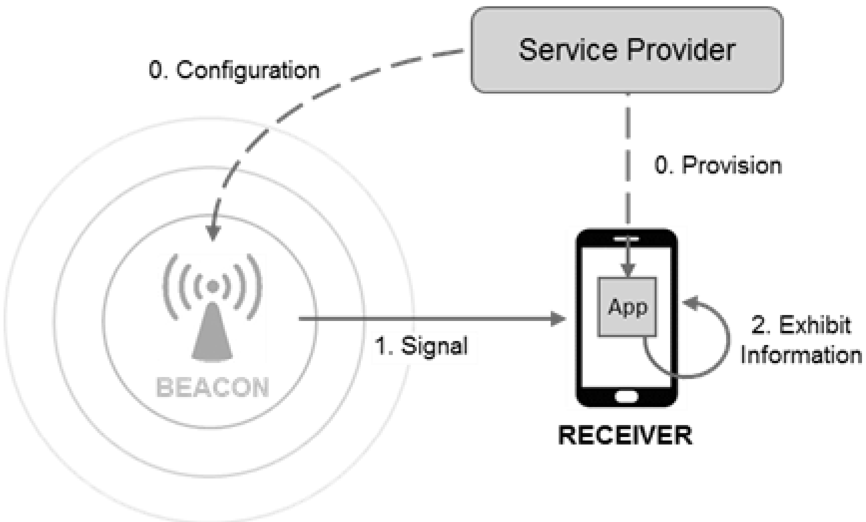

Figure 4: Offline museum app archetype

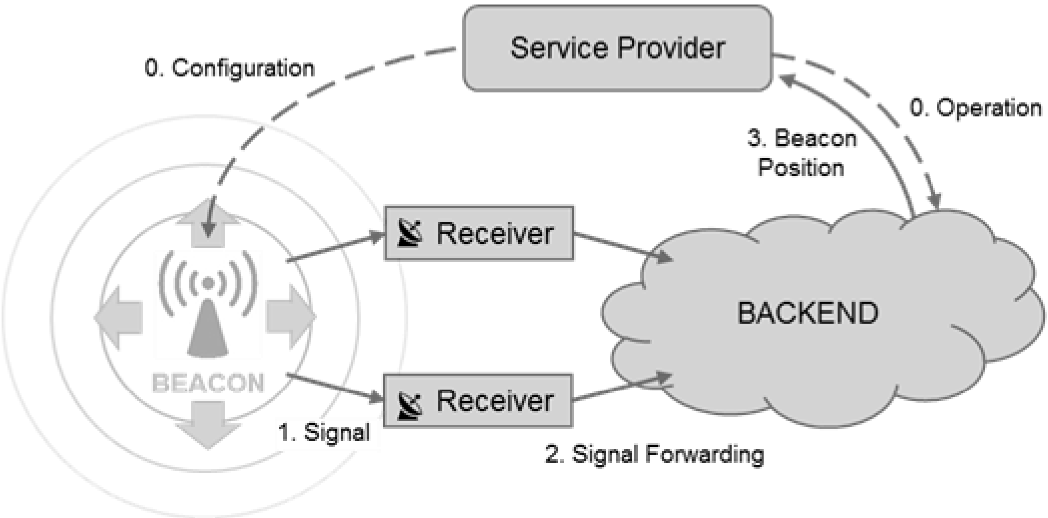

Figure 5: Asset tracker archetype

Beacons are no longer stationary, but instead move through a predetermined space. The idea is that beacons are attached to assets that need to be tracked. The receivers, which are no longer mobile devices, are fixed in place. Practically, the role of the receiver can now be assumed by Bluetooth dongles, which are connected to the backend in some way (e.g., Wi-Fi). Beacon signals are received and forwarded to the backend, which can then localize and track the beacons and consequently the assets. For the task of converting beacon signals into localization information, specialized algorithms have been developed. One such algorithm is for example Fingerprinting [12].

As a practical example, consider a hospital with many assets to be tracked (patients, beds, important equipment etc.) and many rooms in which these objects might be located. In this hospital, one beacon is assigned and attached to every asset and every (relevant) room is equipped with Bluetooth receivers. With this infrastructure, hospital management is capable of tracking every asset within the building. Using low-end hardware, room-level accuracy can easily be achieved, which can be of enormous benefit for hospital staff when locating patients or equipment.

5 MODELLING AND ALGORITHMIC IMPLICATIONS

We now look into the question of how to model beacons and beacon applications. In particular, we will examine models for a particularly interesting part of the architecture – the back end. In detail, we will look at triggering events and at how information with a limited audience can be assigned. One core requirement is that processing events and triggering actions occur in a timely manner, especially before all other events are known to the system. This leads to the consideration of online algorithms, which are capable of dealing with this uncertainty.

5.1 Triggering Events

We look at events that happen once a receiver reaches a beacon. In this context, beacons and their activities can be captured by the concept of event-condition-action rules (ECA rules for short) as known, for instance, from the area of active database systems [10][16]. In the event that a receiver or user gets near a beacon, the receiver recognizes this event and asks its backend to evaluate a condition associated with it. If the associated condition is satisfied, a corresponding action will be triggered, typically towards the customer. This allows us to consider rules as being where:

- Events signal location presence, which technically depends on the range that has been set for the beacon in question.
- Conditions can be as simple as Boolean expressions, i.e., formulae consisting of elementary expressions of the form "`a op x`", where `a` is from the underlying application or an attribute, `op` is an operator such as =, <, >, and `x` is a value. The application-related part can be related to a shop or retailer, to a product, to a customer profile, or be based on external factors (e.g., time of year, time of day, any calendar characteristic). Elementary expressions can be combined into propositional formulae by the Boolean operators `and`, `or`, `not`; thus, formulae are assumed to always evaluate to yes or no.

- Actions are of the form "send message".

As an example, consider the coffee shop once more. Conceptually, the following may happen: When the customer passes the beacon at the shop entrance, the customer's receiver (e.g., mobile app) will recognize the beacon and inform the back-end, which may evaluate the following condition:

```
cust_type = "owner of loyalty card" and
cust_drink_type = "tea"
```

If the condition is satisfied, i.e., if the customer indeed holds a loyalty card for that shop and is a tea drinker, the action could be to send a tea-discount-voucher to the customer's device. Thus, the complete ECA rule in this case is as follows:

```
upon event= "entry"
if cust_type = "owner of loyalty card"
   and cust_drink_type = "tea"
then action = "send discount coupon"
```

Notice that a variety of other ECA rules can easily be expressed in this way. For example, consider:

```
upon event= "entry"
then action = "send discount coupon"
```

This rule has an empty condition, which states that *every* customer who enters the coffee shop will be sent a coupon. Similarly, consider:

```
upon event= "entry"
if   cust_type = "owner of loyalty card"
   and cust_drink_type ≠ "tea"
then action = "send discount coupon"
```

This rule states that only those customers who do *not* drink tea will receive a coupon.

The ECA mechanism is easily extended to incorporate time constraints as well, for example to express that a customer will only receive a coupon (say, for the next visit) if they have actually been consuming something in the coffee shop (i.e., payed for a product) or stayed there for more than 15 minutes, e.g.:

```
upon event= "exit"
if cust_payment = "yes" or
   cust_stay_duration > 15min
then action = "send discount coupon"
```

The ECA model allows for shops that actually do not sell products directly but act as "intermediaries" for other shops. An example of such a shop is a bank wishing to bundle services requiring a physical presence from partners in different industries, yet in the local neighborhood, facilitated or enabled by beacon technology. Since the goal for the bank is to attract (younger) and retain (older) customers through the provision of attractive services from the partner companies, the bank will pay these other companies to offer the services. The bank will act as a broker beyond financial services, e.g., roadside assistance, car services, other non-digital services, where the relationships to the services a bank is associated with could be exclusive or non-exclusive and could resemble a loyalty card (but there needs to be more to it than just a loyalty card).

In this context, let us return to the example of the small town wishing to improve the local economy. In this case, the shops would install beacons and whenever a customer passes a shop "upon event = pass" will receive relevant offers "then action = send offline-only promotion code". As a result, the customer may enter the shop and receive further information. When they buy products, they will receive points based on how long they have been in the shop or depending on the number of shops they have visited or similar.

```
upon event= "exit"
if cust_payment = "yes"
   and count(offline stores) > 3
then action = "award 50 reward points"
```

5.2 Assigning Coupons Using Online Algorithms

Having formalized how actions are triggered in principle, we will now look at more involved scenarios, where information is evaluated by not only ECA rules but also using economic rational. To this end, consider a shop wishing to send coupons to some customers in an attempt to increase revenue.

Looking at customers, we assume that a customer c has a profile P_c of interest, which could represent a buying history or a wish list consisting simply of product ids. Obviously, an opportunity of a shop s arises when there is a customer c such that P_c and O – the set of products a shop has on offer – have a non-empty intersection. If a customer's position falls into the range or area of a beacon of a given shop, the beacon signal will trigger an action on the customer's device, provided one of the shop's rules fires. We assume that the customer will then receive a message m containing a coupon for the shop.

More specifically, suppose shop s currently has coupons $m_1, \ldots, m_r$ to distribute as part of a promotion, each of which has a certain conversion probability and can be sent once (there may be multiple copies of the same coupon which we consider as distinct coupons). We need an assignment algorithm A that chooses coupon m_i that has the highest conversion probability and sends it to customer c if c "arrives" at time t within the range of a beacon associated with s. Since at time $t' > t$ another customer might arrive who has a higher conversion probability for the same product, but A cannot know this. A needs to be an *online* algorithm [6],

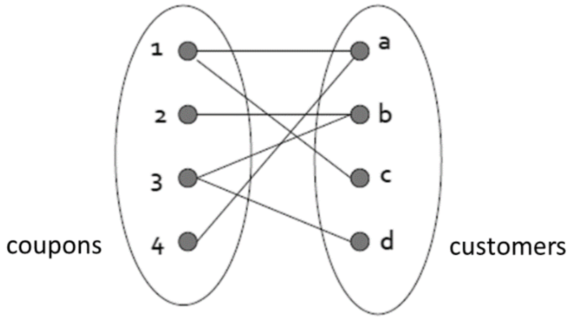

Figure 6: Matching in a Bipartite Beacon Graph

which can make a decision just based on the current situation and without any knowledge of the future.

This problem is also known as the secretary problem [7], which is typically modeled as a graph with two disjoint sets L and R of nodes s.t. edges are only from L to R or vice versa, but not within L or R (i.e., a "bipartite" graph). We here apply this problem and its solution in the context of beacons.

Consider the following situation: We are given a bipartite graph with nodes L ∪ R (for left and right side, resp.). Let the nodes in L represents coupons a shop can distribute, and the nodes in R represent customers. An edge between coupon i and customer x means that i is in x's profile. For example, in Figure 6, customer a has items 1 and 4, b has 2 and 3, c has 1, and d has 3 in their profile.

Thus, the basic problem is the following: Coupons are fixed, but customers arrive in random order. When a customer arrives, the customer is sent a coupon that matches her/his interest, and the goal is to establish as many matchings as possible. A *perfect matching* is achieved when all nodes of the given graph are matched. Obviously, an offline algorithm, having complete knowledge of the input, can achieve this, since (1,c), (2,b), (3,d), (4,a) is a perfect matching.

However, in an online situation this is no longer possible. Indeed, assume that customers arrive in the order a, b, c, d, and we match (1,a), (3,b). Then no further match is possible, since coupon 1, the only choice for c, is taken, and so is coupon 3 (taken by b). Following Rajaraman et al. [11], the competitive ratio of our algorithm is at most ½.

As a first refinement, we take the conversion rate of a coupon or customer into account. Let us assume that the profile of a customer consists not just of product ids, but of pairs of the form (pid, conv-rate), i.e., for each product id there is an indication of how likely the customer is to convert a coupon for that product into an actual buy. Now we can assign weights to the edges of our bipartite graph in such a way that the respective

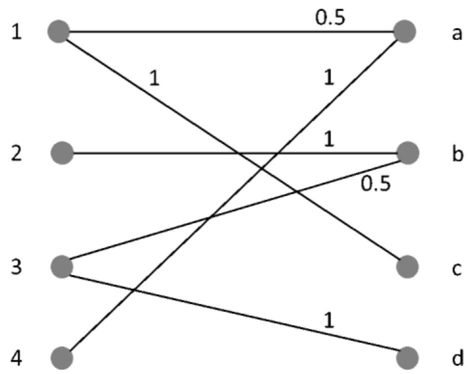

Figure 7: Weighted Matching in a Beacon Graph

conversion rate is indicated. For example, consider the graph in Figure 7. In this section the conversion rate for customer a on coupon 1 is .5, i.e., there is a 50% chance that a will utilize 1. On the other hand, a will make use of coupon 4 for sure.

Kesselheim et al. [7] present an optimal algorithm for matching on weighted bipartite graphs, which can straightforwardly be adapted to the case of coupon distribution. The cardinality of L and R is the same by definition. We will refer to it as n = |R|. Then, the optimal strategy is to skip the first n/e customers, where e denotes the Euler constant of approximately 2.72. For all subsequent customers the optimal matching is calculated on the graph as available in a particular step. If in this way a match with an unassigned coupon is possible, it is assigned to the customer immediately. With a competitive ratio of 1/e, the upper and lower bound of the secretary problem, this algorithm solves the problem as good as possible.

6 CONCLUSIONS

Beacon technology is particularly popular at the moment, in particularly since beacons – unlike their RFID "predecessors" – often come in the form of small computers and hence exhibit some programmable intelligence. Moreover, beacon costs are still falling, so that it is reasonable to assume that beacon technology is still on the rise from a commercial perspective. It is therefore appropriate to establish concepts, models, and methods that are applicable to this technology and that have proven beneficial before.

After having characterized beacon applications based on their core properties, we have identified three major archetypes of beacon scenarios in this paper, and we have started to associate proven techniques with them. One is ECA rules as known from active databases; another is online algorithms as known, for example, from online advertising.

Clearly, there is significant room for further research, both in the area of databases as well as in that of algorithms. On the other hand, there are also economic issues to be resolved. Indeed, statistics show that many retailers do not see an immediate benefit in beacon technology and are afraid of high investment cost; this has happened with RFID technology, for which comparably expensive handheld devices were made obsolete by the arrival of smartphones. Moreover, in spite of repeated attempts to integrate beacon technology into suitable applications, so far no killer application scenario has emerged. So the ultimate likelihood of widespread beacon success remains unknown.

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