Hyperlocal Context to Facilitate an Internet of Things Understanding of the World

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ABSTRACT

The Internet of Things (IoT) holds the promise for computers to understand our world by means of technology. Today, computers observe and identify the world, but unless they interact to optimally share all relevant information, their understanding remains incomplete. We argue that location-based device discovery is a prerequisite for the required IoT interactions. Based on this, we introduce the concept of hyperlocal context, a combination of device identity, location and information resources, which represents a digital understanding of the world at a human scale. The considerations for the implementation of hyperlocal context as well as current and future applications are presented.

Keywords

Hyperlocal context; Internet of Things; Location-based discovery;

INTRODUCTION

In the words of Kevin Ashton, who coined the term Internet of Things (IoT), technologies will “enable computers to observe, identify and understand the world—without the limitations of human-entered data” [1]. Today, sensors observe our world in countless ways, such as temperature, light, proximity and sound. People and objects are uniquely identified through technologies such as Radio-Frequency Identification (RFID) and image recognition. Such observation and identification occurs without human intervention. But do these technologies understand the world? At what level of understanding is there an IoT?

It is difficult to quantify an understanding of the world, and we will make no attempt to do so. However, it is clear that the level of understanding is proportional to the level of observation, which includes fundamental concepts such as identity (who/what), location (where) and time (when). For this reason, the IoT hinges on the ability for computers to maximize their understanding of the world by interacting to collect and distribute all pertinent information.

In this paper we use the term ‘device’ to refer to computers which observe and identify the world. We argue that location-based device discovery is a prerequisite for IoT interactions. Based on this, we introduce the concept of hyperlocal context, which represents a digital understanding of the world at a human scale, and present its real-world applications.

DISCOVERABILITY AND PHYSICAL LOCATION FOR REAL-TIME INTERACTION

Imagine a situation where multiple independent devices collect information about a given space. Here we will show that the discovery of these devices is a prerequisite for information exchange and that physical location provides an ideal foundation for the discovery mechanism.

Discoverability

In order for two devices to exchange information, otherwise known as Machine-to-Machine (M2M) communication, the devices must first be aware of one another's existence. For instance, a client device may be programmed with the Uniform Resource Locator (URL) of the server to which it sends data. In an IoT free of human-entered data, devices must autonomously establish such awareness. In other words, IoT devices must be discoverable in order for interactions to take place.

Consider the example of independent devices collecting information about a given space. Regardless of how they are discovered, the result can be expressed as a collection of their unique device identifiers. In general, a subset of each collection of devices will share an understanding of the world. In the next section, we argue that physical location effectively defines this subset.

Physical Location

Consider again the example of a given space which includes independent devices collecting information. Is the space as large as a factory or as small as a room? Are the devices observing the same metrics but at different locations within? Are people and objects being identified and observed as they move about the space? Are the devices themselves mobile? These static and dynamic factors influence which devices will share an understanding of the world at any given instant.

The physical location of the devices will largely determine the extent of the overlap in their understanding of the world. Moreover, the mobility of people and objects being observed and identified throughout the space introduces real-time dynamics. Imagine that our space is a conference room with a few environmental sensors. When the room fills with people carrying smart devices, each of which is equally capable of sensing its environment, the potential collective understanding of the space is greatly increased. In order to take advantage, the discovery mechanism must therefore be sensitive to the real-time location of all devices.

In summary, maximising the understanding of the world is predicated on an awareness of all devices that have the potential to contribute relevant information. This requires a mechanism for device discovery within a framework of real-time location. In the following section we outline the current state of the converging fields surrounding location-based discovery.

IDENTIFICATION, LOCATION AND CONTEXT

Location-based device discovery is predicated on an ability to uniquely identify and locate devices. Here we provide a brief summary of the relevant considerations in both of these domains, and how together they extend to provide contextual awareness.

Unique Identification

The importance of identifying objects in order to interact with them and bridge the gap between the physical and virtual world has been described in [15].

Barcodes are an example of machine-readable identifiers. The Universal Product Code (UPC) is a common standardized version of the barcode. The Electronic Product Code (EPC) [6] is an industry standard that generalizes the UPC to provide a universal identifier for physical objects anywhere in the world, and which can be stored on RFID chips. These transfer a unique identification code using radio signals.

Active RFID devices use an internal power source to transmit their identifier to their surroundings. Attached to objects or people, active RFID devices allow identification at a distance often measured in tens of metres. Attached to fixed locations, active RFID devices allow places to be uniquely identified by any listening device in range.

Location

Systems that locate devices in space are typically referred to as real-time locating systems (RTLS) or indoor positioning systems (IPS).

One approach to location involves devices in fixed locations identifying themselves to their surroundings. For example the periodic, uniquely identifiable broadcasts of WiFi routers can be used by a nearby listening device to determine its own location based on, for instance, their signal strength and the known location of the routers themselves. This approach has recently been extending using Bluetooth Low Energy (BLE) beacons, which are essentially active RFID devices attached to specific locations, facilitating indoor positioning by mobile devices [18]. With this approach the 'self-supported' listening device bears the computational burden of calculating its location.

The opposite approach is for fixed infrastructure to listen for the wireless transmissions of uniquely identifiable devices in range. In this case the location of the transmitting device can be determined in a similar manner by the infrastructure, which has knowledge of its own location. For the 'infrastructure-supported' approach, the meaning of 'device location' is very similar to 'device sensing', hence the close relationship between RTLS/IPS and wireless sensor networks (WSN).

While both approaches enable a host of applications, their current state suffers from limitations which hinder the progress towards a sustainable IoT. From [12] and supported from our own experience, both tend to be implemented as disjoint networks for dedicated services in local niche applications, and are usually pre-configured to serve a single purpose service in a local network domain, which impedes the sharing of information among multiple networks and/or technologies. Moreover, these are often based on proprietary technology which makes standardization efforts impractical.

An example of this limitation is the EPCglobal Architecture Framework [7], the de-facto global standard, which only supports asset identification using passive RFID devices [12]. More complex active RFID and sensor devices are not supported.

Finally, most RTLS/IPS have significant complexity (e.g. algorithms, precise timing requirements, network architectures), require extensive calibration (e.g. fingerprinting, radio survey, antenna positioning), and suffer from non-negligible location errors and variability over time in dynamic environments [25, 10, 11].

Context Awareness

RFID and location technologies are together key enablers of the IoT by contributing to the contextual understanding of a physical space through the identity and location of the devices it contains. The addition of sensor data collected by these devices, as well as accessory information enriches this contextual awareness.

Many challenges remain and we see a legitimate need for new device discovery mechanisms within a framework of real-time location [19, 2, 25, 20].

Moreover, the distinctions between the self-supported and infrastructure-supported approaches presented in the previous subsection have similar implications for contextual-awareness [13].

In the following section, we discuss the implementation of a mechanism for device discovery within a framework of real-time location.

IMPLEMENTATION OF LOCATION-BASED DISCOVERY

As we have seen in the previous section mechanisms for location-based discovery are manifold. Here we present one such implementation which leverages location-aware smartphones. We comment on its suitability for IoT devices before presenting an alternative infrastructure-based mechanism which addresses the main challenges we have identified so far.

Location-Aware Device Discovery

Today, ambient social networking applications such as Highlight [14] Sonar [22], SocialRadar [21] and many others enable their users to discover one another based on the physical proximity of their smartphones. These applications periodically send the smartphone's location to the provider's server such that a list of all participants and their locations is centrally maintained in real-time. Based on this list, the provider may calculate proximity and push relevant content, encouraging the participants to connect and interact.

Although this may appear analogous to the requirement we previously defined, such a mechanism is an unlikely candidate for the IoT for two reasons. First, as we've described, location-awareness adds a non-negligible energy and computing burden, which is out of reach to many resource-constrained IoT devices. And, second, this discovery mechanism excludes the participants from competing applications. The IoT requires vendor-agnostic device discovery which transcends walled gardens.

Infrastructure-Based Location

We argue that the devices of the IoT need not be location-aware. Instead, the communication infrastructure may assume responsibility for locating the devices it connects. For the purposes of this discussion, we will use the term 'node' to represent an element of wireless infrastructure such as a base station or access point. Consider the case of a wireless device which communicates with an infrastructure node. If the location of the node is known, the device may be estimated as having that same location. This imposes no additional requirements on the part of the device.

With this approach, the location resolution is inversely proportional to the radio range and node spacing. For example, a device connected to a WiFi access point, where the radio range is measured in tens of metres, will be more accurately located than a device connected to a cellular tower, where the radio range and tower spacing is often measured in kilometres. Triangulation methods can significantly improve the location accuracy when devices are in simultaneous contact with multiple nodes, but these require additional computation and are outside of the scope of this paper.

```
{
  "node": {
    "mac": "12:34:56:78:9a:bc"
  },
  "devices": [
    {
      "mac": "aa:aa:aa:aa:aa:aa"
    },
    {
      "mac": "bb:bb:bb:bb:bb:bb"
    },
    {
      "mac": "cc:cc:cc:cc:cc:cc"
    }
  ]
}
```

Figure 1. JSON representation of node-level device location

Infrastructure-based location has the benefit of consolidating device identity and location information at the level of the infrastructure node. Imagine that each node runs a lightweight server providing an Application Programming Interface (API) capable of listing all connected devices. Figure 1 shows how this API might return the collection of devices in JavaScript Object Notation (JSON) format. The absolute or semantic location of the node would likely be known only externally.

Such an infrastructure with nodes running lightweight servers with an API represents a middleware architecture that acts as a gateway between the IoT devices and the IP network (either local or Internet-connected). This would address many of the considerations presented in [5, 23].

It is important to note, however, that unless all devices in physical proximity connect to the same node, their collection will instead be distributed across multiple nodes. Consider again the example of independent devices collecting information about a given space. If half communicate with a WiFi access point and the other half communicate with a cellular tower, not only will the awareness of these devices be distributed across two infrastructure nodes, but the location accuracy of the two sets will differ significantly. In this case, a single, complete collection of discovered devices would have to be maintained at a network location accessible to both nodes and the devices they connect. We expand on this discussion in the Considerations section.

The reelyActive Infrastructure Approach

At reelyActive, we have addressed the aforementioned concerns by designing an infrastructure which simultaneously supports nodes of various radio standards which may be repeated with a given spacing in order to standardize the location accuracy [5]. By design, this infrastructure consolidates the location and identity information from all nodes at one endpoint where a single, complete collection of devices and locations may be maintained and accessed through a RESTful API. The reelyActive infrastructure approach hence aims to provide a flexible middleware solution.

Specifically, reelyActive nodes are called 'reelceivers' and these connect in a wired, linear daisy-chain topology called a 'reel'. Power and network connectivity is distributed from the endpoint along the reel, which simultaneously supports reelceivers of different wireless technologies. The wireless range of a reelceiver is similar to that of WiFi, the most prevalent wireless Local Area Network (LAN) infrastructure. The reel infrastructure is best classified as a LAN for low-power wireless devices.

By strategically placing reelceivers at human-recognizable points of interest, semantic location is possible, for example: “the item is in the supply closet”. For any given wireless transmission, the closest reelceiver may be estimated simply as that with the greatest received signal strength (RSSI). Location granularity is determined by the spacing and placement of reelceivers.

The infrastructure supports bidirectional communication and the lightweight server hosted at the reel endpoint acts as the main gateway interface. It applies protocol translation, routing and mapping between the reel communication protocol on the infrastructure side, and standard RESTful requests on the IP network side.

In summary, an infrastructure-based location system which consolidates the identity and location of all connected devices is ideal, especially for resource-constrained, wireless IoT devices. reelyActive infrastructure approach is specifically designed for this purpose and acts as a gateway between the devices of the IoT and the IP network. When the collection of all discovered devices is complete, accessible and organized based on location, this provides the foundation for contextual understanding, as we will show in the next section where we introduce the concept of hyperlocal context.

HYPERLOCAL CONTEXT

In the Introduction, we speculated on the level of understanding necessary for there to be an IoT, and argued that the level of understanding is proportional to the level of observation and identification. In the previous sections we showed that through location-based discovery, it is possible to maintain a complete collection of all the devices that have the potential to contribute to this understanding for a given space. By combining this hyperlocal collection of devices with their associated resources, we obtain a contextual representation of that space.

The term hyperlocal is often used to define mobile applications which provide content specific to a constrained geography and moment in time, typically at a human scale.

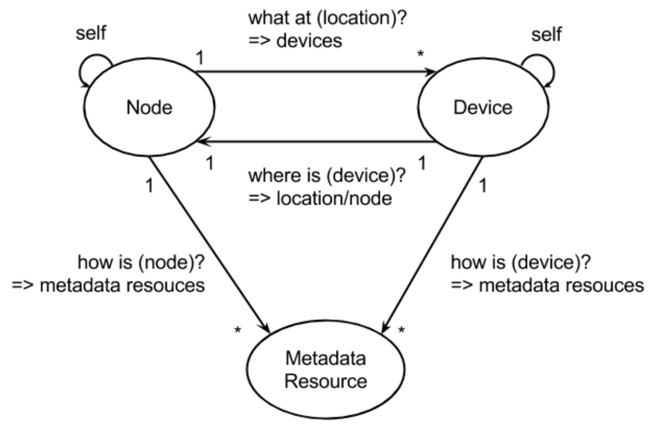

Figure 2. Schematic representation of hyperlocal context API resources

Context is defined as “the circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood and assessed” [16]. We therefore propose the term hyperlocal context to mean a digital representation of a space and time at a human scale.

Hyperlocal context is designed to be consumed over IP networks as a RESTful API. It therefore defines a schema of API resources as represented in Figure 2. There are essentially three types of API resources: a device resource, a node resource and a metadata resource which may be associated with each. A device has a node resource for its location, and a collection of associated metadata resources. A node has a collection of device resources at its location, and a collection of associated metadata resources as well. Each metadata resource is simply a metadata value, typically a URL pointing toward another API resource.

Although simple, this model nonetheless provides a powerful semantic for answering questions about the context. The device-to-node relation answers the question “where is (device)?”. The node-to-devices relation answers the question “what is at (location)?”. And the relations toward associated metadata resources answer the question “how is the (device/node)?”. Also every resource state has a timestamp to keep track of the time dimension.

In its simplest form, hyperlocal context is represented as the description of a node resource which enumerates what is present at a location as a collection of device resources, and provides a collection of metadata resources associated with itself. In other words, “what is at (location)” and “how is the (node)”. Figure 3 shows the JSON API response provided after such a request. From the perspective of a device, getting the hyperlocal context would mean asking first “where is (device)” and then asking “what is at (location)”. Associated metadata resources, which are typically accessed through API URLs on the IP network, provide access to all relevant information be it static

```
{
  "node": {
    "mac": "12:34:56:78:9a:bc",
    "self": "http://api.somehlcserver.com/nodes/
              12-34-56-78-9a-bc",
    "devices": [
      {
        "mac": "aa:aa:aa:aa:aa:aa",
        "self": "http://api.somevendor.com/
                  devices/aa-aa-aa-aa-aa-aa",
        "location": "http://api.somehlcserver
              .com/nodes/12-34-56-78-9a-bc",
        "metadata": [
              "model": "http://docs.somevendor
                 .com/devices/modelnumber/",
              "specs": "http://docs.somevendor
                 .com/devices/modelnumber/specs"
        ]
      },
      {
        "mac": "bb:bb:bb:bb:bb:bb",
        "self": "http://api.othervendor.co/
                v1/dev/bb-bb-bb-bb-bb-bb",
        "location": "http://api.somehlcserver
              .com/nodes/12-34-56-78-9a-bc",
        "metadata": [
              "model": "http://docs.othervendor
                 .co/dev/modelnum/",
        ]
      }
    ],
    "metadata": [
      "venue": "http://api.someprovider.com/
                wiki/someuuid"
    ]
  }
}
```

Figure 3. JSON representation of hyperlocal context

```
{
  "mac": "aa:aa:aa:aa:aa:aa",
  "self": …,
  "location": …,
  "metadata": [
    "type": "Temperature Sensor",
    "value": "21",
    "units": "Celcius"
  ]
}
```

Figure 4. JSON representation of explicit information as key-value pairs for a given device

information about the device/node or its latest observation data. By following RESTful principles, resource discovery is achievable just by navigating the relations between the resources. Alternatively, all relevant information can be included explicitly for each devices as a set of key-value pairs as illustrated in Figure 4. This is in fact a generalization of the JSON of Figure 3 where the resource values are not limited to URLs but can be any kind of metadata. Any computer, whether it be a contributing device or an external agent, can leverage hyperlocal context to maximise their understanding of the corresponding space at the given time.

In summary, hyperlocal context combines, for a given space and time, a collection of all relevant devices and their properties and observations, such that computers can construct a digital understanding of the physical world. In the following section we discuss considerations for the general use and implementation of hyperlocal context.

CONSIDERATIONS

Hyperlocal context is a relatively simple concept, however, a generalized implementation of this concept requires careful design. Here we present, at a high level, some of the most prominent considerations.

Device Compatibility

As long as devices expose a unique identifier when they connect to an infrastructure node, as we have shown, they may be included in a location-based collection. For instance, in the case of WiFi and Bluetooth Low Energy a MAC address may serve to uniquely identify each device. This enables vendor-agnostic location-based device discovery.

Hyperlocal context requires resources to be associated with each device. This is subject to two constraints. First, the unique identifier must be matched with its corresponding resource and, second, that resource must be available and shared. In other words, even if, say, a MAC address can be associated with a specific vendor, an API specific to that device must exist with accessible permissions. As we will show next, the latter facilitates opt-in participation, privacy and security.

In the case of reelyActive devices, an EUI-64 identifier is employed and a resource URL provided for each.

Participation, Privacy and Security

Participation in hyperlocal context, namely the provision of a valid resource to be associated with a given device, should be opt-in for the device owner. We have shown that it is often possible to identify and locate a device based on its unique identifier, however, it should not be mapped to a resource without the owner's consent.

Similarly, with respect to privacy, the wishes of the device owner must be respected in addition to any privacy laws specific to the given jurisdiction. A deeper analysis of privacy considerations is outside of the scope of this paper and will surely be an ongoing subject of discussion in the IoT.

Observations, identities and locations may contain sensitive information which would require secure transfer from one computer to another. At the resource level, the resource provider is free to manage this security layer. The hyperlocal context provider may also optionally implement and manage a layer of security.

It is interesting to note that initiatives such as personal data lockers, for example [24], and platforms such as Evrythng [8] could potentially manage the participation, privacy and security of the resources associated with people and things, respectively.

Where should Hyperlocal Context be Maintained?

As we have shown, the identity and location of devices can be consolidated at the level of the infrastructure nodes or above. Hyperlocal context may therefore be maintained at this level or above, exchanging information via Internet Protocol (IP) on the IP networks.

Maintaining hyperlocal context at, or close to, the level of infrastructure nodes allows implementation within a single network which may be favourable when Internet-connectivity is sparse or unavailable, or when there are concerns about data transfer over outside networks. Maintaining hyperlocal context on cloud servers may be favourable for scalability, efficiency and universal accessibility. Ideally, both possibilities and hybrids would be supported, perhaps architecturally inspired by a hierarchical system such as the Domain Name System (DNS) and/or the EPCglobal Architecture Framework [7] and the Object Naming Service (ONS) which returns the IP address of the server which has information about a certain EPC. Further discussion is nonetheless outside of the scope of this paper.

Openness

As no single vendor can control the IoT, the concept of hyperlocal context should be open to refinement and standardisation, and its implementations made as accessible as possible within the constraints of participation, privacy and security.

APPLICATIONS AND RESULTS

Initial applications have centred around the visualisation of hyperlocal context in closed ecosystems where devices represent people. Here we present these applications and comment on the results.

Notman House

Notman House is a collaborative space in Montréal, Canada frequented by a heterogeneous group of members of the startup community with an interest to discover and interact with one another. In August 2012, the space was outfitted with reelyActive infrastructure, and many members carry an active RFID tag to uniquely identify themselves in the space. Each participant provides information including their first and last name, profile photo and URLs for social networks and relevant websites. The hyperlocal context of the space therefore includes this information for all people who are present.

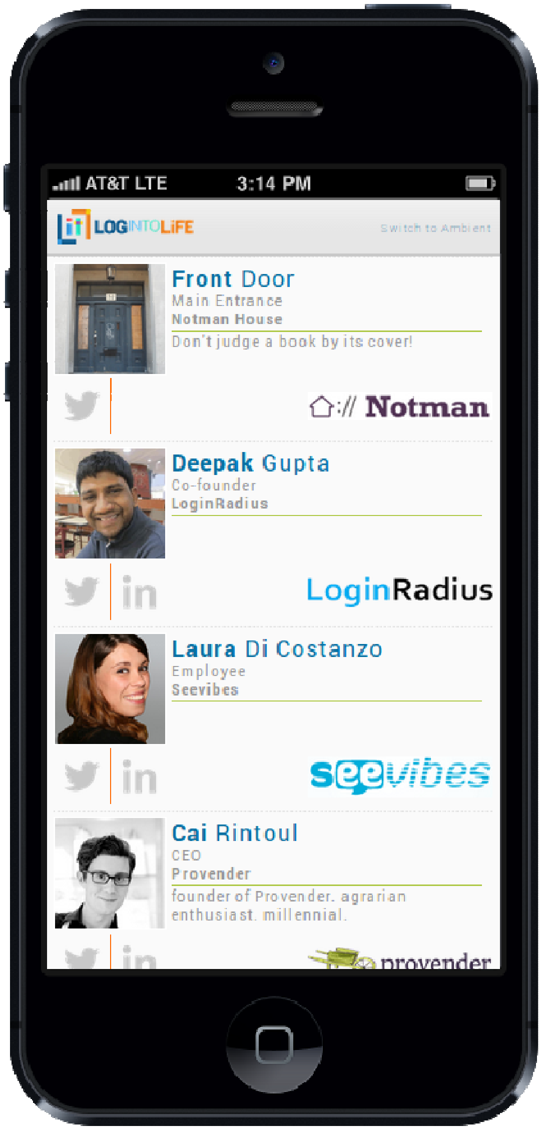

Figure 5. Hyperlocal context visualisation on a mobile device

In order to facilitate real-time interpersonal discovery, we wrote a web application which allows the visualisation of this hyperlocal context as a webpage, accessible from anywhere on any device [17]. Figure 5 shows this webpage on a mobile device. Moreover, we installed flatscreens on-site to display this real-time visualisation as ambient information. A third-party has successfully integrated the hyperlocal context to provide a customized experience for users of their mobile app [4]. The response to the project continues to be positive as it now celebrates one year of continuous operation and evolution.

International Startup Festival 2013

The 2013 International Startup Festival (ISF) was hosted in Montréal, Canada at a venue consisting of several large tents. Similar to the Notman House deployment,

Figure 6. Hyperlocal context visualisation as ambient information on a flatscreen with Hexoskin integration

reelyActive infrastructure was distributed throughout the site, however, here each infrastructure node represented a unique tent and was paired with a flatscreen. In other words, each tent represented a distinct hyperlocal context which was visualised as a unique webpage on the flatscreen.

Nearly one hundred participants carried identifiable devices at the ISF, which also represented the first integration with an external device vendor. A Hexoskin device [9] was associated with one participant. Hexoskin provided a URL for a dynamic image which overlayed heart rate, breathing and activity levels on the participant's profile photo. As shown in Figure 6, this real-time information was then displayed as an image on the flatscreen nearest the participant.

For both of these applications, hyperlocal context is/was maintained on reelyActive servers in the cloud with device resources such as profile images linked to a variety of sources on the Internet.

Future Applications with Bluetooth Low Energy

Bluetooth Low Energy is a recent wireless communication technology which is being adopted by many devices including the latest smartphones [3]. In our opinion, this is a promising technology for the IoT as it allows for the unique identification of a heterogeneous mix of devices with location at a human scale thanks to an indoor range on the order of tens of metres. At reelyActive, we have developed a BLE node so that these devices may easily contribute to hyperlocal context.

We expect the next wave of applications to include enhanced retail, public transit and institutional experiences, followed by the connected home.

CONCLUSION

The IoT will enable computers to understand our world and hyperlocal context facilitates the interactions required for them to collect and interpret all of the supporting information. We have shown that location-based device discovery lays the foundation for hyperlocal context, and have described successful real-world implementations. It is our intent to advance the proliferation of hyperlocal context through open collaborations, so that it may evolve as an integral element of the IoT.

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