I3: An IoT Marketplace for Smart Communities

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ABSTRACT

There are many barriers preventing the adoption of the Internet of Things (IoT) in smart communities and smart cities, including interoperability, concerns about vendor lock-in, economic constraints, and privacy issues. We present a "marketecture" and platform called the Intelligent IoT Integrator (I3) that addresses these problems through the development of a marketplace that facilities the easy movement of real-time IoT data streams between device owners and third-party applications, based on the establishment of suitable incentives and usage agreements. We envision the system scaling gracefully over time as different I3 community instances peer with each other.

1. INTRODUCTION

Applications of the Internet of Things (IoT) in smart cities and smart communities, involving real-time data streams, have been growing steadily [Schaffers et al. 2011, Perera et al. 2014]. These include vehicular traffic sensing [Pan et al. 2012], parking occupancy and reservations [Ji et al. 2014], security and surveillance [Mazerolle et al. 2000], air quality monitoring [Xiaojun et al. 2015], and even smart trash cans [Glouche and Couderc 2013]. These applications promise to improve the lives of citizens through enhanced health, safety and convenience. However, the first generation of IoT deployments (IoT 1.0) for smart cities have run into several challenges that pose a formidable barrier to wider adoption.

For one, IoT 1.0 applications have been developed independently. Often the same entity is involved with every step of developing and deploying the IoT application, from deploying sensor and actuator hardware to setting up and configuring the network and middleware system to building the end-user applications and dash boards. Different agencies in a city may simultaneously test and adopt different IoT applications in this manner, each developed as a vertically unified system, a separate silo.

In response to this piece-meal approach, vendors have been developing vertically-integrated, competing proprietary solutions for IoT and pitching them to cities.

Beyond the proof of concept stage, however, adoption is inhibited as cities come to understand that products from different vendors don't work with each other. This lack of interoperability limits the possibility of connecting different flows of data to each other or develop fundamentally new applications to derive greater value over time through a *data-centric network effect*. Cities and communities are also nervous, for political and economic reasons, about being locked in to a single vendor for all applications.

The IoT 1.0 model relies on significant capital expenditure by governments to make cities smart. As local governments are financially constrained from making large infrastructure investments, this has delayed the deployment of these technologies. Motivated by these concerns, we present an alternative vision for IoT-powered smart communities, a real-time data marketplace architecture and middleware platform that we refer to as the *Intelligent IoT Integrator* (I3).
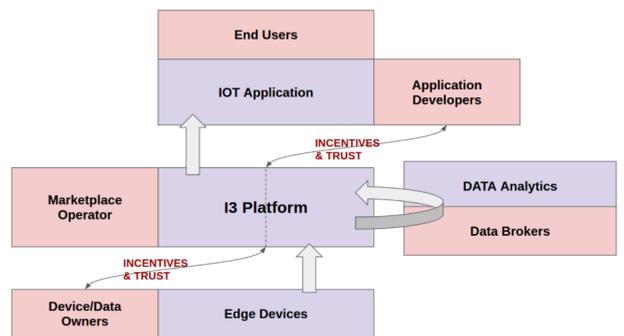
2. THE I3 CONCEPT

Figure 1: The I3 Concept

IoT is fundamentally about dynamic data, data in motion. To build smart communities based on IoT, we need to be able to build "data rivers" that allow data streams from different entities to be merged together and analyzed, processed, and acted upon as needed to support a diverse set of applications.

Just as the traditional Internet architecture promotes scalability and interoperability by placing the narrow waist of the architecture at the IP layer ("everything works over IP and IP works over everything"), I3 places a narrow waist at a data-exchange middleware layer above the transport layer. As shown in figure 1, I3 allows diverse device owners to contribute (sell) data streams, while different application developers can connect to I3 to obtain (buy) one or more streams meaningful to their application. Further I3 also allows for the possibility of data brokers that buy "raw" data, apply data analytics (using various machine learning, data cleaning, aggregation, visualization pipelines) and sell "refined" data streams back through I3.

3. DATA OWNERSHIP, ECONOMIC INCENTIVES, AND TRUST

While the idea of allowing different data sources and data consumers to connect to each other through standardized middleware and protocols is not new, exemplified for instance, in protocols like MQTT [Banks and Gupta 2014] and CoAP [Shelby et al. 2014], a key novelty of I3 is that these flows of data are mediated through end-to-end agreements between device owners and application developers about economic incentives and usage rights.

A fundamental principle embodied in our vision of I3 is that *device and data owners should have the right to decide when they will share their data (or access to their devices, in case of actuators), with whom, and at what price.* They may also set usage conditions on the data - *e.g.*, some device owners may not wish to allow re-sale of the data they provide. Data owners may also choose to create different raw, aggregated or anonymized versions of their data streams for use by different types of end-users.

By being able to monetize their data outputs beyond a single application, device owners are incentivized by I3 to share data with others. Application developers in turn are able to benefit by having device owners compete to provide valuable data. The community benefits because a) I3 can create an economically self-sustaining business ecosystem around IoT, b) there is an incentive for companies to deploy IoT devices densely, and c) knowledge and expertise within the community can be tapped by data brokers and application developers to improve the lives of citizens through applications relevant to them.

Over time, we envision that device owners (sellers) and application developers (buyers) on I3 will also have opportunities to rate each other, providing greater trust through reputation mechanisms.

4. SCALING THROUGH PEERING

We envision an I3 domain controller deployed in each community, or possibly even multiple I3 domain controllers in a city, such as for downtown areas, malls, campuses, etc. Just as the Internet was designed as a network of networks connecting autonomous systems through BGP and peering relationships, so too we envision that each I3 domain controller could establish peering relationships with other (nearby) I3 domain controllers in order to enable richer applications that span multiple proximate communities.
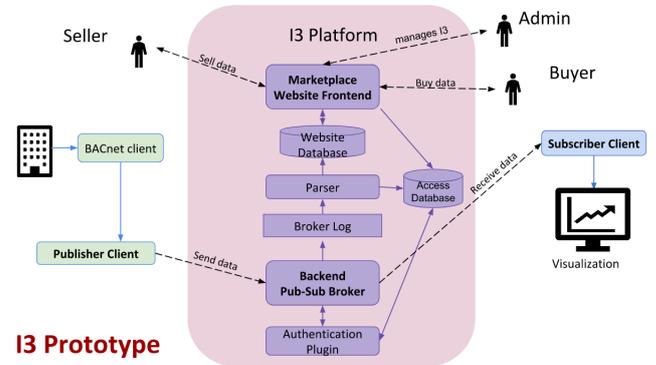

Figure 2: The I3 prototype

5. PROTOTYPE AND CURRENT STATUS

We have built a simple proof of concept implementation of an I3 domain controller by combining a simple MQTT pub-sub broker on the backend with a Python Django-based web marketplace front-end using a mysql database. The front end allows buyers and sellers to post, find and transact over real-time IoT data products including agreements on data usage terms and conditions. Once payment information is provided, the buyer is able to launch a subscribe client to listen to corresponding streams from the seller. The streams are metered for billing purposes, and turned off automatically when the payment or agreement period ends. We have tested our implementation at the USC campus using a BACnet client that allows end users to access sensors deployed in buildings, as well as for city-scale data using various public sources of dynamic data such as LA's airport parking lots, 311 data, etc. While the initial prototype uses static pricing, traditional payment processing and centralized transaction logging, we are currently also exploring the use of dynamic pricing, cryptocurrencies, and distributed ledger technologies.

In November 2017, the I3 consortium was launched at USC, as a public-private partnership, in collaboration with the city of LA and several companies [Blumenthal 2017, I3 2018]. The goal of the consortium is to develop and release an open source software implementation of I3 that can be, after initial testing at USC and the City of Los Angeles, deployed and adapted to other communities in California and beyond.

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