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# Study of Resource Discovery trends in Internet of Things (IoT)

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**ABSTRACT**

**Internet of Things (IoT) ecosystem is progressing at an enormous speed with interconnection of various heterogeneous smart devices. IoT computing paradigm is different from the traditional system where the end users are well aware about the software installed on their personal devices and their services. However, in IoT, people may not be aware about the available resources, services and capabilities provided in an open public space. Thus there is a need for strong interaction between things and people in IoT. Automatic resource discovery forms the core functionality for configuration and maintenance of the deployed objects and integration of new devices with least human intervention. In this paper, we present the current resource discovery, service technologies in IoT and their advantages and shortcomings. A comprehensive view of the various challenges involved in resource discovery and service integration in IoT ecosystem is analyzed. The insight for future research, standardization of work is provided.**

Keywords – **COAP, IoT, Resource discovery, services, semantics**

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## I. INTRODUCTION

The Internet of Objects (IoT) envisions the integration of physical world into digital world by bringing together smart devices and people through internet. The rapid adoption of IoT in the society is experienced through its adoption form industrial usages to home automations. Thus the need for consumer centric applications and services in all domains like intelligent home control, transportation systems, smart grids, smart metering, eHealth monitoring, environmental monitoring etc is needed. It is estimated that 50 Billion smart object with be connected to internet by 2020[1].To enable such services with least human intervention, these smart devices should interact with IoT ecosystem and among themselves and should expose their services.

In the scenario of smart cities, it is envisioned that millions of similar services will coexist in the IoT ecosystem, similar to millions of mobile apps available today in app stores. The main difference between mobile app model and IoT model is that users have full control over which devices , what apps and software services needs to be installed in case of mobile app model. However, in IoT this user control lacks, user may not be aware about the available resources, their services exposed and capabilities in public space. Also the user may need to choose the best service amongst the available similar service in IoT ecosystem.

This paradigm renders new ways to create value-added service to the users by dynamically assembling different types of capabilities of these smart devices. To mention a few capabilities: sensing, communication, computation, services, semantic, identification etc. To realize IoT solution, dynamic automatic discovery of these smart devices as resources, services is indispensable.

This discovery mechanism involves configuration management, registration/un-registration, service exposing, semantic integration. Thus resource discovery forms the fundamental requirement to make any IoT solution success. However these smart devices are resource constrained, diverse in nature and capabilities, and are connected through heterogeneous protocols to the internet. These present some of the challenges that the standardization bodies need to look-up on while resource discovery mechanism is proposed.

Discovery is incomplete without **retrieving** information and **ranking** it up. Retrieving objects means discovering the object description (properties, capabilities and metadata). Ranking would provide grading to the retrieved objects based on the context.

For resource discovering, every smart device in IoT is conceptualized as a resource with its properties, capabilities, means to access it. Depending on the application domain and requirements, these resources can be physical things, associated metadata or the services offered by these things. The resource discovery scope can be categorized as local or remote. Local discovery scope is limited within the gateway of an application provider such as home automation, on the other hand remote discovery scope spans across remote network such as smart city perspective. The discovery can be scheduled one-time or may be event based like publisher-subscriber.

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So, the world around us will be surrounded with objects that have dual phases- physical existence and digital representation. Most of these objects may lack a UI (screen, button etc) that would let a person to interact with it directly. So the main challenge is to discover, identify, interact, bringing service awareness about these objects in a seamless fashion.

The rest of the paper is organized as follows. Section II compares the traditional Web discovery model with CoAP[2] resource discovery in IoT, Section III presents the survey on various approaches for resource discovery and captures their pros and corns. Section IV highlights the challenges involved in resource discovery in current state-of-art, section V concludes with future work.

## II. COMPARISON OF TRADITIONAL WEB DISCOVERY MODEL AND RESOURCE DISCOVERY IN IOT

The basic unit of addressing in World Wide Web (www) is URL (Uniform Resource Locator) which is accessed over the application protocol HTTP (Hyper-Text Transfer Protocol). Traditional resource discovery in WWW is performed by search engines which dispatch web crawlers to pull the requested data. Following are the main characteristics of traditional resource discovery via search engines.

- Web crawlers are deployed by search engines which follow a pull model to fetch resource information. Search engines are the receivers which dispatch the crawlers to pull information from various URLs referring website.
- List of similar resources discovered by the search engines for a given request is generally ranked by the optimizers in the search engines.

**Challenges in resource discovery in IoT**

- IoT devices are mostly power constrained, so to save power, they “wake-up” or become active only when required to perform a specific function. For eg: A fire detector sensor in home automation system may become active , connect to the web to send warning messages to a remote controller only when it senses a certain smoke amount in its atmosphere. All other time, this fire detector sensor will be asleep, unreachable via web. Hence this smart device cannot act as a mini Web server to be discovered in IoT ecosystem.
- IoT devices are generally connected using low power, lossy wireless networks which are more susceptible to interference, loss of connectivity.
- IoT devices are generally deployed in semi-closed infrastructure or network. In case of home automation system, the light or heating sensors are internet connected using fire-walled gateway. So these smart devices are discovered by authorized home owners using smart mobile phones. These devices cannot be discovered by web crawlers dispatched by a search engine. Web crawlers cannot reach fire-walled gateways limiting the remote discovery of these devices.

**Resource Directories (RD) in CoAP [2]**: IETF standardization to address IoT resource discovery is based on a logical network node called Resource Discovery (RD) defined for Constrained Application Protocol (CoAP). CoAP is based on *REpresentational State Transfer* (REST) on top of HTTP functionalities. RD is applicable to domain(s) (logical group of IoT devices) and not the entire web. RD domains are building –wide, campus wide etc. There is one to one mapping between RD and semi-closed network in IoT. Resource registration is based on push model, where IoT devices act as mini web servers (IoT servers) pushing their service information (URI) into RD. Clients can look up the resources. IoT servers communicate with RD using CoAP (based on REST) protocol by using Link format[3] payload in CoAP messages. URI, hyperlinks, metadata is only sent from IoT devices to RD using Link format.

**Table1. Comparison of Web Search and Resource Search in IoT**

| | Traditional Web Search Engine | IoT Resource Discovery |
|---|---|---|
| 1 | Target websites are pulled using Web Crawlers and provided to interested nodes. | Target devices push their services on the Resource Discovery. |
| 2 | Nodes can fetch the entire website, hyperlinks, URI metadata, application content | No application content is transferred to node except for URI, hyperlinks, metadata |
| 3 | HTTP is the transfer protocol used | CoAP is the transfer protocol |
| 4 | Resources can be discovered in global scope throughout Internet | Resources can be discovered locally within the scope a RD |
| 5 | Resource discovery results are ranked | Efficient ranking is not supported |
| 6 | Resource discovery results are not machine readable | Resource discovery results are machine readable in Link Format |

In Table1, the comparison between Web search for web pages and resource search in IoT with respect to CoAP is presented. fig 1 represents the request and response examples in CoAP using GET method.

As shown in the fig 2, the IoT object called as end points [2] finds the appropriate Resource Directory (RD) with respect to a domain. Once RD is found, End Points register their URI with the resource directory (RD). Any

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| REQUEST | RESPONSE |
|---|---|
| GET coap://gyser.net/temperature | |
| Method= GET | 2.05 Content |
| URI-Scheme=coap: // | "34.9 F" |
| URI-hostname=gyser.net | Response code=2.05 (SUCCESS) |
| URI-path=/temperature | Value=34.9(Fahrenheit) |

**Fig1. CoAP GET Request and Response examples**

interested client can then look up the appropriate resource from the RD. However, there are major limitations in CoAP-RD based resource discovery. CoAP specification does not specify the procedure for a smart device to join the RD first time and announce itself. Scalability is lacking due to the centralized RD concept in CoAP. It lacks the support for remote client to look up RD and query the resources.

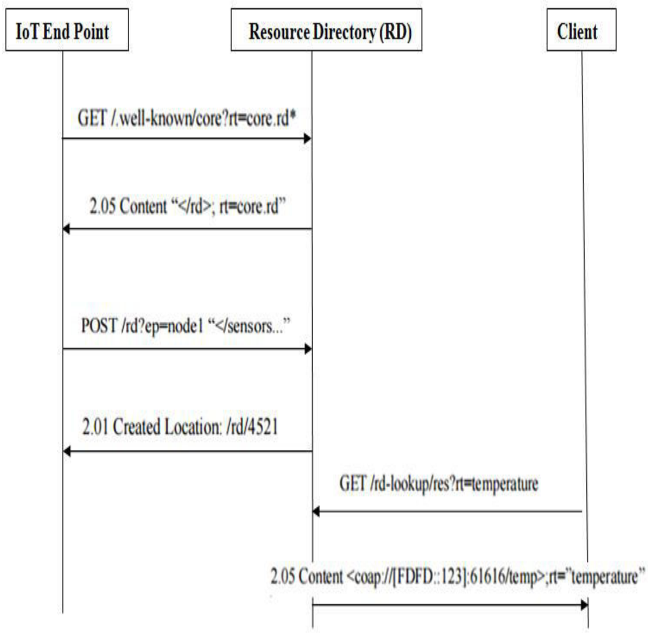


Fig2. IoT EndPoint finding RD, registering its URI, Client look-up for service discovery

## III. RELATED WORK

The study of various current trends in resource discovery in IoT from various perspectives such as spatial proximity, network association, directory domain, peer-to-peer configuration and based on resource semantic has been carried out.

*A. Discovering Resources Around Me*

It includes technologies to discover the things in a spatial proximity. Following are some of the current technologies available in this category.

- **Optical markers**: It is a pull model where the things in the near vicinity are discovered by client using barcodes and QR codes and then decoded using apps. Remote discovery is not supported.
- **Near Field Communication**: It is build on RFID with max range of 10cm.It operates Ism band of 13.56MHz.It doesn't support any higher level discovery and supports only local discovery.
- **Bluetooth Beacon**: Bluetooth, a low energy, short range protocol allows the any object to broadcast its digital identity ubiquitously. A beacon [4] device sends out unidirectional signals consisting of unique ID for that specific beacon. The user's mobile device, if Bluetooth turned on, will receive nearby beacon, identifies ID and triggers the notification. It may not be effective if the Bluetooth is turned off on user mobile, or user app does not recognize a specific beacon ID, beacon source being fixed as users move away from source, beacons become invisible ineffective. Google Eddystone is an open beacon format from Google for Android and iOS. It helps user devices to discover content and functionality remotely via android, naive apps or web. Apple iBeacon is a cross-platform implementation of iBeacon. Facebook pilot project called PlaceTips is a real world discovery mechanism based on beacon and GPS integration.
- **Wi-Fi Aware**: It is a ubiquitous wireless protocol that will discover and connect nearby devices. Wi-Fi Alliance, a non-profit organization will certify the devices with this feature by 2016. Wi-fi Aware devices broadcast a short unidirectional signal that contains its ID, application data like URL. It can act as a broadcaster and a receiver also. However, if Wi-Fi Aware is not turned on or required app is not running, signals may be ineffective.
- **Google Physical-Web/UriBeacon**: It is an open-source project that discovers and interacts with connected devices like clicking links in a list of search results. Device broadcast unidirectional beacons containing URL. Operating system of the user mobile device detects Physical Web signals and displays them as link on the web browser. This project is protocol-agnostic. It doesn't mandate the user to install the specific apps. It presents the nearby devices like coffee machine, shopping mall, concert hall like a link in the search result of the web browser. User can click on these links to know the details about the products and information.

*B. Discovering Resources on my Network*

It includes technologies to discover the things as endpoints in a known network. Following are some of the current technologies available in this category.

- ***Multicast DNS*** **(mDNS)[1]:** mDNS is an extension of Internet DNS protocol. mDNS queries the names by sending an IP multicast message to all the IoT nodes in the local network. When the target node receives its name, it multicasts a response message which contains its IP addresses. All nodes in the network that obtain the response message update their local cache using the given name and IP address. It is used along with DNS-SD (DNS-Service Discovery) to query the devices. It was implemented by Apple

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Bonjour. It is built on top of IP and UDP protocols.

- **Multicast CoAP [1]**: CoAP is extended to support sending requests to IP multicast groups. It is based on IP, UDP and CoAP. When a client makes a request, all COAP nodes multicast address to discover CoAP servers. CoAP server listens on the nodes address and reply back to clients.
- **Simple Service Discovery Protocol (SSDP)**: It is discovery protocol used with UPnP (Plug and Play devices). A SSDP client multicasts a HTTP UDP discovery request to SSDP multicast channel. The SSDP service that hears to these channels on receipt of a matching service request responds back unicast HTTP UDP response.
- WS-Discovery: It specifies multicast discovery via web services based on SAOP.
- XMPP[5] Service Discovery: It discovers information about XMPP entities. It finds the capabilities of an entity and the items associated with an entity. This technology is based on IP, TCP and XMPP.

*C. Discovering Resources by searching in Directories*

It includes technologies to discover the things in specific directories. User requests are handled by these directories.

- XMPP IoT Discovery: It is based on searching things and its metadata in the XMPP registry.
- HyperCat: It is an open, lightweight standard representing a JSON based hypermedia catalogue format to expose things over web. It exposes URIs each with a set of relation-value pairs. Each URI can contain many resource description frameworks like RDF. Semantic annotations can be provided build on top of HTTP, REST, and JSON.
- Mobile digcovery [16] is a mechanism for global service discovery in IoT. It has a centralized infrastructure, 'digcovery' that allows registration of sensors. Digrectory is responsible for integrating devices of different technologies like RFID, Bluetooth, Zigbee, NFC, Wi-Fi, legacy technologies. Each digrectory is employed to handle different resources, one for each domain like NFC, 6LowPAN, webservices, mDNS, IPv6 etc. Digrectory enables digcovery to look-up these devices through search engine Elastic Search. The mobile application takes advantage of geo-location and context awareness for discovery phase.
- The paper [15] proposes a discovery service for smart objects over an agent-based middleware. It indexes all smart devices connected to its registry based on domains. It is service oriented discovery framework based on REST and JSON. If same objects are shared among different domains, then indexing is ambiguous.
- The paper [14] proposes a framework based on semantic which employ service advertisement of smart object. This advertisement includes service metadata like name, id, endpoint, location, and semantic annotation links.

*D. Discovering Resources in distributed, peer to peer (P2P) fashion*

In this [11] approach, the directory is distributed across the peers. Distributed hash tables (DHT), maps the search space into a numeric range allocating servers to that range. It requires Peers in the P2P overlay act as resource directory (RD).The technique works well for scale free networks. It requires Peers in the P2P overlay to host parts of the RD and to have full connectivity and certain computing power in order to forward overlay messages, keep a consistent DHT and routing tables in the node. P2P Overlays tolerate certain amounts of churn but it would be impractical for constrained devices to participate as full peers on the DHT. CoAP usage for RELOAD: REsource LOcation And Discovery (RELOAD)[2] is a DHT-based (chord) P2P protocol of IETF. It enables CoAP nodes to create a P2P overlay storing, look up service, caching of sensor information.

In [12], a mechanism for usage of P2P technologies to enable service discovery is proposed. IoT gateways keep tracks of any object joining or leaving the network. IoT gateways are then interconnected through 2 P2P overlays. Distributed local service (DLS) and distributed geographic table (DGT) helps to provide global service discovery. DLS provides name resolution service to identify the information needed to access the resource.DGT is used to identify the presence of IoT gateways in a neighbourhood. The CoAP server maintains the list of registered objects. Objects get registered/un-registered through these IoT gateways playing a key role. Service look up happens by sending GET request to ./well-known/core.

In [8], author proposes distributed resource discovery (DRD) architecture. It uses a P2P overlay to store the information related to the constrained devices. Resource Description Registration stores information related to constrained devices into the overlay using hashing of the CoAP URI/IP address. The DRD employs a resource discovery component (RDC) to find the requested CoAP URI . It generates a key by hashing the CoAP URI. This key is searched in its local cache, if not then it searches it in the overlay.

*E. Discovering Resources based on semantics*

It includes technologies where objects are discovered based on semantic interpretation. Sensor Markup Language (SenML)[6] is a standard for representing sensor data and parameters. SenML is compatible with JSON (JavaScript Object Notation) and Efficient XML Interchange (EXI).Some semantic expressive languages like Notation (N3), Turtle6, however they are not designed for constrained devices and constrained application protocols lie SenML. CoRE Link Format is a standard to represent resources, attributes, their relationships. REST facilitates loose service coupling.

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Resource Description Framework (RDF) defines metadata independent of the application domain to which the object belongs to. It has main data types: Resources, identified by IRIs (internationalized Resource Identifiers), Properties define the attributes and the relationship between them, Statement are triples of Resource, Property and its value representated as "subject", "Predicate", "Object".

In [9], author has proposed approach to apply REST description format and semantic reasoning on IoT environment to create a web-like mash-up. RDF and RESTdesc are used for machine-readable linked data and web services which are mainly static. However IoT requirements are dynamic services subjected to frequent changes on the physical devices. CoAP-RD is used to register the devices in IoT ecosystem using CoRE Link Format. A Reasoning Server based on Rpolog-EYE is used which provides a Notation3 parser, knowledge base, query interface to keep the services and its discovery up to date. However this approach works only for mediums-sized IoT mashups. The parser has an overhead to parse the service descriptions.

Author has proposed a semantic based framework for resource discovery in terms of service advertisements in [10].This advertisement consists of metadata information about the service like name, id, location, endpoint, and annotation links.

In [7], the service discovery happens in terms of the Web of Things. Semantic web technologies over RESTful web services are employed and JSON is used for interoperability. If the device does not support web based API, then it cannot be discovered.

The requirement of discovery in terms of semantic needs the following: All the objects are addressed using unique URI, HTTP URIs are accessed over HTTP, Resource Description Framework (RDF) representation of URI that are looked upon by machine or people, interlinking URIs to URIs.

## IV. OPEN ISSUES

1. Lack of standard nomenclature to describe resources, units and domains: Currently standardization is missing in terms of syntax for resource description. The lexicon for the various terminologies representing resource description, properties, and capabilities should be uniformly adopted. Resource discovery using Synonyms usage fails. Standardization in resource metadata discovery needs to be defined. Lack of research work in semantic based resource discovery
2. How do we identify the similar capabilities amongst device: Since the IoT ecosystem is exploding at an enormous rate, many vendors are playing critical roles in market with their various IoT products. So multiple devices can coexist in an IoT ecosystem with similar capabilities. To discover the object with the best capability given the number of objects is a big challenge.
3. No standard technique to ensure uniformity in the ranking of the service: Ranking the capabilities based on similar features is a challenge; no work is standardized currently and is an open research area.
4. Techniques for periodic evaluation of the ranking: Since these devices need to continuously provide their services, periodic evaluation of their ranking is a must. So the time interval for evaluation needs to be identified for various domains, the methodology to be followed whether it should be event based, push/pull model, publisher-subscriber evaluation needs to be evaluated.
5. Asynchronous notification to the end user when there is a better service based on ranking is a quality of service parameter in IoT ecosystem and is a competitive edge for the various competing vendors in the IoT market.
6. Replace the current device with the next higher ranked device: Provision should be provided for fault resilience. Not only in terms of fault but also lower service ranking should be criteria so that devices can be upgraded at runtime without affecting the end user services.
7. Fault resilience should be handled in IoT ecosystem either by reducing the capability to 0 or by distributing the capability to other devices in the same domain.

## V. CONCLUSION

In this paper, the existing mechanism for resource discovery in IoT is studied and a comprehensive review of same is presented. Also, the existing gaps in resource discovery are analyzed and need for standardization is highlighted. In future, semantic based [19, 20] automatic resource discovery mechanism for API based devices would be proposed.

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