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Resource Discovery Classification for Internet of Things: a Survey

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ABSTRACT

Internet of Things (IoT) is widely implemented in applications that require immediate interaction and fast response. Resource discovery is an essential step in any IoT system where the resource can be an object/device/thing/sensor, data, or service. Several resource discovery techniques were proposed in literature to discover various types of resources. This paper surveys existing IoT resource discovery techniques and classifies them with respect to discovery approach. In particular, the paper focuses on discovery techniques for object/thing/device and service. A set of properties are suggested to be used as evaluation parameters for discovery techniques, and these properties are mapped against discovery technique classes.

KEYWORDS

Internet of Things (IoT), Resource Discovery, Service Discovery, Device Discovery, Resource Discovery classification.

1 INTRODUCTION

Internet of Things (IoT) is the communication technology that extends from connecting every person to connecting everything (objects and devices can be accessible at any time and any place via Internet) [1]. European Research Cluster of IoT (IERC) defines IoT as: "The Internet of Things allows people and things to be connected anytime, anyplace, with anything and anyone, ideally using any path/network, and any service" [2][3][4]. IoT objects can be readable, recognizable, locatable, addressable, accessible and controllable via an IoT communication network and applications [5]. According to many studies [6][7][8] [9], the number of devices connected to the Internet will grow exponentially, and is expected to reach 14.6 billion by 2022[10].

Resource Discovery "refers to crawling, finding, and allowing IoT resources to be found/discovered automatically or manually" [11]. An IoT resource can be an object/device, data, or service [6][12][13][11][14].

Resource Discovery is an essential step in any IoT system to work properly[15]. To implement a successful IoT platform, there must be mechanisms that allow the automatic discovery of resources in addition to resource properties, operations and accessibility [12][13][16]. Heterogeneous IoT resources wait to accurately be discovered. The user will not be aware of these resources until they have been discovered.

In the future, IoT applications will gradually increase and effect human life style, e.g. [17][18][19][20]. IoT objects and applications will soon be everywhere (e.g., homes, companies, hospitals, factories, vehicles, roads, and even wearable devices) [6][8][21][5]. IoT applications are classified into three main categories according to [22]: society, environment, and Industry. The society applications examples are healthcare, smart home, and security and surveillance. Environment applications examples include pollution control, smart agriculture, smart farm, and disaster management. And the Industry applications examples are smart power plant, supply chain management and warehouse and storage. Given the diversity of IoT applications, research requires more efforts in dynamic heterogeneous resource discovery [6][23]. There are some applications that overlap among the three categories. A number of surveys considered IoT resource discovery. In [14] Vandana *et al.* investigate resource discovery trends in IoT environment, and make acomparison between traditional web discovery and IoT discovery techniques. Open issues in resource discovery are also discussed in this study. In [24] Shinde *et al*. survey and concentrate on important requirements of the service discovery mechanism in IoT. The authors analyze services depending on three functions: user preference (depending on requirements), context awareness, and lightweight approaches. Fathy *et al*.[11] provide basic information on IoT systems and categorize them into data, resource, and high level abstraction. They also classify the ranking and discovery approach for large-scale environment depending on these categories. Bröring *et al*. [12] introduce a novel categorization of the available discovery technologies. Aziez *et al*. [25] propose a comparative study of service discovery that is categorized based on semantics, context, Quality of Service (QoS), Bio inspired, federated search, and others. The study also mentioned the description, context awareness, and the architecture of services.

This paper attempts to survey and classify the existing resource discovery techniques in IoT. In particular the paper focuses on discovery techniques for object/thing/device and service as IoT resources. On the other hand, data discovery in IoT is part of the middleware layer and emphasizes on data analysis and pattern recognition, and is therefore not considered in the scope of this work. In addition, a set of evaluation criteria are suggested to assess resource discovery techniques and illustrate the criteria that each recourse discovery class provides. The work in this paper provides a guideline to predict discovery technique properties based on the classification of the technique. This helps when certain criteria are critical/necessary for a specific IoT service. There exists a strong relationship between the discovery process and the routing process. The properties of the discovery process influence the efficiency of routing. The relationship between the discovery and the routing process, and the discovery of alternative resources in case of the main resource failure is not covered in this work and requires further investigation.

The remainder of the paper is organized as follows: Section 2 explains Resource Discovery, and Section 3 proposes the classification of resource discovery methods. In Section 4 the suggested properties to evaluate resource discovery methods are revealed. Section 5 maps between proposed classification and criteria. Finally, Section 6 is conclusions.

2 RESOURCE DISCOVERY

The diverse nature of IoT device capabilities, properties and communication technologies adds to the complexity of effective realization of IoT platforms. The traditional web based discovery service is not suitable for IoT because of the different requirements of IoT [13]. Many techniques are used to discover the resources. The IoT middleware layer provides the support to the discovery function. In [6] a set of functional requirements for IoT middleware are outlined. These requirements include functional requirements such as resource discovery, resource management, data management, code management, and event management. They also include non-functional requirements such as scalability, reliability, real-time or timeliness, availability, security and privacy, ease of deployment, and popularity. A comprehensive review of existing middleware systems for IoT can be found in [26]. A remote management platform that focuses on ease of configuration and remote installation is proposed in [27]. It allows a number of features such as configuration, monitoring, diagnostics and service provisioning without manual intervention of a technician. New devices are automatically detected at the border gateway, and automatically the required drivers are installed as plugins, and communicate to the remote management system via the Internet using Representational State Transfer (REST) messages.

As shown in Fig. 1, the resource discovery in IoT environment starts from discovering the **devices** and things as a first step via different methods (e.g. IoT gateways). The **data** is discovered via the middleware layer majorly as the second step, and finally **services** are discovered by the clients or consumers of the IoT application. Following, the discovery in various IoT resources is explained.

2.1 Service Discovery

The main objective of Service Discovery is not simply device discovery, but the function that it provides [28]. A number of IoT services will be available to provide different services to the end user at the IoT upper layer; several services can be available in one place such as city or home etc. Unfortunately, the traditional web services are not suitable for the IoT system due to its nature [24]. Service description and discovery in the traditional web is discussed in [29]. Service Discovery must be user-centric according to its requirements. The discovery operation must be lightweight and responsive to the changes and events such as changing location, preference, etc.

2.2 Data Discovery

Data in IoT generated by IoT devices is real and raw data from the environment (observation and monitoring), or context-data that describes the object's status, properties, and operation (e.g. battery life, location, etc.) [22]. IoT data can be classified into three types: **static data** such as object properties (e.g. manufacturer details), **semi-dynamic data** which is the discrete change in the data, for example object status (e.g. light, door open ,etc.), and **dynamic data** that continuously changes over time (e.g. observation data) [22][11].

IoT Data is a type of big data [11]. The characteristics of IoT data are similar to big data characteristics (the five v's: volume, velocity, variety, veracity, and value). Volume is the size of data available to users, velocity is the speed of data generation and collection by the IoT resources, variety is the diversity of data types, veracity is the accuracy of the data, and value is usefulness of the data. IoT data adds new characteristic to big data characteristics which are data distribution and spatio-temporality. Distribution refers to the covered area and spatio-temporality refers to the spatio data location and time consideration in IoT data [11].

IoT data can be numbers, symbols, etc. which is collected as raw data requiring preprocessing and analysis (e.g. using mathematical functions)[11]. IoT data uses various file formats to store and transfer data such as JavaScript Object Notation (JSON), eXtensible Markup Language (XML), Comma-Separated Value (CSV), etc. [11]. Also, IoT data needs to be integrated and aggregated from different sources to compose the IoT services and applications. Data abstraction focuses on changing the data to meaningful words used by the application [11]. Finally, IoT middleware layer controls all the IoT data management operations such as data acquisition, data processing, data storage, etc.[6].

2.3 Device Discovery

Device Discovery involves the awareness of the system of appropriate devices in its vicinity. It is considered an initial step to register or

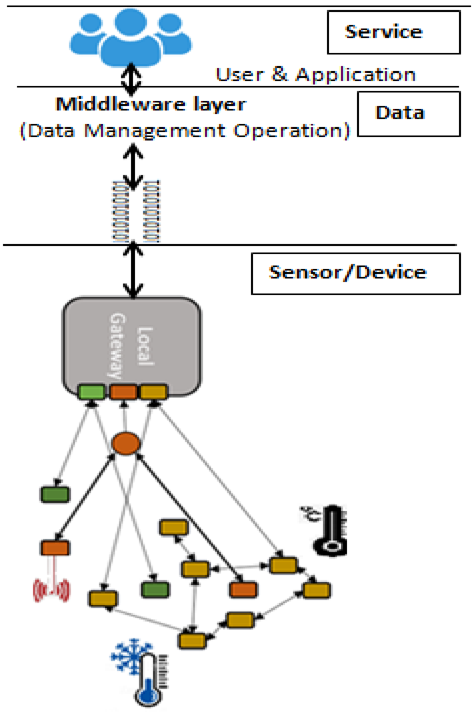

Figure 1: IoT resource discovery

reregister devices in the system enabling other processes such as data acquisition, device management and monitoring [30][31][27]. The word "object" is used in IoT to refer to entity, device, or thing [22]. Physical objects with enabling technologies (e.g. Radio-Frequency Identification (RFID) tag, sensor, communication devices etc.) are used to facilitate IoT applications read and monitor the environment [22]. IoT Devices (e.g. Bluetooth

Low Energy BLE based) facilitate the discovery by advertising themself to other devices or applications to be detected (via scanning), but unfortunately spend excessive time and power during this process [23][32].

In IoT, things interaction is significant to IoT systems, to communicate, facilitate, exchange and process metadata among each other. In Fig. 1, there is a dependence relation that links the IoT resources. Devices sense (and collect) data, and forward it to services. The end user acquires these services which rely on device data. This implies that devices affect all other resources, and thus IoT applications basically depend on the devices.

IoT Device Discovery techniques must be lightweight and support real time and event based discovery. Moreover, IoT devices are not similar, so the discovery must respect the device diversity, location (local or remote) and nature and limitation (e.g. sleep/idle mode to save the device battery power)[12][13].

In IoT, device heterogeneity is considered the main challenge in all operations including discovery, and more research is yet required in dynamic heterogeneous resource discovery[6].

3 PROPOSED RESOURCE DISCOVERY

Resource discovery techniques can be classified with respect to discovery technique into: protocol-based, architecture-based, web-technology-based, semantic-based, location-based and clustering-based. The proposed classification is shown in Fig. 2.

3.1 Protocol-Based:

Several discovery protocols have been proposed in literature and mainly depend on Domain Name System (DNS), Object Name System (ONS), and Constrained Application Protocol (CoAP) protocols. One of the most used protocols that support resource discovery is CoAP that was developed by the IETF CoRE Working Group. CoAP is a web transfer protocol for resource constrained devices based on REST run over User Datagram Protocol (UDP) [33][34]. CoAP protocol treats all IoT components as resources, and uses the unique universal resource identifier (URI) (stateless) as HTTP protocol. It also has four methods: (GET, POST, PUT, DELETE) similar to HTTP Protocol[33][34] and provides services in the application layer. CoAP features include a low header overhead, built-in resource discovery and service discovery, multicast support and asynchronous message exchange. CoAP protocol is compatible with HTTP protocol in the upper layer and is coupled with IPv6 over Low-power Wireless Personal Area Networks (6LowPAN), and resource observation [35][33][34].

In [36] Simple Service Discovery Protocol (SSDP) based on Simple Object Access Protocol (SOAP) web technology is utilized in the upper layer. The protocol low layer depends on Internet Protocol(IP) and UDP protocols. The protocol uses multicast (for request) and unicast (for response) between the server and the client to discover services.

The work in[37], proposes a protocol for device and service discovery. The protocol integrates with Universal Plug and play (UPnP) and Object Naming Service (ONS). The protocol keeps track of available devices (e.g. in the smart home application) by updating the list of devices automatically, which facilities the composition of services in IoT applications.

A recent study [9] proposes a new protocol based on DNS called DNSNA that supports IP-based IoT environment (for both IPv4 and IPv6 network), to facilitate both device and service discovery. DNSNA provides an efficient DNS name management for IoT devices to easily be recognized by users. DNSNA is divided into three versions: supports DNS naming service for device discovery (in both IPv4 and IPv6), authentication support, and service discovery support. The proposed protocol reduces traffic and respects the IoT resource limitation.

In [38], “TRENDY” service discovery protocol which is based on CoAP protocol is proposed. It uses a grouping mechanism to divide the objects and resources based on location. TRENDY architecture includes a registry to register the service. It also has adaptive techniques to reduce the bandwidth and the overhead.

A context-aware service discovery mechanism using spanning tree and modified Bloom filter proposed by[15]. The proposed architecture based on a hybrid service discovery protocol, to avoid the disadvantages of decentralized protocols, such as broadcasting to search for services, so lead to packet flooding and long search time. The results appear a reduction in packets number compared to[38].

A service discovery protocol called "People Like Us" (PLU) is illustrated in [39]. The protocol is based on the assumption that users belong to the same interest community acquire similar services. The protocol supports objects mobility with less energy consumption.

In [40], a framework called Intelligent Resource Inquisition Framework on Internet of Things (IRIF-IoT) is proposed. The framework has three layers: perception layer to collect the data from nodes, discovery layer for mapping and searching, and application layer utilized as user interface. The framework also uses the semantic Matching Engine using Bipartite Graph for discovery management of resources.

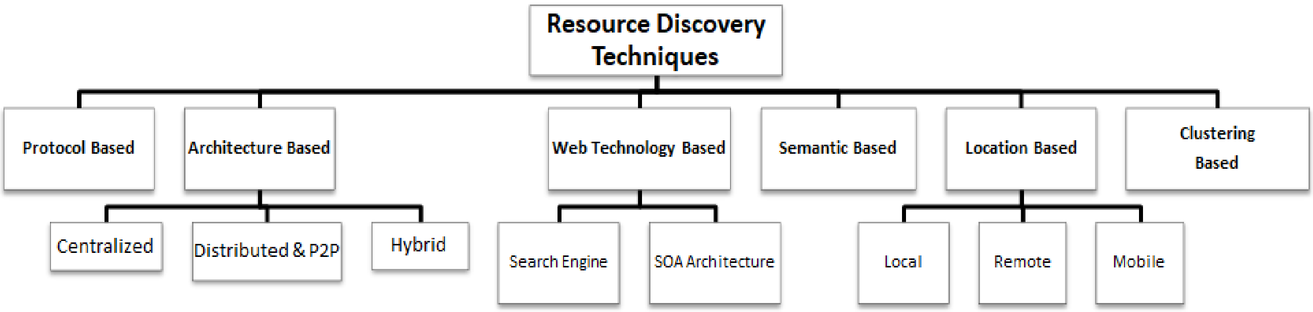

Figure 2: Resource Discovery Classification

In [32], a discovery protocol named *eDiscovery* dedicated for Bluetooth Low Energy (BLE) device discovery is proposed. The protocol modifies the scanning interval according to the environment; if there are no new devices, the interval is enlarged, otherwise, it is decreased to improve the energy consumption.

The work in [41] proposes a lightweight and distributed method based on the exchange of symbolic executable code between nodes. Network discovery according to this study is possible even in constrained devices. The proposed algorithm constructs a network graph, where unicast represents most of the network traffic. The main feature that are supported by protocol-based discovery techniques are, lightweight found in [36][9][38][32][41], and [38][9][39][32] support energy optimization, advanced feature found in [15][41][32][38] social relation studies[38][39], also responsiveness and automation found.

3.2 Architecture-Based:

The architecture-based discovery techniques are divided into: centralized, distributed, and hybrid architecture. In addition, Publish/Subscribe and Resource Directory (RD) discovery techniques are considered architecture supported.

Publish/Subscribe is considered a loosely coupling architecture. The Broker between the service provider (publisher) and the client (subscriber) maintains the information exchange between them with regard to a certain topic. Resource Directory (RD), used by CoAP and Extensible Messaging and Presence Protocol (XMPP) protocols, links all IoT resources and facilitates the discovery in the same network or remote networks [12]. Space resource directory utilizes the device Uniform Resource Identifier (URI) and contains the device metadata [14]. RD optimizing resource power, for instance, each resource that completes the discovery steps can register in the RD and enter the sleep mode [42]. Djamaa *et al.* propose a hybrid centralized/distributed resource discovery approach [43]. The architecture switches between centralized and distributed architecture with respect to network state to cope with the limitation of available resources. The proposed architecture is based on CoAP which has useful functions and features that help design the architecture, such as unicast/multicast communication, scalable protocol, discovery feature, and power efficiency. Experimental evaluation and analysis are carried out and highlight various discovery features including time and cost efficiency, adaptability and scalability.

The work in [44] proposes a peer-to-peer based architecture for resource discovery supporting both local and global capability. The scalability and the distribution of IoT objects lead to human intervention difficulties, so large scale and self-configuration mechanisms complement each other. The architecture depends on IoT gateways to control and interact with other IoT elements, and keeps track of the join and leave objects. The architecture also uses a distributed local service (DLS) and distributed geographic table (DGT). The proxy maps the connection between CoAP and HTTP protocols in the architecture. The discovery technique proposed in [42] benefits from the Open Connectivity Foundation (OCF) and the IoTivity, which is: "an open source software framework enabling seamless device-to-device connectivity to address the emerging needs of the Internet of Things"[45]. It employs the RD to implement a new architecture that is linked with another architecture called CAMPIE as middleware. The architecture connects various and heterogeneous devices and builds services independently to facilitate service discovery and service composition.

Resource discovery depends on the IoT system architectures and the techniques used; any architecture and technique have their advantages and limitations in the discovery. For example, centralized architectures cannot scale well in the IoT [6], but they can facilitate resource discovery and registration. Most of the architectures above support efficient energy consumption and mobility such as [43][42], whereas [13][42- 44] supports scalability, lightweight [42-43] integration [42][44]. Some architectures are considered complicated specially the hybrid architectures.

3.3 Web Technology-Based:

Several web technologies and techniques are used in resource discovery such as search engines, web service techniques, (XML), (JSON), (RESTful), (SOAP), Web Service Definition Language (WSDL) etc. There are many proposed online IoT search engines [46][47][48][49][50].

The search engine proposed in [51] is a hybrid search engine base on *SpatialTemporal, Value-based, and Keyword-based Conditions* called IoT-SVK search engine as an abbreviation. The architecture contains three layers (sensor and device monitoring layer, IoT-SVK storage, and IoT-SVK index layer). The engine supports real-time multimodal query processing.

A second search engine model based on resource discovery framework for IoT is proposed in [52]. The model can discover resources and their capabilities, properties, and URIs regardless of connecting technologies. Registry is used to store and index the resources and their configuration. Consumers' queries use RESTful to reach the model. The proposed model is applicable to integrate with different architectures. Fortino *et al*. propose an integrated and dynamic framework to describe services and operations of smart objects (SO) using object metadata, for example, features, operations and services [53]. REST architecture is used for discovery, requesting, indexing, and search of smart objects in the IoT network. The framework is built to be easy to integrate with other IoT middleware. The framework supports the dynamic selection based on functional characteristics (the services of the original device) and non-functional characteristics (e.g. QoS). The authors of [54] propose an approach based on RESTful service architecture implemented in IoT environment. The Device Profile is used to identify each IoT device in the IoT system. The approach is lightweight to respect the natural limitations of IoT resources. It offers not only searching for running services but also deploys missing functionalities on demand. The Service Oriented Architecture (SOA) is used and applied in the IoT system to facilitate the discovery, query, and selection of the services. In [13] the authors propose a framework to automatically discover IoT devices. The proposed framework contains three layers. First, the proxy layer which provides binding to specific protocols and also facilitates the integration of legacy devices to be discoverable by the framework. Second, the discovery layer contains four main building blocks, namely, configuration registry, search engine, indexing Application Programming Interface (API) and lifetime. Third, the service enablement layer which is a function to access control or restricts the search operation to the resources. The authors analyzed a gap in the IoT standardization, and suggested a list of recommendations. The authors of [55] propose a framework for a smart object application. The framework uses XML to advertise objects. The advantage of this approach is that it adds a level of abstraction to develop applications that work for smart object environment. It also facilitates developer work and the component management in the system as well as eases the model expandability. The common features supported by web-based technology techniques is advanced feature, the integration and abstraction such as in [13][53][55][52]. Web-based discovery is lightweight [54][52], resource capability found [52-53] and supports mobility [51] and energy optimization [54][53].

3.4 Semantic-Based:

Semantic based modeling is a knowledge representation of IoT resources. A number of semantic-based approaches have been proposed in literature.

Paper [56] proposes a mechanism for smart objects using a semantic-based framework, and an ontology designed to implement semantics in a cloud environment. The proposed proxy framework facilitates service registration and services discovery. The paper also discusses the strong relation between registration and discovery. The architecture is implemented on two cases: private and enterprise environment.

The work in [57] proposes DiscoWoT which is a RESTful mechanism for semantic service discovery of smart objects and/or things. DiscoWoT services depend on multiple discovery strategies or multiple mapping schemas to identify resource semantically; the mechanism supports the runtime modification of the discovery strategies. The approach also focuses on utilizing the smart thing by facilitating discovery and selection.

According to [23][58][32], BLE based devices can be classified into *advertiser* and *scanner* devices. These devices spend a long time and consume lots of power to be discovered by the application. Such IoT applications with heavy user interaction need efficient energy plans without influencing the application's responsiveness. The techniques proposed in [23][58][32] customize and adapt the discovery parameters of BLE devices in advertising and scanning based on user’s behavior. The strategies reduce energy consumption and increase responsiveness.

A semantic broker–based architecture is proposed in [58] to facilitate device discovery and recommendation In IoT. The architecture clusters the resources using the semantic similarity metric to enable the discovery, recommendation, and filtering of the resources. The architecture supports both functional and non-function requirements for the selection and also reduces the search space.

The model in [59] uses the IoT device annotation and description to propose and build a rule based recognition that facilitates the IoT device discovery. The proposed model generates automatic rules from the website description of the IoT device by the Name-Entity Recognition (NER). The ontology approach is used exclusively for service discovery. In [60] a web service discovery mechanism based on ontology is proposed. The ontology bootstrapping combines two methods: the Term Frequency/Inverse Document Frequency (TF/IDF) and web context generation. These methods are used to evaluate the Web Services Description Language (WSDL) descriptor and

integrate and generate an accurate ontology, verified by Free Text Description.
Semantic-based discovery techniques widely support responsiveness evident by [57][23][32], and other advance discovery techniques such as [23][32][56][59][58][60] , energy efficient and lightweight and responsiveness found in [56][57][23][32][58].

3.5 Location-Based:

To discover available resource in an area, location based discovery approaches are needed to allow the interaction between the IoT application and resources. A variety of location data is used such as place identification, geographical coordinates and tags, supported by technologies such as RFID, GPS and BLE [22].
To differentiate between local and remote discovery techniques, the local discovery techniques are restricted to the IoT local gateway such as smart home gateway. Other discovery techniques that cover areas larger than the local network are considered remote [14]. The mobility aware discovery techniques can use local and remote discovery techniques in addition to the support of user mobility.
In location discovery there are static, semi-dynamic and dynamic resources. In static location discovery, resources, users and consumers are fixed in one location whereas in semi-dynamic, if the resource is static, users and consumers are dynamic and vise verse. In dynamic location discovery, resources, users and consumers are completely dynamic and mobile. For example, in smart homes there are static resources but dynamic users, and in smart cities dynamic resources such as vehicles can be semi-dynamic or dynamic. IoT devices can randomly change their locations, therefore mobility management is considered an issue that can be solved using edge computing as suggested in [22].
For the local and near connections, the Near Filed Communication (NFC) is used to build a small network around users[12]. Local discovery techniques aka "resource discovery around me" are used in [12][14]. In [61], a novel resource discovery mechanism applied in 3-dimension Cartesian coordinate system is proposed. The study reviews the types of existing resource discovery approaches and categorizes them into three groups. First, social connectivity based methods, second the movement pattern methods, and finally preference similarity based methods. The mechanism which is based on both user preference and movement pattern is proposed to reach a search upper level. The whole area is divided into square units of equal area. Smart devices in the same area are considered a sub community. Devices in the same sub community have similar preferences and movement patterns.
The proposed mechanism achieved search efficiency and reduced average delay.
Paper [62] proposes a Context-Aware Resource Discovery (CARD) framework based on machine learning techniques. The proposed framework works in various dynamic scenarios and environments (e.g. smart building and smart cities) compatible with existing discovery protocols. The framework reduces the energy consumption and discovery latency. The framework also supports multiple static and mobile node discovery.
Mobility is supported in location base technique in [61][62], and energy is optimized in[61][62], in addition to advanced feature, integration and social relation also found.

3.6 Clustering-Based:

The clustering and grouping based discovery focuses on the relations that link the resources and construct the groups or communities (e.g. frequent use of the same resource).
A novel clustering technique for resource discovery is proposed in [16]. The technique called iterative k-means clustering algorithm (IKm-CA) is used for discovery and to group or cluster information using similarity coefficients of Vector Space Model (VSM). Another clustering based architecture for resource discovery is proposed in [63] and introduces a sharing mechanism for disconnected networks. The model reduces the communication overhead between the nodes in the group using a contact probabilistic algorithm.

The study in [64] proposes a schema for community detection called Community Detection in an Integrated IoT and SN (CDIISN). According to the study, the community can be formed by at least 4 members. Two community detection techniques are introduced: Node Centric and Hierarchy Centric. All the related work is based on community detection in the Sensor Network (SN) environments. The integration between IoT and SN is also discussed.

IoT devices frequently interact with sets of other devices and users called a group or sub community. A group must have a specific or common feature that links the group members (e.g. location, or function etc.). This interaction builds a social community that can easily be discovered, detected and recommended [22]. cluster-based techniques based on interaction and social relation, lightweight, integration and energy optimization are common features in cluster-based techniques and are considered in [63][64]. Routing and energy efficient in the cluster[65].

The summarization and comparison between surveyed studies are shown in Table 1 and Table 2.

4 RESSOURCE DISCOVERY PROPERTIES AND CRITERIA

Many properties and criteria can be identified to differentiate and evaluate the discovery approaches and techniques in IoT systems. These properties are:

1. **Automation:** the system is automated and self-configured without human intervention.
2. **Scalability and discovery boundaries:** the area covered by the discovery function in the system.
3. **Privacy:** whether the discovered resources are public to discovery by others or are proprietors owned by a user**.**
4. **Responsiveness:** the duration to discover the resources of the system. In other words, the average response time of the discovery operation.
5. **Mobility awareness:** the system's support for moving resources.
6. **Abstraction and integration:** the ability of the discovery operation to complete regardless of the underlying technologies of the IoT infrastructure, and being able to integrate with other architecture, framework, or technologies.
7. **Frequency:** whether the discovery is periodic, or performed once.
8. **Reliability:** the resource (service/data/object) can be trusted, for example using trust ratio.
9. **Event based dynamic discovery:** the extent to which the discovery feature is continuous and responds to events. For example, if changing the device location results in a new discovery scan feature or not.
10. **Lightweight:** to suit the IoT resource capabilities and limitation.
11. **User preference:** to what extent the discovered resource depends on the user interests (e.g. specific price).
12. **Resource interactions:** the discovery supports the social relation between resources.
13. **Energy Efficiency:** simple discovery techniques for efficient energy consumption.
14. **Resource capabilities:** resource capabilities, properties and metadata.
15. **Consumer:** who benefit from the discovery methods.
16. **Resource diversity**: the ability of the discovery technique to discover a variety of resources in terms of type and function.
17. **Advanced features:** support resource filter, search, rank, index, QoS, on demand, registering, support routing, context aware also, and etc.

5. MAPPING BETWEEN PROPOSED CLASSIFICATION AND CRITERIA

The proposed classification and proposed criteria suggested in the previous section are mapped together. Table 3 associates the above properties to IoT resources (device/thing/object, data, and service). Table 4 shows the proposed resource discovery classification mapped against the suggested properties.

In the criteria, the advanced feature, user preference, and resource capability are mostly for service discovery. On the other hand, social relation is mainly for device discovery. Frequency, event-based (integration), responsiveness, and automation facilitate discovery operation. The social relation and grouping are reverse to diversity.

Some protocols and technologies found in literature support resource diversity and scalability such as DNS and ONS, IPv6, 6LowPAN, and search engines.

6 Conclusions

Recourse Discovery of the IoT infrastructure is one of the main and essential operations in IoT systems, as systems depend on resources to provide information to end users. This survey covered attempts for IoT resource discovery and focused on service and device/object/thing discovery.

Recourse discovery can be categorized with respect to discovery technique into architecture-based, protocol-based, semantic-based, web technology-based, location-based, and clustering-based.

The paper also suggested a number of properties to evaluate resource discovery. These properties are mapped against resource discovery techniques categories.

The future work will take advantage of desired properties of resource discovery techniques explored in this paper and investigate the possibility of integrating two or more techniques to improve the discovery process. Other future works includes grouping devices with respect to location, function and application and to evaluate the influence of resource discovery accuracy on system performance.

Table 1: Resource Discovery Techniques

[Ref]	**Device/ Object/ Thing**	**Services**	**Architecture**	**Protocol**	**Web Technology**	**Semantic**	**Clustering**	**Location**	**Description**
[13]					√				A framework for legacy environment integration
[15]				√			-		hybrid service discovery protocol by using spanning tree and modified Bloom filter
[53]					√				Dynamic framework for IoT resource and smart object discovery based on RESTful to discover, request, index, and search. Easy integrated to IoT middleware
[43]			√		_				Hybrid architecture using CoAP protocol
[60]		√	_		_	√			Service discovery using ontology and RESTful Term Frequency/Inverse Document Frequency (TF/IDF)
[54]					√				A lightweight approach using Device Profile (DP) that describes each IoT device
[44]			√		_				P2P architecture based on HTTP and CoAP protocols
[53]			_		√				Centralized architecture using RESTful
[56]		√			_	√			Sematic discovery using ontology
[38]		√		√					New protocol called “TRENDY” for service discovery based on CoAP, adaptive mechanism to reduce traffic overhead
[36]		√		√					Services discovery protocol using UDP and SOAP
[55]		√		_	√				Framework for distributed smart objects, abstract IoT application development
[61]			_		_			√	Novel resource discovery that supports the movement in the same sub community
[40]				√					Intelligent Resource Framework on Internet of Things (IRIF) based on semantic matching engine using bipartite graph for discovery management
[59]	√					√			Automation rule based model for better recognition of the IoT devices description
[57]		√				√			Semantic service discovery using SOAP
[16]							√		Iterative K-mean Clustering Algorithm (IKm-CA) using SVM for search
[9]	√	√		√	_				DNSNA Protocol based no IP, CoAP and ONS, supports DNS, authentication, & service discovery
[37]	√	√		√					Discovery protocol for both device and service using ONS
[51]	√				√				Search engine to discover, register, and access IoT resource
[23]	√					√			BLE based solution to save energy by understanding the application environment
[58]						√			Facilitates the discovery and recommendation of IoT resource , supports functional and non-functional requirements
[32]	√			_		√			Protocol for device discovery based on BLE for energy optimization
[63]							√		Reduces communication overhead between resource groups using Contact Probabilistic Algorithm
[64]							√		Community Detection in an Integrated IoT and SN (CDIISN)
[62]								√	Compatible with existing discovery protocols, applied in different environments, less energy consumption and latency, supports object mobility
[39]		√		√					Service discovery protocol supports the user's mobility and social relations
[42]			√						Using RD to implement a new architecture that is linked with another architecture called CAMPIE as middleware
[41]				√					A lightweight and distributed method based on the exchange of symbolic executable code among nodes.
[52]					√				Search engine to discover the resources and their capabilities, properties, and URIs regardless of used connecting technologies.

Table 2: comparison of the Resource Discovery techniques features

	Scalability	Self-Configuration (Automation)	Dynamic	Lightweight	Energy Efficiency	Privacy	Mobility-Aware	User Preference	Integration	Advanced Feature	Diversity	Social relation (Interaction)	Responsiveness
[53]		√		√					√	√	√		
[43]	√			√	√					√			√
[60]									√	√			
[54]	√			√	√			√	√				
[44]	√	√	√			√			√				
[56]						√			√	√			
[55]	√	√					√			√			
[61]			√	√	√		√	√			√		
[9]	√	√		√	√				√				
[37]		√	√						√				
[51]	√				√			√		√			√
[23]			√		√					√			√
[58]			√	√	√			√		√		√	√
[32]			√		√								√
[63]					√							√	
[64]					√			√	√			√	
[62]					√		√		√	√			√
[39]					√		√	√				√	
[42]	√				√				√	√	√		
[41]			√	√					√	√			
[52]	√	√						√		√	√		
[15]				√						√			
[13]			√			√			√	√			√
[38]				√						√		√	

Table 3: Resource Properties & IoT Resource

No	**Discovery Properties**	**Resource**		
		Device	**Data**	**Service**
1	Dynamic Resources	√		√
2	Lightweight	√		√
3	Privacy	√	√	√
4	Reliability	√	√	√
5	Abstraction and integration	√	√	√
6	Frequency	√		√
7	Scalability	√	√	
8	Mobility awareness	√		√
9	Responsiveness	√	√	√
10	Energy Efficiency	√		√
11	Automation	√	√	√
12	Resource interaction	√		
13	Users preferences			√

Table 4: Mapping of Resource Discovery techniques' classification against suggested properties.

No	Resource Discover Techniques Classification		Supported Properties									
			Privacy	**Scalability**	**Lightweight**	**Mobility**	**Responsiveness**	**Dynamic**	**User Preference**	**Reliability**	**Social Relations**	**Automation**
1	Architecture Based	Centralized	√				√			–		–
		Distributed		√		–	–	√			–	–
		Hybrid		–	–	–	–	–			–	√
		Publish/ Subscribe		–	–	–	√		√	√	–	–
2	Protocol Based				√		–		–		–	–
3	Semantic Based				–		–		√		–	–
4	Web Technology Based			√	√	–	–					–
5	Location Based	Local	√		–	–	√	–		√	–	–
		Remote		–		–	–	–		–		–
		Mobile				√	–	√			–	√
6	Clustering Based		–		–	–	–		–	–	√	–

(√): fully supports, (-): partially supports

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