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RESEARCH

IoT resource discovery based on multi faected attribute enriched CoAP: smart office seating discovery

C. P. Vandana[1] · Syed Asif Basha[2] · M. Madiajagan[3] · Sachin Jadhav[4] · Mohammed Abdul Matheen[5] · Lakshmana Phaneendra Maguluri[6]

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Abstract
With the broad spectrum of IoT domains, heterogeneous devices can amalgamate the physical world into a digital era. The current need of the hour is to discover and retrieve the most pertinent devices amongst similar capable devices in an IoT environment. This paper presents a novel, multifaceted approach to finding IoT-based innovative office seating using semantically enriched Constrained Application Protocol (CoAP). The multi-layered approach is implemented where the devices' specifications are considered for attribute extraction. These attributes are enriched in CoAP protocol. The most pertinent device is retrieved and provided to user space based on multi-attribute-based decision-making. User preferences along with system-generated recommendations, are considered for device ranking. The office seating is modelled as an IoT resource, where in multiple such office seatings in a smart office is considered and the best seating is retrieved. The proposed approach is compared with current state of art and the efficiency of the same is evaluated in terms of bandwidth usage, time of retrieval and accuracy.

Keywords CoAP · MCDM · Mart office seating · Resource discovery · Feature selection

1 Introduction

With the rapid proliferation of the Internet of Things (IoT) [1] paradigm in our everyday lives, making all the spheres as smart, discovery of the most pertinent IoT resource in the user application space is a mandate. The resource most efficient in terms of its core functionality, Quality of Service (QoS) [2], amongst similar capable resources must be retrieved with minimum human intervention and dynamically. Work carried out in the [1] represents the state of art in the resource discovery field in IoT.

The office automation market segment has seen a growth of smart gadgets, which has overwhelmed traditional workplaces with sophisticated monitoring systems [3] to improve staff productivity. However, the abrupt onset of the COVID pandemic has made working from home the new norm. In the post-COVID age, a hybrid work style model is preva-

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lent, allowing employees to choose between working from home and working in an office, depending on their needs. There won't be any permanent desk seating reserved for the There won't be any permanent desk seating assigned to the staff. The office administrator may assign the smart desk to the staff based on need. The office manager can select the IoT resources based on the ranking of capabilities and provide the employee with the ideal smart desk. The ideal office seating position can be found and given to the end employee based on the user's needs and the capabilities provided by the equipment. The remaining paper is organized as Sect. 2 representing the literature review, Sect. 3 presenting the proposed methodology, Sect. 4 depicts the hardware setup employed, Sect. 5 reprsenting the queries executed and showcases the experimental study, followed by Sect. 6 with conclusion and future work.

2 Literature review

The recent work in discovery of devices in IoT domain is summarized in Table 1.

3 Proposed methodology

The pre-processing stage and the resource retrieval stage are the two key stages of the overall technique used for the proposed research work. Unified annotation of the IoT resources from the vendor specified device specifications is carried out in the initial pre-processing stage. Next phase is the attribute selection phase where the key differentiating and QoS specific attributes are selected from the feature set. The IoT protocol enrichment is performed and a semantically enhanced resource repository is created based on the attributes chosen. IoT resources that have been registered are retrieved during the discovery phase based on how closely they fit user requirements. Ranking is done using several criteria decision making. Based on a match between the user's requirements and the top-ranked IoT resources, the optimum resource is returned.

In Fig. 1, the approach used in the proposed research project is depicted diagrammatically. As demonstrated, the semantic annotation of IoT resources is the first step in the preprocessing stage followed by attribute selection phase. In the CoAP IoT protocol [5], these chosen attributes are enhanced for resource registration and discovery, which is followed by ranked device retrieval [18, 19, 20, 21] based on multi-attribute decision-making. The resource annotated to the standard format from specifications is carried out and the effectiveness of the same is shown in our previous work [22, 23].

The discovery engine comprises of solving a multi criteria decision making problem, where the various attributes of the device for the criteria. The protocol is enriched with the attributes and the user query is also semantically eniched. The system generated recommendation for the devices and devices choice based on user preferences, both are considered for ranking the devices. Figure 2 depicts the discovery engine and corresponging discovery workflow. The MADM [24] model based on proximity calculation to the ideal values is computed (Fig. 3).

Table 1 Literature survey

Author of Work/Date	Main Focus	Paradigm	Findings
Ferdousi and Mandal [4](2019)	Protocol Based	CoAP [5], LOAMY	Cloud-based middleware LOAMY for COAP based IoT service discovery. Deployment of LOAMY is expensive in resource constraint nodes
Venanzi Kim [6]	Edge Centric approach	MQTT [5], broker, auto – configuration	MQTT-based context-aware autonomous Service Discovery SD in oneM2M model. Devices register the service in the RD based on discovering the gateway using DNS-SD/mDNS on fog nodes. MQTT broker as fog entity to collect the geo-locations of the nodes continuously and provides list of devices when a node discovery request is received.
Pereira et al. [7]	Edge Centric discovery	JSON MQTT, zero-configuration Distributed Combined (Cloud, Broker)	MQTT-RD extension of MQTT adopted for decentralized discovery & management for multiple devices. The proposed architecture performs well for scalability, latency and processing time.
Xia et al. [8]	Social IoT and ranking	Correlation degree, semantic similarity relativity, Social network among devices based on restricted contact graph	Social like semantic aware service discovery. Service described by ontology tree. Fast service discovery in local network. Devices to train themselves with social link selection issue. IoT devices are constraint and high-end ML algorithms running on them.
Kowshalya et al. [9]	Social IoT	Community detection based on preference, social and movement similarities.	Correlation amongst searched communities for search efficiency. Reduced search delay is demonstrated.
Perera et al. [10]	QOS based	Ontology CASSARAM, SPARQL, Context information	Context aware sensor selection framework, user preferences consideration. Based on sensor ontology and doesn't consider changes in ontology.
AntCluster [11]	QoS based	Context information used for meta heuristic algorithm to group sensors	Sensor semantic overlay network (SSON) developed to adapt to sensor changes. As the sensor count increases, the time complexity increases due to heuristic approach
Skyline [12]	User Preferences	Dynamic Skyline operator for sensor search. Search modelled as a MCDM problem	Dynamic skyline operator employed for context aware selection of best sensor based on user request. Distributed scalable approach by aggregating results of all gateways to get final result. Longer delay in aggregation of result at server from gateways, parallel calculation like MapReduce at gateway level as future work. Based on data sensed and not the sensor profile.
Ojagh [13]	Personalized recommendation	Location based recommendation engine based on user preferences	User context information and orientation from their smartphone pointing direction has also been applied for the recommender algorithm in outdoor environments Study carried out in simulated environment and dependency on smartphone to track the user orientation apart from location.

Table 1 (continued)

Author of Work/Date	Main Focus	Paradigm	Findings
Pattar [14]	Ontology based semantic similarity	Taxonomy for the classification of IoT devices based on their mobility frequency.	Query processing time and storage requirement reduced. Additional communication overhead due to aggregation of results and no standard technique for taxonomy used.
Singh et al. [15]	Ranking of the services	QoS aware AHP and TOPSIS Hierarchical search for IoT resource.	Running time analysis along with framework robustness and sensitivity demonstrated.AHP technique used for weight computation, domain expert input considered Automation of the process for unambiguous human decision making in AHP.
Kaur [16]	Ranking	Fuzzy AHP and Fuzzy TOPSIS for ranking of the network	Ranking robustness based on six parameters. QOS based preferences considered. Weight computation does not consider user preference.
Robles [17]	Semantic based	Lightweight Machine to Machine Resource Pragmatic Distance (LwRPD) find device similarities and similar capabilities devices.	Accuracy of the device selection is compared with existing approaches and proved to be more. Scalability and large-scale deployment studies needed.

4 Hardware setup

Case study was conducted in an office setting using the testbed architecture depicted in Fig. 4. Post COVID era, the office administrator would designate the seating arrangement (smart desk) depending on the capabilities of the available smart devices, instead of allocating a dedicated office space. Each smart desk is represented by a smart sensor board. The seating sections of the office are surrounded by a total of 5 smart sensor boards. Each sensor is made up of a variety of different sensor types that can identify the workplace setting. The on-board sensors are interconnected with the Arduino Uno [25]. The seated position is represented by a sensor board with five different types of sensors on each side.

A sensor board that includes five various types of sensors, each capable of monitoring ambient data, serves as a representation of the seated position. The hardware elements utilised to create a single sensor board are displayed in Table 2. Figure 5 shows the circuit diagram for a single board. The Arduino Uno MCU is used to control the four sensors (temperature, light, gas, and occupancy), as shown in Fig. 6. The LED is linked to enable resource search and the visual realisation of sensor board selection. The wireless interface and battery power source for the board are provided by Node MCU Esp8266.

Using the vendor specifications as a guide, annotation of 20 sensors in a common format is carried out. The framework is developed using Python 3.x.The Arduino Software Development Kit (SDK) is used to register and manage the sensors that the Arduino MCU controls. The language used to interface the sensors with the Arduino MCU is embedded C. RDFLib is used to implement semantically enhanced RD on Berkeley DB.Real-time data collection from the sensors is done using the cloud platform ThingSpeak. Tkinter is used

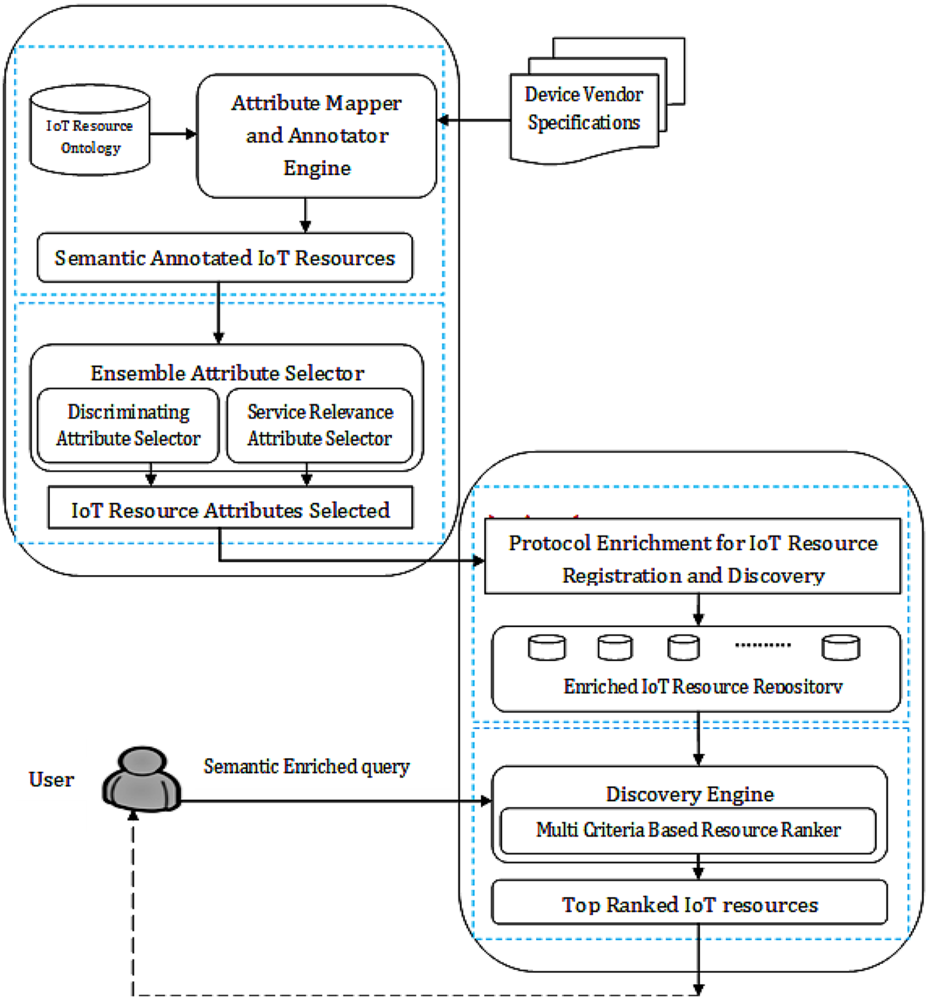


Fig. 1 Methodology of the proposed work

to create a Graphical User Interface (GUI) that visualises all of the aforementioned steps of the suggested framework. The vendor specifications folder is selectable using a GUI interface that is provided in annotated format. An interface for attribute selection that shows the selected attributes. Based on a CoAP client request, the UI will display the semantically enhanced CoAP CORELink format for device registration. The GUI offers resource retrieval that is ranked, captures user preferences, and visualises user queries. The office administrator uses the UI created to choose the ideal seating position for the end employee.

The cloud service ThingsSpeak [17] collects and stores real-time sensor data. The ESP-8266WiFi built-in WiFi module allows the sensor boards to communicate wirelessly with the gateway [23]. The enriched CoAP is deployed on the gateway to function as a CoAP server with enriched RD implementation. The CoAP client offers an interface that makes capturing user requirements easier and building queries using SPARQL [26].

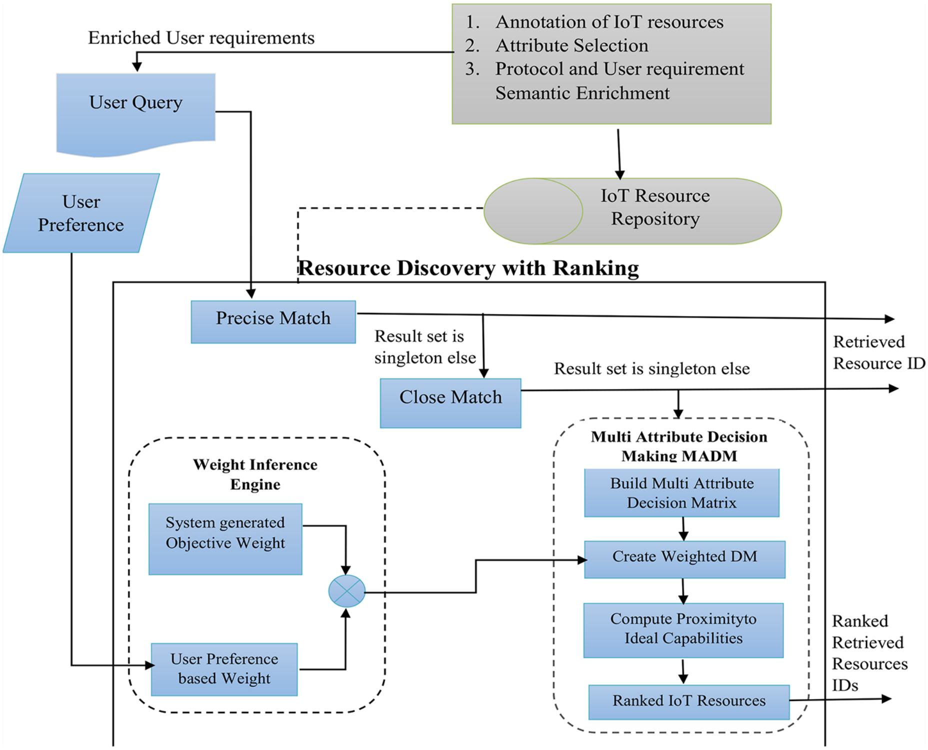


Fig. 2 Resource discovery engine

5 Result analysis

The Table 3 depicts the various queries executed for device discovery in the smart office setup. All the smart devices in the office setup would register with enriched CoAP repository.The enriched CoAP client would make request to the central enriched CoAP server. The requested query parameters and values are used to perform CoAP repository lookup.

This section explains the results of the experimental study carried out using proposed methodology. Figure 7 depicts the device registration Table 4 depicts the CoAP CoRELink format for the various queries corresponding to Table 3. The attributes selected in the previous step are enriched in CoRELink and Resorce Directory (RD). The queries are executed and the responses are captured. The queries are executed on traditional CoAP and enriched CoAP and the performance improvement is measured.

The source code for the implementation is available at [link 1] GitHub - vandanacp/IoTResourceDiscoveryProject.

The devices with the device id as shown in left hand panel of UI in Fig. 7 gets registered to the enriched COAP repository. Th attribute-values are enriched in the COAP COReLink format and sent to COAP server for registration (Fig. 8).

As shown in Fig. 9, there is a reduction of average response time during discovery process by 28% for S-COAP (Semantically enriched) compared to traditional COAP. The dis-

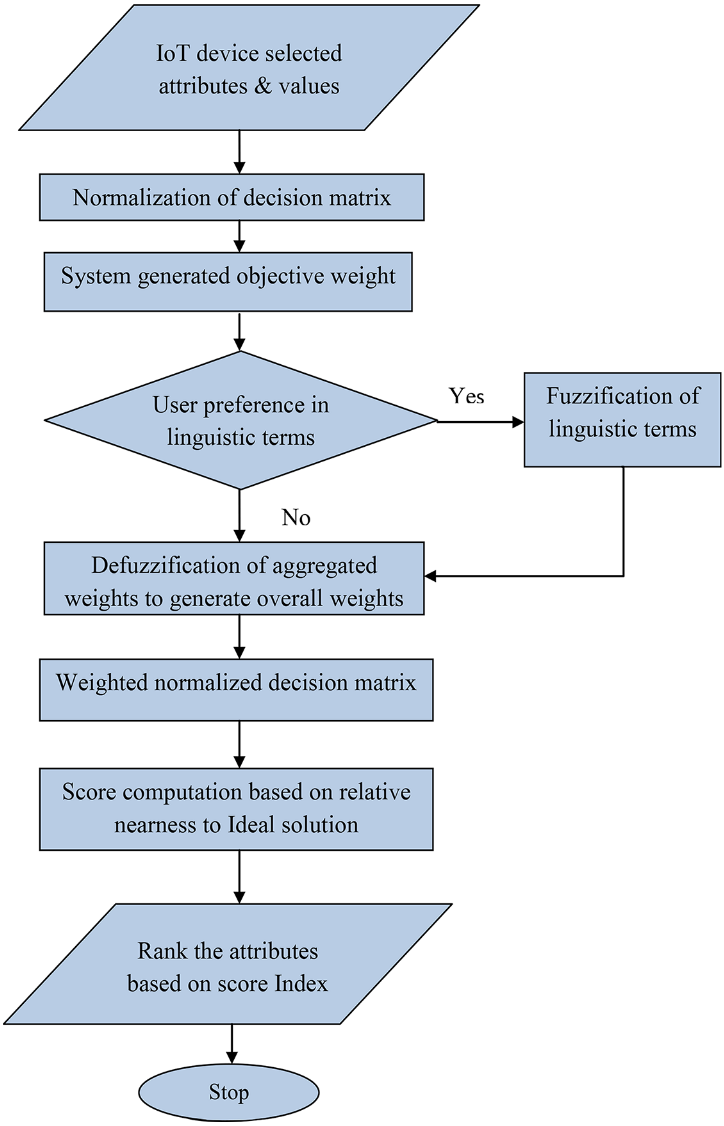


Fig. 3 Flowchart depicting the ranking mechanism of the devices

covery time improvement is due to the precise discovery of the devices with the enriched semantics.

5.1 Ranked Resource Retrieval

The time taken to rank the devices based on AHP-TOPSIS approach is compared with proposed approach. The SPARQL query is exceuted 20 times and the average time taken is

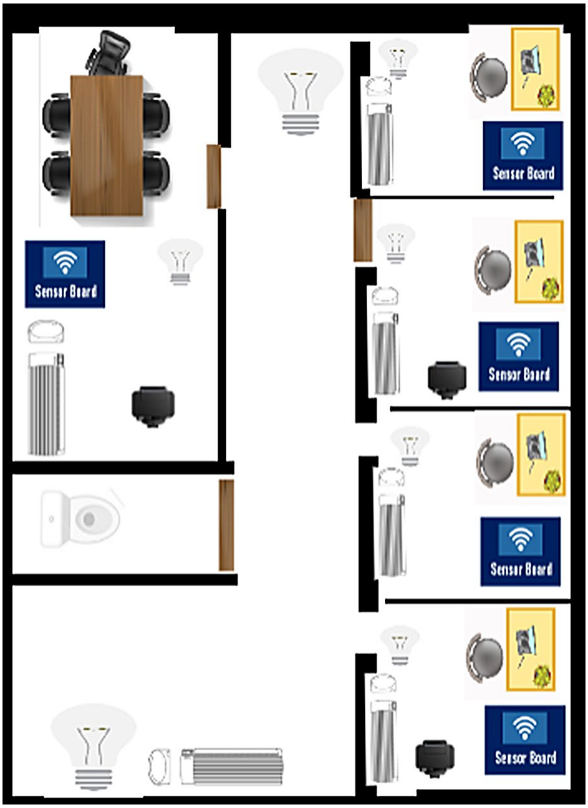


Fig. 4 The office layout for the smart office seating discovery

considered for comparison. There is an improvement of 37% in amount of time to rank the devices as shown in the Fig. 10.

The COAP request and response payload is compared with enriched COAP request and response payload size for all the 5 main queries as shown in Fig. 11. During the registration phase, query1, the response size of enriched COAP is nearly comparable with COAP due to the initial registration process in RD. The exact matching resource is retrieved for all the other queries compared to the traditional query, which does a match based on resposnse type. Hence a bandwidth usage reduction of 40% is observed with semantically enriched COAP protocol compared to traditional COAP.

6 Conclusion and future work

Through this work, we demonstrate the utility of the suggested framework for resource discovery in a smart IoT-based office test bed for locating the optimal seating arrangement. The discovery of smart office seating based on the proposed methodology was culminated by implementation comprising resource description annotation, attribute selection, protocol enrichment, and ranked resource retrieval. The framework can be extended to design a method to detect the collapse of IoT devices. In case of fault management, the detection of

Table 2 The office seating kit with different sensors

Sensor Board	Microcontroller Board	Communication Module	Light Emitting Diode	Power Adapter	Power Convertor Module	Temperature Sensors	Light Sensors	Occupancy Sensor	Gas Sensors
1	Arduino Uno MCU	Esp8266	LED1	Switching Power supply (+5 V 2 A)	5–35 V DC-DC Power convertor TECH1147	DHT11	BH1750	HC7B	MQ135
2	Arduino Uno MCU	Esp8266	LED2	Switching Power supply (+5 V 2 A)	5–35 V DC-DC Power convertor TECH1147	DHT22	VEML6035	APC2-20 N	APC2-20 N
3	Arduino Uno MCU	Esp8266	LED3	Switching Power supply (+5 V 2 A)	5–35 V DC-DC Power convertor TECH1147	DS18B20	LT-1PA01	EX35	EX35
4	Arduino Uno MCU	Esp8266	LED4	Switching Power supply (+5 V 2 A)	5–35 V DC-DC Power convertor TECH1147	ETT-10PT	NS060	HCSR505	HCSR505
5	Arduino Uno MCU	Esp8266	LED5	Switching Power supply (+5 V 2 A)	5–35 V DC-DC Power convertor	LM35	Opt3001	HC24	HC24

the IoT resource fault and its recovery needs to be modelled. Hence, the discovery framework can be extended in the future to detect the faults of these discovered IoT resources.

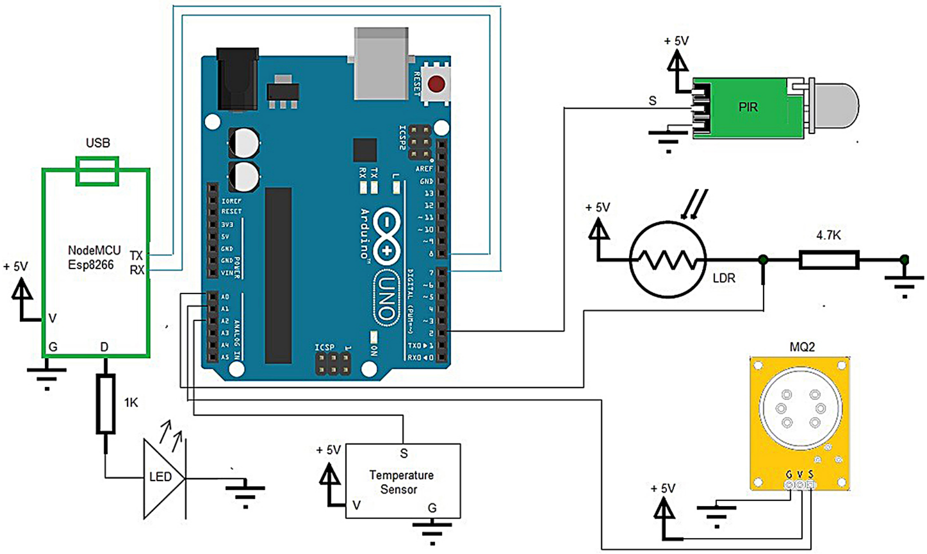


Fig. 5 The circuit diagram of a single sensor board

Fig. 6 Sensor Board hosting 4 types of sensors connected to Arduino UNO

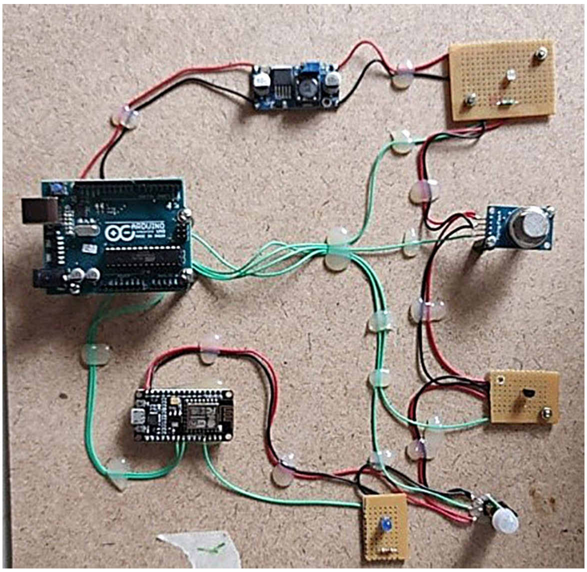


Table 3 Query on the semantic enriched CoAP repository

Query No.	Query Executed
1	All the devices in smart office to register with attribute enriched CoAP repository.
2	Retrieve all the smart office setaing devices deployed.
3	Discover temperature sensor near a smart desk with a medium measurement range, low sensing period and high accuracy.
4	Retrieve light sensor with high measuring range with low current consumption at specified location.
5	Rank the occupancy sensors with coverage > 0.5, detection distance < 3 m to maintain social distance in Office Seating
6	Retrieve gas sensors to detect smoke, LPG with concentration more than 300ppm to monitor air quality in office
7	Recommend the desk location based on best temperature sensor, lighting sensor and PIR sensor

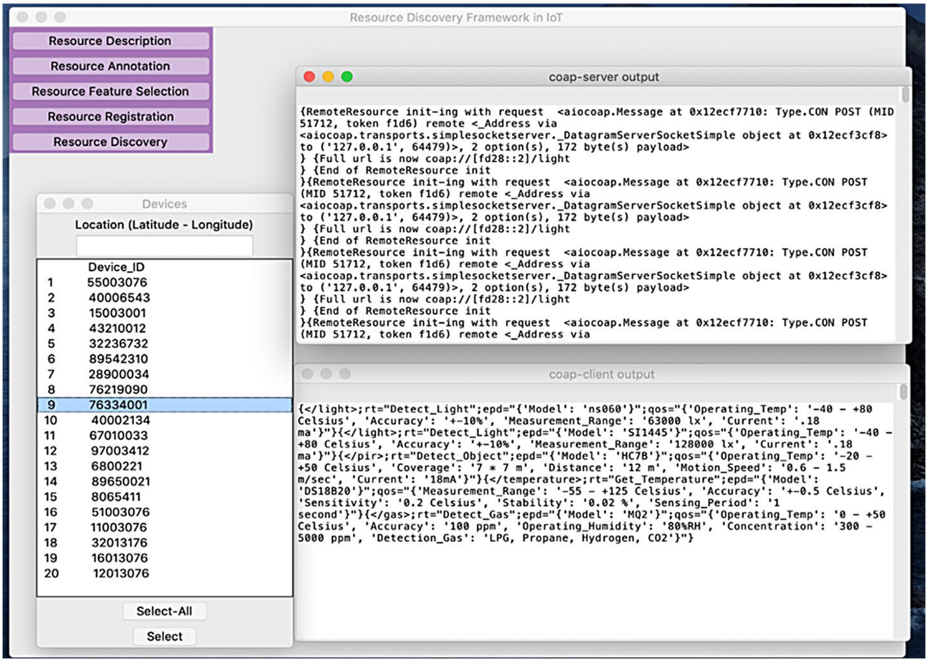


Fig. 7 Device registration and discovery with enriched COAP

Table 4 Enriched COAP based resource registration and ranked discovery

Query	S-COAP Request	Response
Register ALL	POST CoAP://192.167.1.7/rd? ep="55003076"; rt="Get_Temperature";epd="{'Model':'DHT22'}"; qos="{'Measurement_Range': '-40 - +80 Celsius', 'Accuracy': '+-0.5 Celsius', 'Sensitivity': '0.1 Celsius', 'Stability': '0.01%', 'Sensing_Period': '2 second'}; lt=12.427680& lg=76.481653"	Success Response: Code: 200
Query2	GET CoAP://192.167.1.7 / rd-lookup/res	Success Response: Code: 200 Content: { < CoAP://[fd28::2]/temperature> rt=Get_Temperature epd="{'Model': 'DHT22'}" qos="{'Measurement_Range': '-40 - +80 Celsius', 'Accuracy': '+-0.5 Celsius', 'Sensitivity': '0.1 Celsius', 'Stability': '0.01%', 'Sensing_Period': '2 second'}",}
Query 3	GET CoAP://localhost/rd-lookup/res? rt='Get_Temperature';qos= 'accuracy:0.2,mrange:-10 - +20,speriod:2'	SELECT? s?a? b?c WHERE { ?x<info: discovery/iot_resource/service_type> 'Get_Temperature'. ?x < info: discovery/iot_resource/measurement_range>?a. ?x < info: discovery/iot_resource/sensing_period>?b. ?x < info: discovery/iot_resource/accuracy>?c. ?x<info: discovery/iot_resource/device_id>?s }
Query 4	GET CoAP://localhost/rd-lookup/res? rt='Get_Light'; qos= 'mrange: 6000 current=0.2'; location=12.9280058, 77.6902479'	SELECT? s?a? b?c WHERE { ?x < info: discovery/iot_resource/service_type> 'Measure_Light'. ?x < info: discovery/iot_resource/measurement_range>?a. ?x < info: discovery/iot_resource/current_consumption>?b. ?x < info: discovery/iot_resource/location>?c. ?x<info: discovery/iot_resource/device_id>?s }
Query 5	GET CoAP://localhost/rd-lookup/res? rt='Detect_Object'; qos= 'coverage:5×5 det_distance=12'; location=12.9280058, 77.6902479	SELECT? s?a? b?c WHERE { ?x < info: discovery/iot_resource/service_type> 'Detect_Object'. ?x < info: discovery/iot_resource/coverage>?a. ?x < info: discovery/iot_resource/detection_distance>?b. ?x < info: discovery/iot_resource/location>?c. ?x<info: discovery/iot_resource/device_id>?s }
Query 6	GET CoAP://localhost/rd-lookup/res? rt='Measure_Air'; qos= 'detection_gas:'LPG Smoke' concentration gt 3000'	SELECT? s?a? b WHERE { ?x < info: discovery/iot_resource/service_type> 'Measure_Air'. ?x < info: discovery/iot_resource/detection_gas>?a. ?x < info: discovery/iot_resource/concentration>?b. ?x<info: discovery/iot_resource/device_id>?s }

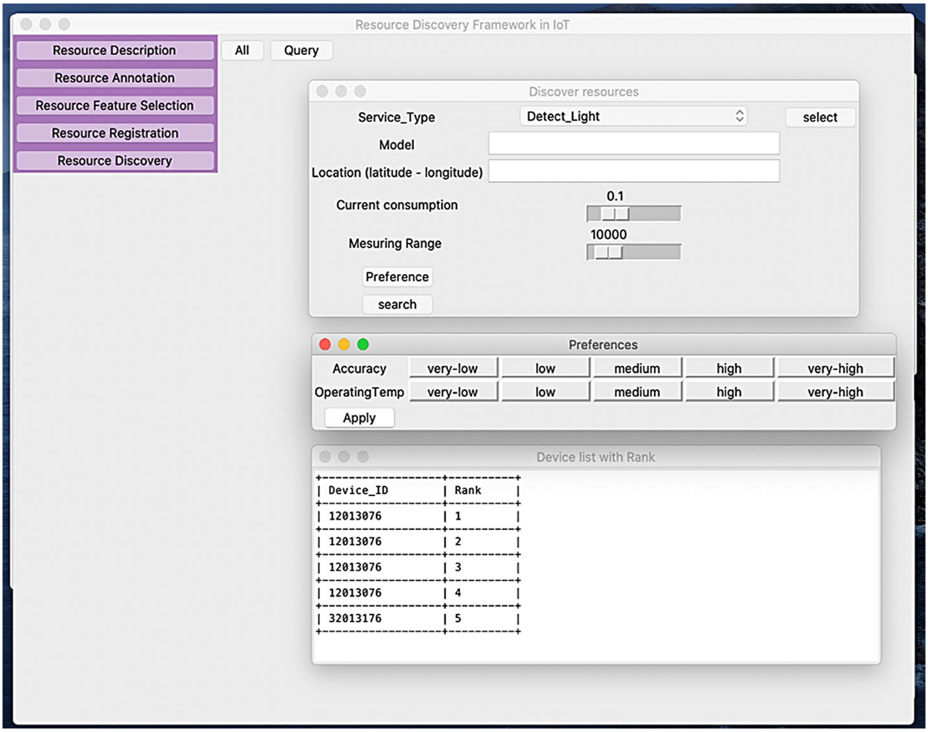


Fig. 8 Device Ranking based on user preference and system generated recommendation

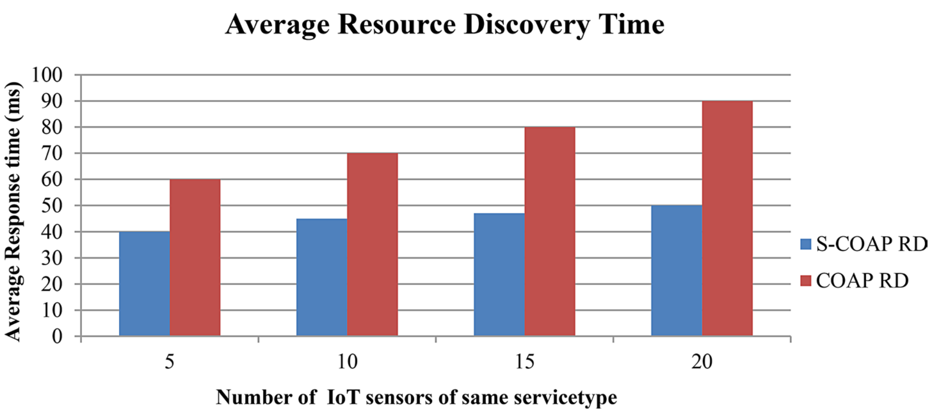


Fig. 9 Resource discovery time comparison

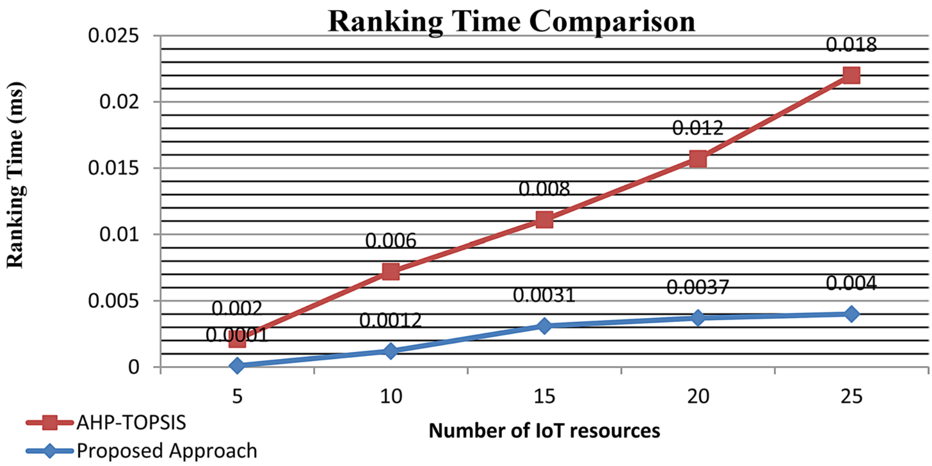
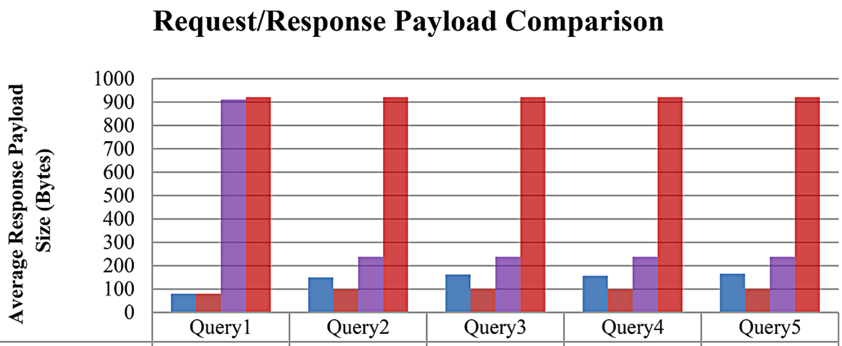


Fig. 10 Ranking time comparison



	Query1	Query2	Query3	Query4	Query5
S-COAP - Request Size	80	150	162	157	166
COAP - Request Size	80	100	101	100	101
S-COAP- Response Size	911	238	238	238	238
COAP-Response Size	921	921	921	921	921

Fig. 11 Resource discovery time comparison

Author Contributions Dr. Vandana C.P led the conceptualization and supervised the project, while Syed Asif Basha implemented the CoAP protocol and conducted data analysis. Dr. M. Madiajagan contributed expertise in analytics and decision-making methodologies, and Dr. Sachin Jadhav provided insights into IoT device specifications. Mohammed Abdul Matheen contributed to data collection and feature selection, and Lakshmana Phaneendra Maguluri brought expertise in IoT systems and resource modeling. All authors participated in reviewing and editing the manuscript, ensuring its intellectual integrity and ethical standards. The final version has been collectively approved by all authors.

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Declarations

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest The authors declare that they have no conflict of interest.

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C. P. Vandana is currently working as Associate Professor and Head of Information Science and Engineering Department, New Horizon College of Engineering. She has completed her Ph.D from Visvesvaraya Technological University in 2023 in the domain of Internet of Things and Machine Learning. She has total 11 years of academic experience and 6 years of Industry experience predominately in Wipro and Accenture. Her industry expertise is in Telecommunication domain using Java and J2EE technologies. She has been recognized as Wipro Certified Java Trainer 2016 as a part Wipro Project Based Learing. Her research area include Network management and security, Internet of Things, machine learning, Internet of Things (IoT), Artificial Intelligence.

Syed Asif Basha is currently working as a Lecturer in Department of Computer Engineering, College of computer science, King Khalid University, Alfara, Abha, kingdom of Saudi Arabia. He has received his Master of technology in VLSI systems Design from JNTU, kakinada, India and Bachelor of Engineering in Electronics & Communication from Visvesvaraya Technological University, Belgaum, India respectively. He has more than 15 years of experience in teaching and administrative work in reputed engineering institutions in India and abroad. His research interests are in Digital Image Processing, Machine Learning and IoT.

M. Madiajagan completed his B.E. Computer Science and Engineering from University of Madras, Master Degree from BITS Pilani, Rajasthan, India also completed his Ph.D. Degree from BITS Pilani, Rajasthan, India in the year 2009. Presently he is working as an Associate Profesor in School of Computer Science and Engineering, VIT, Vellore, Tamilnadu. He is having more than 25 years of Teaching experience in various Institutions and Universities like VIT, BITS Pilani. In BITS Pilani he was Professor In-Charge ICT & Netowrk Infrastructure requirement Analyst and he was one of Architect in implementing the BITS Connect 2.0 Project (CISCO Telepresence Systems). He published more than 25 papers in International & National Journals and presented in International Conferences & got Best Papers Award. He authored Books and Book chapters whiched is indexed by Scoups, Elsevier. He is having more than a dozens of Indian & Australian patents which were published and granted. His current research area are Human Brain Computing Interface (BCI), Artificail Intellengence, Deep Learning, Cyber Physical Security(CPS), IIoT and ICT Healthcare.

Sachin Jadhav is currelty working as Assistant Professor, Pimpri Chinchwad University Pune.He has 22 years of teaching experience. He has completed PhD in Computer Engineering, from Visvesvaraya Technological University (VTU) Public University in Belgaum, Karnataka. He has completed graduation in Computer science & Engineering, in first class with distinction. He has completed his Post Graduation in Computer Engineering from University of Mumbai. He has published many research papers in area of image processing, Artificial Intelligence and Machine Learning. He has published 5 indian patents and 1 Australian patent. He is awarded with Best Educator award by AWS Academy, Best Faculty mentor by Zensar, IBM, Infosys etc. He has certified with AWS certification. He has given training on various technologies on AWS Cloud Services and Cloud Architect certifications, python, java, C, C++ etc.

Mohammed Abdul Matheen received his B.Tech in ECE from Jawaharlal Nehru Technological University, Hyderabad, India in 2010. He has completed his Master of Technology degree in Digital Systems and Computers from Jawaharlal Nehru Technological University, Hyderabad, India in 2012. Ph. D from Vellore Institute of Technology, Tamil Nadu, India. Published articles in various reputed journals indexed in web of science and Scopus databases. Working as adjunct faculty at CRIO, Chitkara University and regular faculty in Saudi Arabia. Research interest includes wireless sensors networks, machine learning, IoT, Multimedia sensors.

Lakshmana Phaneendra Maguluri is a highly accomplished professional with a diverse educational background and a profound expertise in Computer Science and Engineering. Holding Ph.D. in Computer Science and Engineering from Annamalai University, Chidambaram, established as solid academic foundation in Tamil Nadu. Post Graduation in Information Technology from Gandhi Institute of Technology and Management and Under Graduation in Computer Science and Engineering from Seshadri Rao Gudlavalleru Engineering College. JNTUK Ratified faculty and served as Assistant Professor, at Gudlavalleru Engineering College. Currently working as an Associate Professor at Koneru Lakshmaiah Educational Foundation, adding wealth of academic and industry experience to his role. His commitment to academia is reflected in authoring 39 indexed research papers in esteemed databases such as Scopus, Web of Science, IEEE Xplore, Springer Link, and ACM Digital Library. He possesses a strong laboratory experience in these languages and demonstrates a deep understanding of cutting-edge technologies. He actively contributes to and stay updated with advancements in the field. Driven by an inherent passion for learning, embody of self-starting attitude, continually pursuing knowledge and taking ownership of his assignments.

Authors and Affiliations

C. P. Vandana[1] · Syed Asif Basha[2] · M. Madiajagan[3] · Sachin Jadhav[4] · Mohammed Abdul Matheen[5] · Lakshmana Phaneendra Maguluri[6]

✉ C. P. Vandana
vandana.hareesh@gmail.com

Syed Asif Basha
sbashaa@kku.edu.sa

M. Madiajagan
madiajagan.m@vit.ac.in

Sachin Jadhav
srjadhav02@gmail.com

Mohammed Abdul Matheen
matheen03@gmail.com

Lakshmana Phaneendra Maguluri
phanendra51@gmail.com

1 Department of Information Science and Engineering, New Horizon College of Engineering, Bangalore, India

2 Department of Computer Engineering, College of Computer Science, King Khalid University, Abha 614111, Kingdom of Saudi Arabia

3 Department of Analytics, School of Computer Science & Engineering, VIT University, Vellore, Tamil Nadu 632014, India

4 pimpri Chinchwad University, Pune, India

5 Centre of Research Impact and Outcome, Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab 140401, India

6 Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, Guntur Dist, Vaddeswaram, Andhra Pradesh 522302, India