

at smart homes. The proposed methodology grounded on SOAP simple object Access Protocol which aims to offer platform for heterogeneous devices for interoperation. The proposed framework instigated interoperation in numerous home devices to validate the effectiveness and tested in LAN. In [44] the authors presented a new idea to interconnection among heterogeneous devices using a gateway CoAP and protocol (the Propriety FS20) for smart home.

The authors [45] offered a mechanism grounded on the code generative and ontology alignment techniques to meet the interoperability among the devices and services. An Ontology is generated for each device type according to the meta model and then ontology alignment techniques applied to validate the semi automatic perceived communication among parallel devices. Authentication of alignment is done by an expert and classification based on pattern recognition techniques. They used UPnP plug and play protocol and testing is done on HP4515x printer.

The proposed approach [47] consist of Zigbee and UPnP Network Bridge to avoid the drawback of UPnP [66]. Zigbee protocol is used to associating UPnP due to its low consumption in term of energy. Seamless network bridge instigated to assist the interoperability UPnP-Zigbee network in smart homes. The authors proposed [46] a novel OHNet object based home network which works as a bridge aiding the devices using diverse protocols. The proposed method is emulated on several smart home smart grid devices and depicts that it can control such devices. In [48] Simple Object Access Protocol (SOAP) based architecture aided with web services delivering interoperation and scalability for tackling heterogeneous systems.

In paper [50] authors try to improve the semantic Interoperability when they work with heterogeneous IOT devices and makes the hardware and software devices more flexible. Doctor records, checks and maintains all the data of patient, for this doctor doesn't need any vendor device, the method imposed on this paper is that doctor works on three domains 1. User Interface 2. Cloud Computing 3. Semantic Interoperability. SI made all the raw data in to useful meaning and UI helps to collect the data from different IOT devices with SI and clouding system is storing all data, so whenever doctor wants can check the previous record of patient. In this paper authors used RFD for exchanging data raw data in meaningless information.

In paper [52] authors discuss the four requirements for any architecture for smart homes i.e. interoperability, addressability, compatibility, scalability, to maintain these requirements they introduced HEPA with Hexagonal architecture because of its high Interoperability. Each party have adaptors and ports to connect with IOT devices but each company's devices have its own adaptor if third company's devices wants to access with devices by any other company they will use communication protocol and REST protocol will shorten the steps for connectivity.

In paper [55] authors proposed the solution to overcome the barriers and noise in data for this they introduced the node called Interworking Proxy Entity (IPE) works with M2M architecture for conversion of data for which Z Wave is used with XML to describe the format of data omeM2m is used with these two protocols to provide the proper platform for data conversion.

In paper [57] they proposed the model based on Home Automation System for controlling of lights specially daylight

lights. For this they used Zigbee Protocol embedded in RF of 802.15.4. It gives the authority to user to control the remote region like increasing or decreasing the temperature, on or off the light etc.

In paper [59] they give the systematic review how the user can control their devices, for this OSGi based architecture was established for heterogeneous devices with API that gives variety of applications, the OSGi is responsible for communication between devices.

The authors [61] proposed the Ethernet cloud for the smart home environment as basic connectivity interoperability. Cloud connectivity comes with its own challenges in perspective of security and privacy [70]. They focused on the SOAP technology which is a basic key as translator between heterogeneous devices for interoperability [61]. They proposed the smart gateway for interoperability in smart home appliances. And they provided the cloud based server which will collect the data of all homes. They used Python API for interface between sensors and actuators with smart gateway. They provide a WoO architecture which allows the user to easily access the objects of smart home. They use WoO architecture in different applications (smart water tank control, door security control, door security control, lights and fan control, exhaust control) [62]. They presented a methodology which consists of six steps (identification of the user need in smart home, definition of smart home functionalities, classification of smart home devices, definition of information management model, definition of intelligent rules, correlation between devices and information). They implemented their method in energy field called "washing machine scheduling service" to save energy, reduce casts, and satisfy the user [63]. They proposed an architecture of integrated middleware's for data broadcasting. For flexible profile management they proposed some APIs e.g graphics and window APIs. In case of change in existing middleware specification due to version update or correction architecture supports the updated middleware without modification [64]. They proposed a Universal Middleware Bridge (UMB) architecture that consist of UMB core and UMB adopter. They implemented there work on surveillance camera called HAVi-camera for home security purpose. Through there architecture interoperable devices are easily controlled and monitored in home network [65]. To achieve better reliability & scalability of IOT controller based on smart home devices Liu H.B [69] proposed a home gateway grounded on ARM & intelligent control system comprising of home network control nodes based on ZigBee. The gateway is the alteration of TCP/IP, GPRS/GSM and ZigBee protocol. It is used to establishment & management of wireless sensor network and outside the network. Network nodes of ZigBee are responsible for making of internal network inside the smart home

3. CONCLUSIONS

The paper presents state of the art on interoperation among heterogeneous devices in IoT specifically in smart homes. With the growth of connected heterogeneous devices, connectivity among them is going to be a crucial need. We analyzed research articles by the communication protocol, network type, type of interoperability and year of presented work

Table 1. Summary of reviewed literature

Ref	Protocol/ Technique	Network	Type of interop	Application	Year
[38]	Z Wave	HAN	BASIC	Lights, Switches, Door Lock	2016
[39]	RNS	LAN	Network	IGRS, iTopHome	2014
[40]	OpenWebNet	LAN/WIFI	Network	Switch, Actuator	2014
[41]	WOT	LAN	SYNTACTIC	TV, DVD	2013
[42]	IOT DNS	Internet WIFI	Network	Home Appliances	2017
[43]	SOAP	LAN	SYNTACTIC	CCTV	2011
[44]	CoAP, Propriety FS20	INTERNET	SYNTACTIC		2012
[45]	UPnP			Printer HP515x	2011
[46]	OHNet			Smart Home, Smart Grid	2011
[47]	Zigbee, UPnP			Home Network	2011
[48]	SOAP				2008
[49]	Zigbee, JSON	HAN	BASIC	Air Conditioner, Washing Machines	2013
[50]	RFD	WAN	SYNTHETIC	Computer Records	2017
[51]	M2M, OID	WAN	NETWORK	Device Identification	2017
[52]	HEPA, REST	WIFI	SYNTHETIC	Plugs	2015
[53]	RF,ERDF,Zigbee,Bluetooth	LAN/ WIFI	BASIC	Lights, Bulb	2016
[54]	IPv6	WSN	NETWORK	Owen	2016
[55]	TCP/IP, UDP, HTTP,SOAP	HAN	NETWORK	Remotes, Laptops	2016
[56]	IPE, M2M,Z Wave	LAN	SYNTHETIC	Cells	2016
[57]	OSGi, MA	SOA	BASIC	Mobiles	2007
[58]	Zigbee, RF	HAN	SYNTHETIC	AC, Lights	2010
[59]	IPv6	WAN	NETWORK	Machines	2014
[60]	OSGi, API		SYNTHETIC	Laptops	2012
[61]	SOAP, XML	WAN	NETWORK	Frameworks	2008

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REFERENCES

- [1] Blackstock M, Lea R. (2014). IoT interoperability: A hub-based approach. In Internet of Things (IOT), 2014 International Conference on the 79-84. IEEE.
- [2] Soliman M, Abiodun T, Hamouda T, Zhou J, Lung CH. (2013). Smart home: Integrating internet of things with web services and cloud computing. In 2013 IEEE 5th International Conference on Cloud Computing Technology and Science (CloudCom) 317-320. IEEE.
- [3] Elkhodr M, Shahrestani S, Cheung H. (2014). A semantic obfuscation technique for the Internet of Things. In Communications Workshops (ICC), 2014 IEEE International Conference on 448-453. IEEE.
- [4] Elkhodr M, Shahrestani S, Cheung H. (2016). The Internet of Things: New interoperability, management and security challenges. arXiv preprint arXiv:1604.04824.
- [5] Stallings W. (2015). Foundations of modern networking: SDN, NFV, QoE, IoT, and Cloud. Addison-Wesley Professional.
- [6] Atzori L, Iera A, Morabito G. (2010). The internet of things: A survey. Computer networks 54(15): 2787-2805.
- [7] Gubbi J, Buyya R, Marusic S, Palaniswami M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems 29(7): 1645-1660.
- [8] Jara AJ, Zamora-Izquierdo MA, Skarmeta AF. (2013). Interconnection framework for mHealth and remote monitoring based on the internet of things. IEEE Journal on Selected Areas in Communications 31(9): 47-65.
- [9] Sikder AK, Acar A, Aksu H, Uluagac AS, Akkaya K, Conti M. (2018). IoT-enabled smart lighting systems for smart cities. In Computing and Communication Workshop and Conference (CCWC), 2018 IEEE 8th Annual 639-645. IEEE.
- [10] Hsu AP, Lee WT, Trappey AJ, Trappey CV, Chang AC. (2015). Using system dynamics analysis for performance evaluation of IoT enabled one-stop logistic services. In Systems, Man, and Cybernetics (SMC), 2015 IEEE International Conference on 1291-1296. IEEE.
- [11] Machado K, Rosário D, Cerqueira E, Loureiro AA, Neto A, de Souza JN. (2013). A routing protocol based on energy and link quality for internet of things applications. Sensors 13(2): 1942-1964.
- [12] Floerkemeier C, Roduner C, Lampe M. (2007). RFID application development with the Accada middleware platform. IEEE Systems Journal 1(2): 82-94.
- [13] Gubbi J, Buyya R, Marusic S, Palaniswami M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems 29(7): 1645-1660.
- [14] Farhan L, Shukur ST, Alissa AE, Alrweg M, Raza U, Kharel R. (2017). A Survey on the Challenges and Opportunities of the Internet of Things (IoT). In Sensing Technology (ICST), 2017 Eleventh International Conference on 1-5. IEEE.
- [15] Hussain MI. (2017). Internet of Things: Challenges and research opportunities. CSI Transactions on ICT 5(1): 87-95.
- [16] Desai P, Sheth A, Anantharam P. (2015). Semantic gateway as a service architecture for iot interoperability. In Mobile Services (MS), 2015 IEEE International Conference on 313-319. IEEE.
- [17] Ahsan M, Talib MR, Sarwar MU, Khan MI, Sarwar MB. (2016). Ensuring interoperability among heterogeneous devices through IoT middleware. International Journal of Computer Science and Information Security 14(4): 251.

- [18] Pandya HB, Champaneria TA. (2015). Internet of things: Survey and case studies. In *Electrical, Electronics, Signals, Communication and Optimization (EESCO)*, 2015 International Conference on 1-6. IEEE.
- [19] Fersi G. (2015). Middleware for internet of things: A study. In *Distributed Computing in Sensor Systems (DCOSS)*, 2015 International Conference on 230-235. IEEE.
- [20] Josyula SK, Gupta D. (2016). Internet of things and cloud interoperability application based on Android. In *Advances in Computer Applications (ICACA)*, IEEE International Conference on 76-81. IEEE.
- [21] Tayur VM, Suchithra R. (2017). Review of interoperability approaches in application layer of Internet of Things. In *Innovative Mechanisms for Industry Applications (ICIMIA)*, 2017 International Conference on 322-326. IEEE.
- [22] Alexiou A, Raouf D, Liu CH, Zhang Y, Antón-Haro C, Aydin O, France NCSET. (2012). W3-IoT-ET 2012: WCNC 2012 workshop on internet of things enabling technologies, embracing machine-to-machine communications and beyond-Committees and welcome.
- [23] Chen HC, Al Faruque MA, Chou PH. (2016). Security and privacy challenges in IoT-based machine-to-machine collaborative scenarios. In *Hardware/Software Codesign and System Synthesis (CODES+ ISSS)*, 2016 International Conference on 1-2. IEEE.
- [24] Kientopf K, Raza S, Lansing S, Güneş M. (2017). Service management platform to support service migrations for IoT smart city applications. In *Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2017 IEEE 28th Annual International Symposium on 1-5. IEEE.
- [25] Sun L, Wang J, Higgs R, Yang C. (2017). Analysis on the Application of Dense Storage Technology in Logistics Based on the IoT. In *Computational Science and Engineering (CSE) and Embedded and Ubiquitous Computing (EUC)*, 2017 IEEE International Conference on 2: 214-218. IEEE.
- [26] Hsu AP, Lee WT, Trappey AJ, Trappey CV, Chang AC. (2015). Using system dynamics analysis for performance evaluation of IoT enabled one-stop logistic services. In *Systems, Man, and Cybernetics (SMC)*, 2015 IEEE International Conference on 1291-1296. IEEE.
- [27] Lestari D, Wahyono ID, Fadlika I. (2017). IoT based Electrical Energy Consumption Monitoring System Prototype: Case study in G4 Building Universitas Negeri Malang. In *Sustainable Information Engineering and Technology (SIET)*, 2017 International Conference on 342-347. IEEE.
- [28] Medaglia CM, Serbanati A. (2010). An overview of privacy and security issues in the internet of things. In *The Internet of Things* 389-395. Springer, New York, NY.
- [29] Borgia E. (2014). The Internet of Things vision: Key features, applications and open issues. *Computer Communications* 54: 1-31.
- [30] Yong H, Pengcheng N, Fei L. (2013). Advancement and trend of internet of things in agriculture and sensing instrument. *Transactions of the Chinese Society for Agricultural Machinery* 44(10): 216-226.
- [31] Dohr A, Modre-Opsrian R, Drobics M, Hayn D, Schreier G. (2010). The internet of things for ambient assisted living. In *Information technology: New generations (ITNG)*, 2010 Seventh International Conference on 804-809. IEEE.
- [32] Amadeo M, Campolo C, Molinaro A. (2014). Multi-source data retrieval in IoT via named data networking. In *Proceedings of the 1st ACM Conference on Information-Centric Networking* 67-76. ACM.
- [33] Amadeo M, Campolo C, Molinaro A. (2014). Multi-source data retrieval in IoT via named data networking. In *Proceedings of the 1st ACM Conference on Information-Centric Networking* 67-76. ACM.
- [34] Daubert J, Wiesmaier A, Kikiras P. (2015). A view on privacy & trust in IoT. In *Communication Workshop (ICCW)*, 2015 IEEE International Conference on 2665-2670. IEEE.
- [35] Hassanalierragh M, Page A, Soyata T, Sharma G, Aktas M, Mateos G, Andreescu S. (2015). Health monitoring and management using Internet-of-Things (IoT) sensing with cloud-based processing: Opportunities and challenges. In *2015 IEEE International Conference on Services Computing (SCC)* 285-292. IEEE.
- [36] Stojkoska BLR, Trivodaliev KV. (2017). A review of Internet of Things for smart home: Challenges and solutions. *Journal of Cleaner Production* 140: 1454-1464.
- [37] De Silva LC, Morikawa C, Petra IM. (2012). State of the art of smart homes. *Engineering Applications of Artificial Intelligence* 25(7): 1313-1321.
- [38] Yassein MB, Mardini W, Khalil A. (2016). Smart homes automation using Z-wave protocol. In *Engineering & MIS (ICEMIS)*, International Conference on 1-6. IEEE.
- [39] Yang C, Yuan B, Tian Y, Feng Z, Mao W. (2014). A smart home architecture based on resource name service. In *Computational Science and Engineering (CSE)*, 2014 IEEE 17th International Conference on 1915-1920. IEEE.
- [40] Ciabattini L, Cimini G, Grisostomi M, Ippoliti G, Longhi S. (2014). An interoperable framework for home automation design, testing and control. In *Control and Automation (MED)*, 2014 22nd Mediterranean Conference of 1049-1054. IEEE.
- [41] Kamilaris A, Pitsillides A. (2013). Towards interoperable and sustainable smart homes. In *IST-Africa Conference and Exhibition (IST-Africa)* 1-11. IEEE.
- [42] Koo J, Kim YG. (2017). Interoperability of device identification in heterogeneous IoT platforms. In *Computer Engineering Conference (ICENCO)*, 2017 13th International 26-29. IEEE.
- [43] Perumal T, Ramli AR, Leong CY. (2011). Interoperability framework for smart home systems. *IEEE Transactions on Consumer Electronics* 57(4).
- [44] Bergmann OK, Hillmann T, Stefanie G. (2012). A CoAP-gateway for smart homes. In *Computing, Networking and Communications (ICNC)*, 2012 International Conference on 446-450. IEEE.
- [45] El K, Charbel YD, François-Gaël O. (2011). Dynamic service adaptation for plug and play device interoperability. In *Proceedings of the 7th International Conference on Network and Services Management* 46-55. International Federation for Information Processing.
- [46] Kim JS, Kim SJ. (2011). An object-based middleware for home network supporting the interoperability among heterogeneous devices. In *Consumer Electronics (ICCE)*, 2011 IEEE International Conference on 585-586. IEEE.
- [47] Kim SJ, Seo HM, Park WC, Kim SD, Lee YS. (2011). Seamless Network Bridge for Supporting Interoperability UPnP-ZigBee. In *Computers, Networks,*

- Systems and Industrial Engineering (CNSI), 2011 First ACIS/JNU International Conference on 308-313. IEEE.
- [48] Perumal T, Ramli AR, Leong CY, Mansor S, Samsudin K. (2008). Interoperability among heterogeneous systems in smart home environment. In *Signal Image Technology and Internet Based Systems, 2008. SITIS'08. IEEE International Conference on* 177-186. IEEE.
- [49] Soliman M, Abiodun T, Hamouda T, Zhou J, Lung CH. (2013). Smart home: Integrating internet of things with web services and cloud computing. In *2013 IEEE 5th International Conference on Cloud Computing Technology and Science (CloudCom)* 317-320. IEEE.
- [50] Jabbar S, Farhan U, Shehzad K, Murad K, Kijun H. (2017). Semantic interoperability in heterogeneous IoT infrastructure for healthcare. *Wireless Communications and Mobile Computing*.
- [51] Seo S, Kim J, Yun S, Huh J, Maeng S. (2015). HePA: hexagonal platform architecture for smart home things. In *Parallel and Distributed Systems (ICPADS), 2015 IEEE 21st International Conference on* 181-189. IEEE.
- [52] Courreges S, Oudji S, Meghdadi V, Brauers C, Kays R. (2016). Performance and interoperability evaluation of radiofrequency home automation protocols and bluetooth low energy for smart grid and smart home applications. In *Consumer Electronics (ICCE), 2016 IEEE International Conference on* 391-392. IEEE.
- [53] Palma L, Pernini L, Belli A, Valenti S, Maurizi L, Pierleoni P. (2016). IPv6 WSN solution for integration and interoperation between smart home and AAL systems. In *Sensors Applications Symposium (SAS), 2016 IEEE* 1-5. IEEE.
- [54] Toschi GM, Campos LB, Cugnasca CE. (2016). An upnp architecture for interoperability in home area network. In *Consumer Electronics (ISCE), 2016 IEEE International Symposium on* 51-52. IEEE.
- [55] Palma L, Pernini L, Belli A, Valenti S, Maurizi L, Pierleoni P. (2016). IPv6 WSN solution for integration and interoperation between smart home and AAL systems. In *Sensors Applications Symposium (SAS), 2016 IEEE* 1-5. IEEE.
- [56] Toschi GM, Campos LB, Cugnasca CE. (2016). An upnp architecture for interoperability in home area network. In *Consumer Electronics (ISCE), 2016 IEEE International Symposium on* 51-52. IEEE.
- [57] An J, Hwang J, Song J. (2016). Interworking technique and architecture for connecting LAN IoT devices towards standardized IoT service layer platform. In *Consumer Electronics, 2016 IEEE 5th Global Conference on* 1-2. IEEE.
- [58] Wu CL, Liao CF, Fu LC. (2007). Service-oriented smart-home architecture based on OSGi and mobile-agent technology. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 37(2): 193-205.
- [59] Han DM, Lim JH. (2010). Smart home energy management system using IEEE 802.15. 4 and zigbee. *IEEE Transactions on Consumer Electronics* 56(3): 1403-1410.
- [60] Xiao G, Guo J, Da XL, Gong Z. (2014). User interoperability with heterogeneous IoT devices through transformation. *IEEE Trans. Industrial Informatics* 10(2): 1486-1496.
- [61] Kim JE, Boulos G, Yackovich J, Barth T, Beckel C, Mosse D. (2012). Seamless integration of heterogeneous devices and access control in smart homes. In *Intelligent Environments (IE), 2012 8th International Conference on* 206-213. IEEE.
- [62] Leong CY, Ramli AR, Perumal T. (2009). A rule-based framework for heterogeneous subsystems management in smart home environment. *IEEE Transactions on Consumer Electronics* 55(3).
- [63] Perumal T, Ramli AR, Leong CY, Mansor S, Samsudin K. (2008). Interoperability for smart home environment using web services. *International Journal of Smart Home* 2(4): 1-16.
- [64] Iqbal A, Ullah F, Anwar H, Kwak KS, Imran M, Jamal W, ur Rahman A. (2018). Interoperable Internet-of-Things platform for smart home system using Web-of-Objects and cloud. *Sustainable Cities and Society* 38: 636-646.
- [65] Capitanelli A, Papetti A, Peruzzini M, Germani M. (2014). A smart home information management model for device interoperability simulation. *Procedia CIRP* 21: 64-69.
- [66] Song HY, Park J. (2006). Design of an interoperable middleware architecture for digital data broadcasting. *IEEE Transactions on Consumer Electronics* 52(4).
- [67] Moon KD, Lee YH, Lee CE, Son YS. (2005). Design of a universal middleware bridge for device interoperability in heterogeneous home network middleware. *IEEE Transactions on Consumer Electronics* 51(1): 314-318.
- [68] Kim JE, Barth T, Boulos G, Yackovich J, Beckel C, Mosse D. (2017). Seamless integration of heterogeneous devices and access control in smart homes and its evaluation. *Intelligent Buildings International* 9(1): 23-39.
- [69] HB L, Ding XK, Wang T. (2016). Research and implementation of smart home system based on ARM and ZigBee. *Review of Computere Engineering Studies* 3(4): 86-89. <https://doi.org/10.18280/rces.030402>
- [70] Gupta ASB, Thakur SS. (2017). Cloud computing: its characteristics, security issues and challenges. *Review of Computere Engineering Studies* 4(2): 76-81. <https://doi.org/10.18280/rces.040207>