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Hierarchical Modeling of Complex Internet of Things Systems Using Conceptual Modeling Approaches

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ABSTRACT Popularity of the Internet of things (IoT) is currently on the rise. Academia as well as industry is equally fascinated by this disruptive technology. The IoT research and implementation have succeeded securing their place in numerous domains including, but not limited to, business, transportation and logistics, health care, smart cities, and agriculture. Conceptual modeling is pivotal to the design and implementation of a system. Various modeling approaches have been used for a variety of the IoT applications and case studies. In this paper, we examine various innovative applications of the existing conceptual modeling approaches for the IoT. We analyze the use of these approaches against different concerns in isolation as well as in mutual combination for the IoT. We also define a set of terminologies that we frequently encounter in this manuscript and those likely to be used while adopting proposed modeling approaches for the IoT scenarios. This study also attempts to reconcile different modeling approaches toward a unified modeling system. For this purpose, we map various conceptual modeling approaches against different layers of functional model of the IoT reference architecture. There is also a scenario in the end of the paper which elaborates the use of different modeling approaches in hierarchy for a complex IoT system.

INDEX TERMS Agent-based modeling, ambient-oriented modeling, aspect-oriented modeling, conceptual modeling approaches, contract-based modeling, fuzzy-logic modeling, the Internet of Things, network-based modeling, object-based modeling, ontology, service-oriented modeling.

I. INTRODUCTION

A variety of new avenues have come to light in recent decades such as real-time and embedded systems, internet of things, Blockchain, pervasive computing, multi-agent systems and hybrid systems control. These avenues are closely interconnected and are equally attracting the interest of both the researchers and the industry professionals towards the temporal aspects of computing in various engineering domains along with computer science [46].

Internet of things (IoT) has stepped in as a disruptive technology. It has opened new gateways for electronic devices by introducing the concept of connecting every device to the internet. New work-flows are emerging as a result of increase in device to device connection. It also has given a boost to the area of autonomous agents and its application is increasing significantly, such as being applied in complex systems like transportation, logistics and consumer robotics. Different modeling and analyzing approaches exist for examining the behavior of such systems [75]. These modeling techniques can also be used in combination to analyze such systems.

Automaticity and intelligence have also gained great significance. Computing systems can self-manage with the combination of many fields of computing under the concept of Autonomic Computing. It is similar to multi-agent systems, hence it was considered as a hype topic in its initial days [54]. Autonomic computing is providing minimal input of human to machines. A term, ‘Robotic Process Automation’ is used for such autonomous systems. These fundamentals of autonomic computing lead to fully automatic business processes and workflows [49].

Due to the availability of larger information technology resources, more and more complex systems are being developed. These complex systems sometimes contain many subsystems interconnected with each other. A system which is composed of a number of independent systems is described

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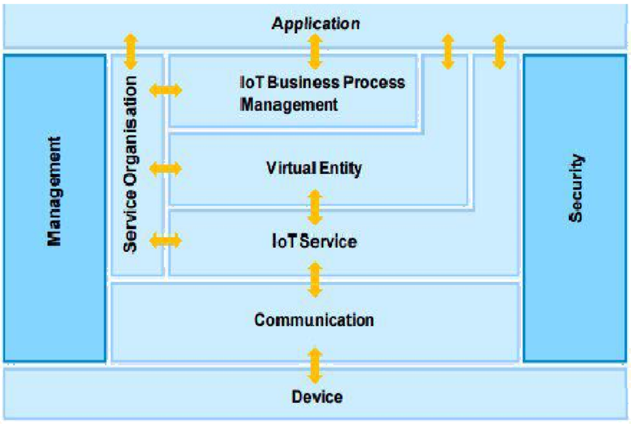

FIGURE 1. Functional model of IoT reference architecture [14].

by the term System of systems (SoS). The sub systems in SoS perform their individual tasks to contribute towards a common goal of the System [80]. Hence, while designing systems in which there are many agents, one should also consider trust and reputation to find a reliable partner. An important feature of Mobile Agent paradigm is how it protects itself from distinct security attacks [7]. A much greater amount of 'device to device' and 'device to services' interaction is expected as a result of emerging pervasive computing services. This interaction will be held in open and dynamic environment calling for suitable models and infrastructures. However, the models should be able to depict spontaneous, positioned and self-adaptive interactions between different agents [23].

When two systems have the same behavioral properties, they may be termed as bisimular. Due to the associated bisimulation proof method, bisimulation is among the leading trends of behavioral equivalences. Bisimulation proof method can be further enhanced using "Bisimulation up-to" techniques [92]. Software engineers use the bisimulation proof method for the verification of the systems or to know about the correctness of the system behavior at the early stage of software development.

Smart spaces are an emerging area of interest for application development in Internet of Things. The use of this approach encourages cooperation among devices and ubiquitous interaction. The properties of smart spaces include Adoption, Communication Interoperability, Semantic Interoperability, Openness, Extendibility and Self-management [16]. Smart spaces provide a fusion of the information world with the physical world by use of semantic-driven resource sharing. In smart space, knowledge from both physical and information world is selectively encompassed to serve for the requirements of users [60].

In Figure 1, the functional model of IoT reference architecture 'IoT-A' is shown. This model divides the functionalities into two main functional groups, transversal and longitudinal. There are seven longitudinal functional groups: device, communication, IoT service, IoT virtual Entity, IoT business process management, service organization and application. There are two transversal functional groups: Management and Security so in other words we may say that there may be up to seven functional layers of a system containing IoT and two non-functional aspects i.e. management and security. Since, for engineering a system with IoT, one may have to analyze the behavior of the sub-systems, system as a whole or components and objects of the system.

Due to the seemingly unsurpassable number of IoT applications and interaction of IoT with a wide range of domains, it seems to have increasingly complex systems with a large amount of data along with more and more objects interacting together. However, such interaction of the objects will be diverse in its manners and heterogeneous in the ways of using and manipulating data. So, appropriate modeling approaches will be needed to verify the system at its initial stage. Complex IoT systems may be an integration of smart objects, software applications, services, business processes, virtual representations and communication along with security and management. Modeling may be required for analyzing such systems or providing visual representation of certain modules to different stakeholders.

The problem while modeling IoT systems is that, due to a combination of different domains it seems none of the modeling approach may alone provide coverage for all aspects. No systematic modeling process exists for IoT. However, before modeling complex IoT systems answers of following questions may be required

- Which of the conceptual modeling approaches have already been used for IoT in isolation or in combination?
- Are there some other techniques which may be used for modeling complex IoT systems?
- How is it possible to use multiple modeling approaches in combination in a hierarchical manner to model complex IoT systems?

To answer these questions, this paper includes a literature review of conceptual modeling approaches for IoT. It attempts to rationalize the use of different modeling approaches and mapping those modeling approaches with the functional model of IoT reference architecture. Following the introduction, the rest of the paper includes an overview of the modeling approaches in section-2.This section also contains definitions of the terms most frequently used by these approaches. In section-3, a comparison of the use of isolated modeling approaches for IoT paradigm has been made. The use of these modeling approaches in combination for IoT has also been presented in this section. In section-4, we map modeling approaches with the functional model of IoT reference architecture and in the end of this section we provide a scenario example to elaborate the application of different modeling approaches in combination in a top-down hierarchy. The last section concludes this study and also suggests its possible future extensions.

II. OVERVIEW OF CONCEPTUAL MODELING APPROACHES

A. AGENT-BASED MODELING

Agent based modeling (ABM) is used in a variety of ways. It is used to model complex systems to predict the behavior of the system against certain courses of action. Due to its simulation friendliness, it has been highly accepted for predicting large scale emergencies [51]. The strong aspect of agent based modeling is its simulation friendly models which increase the analysis capabilities for business process simulations. There are several simulation frameworks for ABM; however, the analysis is dependent on the underlying frameworks. For software engineering purposes, a large number of tools are using component based software engineering techniques [91].

Agent based modeling may be used to analyze complex scenarios like world politics by organizing actors as agents and meta-agents [84]. It may be used for macroeconomic research as well. It helps to model system with heterogeneous interacting agents [90]. This modeling approach has provided an alternative to mathematical modeling where there is heterogeneity in agents and the environment is complex [18]. Agent based models and simulations may be used to analyze the behavior of people in emergency conditions and disastrous situations [113].

In Belief, Desire and Intention (BDI) agents belief is an important feature of the agents. Agents work on the basis of this belief. Belief change has achieved significant attention in recent times. Belief contraction, revision and belief merging are some aspects of this research [33].

B. ASPECT-ORIENTED MODELING

Aspect-orientation in its early stage was used at programming level apart from the modularization purpose. It separates the crosscutting and non-crosscutting concerns and has now been used in development phases of software engineering. Due to its effectiveness, Aspect-Oriented Modeling (AOM) has been proposed in a variety of goals, notations and levels of maturity [89]. Aspect-oriented software development introduces aspect as a modular unit that separates the concerns. For the description of the way in which aspects interact with the rest of the system and other modules, they should have explicit interfaces. The intra-system interaction of the aspect may be homogeneous or heterogeneous [26].

Aspects separate several components in a system. An Aspect may be defined as a requirement partially implemented in more than one classes [45]. "Aspect-oriented" is a complete methodology which supports software development life-cycle at all the phases through model driven architecture [127]. Aspect oriented modeling may be used for Quality of Service modeling on the basis of Graphical notations together with formal notations [70]. It is a powerful tool for modeling security concerns of software. It may be used as a part of security engineering process for securing system against certain attacks [118]. Aspect-oriented modeling may

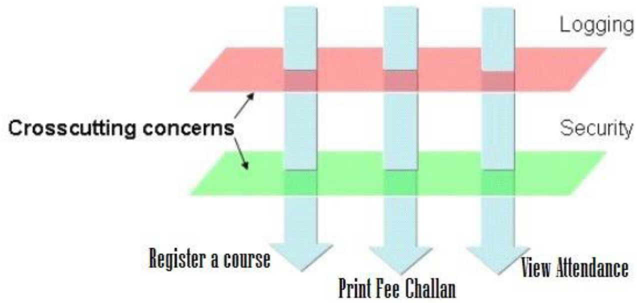

FIGURE 2. Crosscutting and non-crosscutting concerns [87].

play a significant role in the development of distributed systems for IoT by providing support to design, components interaction and integration [24]. Crosscutting concern is the one that is required to perform the core concerns. The difference between crosscutting and non-crosscutting concerns is shown in Figure 2.

Internet of Things offers a number of useful applications for different domains of life including smart city, agriculture, industry and transportation. A number of problems arise like; missing data leads to unreliable outcome due to human intervention errors. Aspect oriented modeling has been used together with multi-agents to tackle the missing data problem in IoT healthcare applications [10]. This modeling reduces the complexity of modeling by dividing it into modules. It improves the robustness, adaptability, reusability and maintainability of software systems. It may also be used for business process modeling [117]. Aspect oriented modeling works on the basis of separation of concerns for improving the quality of models. Common Aspect-oriented approaches are [31]

1) Xerox PARC Aspect-Oriented Programming: its model is based on join points and points-cuts.
2) Subject-Oriented Programming: it is based on the division of the system in subjects and then composition rules for those subjects.
3) Adaptive Programming: the main property of this approach is that the object should interact only with the immediate friends.
4) Composition Filters: it works on the basis of distinguishing between class like objects and filters.

Aspect oriented modeling may be used in integration with formal methods [73]. It may also be used to handle security concerns in software at a very early stage [76]. Aspect-oriented modeling works on the basis of separating the crosscutting and non-crosscutting concerns [97]. Typical Aspect oriented Programming structures include join points, point-cuts, advice and declaration. Join points and advice is used to address the concern and for the sake of regrouping, the advices are taken from point-cuts and advice [67].

C. NETWORK-BASED MODELING

Network based modeling is based on graph theory with an additional information loaded on edges and nodes [79].

This information loaded on nodes and edges helps to identify symmetric and asymmetric relations among objects/nodes. It may also help in characterizing the application leading to the provision of deeper insight into the structure and patterns of data [17]. Network based modeling has been used for a variety of research areas from social sciences to engineering and technology, including public opinion transmission [50], financial systems [52], biomedical process and systems [19], [77], design and manufacturing [125], Genetics [83], Microbiology [119], Strategic relationships [86], geomagnetic fluctuations [131], traffic networks [58] wireless network, sensor network, smart grids, supply chain, transportation systems [99], negotiation methods for suppliers[105] and big data mining [74].

Web 2.0 has made the concept of ''world as a global village'' a reality. Network modeling can be used to study relations in social media networks by using parameters like network density and node degree [3]. Different areas and groups of people have different behaviors to certain situations. Network based modeling may be used to predict the behavior of a certain group against certain situations by analyzing data on social media [47].

While constructing a network for analyzing a system, one needs to breakdown system into subsystems as per requirement of granularity. Afterwards, relations between subsystems are developed. In some conditions, there may be weighted value calculated to determine the strength of relation among nodes [29]. Network-based modeling may be helpful in creating abstract models and understand structural dynamics of a system or product. It can also help in understanding the engineering processes of certain products. It may also help in understanding the environment in which a system will operate [28]. However, networks to explain the relationship of objects in physical space, information space and social space constituent to the characteristics of IoT are rarely found [126].

D. FUZZY-LOGIC MODELING

Generally, electronic devices and especially computers deal with binary values of 0 and 1, meaning either true or false. But, in the real-world, things are not always either black or white. Fuzzy logic describes a way to use linguistic values like very low, low, high and very high. It uses a Membership Degree which describes the truth level or certain parameters [81]. While developing a fuzzy inference system one has to follow three typical steps. In the first step, fuzzification of variables is done in which crisp values are replaced by linguistic terms. In the second step, the rules are formatted which express knowledge. In the third step, the fuzzy values are again converted and this step is called deffuzification [55]. However, a fourth step of aggregation may also be included [94]. Fuzzy logic is very effective for data mining and processing and is used in optimization problems and adaptive systems [2].

Fuzzy modeling provides a transparent interface and a flexible tool for non linear systems modeling using a combination of different modeling and identification methods. Fuzzy modeling interpretation is similar to human way of describing reality. Fuzzy systems are basically knowledge based systems and often use a combination of numerical and symbolic processing. These systems can also allow nonlinear mapping with universal approximates. Hence, fuzzy modeling quantitative data and qualitative knowledge can be complimentarily used in combination. The rule of a fuzzy logic system has an antecedent and a consequent. Reference points in a certain given space are called reference fuzzy sets and the collection of these sets is named as fuzzy partition. The level of granularity of a certain model can be determined by the number of linguistic terms in a partition. Knowledge base of a fuzzy system is a database together with rule base. Fuzzy relational models, Takagi-Sugeno fuzzy models, State-space modeling and Input-output models are the most common ways of fuzzy systems modeling [6]. The fuzzy modeling steps may be explained as: in the first step, aggregation of antecedents in each rule takes place which may use AND connective. In the second step, IF-THEN connective makes implication relation of every single rule. In the third step, ALSO connective is used for aggregation of rules. In the fourth step, the input is used to obtain the output for the inference from the set of rules and in the last step the output is defuzzified [39].

Fuzzy logic may be used for energy aware routing protocols to manipulate the data for finding the best route to efficiently transferring data [93]. It may also be used in Internet of Things based risk monitoring systems for evaluating the cold-associated occupational safety risk [108]. It may also be used for clustering in local networks of IoT and election of cluster head [64]. Moreover, Fuzzy logic works just like human interpretations with more than two states output making it capable of dealing IoT systems like controlling indoor temperature in relation to outdoor temperature in an energy efficient way [71]. It may also be helpful in modeling the qualitative aspect of day-to-day traveling choice of travelers for travel time perception [58]. According to [100], important applications of IoT include safety management, fire monitoring and fire fighting systems. Fuzzy logic was introduced by Lutfi Zadeh to deal with information containing vague and linguistic terms based knowledge. It helps to convert human reasoning in mathematical form with the help of rigorous mathematical notations. In IoT Fuzzy logic may be used in various applications where there are evaluations in likert scales.

E. OBJECT-BASED MODELING

Two terms Object-based modeling and object-oriented modeling have been used for representing different point-of-views. Object-oriented modeling was introduced for software engineering purpose. This technique is used to construct objects using a collection of objects. It models application as well as database development, transforming to unified data model and language environment. It consists of three phases; the first is analysis phase which is abstract level where external details are focused. The second is design phase where further, still limited details are available. The third is implementation phase where the focus is on the construction and functionality of the system [1]. The behavior and physical deployment of a system may be explored with the use of object-oriented modeling. Object-oriented modeling helps in understanding the procedures and detecting flaws in initial stage of software development [101]. From the software engineering perspective, object-based modeling can be well integrated using programming languages. It allows relationships modeling and also offers processing tools. However, the difficulties with this type of modeling are lack of standards as well as validation. The information retrieval is also hard in object based modeling [85].

Object-based Modeling accounts physical objects extending object-oriented modeling. Every component in object-based model is treated as discrete entity. Many descriptions of a system are possible using this type of modeling. The number of attributes used to describe each object can be adjusted determining the sophistication of the model. Rule-based expressions are used to describe the relationships between objects. The global dynamics of the system are achieved by combining the activities of all objects. It may be used for both existent and hypothetical complex systems modeling. It may also be used for investigating the complex as well as general system problems. This approach of modeling has been used for different scientific areas [59]. Smart-object based modeling may be used for IoT systems modeling taking smart objects as fundamental building blocks. Different levels of meta-models may be used for software development of IoT systems [42]. As there are different objects connected through internet, so IoT requires object-oriented privacy model [32].

The assembly modeling system can be automated with the help of modularization, integrated object-oriented templates and automation algorithms. Modularization will be helpful in enhancing robustness, reliability, flexibility and expandability of the system. The object-oriented templates will be helpful in re-usability of components as well as changing components independently. Relational assembly metrics can be retrieved with the help of automated algorithms for the purpose of assembly planning [115]. Object-oriented modeling has also been used for knowledge base applications. To organize and store the knowledge of objects or entities one may use knowledge base. IoT based snow-melt flood early-warning system may use object-oriented modeling approach [40].

F. SERVICE-ORIENTED MODELING

Service-oriented architecture and multi-agent systems in combination provide flexible and intelligent systems development. IoT allows the connection of everyday use objects and devices used by end user through internet in an intelligent way. Intelligent connection of subsystems and devices require Networked Devices, Proper Communication Approaches, Open and Interoperable Standards, Simulation Visualization and Validation Methods, and Secure Infrastructure [114]. Service-oriented abstractions are replacing application-oriented solutions in industry. An emerging challenge in IoT is the modeling and analyzing the reliability of service-oriented systems [15]. Service oriented architecture helps in developing business applications to solve complex problems by separating software functionalities and information sources as modular service components. These service components may be reused as a single service or may be used in combination or aggregation to provide a service. Hence, it leads to a system with more flexibility and independence of components [30]. Service performance requirements in IoT are difficult to meet due to limitation of resources including bandwidth, mode processing abilities and server capacities. Congestion control needs to be properly modeled and analyzed. However, accommodating diverse objects during modeling and analyzing congestion control for service access is quite challenging [53].

OWL-S model has been proposed to be used for IoT in [121] with some extensions. OWL-S mainly consists of service profile, process model and grounding. OWL-S uses four attributes for specification i.e. inputs, outputs, preconditions and effects. Context preconditions may be used for the specification of the context requirements by specifying them as an input [121]. One of the new service-based architectural styles for distributed software systems is Micro-service Architecture. In addition to service identification, composition and provisioning, micro-services are self-contained on the implementation and operation level and exactly one business or technological capability distinct from other services is the responsibility of each micro-service [88]. Service Oriented Architecture Modeling Language, Service Oriented Reference Model, Service Oriented Reference Architecture, Service Oriented Architecture Ontology, Web Services Architecture and Web Service Modeling Ontology are some well-known models, meta-models and ontologies for software services [35].

G. AMBIENT-ORIENTED MODELING

The main features of ambient are Narrowness, Inclusion and Mobility. Narrowness means that an ambient has limited location. Inclusion means that an ambient may include other forming hierarchies. Mobility of an ambient means its ability to change location and during the change in location the ambient takes its sub-ambient with itself. For modeling, an ambient has an identifier and corresponding magnitude of local agents. With the help of dynamic environmental changes, ambient-oriented modeling provides a way to track processes in specific area [48].

Internet of Things is linking physical world objects and virtual world by adding a level of intelligence to physical world objects. Due to a large number of physical objects with vast diversity going to be connected through internet will lead to more complex systems and much complex environment. This combination of objects involves ambient systems and from software development perspective lay in the domain of ubiquitous computing. In [98], Discrete Event Specification

System formalism has been used by modeling and simulation scheme being proposed to manage software development of ambient systems.

H. CONTRACT-BASED MODELING

There are some contracts in which customer has rights but not obligations. Such contracts are normally known as options and two standard options exist i.e. European and American options. Options have different types like standard options, exotic options, multi-assets options and multi-exercise options [27]. If there is firm commitment in contract, then it will be termed as a forward contract. In this type of contract for internet storage providers, the risk at consumer side is higher whereas service provider will have no risk. In spot prices, the provider has high risk whereas, consumer has no risk. Hence, options and vis-forward contracts are comparatively better as risk is distributed among both consumer and provider [38].

Four basic types of contract models are Obligation free contracts, User Centric Contract, Provider Centric Contract and Customizable contract. In obligation free contracts both parties have no restrictions. In user centric contract, there are restrictions on service provider to deliver an up to the mark service. In provider centric contract, there are restrictions on the user to work within given boundaries or according to certain rules. In customizable model, there may be a mix of the previous models with flexibility to bring the change [21].

Contracts may be used within software for guarding one part of the program from other. These contracts monitor the program execution on the basis of the constraints defined by the programmer. Contract systems are habitually used in object-oriented programming languages [103]. For the sake of programming, the contracts may be written for first-order functions or higher order components for checking the truth of the claims made for the flow of values in a program. However, first-order contracts are easy to understand and interpret, whereas high-order contracts may have different interpretation and views about satisfaction. Various notions and languages for contract satisfaction exist [36]. Program contracts describe the intended behavior of all features of a program, whereas in change contract the unchanged features of a program across program versions are not described [123]. Predictive contract mechanisms may be used for frightening against the inconsistency problem raised due to network latency. This network latency is generally produced by state changes communications [128]. For web services the behavioral description can be made through contracts. Using contracts, the successful interaction between the client and services is statically ensured. By using theory of contracts the client and service may be formalized compatible to each other and a service may be replaced by other safely [22].

While developing modern systems in distributed environment, the interoperability of components is ensured with contracts. So, the contracts are used to test the overall properties as well as sub-properties in a system [65]. The concept of an interaction contract between components existed more than a decade ago [12]. E-commerce is also based on contracts. These contracts are mutually agreed by both the service provider and the client. There are rights and obligations mentioned on these contracts on the basis of which the access is guaranteed to the client. Contracts are generally dynamic as new contracts emerge and old contracts end also, while some contracts renew after ending. Certified Policy may be used for the purpose of access control to avoid problems emerge due to dynamism of contracts [110].

In [37] contract-based modeling (CBM) and reasoning of timed safety requirements has been presented. This article states contracts as an important asset for the correct design of systems. The literature review of this i.e. cited article explains that assumption and guarantee or pre-conditions and post-conditions are two sides of a contract. For software engineering purpose, the contracts may be divided into four types, i.e. behavioral contacts, synchronization contracts, syntactical contracts and quality-of-service contracts.

I. DEFINITIONS

Agent:	*An agent may be a physical or virtual Entity which has automaticity and intelligence to play a certain role in specific system functionality.*
Ambient:	*An ambient may be a physical or virtual entity which may act as a container with mobility, inclusion and narrowness.*
Object:	*An Object may be physical or virtual entity with a set of attributes under consideration.*
Component:	*An independent part of a complex system containing a set of entities or individuals which provide certain functionality.*
Contract:	*A mutually agreed condition for an event to happen or a service to be provided.*
Aspect:	*In simple, a concern against the system which is typically a functionality of a system. Relationship A mutual point of interest between two or more objects/ agents/ ambient/ components that force them to act in combination/coordination or integration.*
Fuzzy:	*If a system/ object/ ambient/ component/ agent is considering in between values of true or false, then that may be termed as fuzzy.*
Rule:	*Rule contains a set of instructions for an agent/ ambient/ component/ object/ system to provide a way to deal with specific condition.*
Service:	*A virtual entity with standardized way for inter-operability which cannot be owned but can be consumed.*
Crosscutting:	*A feature/ functionality/ property/ requirement of a system which is required for the quality or execution of the other more than one feature/ functionality/ property/ requirement is called a crosscutting feature/ functionality/ property/ requirement.*

Non-crosscutting:	*A feature/ functionality/ property/ requirement which may not be required for the quality or execution of the other more than one feature/ functionality/ property/ requirement is called non-crosscutting feature/ functionality/ property/ Requirement.*
Device:	*A physical electronic entity which is used to provide specific functionality.*
Meta-agent:	*The agent which reasons about the other agents in the system is known as meta-agent.*
Model:	*A representation of a system, event or a process is provided as a physical, logical or conceptual model.*
Meta-model:	*A model which provides the picture of a process or a functionality of other model is termed as meta-model.*

J. WHEN OR WHERE TO APPLY

From the previous subsections we find that different conceptual modeling approaches are appropriate for different concerns and objectives. In Table 1 we aim in showing the appropriate use of these modeling approaches respective of the aims and objectives of certain model to be developed.

III. MODELING IoT SYSTEMS

The emergence of IoT has disrupted existing business models. From information technology the trends of hotspot shifted towards cloud manufacturing, self service and mass customization [56]. Internet of Things is attracting ubiquitous environments to evolve according to it. Research community is actively involved in conducting research to implement IoT environments. There is a need to design IoT environments in advance to check their compatibility with business goals [66]. The IoT allows devices to interact with applications in an entirely decoupled way. However, maintaining the quality of data being exchanged during the interaction and privacy of data are key issues. Different access control mechanisms may be used for tackling these issues [69]. Context contracts may be designed to keep the quality of the context in such decoupled systems. Such contracts will be customizable at run-time so that new clauses may be added or existing clauses may be edited or removed [72].

IoT environment is composed of heterogeneous devices connected through internet with different intentions and goals. Different groups of objects have different operating systems and work on the basis of different protocols and standards for communication. However, IoT aims at seamless interconnection of heterogeneous devices to provide services for business, logistics, agriculture, management and other social processes. The devices connected may be tightly coupled or loosely coupled depending on their goals. For modeling IoT, Agent based computing can be used in integration of cloud computing paradigm for modeling systems with loosely coupled devices [41]. Heterogeneity of operating system is an issue in IoT. Devices connected through internet have different ways to present data however; it may be a hindrance in communication among devices. Limitation of storage and weak micro controllers are also a hindrance to tackle with heterogeneity [130]. IoT systems may be treated as multi-agent systems where single object has autonomy and smartness. This will result in providing viable solution for programming, development and management of agent-based smart object systems [96]. A term Internet of Agents (IoA) has risen from the combination of internet of things and agent oriented technology. Agents own the property of autonomy and intelligence. This combination has been used by a number of domains including smart industry, smart city and smart health applications. To deal with heterogeneity is one of the major issues faced by Internet of Things in using agents. Software Agents may be used in Internet of Things application to deal with issues emerging due to heterogeneity. Internet of agents may use semantic contracts for development of an intelligent ecosystem or end-user participation is taken as mandatory in an IoA as an evolutionary process [112].

IoT has provided a way of connecting machine to machine as well as human enabling the creation of smart services. Due to large number of devices connection, IoT services seem to

TABLE 1. Suitability of modeling approaches.

Modeling Approach	Suitability of Application
Agent-based Modeling	Where simulation is required, for flexible models and also, easy for molding system with heterogeneous entities
Aspect-oriented Modeling	Normally used in software engineering. Promotes ease of reusability and up gradation of system by modularizing the crosscutting functionalities
Network-based Modeling	Uses Graph Transformation and may be used to identify symmetric and asymmetric relations among objects/nodes
Fuzzy-logic Modeling	Most appropriate for non-linear systems modeling and where there is data related to human behaviors
Service-oriented Modeling	For modeling modules as services and micro-services. The focus of each service or micro-service is on the provision of the functionality
Object-based Modeling	For basic physical devices interacting with the system or for smaller modules of software which combine and interact with others to provide the desired functionality of a system
Ambient-oriented Modeling	For the purpose of modeling where the entities involved in model are working as containers and are changing location within a limited spatial location
Contract-based Modeling	Representing components, modules or devices in graphical form with pre and post conditions

be more complicated. For analyzing such services no specific tools or techniques exist [120]. Internet of Things enclosure is continually expanding with the addition of new devices, services and systems every day. Although no systematic modeling and simulation process exists, yet agent based modeling and service oriented modeling paradigm can be used together for such systems [43]. Agent based modeling is effective for modeling complex systems due to allowing deep investigation of components interaction [57]. The devices in IoT can sense environment, interact, cooperate and coordinate actions with other devices. These devices and actions may be classified in different types as agent, context, model, service, social and object [111].

Scalability is one of the key features of internet of things and hence it is difficult to handle while modeling IoT system through traditional approaches where it is difficult to maintain details at node level [5]. The IoT devices may be fully or semi-automated with a minimal human input. It leads to open and distributed systems where new devices may be added. Blockchain is a technology which supports securing the system while keeping it open. It may be used for IoT to keep connections without an intermediary [63]. Blockchain may be used for access management in IoT. Key properties of Blockchain are Decentralized control, Data Transparency and auditability, Distributed and Replicated Data, Decentralized Consensus and Security [82]. Smart contracts are used by Blockchain which help in self-enforcing the agreement before any transaction [62].

Keeping the end user data privacy is a critical issue in IoT. End user even does not know who is accessing his/her data and where it is used. End User License Agreements are normally used for implementing the informed consents but it has many limitations. Usage control policies may be defined and monitored to overcome these limitations [78]. Contract monitoring services may be used to control the data flow monitoring and for the specifications of the contracts [11].

According to [106], Servegoods are physical objects with service-oriented layer. Connecting the Servegoods through internet and adding sensors along with automicity leads to internet of things. Real Time decision making and artificial intelligence have an important role in IoT. According to [116], in multi-agents systems, sometimes the state of one agent is dependent on the change of a state in another agent. In this scenario the agent keeps the record of the other agent's state. This sort of learning is named as coordinated learning. In large-scale internet of things coordinated learning may be an important technique where the agents are not self-adaptive.

The devices connected in Internet of Things provide real-world services. The integration of these objects with digital world and accessibility of these heterogeneous physical objects on large scale demands structured and machine-processable approach. In [34], a semantic modeling approach has been presented for different components in an IoT framework. Automated association mechanisms may also be used to integrate model into IoT framework. Task model is used to elaborate the work-flow to accomplish a task against certain goals by users. This model is effective for designing the interface against certain user requirements [20]. Internet of Things technology has attracted enterprise systems for adoption in Production Logistic and Supply Chain System (PLSCS). Development of such systems involves numerous participants. There is a lack of unified coherent modeling frameworks for such systems. The modeling complexity in such systems may be reduced by using layered and top down modeling [109].

According to [68], the three layered architecture of Internet of Things may be described as application layer, network layer and sensing layer. The application layer is concerned more about business process modeling, workflows and the functionalities for the end user. The network layer is composed of service entity arrangements, virtual entity & information, and resource module. Service entity arrangements control access to service. Virtual entity and information connects the virtual entities for a specific service on the basis of available information. The resources module notifies services and application software about events. The sensing layer contains devices which collect the information from the real world. At edge nodes, the consensus decision for services may be difficult due to the lack of information or overloading of information to use for the deployment of service-oriented internet of things [68]. The categories of services provided by internet of things according to characteristics may be divided into Networking Service, Informational Service, Operation Service, Security Service and Management Service [124].

Internet of things has also affected the traditional E-commerce business models. From shipping of goods to retail stores and inventories IoT devices are playing vital roles in IoT based business models. However, still there is much to improve in these business-models and researchers are focusing on this. Blockchain and smart contracts have made the systems of payments more atomized and in future seems to play a vital role in IoT based business models [129]. As IoT faces requirement and development issues, agent-based modeling may be useful in tackling with development issues [95]. Currently, there is no standard modeling methodology available for internet of things. Agent-based modeling in conjunction with network-based modeling can be used to model specific scenarios of internet of things [13]. There is a need to use agent-based, adaptive parallel and distributed simulation approaches together. Also, for a more detailed and more realistic analysis there is a need to use multi-level modeling [4].

In open systems, new devices may continuously join or leave the system and create impact on operating conditions. Hence, open systems operate in trustless environment with heterogeneity and conflict of interests among participants, increasing the possibility specifications mismatch. In such systems, generally there are two types of participant service provider and service consumer. The interacting agent may be designed and owned by different teams. Participants may enter or leave at different times and also different organizations may form coalitions to attain their goals [25].

TABLE 2. Techniques previously used for conceptual modeling of IoT systems.

Technique	Security/ Privacy	Applications	Network	Services	Data Related	Contracts Centered
Agent-based Modeling (ABM)	-	[93]	-	-	-	[76]
Aspect-oriented Modeling (AsOM)	[23][116]	[100][23]	-	[9][8]	-	-
Network-based Modeling (NBM)	-	-	[124]	-	-	-
Fuzzy-logic Modeling (FLM)	[59]	-	[91][62]	[106]	[2][92][69]	-
Object-based Modeling (OBM)	[31]	[107][96]	-	-	[39]	-
Service-oriented Modeling (SOM)	-	[43]	-	[105][43]	-	-
Ambient-oriented Modeling (AOM)	-	[47]	-	-	-	-

There are certain differences in modeling considerations for internet of things services and general software services. In general software services, the modeling does not need consideration of routing process as, there is a centralized Universal Description, Discovery and Integration (UDDI). However, in IoT there are decentralized and heterogeneous devices so routing is an important parameter in IoT service modeling. In general software services modeling, the focus is on functionalities provided by the service; however, in IoT case the devices are also an important consideration. Another point of consideration with devices/objects may be that a device or an object may be capable of providing more than one service but may not be able to provide more than one service at the same time [122]. An approach to service modeling for internet of things has been proposed in [44]. This approach uses two steps modeling; in the first step meta-modeling is executed while in the second step operational modeling is carried out. In the modeling stage, for descriptive purpose high level representations are provided. In the operational modeling stage the services are formalized using specific notations for assistance in further phases. Agent-based modeling may be combined with service-oriented architectures to deal with the complexity of cyber physical systems. This combination involves three stages; inter-model simulation, intra-simulation and the individual agent's simulation and modeling [104].

On the basis of our review, we have divided the key aspects to model in internet of things systems and environment in different categories as shown in Table 2. In this table the use of different modeling approaches has been compared across these aspects and the description of this use is as following:

Security/Privacy Modeling: Security and privacy is counted as a major issue to deal with in IoT. So, considering and representing this is an important aspect to model while modeling IoT systems. From our literature survey it seems that researchers have been conducting research for this aspect of IoT since 2014. It seems that Aspect-oriented Modeling, Fuzzy-logic Modeling and Object-based Modeling have been used for this purpose.

Applications Modeling: The interest of end user is always in the reliable, adoptable and easy to use software application. Hence, to meet the end user expectations and to develop up-to-the mark application, one needs to model application properly. Agent-based Modeling, Aspect-oriented Modeling, Object-based Modeling and Service-oriented modeling have been used by research community for modeling IoT applications.

Network Modeling: As IoT aims to involve trillions of devices connected through internet so, modeling connections and links is an important aspect. For example, analyzing which of the routing protocols may be effective in a specific scenario and for a certain system. Network-based Modeling and Fuzzy-logic modeling have been used for analyzing the networks related matters.

Services Modeling: Services is an important functionality in IoT. These services will be slight different from web service as these services include physical devices as well. For example there may be a temperature sharing service which shares temperature of a specific building. So, this service will have a software application as well as some temperature sensors. Aspect-oriented Modeling, Fuzzy-logic Modeling and Service-oriented Modeling have been used to analyze services in IoT.

Data Related Modeling: It is expected to have trillions of devices connected through internet using IoT. These devices will be capable storing and sharing information. This storing and sharing of information at such a large scale will generate a larger amount of data. So, modeling that data and extracting useful information and manipulating data in an effective manner require using appropriate modeling techniques. Fuzzy-logic Modeling and Object-based Modeling have been used to model and analyze IoT data centered applications and scenarios.

Contracts Modeling: Contracts play an important role when there occurs a deal between two or more stakeholders. For software and web services, service level agreements are used as contracts. Design by contract is a software development methodology which uses contracts throughout software development life-cycle. Blockchain uses smart contracts for providing open environment for interaction among trustless parties. Provision of services in IoT will also require contracts in future. The contracts will be helpful in the monitoring of the quality and guarantees of services. Agent-based modeling has been used to model contract centered systems.

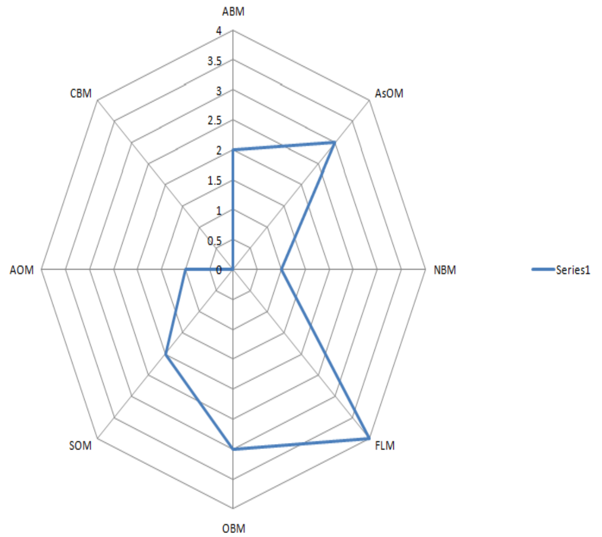

FIGURE 3. Graphical representation of modeling approaches used for IoT.

Figure 3, shows the graphical representation of Table 2. The radar graph shown in this figure has eight variables. These all variables are conceptual modeling approaches. The graph shows the use of these modeling approaches for IoT depicted by literature survey.

In the above description we can analyze that none of the conceptual modeling approach in isolation may fulfill the requirement of all the aspects. Every modeling approach has some limitations. However, some researchers have used a combination of different techniques to model IoT systems, scenarios and processes. The use of modeling approaches in combination is as following:

Agent-based Modeling: Agent-based Modeling have been used for IoT systems and processes modeling in combination to various approaches including Aspect-oriented Modeling, Network-based Modeling, Fuzzy-logic Modeling, Object-based Modeling and Service-oriented Modeling [10], [13], [61], [43], [41], [114] [104].

Fuzzy-logic Modeling: Fuzzy-logic Modeling has been used in combination to Agent-based Modeling. Also, use of Service-oriented Modeling, Ambient-oriented Modeling and Fuzzy-logic modeling has been seen in combination [108]

IV. HIERARCHICAL ORDERING OF CONCEPTUAL MODELING APPROACHES

In this section we discuss the application of conceptual modeling approaches for IoT systems. This section is divided in three sub-sections. In the first sub-section we provide definitions of the commonly used terms for the sake of avoiding confusion. In the second sub-section we provide mapping of these conceptual modeling approaches against the functional model of IoT reference architecture. In the third sub-section we provide a scenario to elaborate our mapping of conceptual modeling approaches with IoT-reference architecture.

Figure 4 shows meta-model of modeling system with IoT. It starts with Internet of Things based system which is under consideration. So, this system of interest will have some hardware devices. These devices will definitely have a role in the model. There will also be some stakeholders who will have interest in the system. These stakeholders may have two types of concerns with the system. The first type of the concern will be non-crosscutting concern and the second type of the concern will be the crosscutting concern. These concerns will be programmed in application. There will also be a communication mechanism for communication among device to device, device with the application and also the application with the stakeholder. The requirements for the model may vary based on the purpose of the modeling. On the base of the purpose the type of modeling approach will be selected. Hence, model may use either of the modeling approach which fulfills the requirement.

A. MAPPING MODELING APPROACHES AGAINST FUNCTIONAL MODEL OF IoT REFERENCE ARCHITECTURE

Model-based engineering is used in different fields of engineering i.e. Software Engineering, System Engineering, Mechanical Engineering and Electrical Engineering. Sensors used in Internet of Things are usually electronic components whereas, actuators are electronic devices which enable or disable mechanical part of a system to perform certain action and the tags are chips which are linked to application manipulating data. Hence, complex IoT systems may be developed by different teams i.e. team of system engineers, team of software engineers, team of electrical engineers and team of mechanical engineers. Due to collaboration of teams from different domains issues like communication gap may rise. Secondly, analyzing the system at the design stage will be a difficult task. Models may provide a visual representation or virtual prototyping of the system.

Based on literature review and discussions in previous sections we propose the possible use of different modeling approaches at different layers of functional model of IoT reference architecture while designing a system with IoT in Table 3. This mapping may be used to search for an approach which have already been used for similar purpose or may be used for specific purpose. It will also help in using a combination of modeling approaches in hierarchy i.e. a separate approach for every layer of IoT-A reference architecture or using a single modeling approach at maximum layers and combining it with other suitable approaches in remaining layers according to expertise of teams or requirements. Although, this mapping may not be sufficient to match with the details and easiness of a framework yet, it seems beneficial for technically sound professionals of domain. The description of derived knowledge is as following:

The functionality groups described by [14] in functional model of IoT-A reference architecture may also be termed as crosscutting and non-crosscutting concerns with respect to aspect-oriented modeling in place of the terms being used i.e. transversal and longitudinal. We may also say that service

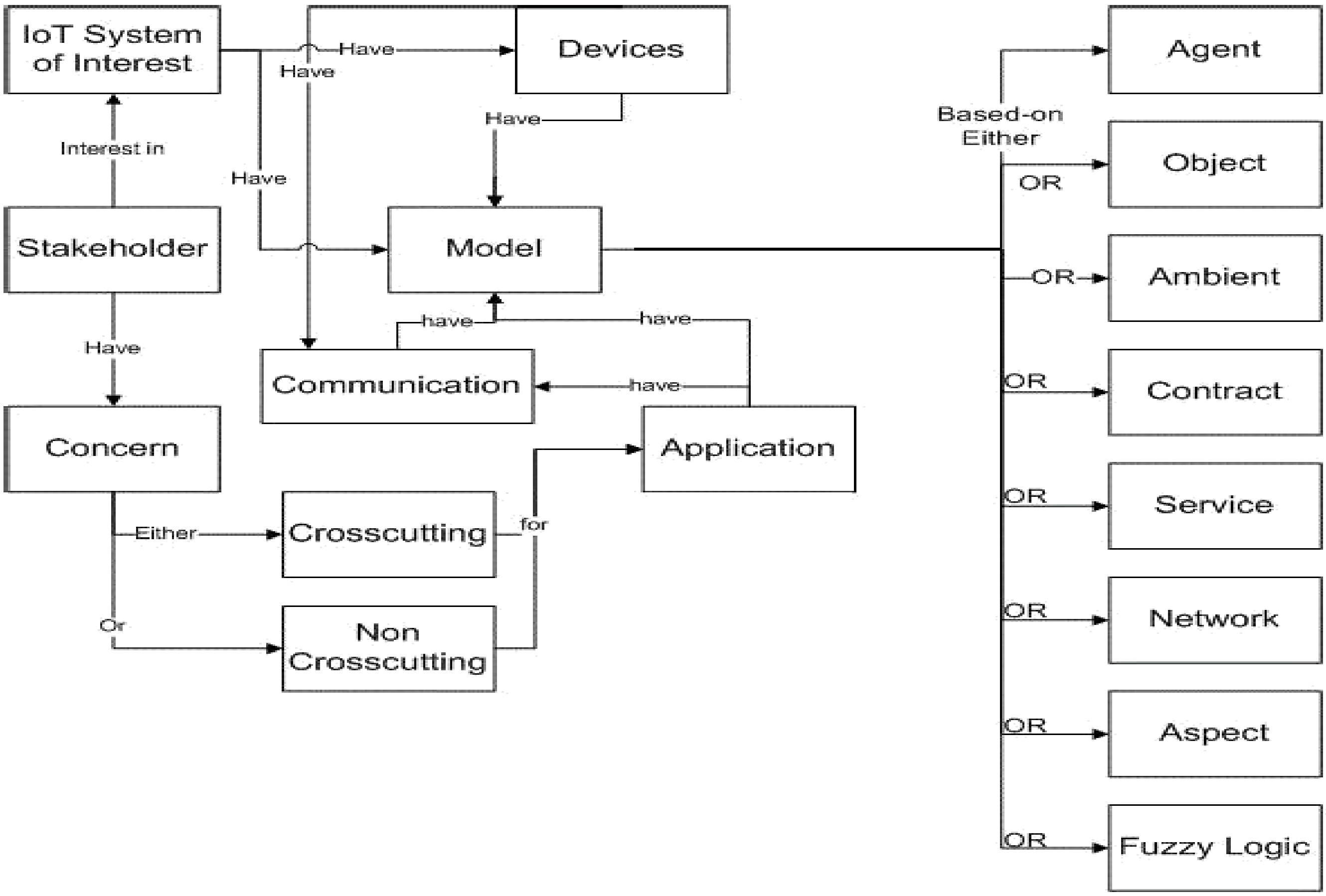

FIGURE 4. A meta-model for modeling an IoT system.

organization is also a crosscutting concern to IoT Service, Virtual Entity and IoT Business Process Management.

As we elaborate the device functionality group into sub-groups termed as agents, ambient and objects, we may expect that agent-based, ambient-oriented and object-based modeling may be used individually or in-combination according to specifications of the devices being used for the desired functionality of the system under consideration. Figure 5 explains this mapping. In this figure on the top we show IoT devices. There may be two types of IoT devices. First type is termed as basic devices which are sensors, actuators and tags. Second type is Industrial and Enterprise IoT devices which include a large number of IoT devices designed by using the basic IoT devices. Industrial and Enterprise devices include smart watches, smart meters, smart televisions and smart cars. Now, the basic devices may be treated as objects and hence object-based modeling may be used to model at this level. Whereas, Industrial and Enterprise devices may be of two types i.e. intelligent and autonomous devices which don't fulfill the criteria of ambient are treated as agents and while modeling system with such devices, agent-based modeling approach may be used. Those devices which fulfill the criteria of ambient i.e. have mobility, inclusion and narrowness will be treated as ambient in model and ambient-based modeling may be used.

In the communication layer, network-based modeling and fuzzy-logic modeling will be helpful in sorting symmetric and asymmetric relations as well as modeling the routing protocols. So, device layer in combination with communication layer refers to a possibility of use a combination of some from agent-based modeling, ambient-oriented modeling, object-based modeling, fuzzy-logic modeling and network-based modeling.

Above communication layer, there are IoT services and hence service-oriented modeling, aspect-oriented modeling and fuzzy logic modeling best suites this portion of functional model. These techniques have already been used as shown in the column "Services" of Table 2. So, when starting from base i.e. device layer, we may say that while modeling this portion in combination with the underlying layers, there may be a need to use service-oriented modeling, aspect-oriented modeling or fuzzy-logic modeling in combination with approaches described in above postulate.

Next to IoT service layer there is a virtual entity layer. This virtual entity may be a representation of any agent, ambient or object and its interactions also, including its environment

TABLE 3. Application of modeling approaches at layers of the functional model of IoT reference architecture.

Layer	Mapped Modeling Approaches	Description
Devices Layer	*Object-based Modeling* *Agent-based Modeling* *Ambient-oriented Modeling*	*Devices depending on their type i.e. Tags, Sensors and Actuators as Objects* *Agents have intelligence and Ambient have inclusion narrowness and mobility*
Communication Layer	*Network-based Modeling* *Fuzzy-logic Modeling*	*Representing networks as graphs with extension of details at nodes, Complex mechanisms and data manipulation by FLM*
IoT Service Layer	*Service-oriented Modeling* *Aspect-oriented Modeling* *Fuzzy-logic Modeling*	*Modeling Services based on provide interface, separation of crosscutting and non-crosscutting provides and complexity resolution*
Virtual Entity Layer	*Object-based Modeling* *Fuzzy-logic Modeling* *Agent-based Modeling* *Ambient-based Modeling*	*Creation of Virtual Objects resembling to real,* *Extracting information in an efficient way* *Creation of virtual intelligent and autonomous objects* *Creation of virtual ambient*
IoT Business Process Management Layer	*Aspect-oriented Modeling* *Agent-based Modeling*	*Business process models, work-flows and process automation mechanisms*
Application Layer	*Aspect-oriented Modeling* *Object-based Modeling* *Agent-based Modeling* *Contract-based Modeling* *Service-oriented Modeling*	*Separation of concerns, Modularization through creation of objects, combination of objects as components or agents, dependencies and pre and post conditions and actions to do, independent components without require interfaces*
Service Organization	*Service-oriented Modeling* *Contract-based Modeling* *Aspect-oriented Modeling*	*Aggregation of different services, negotiation boundaries for the services, contracts about services* *Orchestra role for keeping sequence* *Separating the access areas about different stakeholder*
Security	*Aspect-oriented Modeling* *Contract-based Modeling* *Fuzzy-logic Modeling* *Object-based Modeling*	*Pre and post conditions for interaction with system* *Handling interaction among trustless parties* *efficient utilization of data*
Management	*Contract-based Modeling* *Agent-based Modeling*	*Finding faults in the system and reporting and resolving* *Prevention of system failures and fulfilling requirements*

of operation. The virtual entities may be used to extract and manipulate the data in a way similar to a real one. So, at this level we may use agent-based modeling, ambient-oriented modeling or object-based modeling as per features of the virtual entity. However, for the manipulation of the data and especially human data related to human behavior Fuzzy-logic modeling seems to be more suitable.

Above virtual entity layer there may be another layer termed as IoT Business Process Management layer. At this layer business processes are modeled and workflows are defined. Agent-based modeling and Aspect-oriented modeling may be used for modeling of processes and workflows at this layer of IoT system as discussed in the previous sections.

There is a functionality group parallel to Service layer, Virtual Entity layer and Business Process Management Layer. This group is named as Service organization. At this level, service-oriented modeling may be used for the modeling of all entities interacting with the service and functions like services orchestrations and services aggregations. Every service contains some contracts which are generally termed as Service Level Agreements. For modeling this portion based on these contracts, contract-based modeling may be used.

Aspect-oriented modeling may be used to define interfaces of services and for the separation of the concerns. There is another functionality group termed as Security. Security of a system is an important aspect to model especially when connected through internet. Security contains different functions

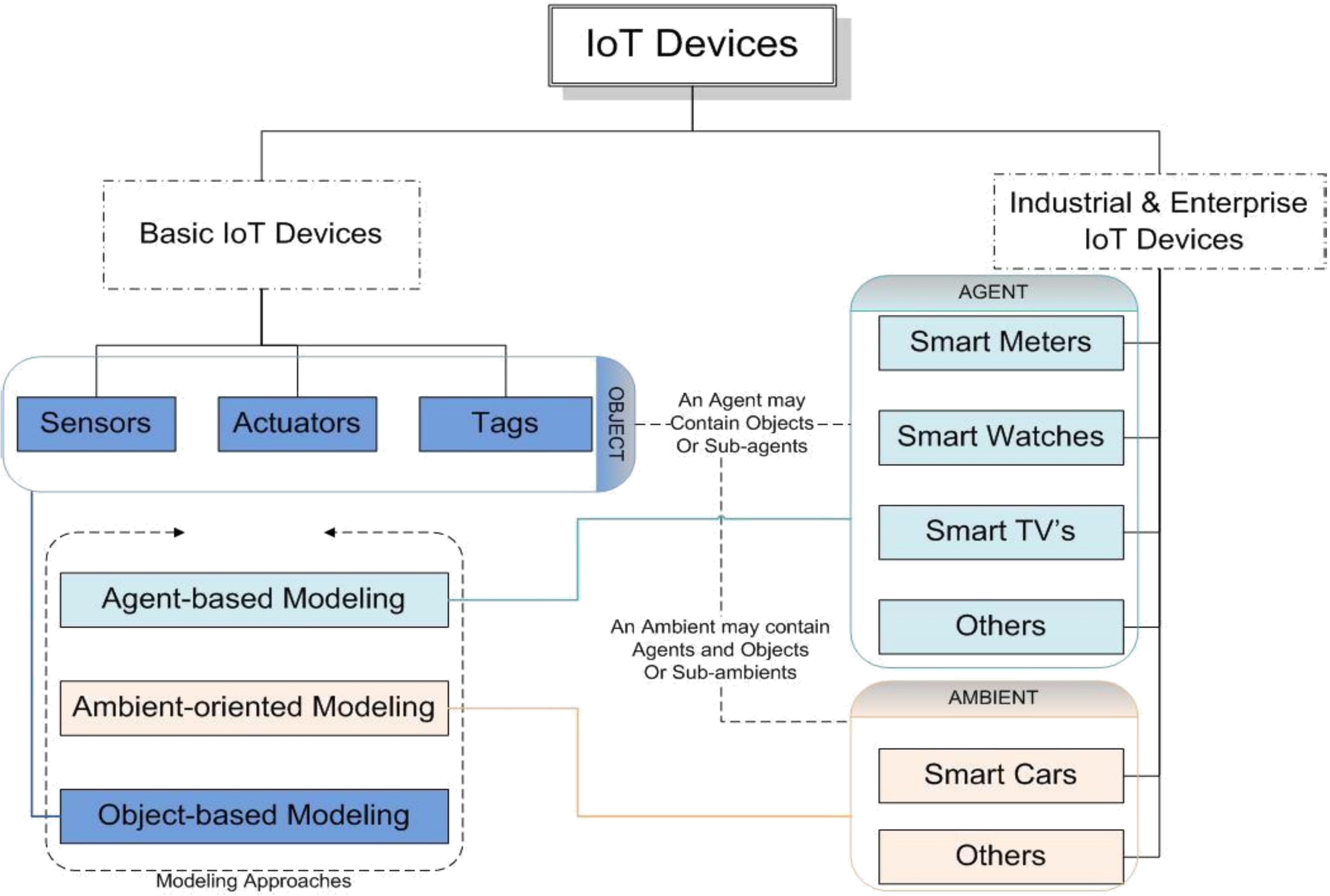

FIGURE 5. Device layer mapping with modeling approaches.

like authentication, authorization, data security and communication security. Aspect-oriented modeling may be used for access control management of IoT system. Contract-based modeling may be used when this aspect of system is modeled based on the pre-conditions and post-conditions of every action. Object-based modeling and Fuzzy-logic modeling have been previously used for the security aspect as shown in Table 2.

Management functionality group is another parallel group, which is required to perform functions at multiple layers. This functionality group contains functions like faults handling and monitoring performance against certain requirements. Contract-based modeling may be used to increase the correctness of the system. Agent-based modeling may be used to find faults in the system at early stages of development i.e. design and implementation.

The top layer in IoT-A reference architecture is named as Application layer. This layer provides an interface to the user or other system to interact with the IoT system. It may also contain the logic of interaction among various components and the procedures of interconnection between them. Model Driven Architecture is used in combination to Service-oriented Architecture may be fruitful to address the challenging issues currently faced by enterprise information systems [107]. So, model driven software development is based on models which guide during development, testing, validation and software evolution phases. At this layer Aspect-oriented modeling may be used to separate the crosscutting and non-crosscutting concerns of a user. The crosscutting concerns may be scattered over different layers, however designing them as modules will promote reusability and easy to manage. Service-oriented modeling may be used if the service-oriented architecture for the application is aimed. Object-based modeling may be used if object-oriented software development methodology is likely to be adapted. Agent-based modeling may also be used for the purpose of model-driven software development by creating agent-based model of the application and analyzing the model through simulations. Contract-based modeling may be used for enhanced correctness measures of the system or using design-by-contract approach of software engineering.

While using these modeling approaches in hierarchical manner, management and security are crosscutting concerns across various layers. So, before choosing a modeling approach for certain layer the crosscutting concerns overlapping the layer should also be considered. There may be certain cases in which the chosen modeling approach may not be suitable for the crosscutting concern. So, intersecting approaches which may be suitable for both crosscutting and non-crosscutting concerns should be chosen. In other case separate models for crosscutting functional group and non-crosscutting layers may be formulated. In this case the model of non-crosscutting layers should consider the models for crosscutting functional group.

From the above derived knowledge, a lack of unified modeling approach for IoT when modularization of IoT system can be seen. Secondly, there will be a need of platform specific and platform independent modeling for better representation of system for different viewpoints. This research considers different modeling approaches opening a way to formulate ontology for complex IoT systems modeling. So, these points raise a requirement of a unified framework for modeling complex IoT systems. Such framework needs to address the requirements at different levels and define rules to use particular modeling approach in certain conditions. It seems that framework with hierarchical modeling may provide maximum coverage to different aspects of complex IoT systems by opening an opportunity to use multiple modeling approaches at different levels.

B. SCENARIO

Let us consider scenario of service-oriented IoT application in the universities located in twin cities of Pakistan i.e. Islamabad and Rawalpindi for the purpose of collaboration and resource sharing. There are almost twenty six Higher Education Commission of Pakistan (HEC) recognized universities in twin cities i.e. twenty one in Islamabad and five in Rawalpindi. Suppose there emerged a consensus among universities to be smart and share resources. To be smart includes, all universities have smart parking, emergency respond systems, smart waste management systems, smart class rooms and smart air quality monitoring systems. Secondly, these universities have signed a Memorandum of Understanding (MOU) to share their free resources with each other. Now, consider a scenario of this cooperation among universities where Air University Islamabad is organizing a three days international conference. It is expected that two hundred additional vehicles will arrive university. University has a parking space of just one hundred and twenty additional vehicles. Hence, Air University requires arrangement for this additional parking space. Meanwhile, there are some other universities at a walking distance from Air University i.e. Bahria University Islamabad and National Defense University Islamabad. Bahria University has a free space of two hundred and thirty vehicles. Air university pay rent for the free space and accommodate additional vehicles there. Also, Air University needs some additional garbage collectors due to the arrangements of refreshments and lunch within university as well as increase in number of visitors. NDU can provide the required garbage collectors. Now, these are some services provided by other organizations. Definitely they will have an agreement and have some transaction of money. Moreover, there is a need of shuttle service from Rapid-bus transport station to the University for the people who are using public transport.

This system may better be modeled by hierarchical modeling. The system is composed of subsystems and there is a need to model the system at abstract level as well as modeling subsystems and then down the device or object level. There may be two ways of hierarchical modeling, top-down and bottom-up.

We start from top-down and at the top there will be a software application. This application will provide interface to the users i.e. administration of different universities. Here separation of concerns may be determined by using aspect-oriented modeling. The crosscutting concerns may include security, login, reliability etc. and the non-crosscutting concerns may include searching of available resources, publishing of extra resources and binding of purchased resources. Object-oriented modeling may be used if there is an intention of developing application through object-oriented software engineering. In object-oriented modeling different modules or classes will be generated and level of cohesion and coupling will be determined. Object-oriented model may have a login class, a resource binding class, resource publishing class and transaction class etcetera. Contract-based modeling may be used for application development by defining different components and binding those components through contracts. The contracts will show the conditions of the interaction of the components. The "requires" and "provides" interfaces of the components will provide a base for defining the contracts. The contracts will be the conditions on the basis of which certain component will make any decision. Agent-based modeling may also be used at this layer by treating different components as agents and defining rules about the execution of the components. Agent-based modeling will help in simulating the model and analyze the behavior of different components according to the rules. These models will lead to the model-driven development of software engineering practices.

Contract-based modeling may be used to model the application based on contracts. Figure 6 and figure 7 show rules for visual contracts of resources renting process designed in Attributed Graph Grammar (AGG). There are eight rules figure 6 shows four rules i.e. create HEC, add University, Map University and add Resource. Figure 7 shows rules for mapping resources, requesting resources, acquiring resources and sending bills. Figure 8 shows the type-graph of visual contracts for these visual contracts and Figure 9 shows the start-graph of this model.

From top to bottom, second layer is the business process management layer where the business process model is formulated. At this layer, the procedures of renting out the resources will be defined. There will be workflows for the business processes. Agent-based modeling may be used at this stage. Agent-based simulations may be used to analyze

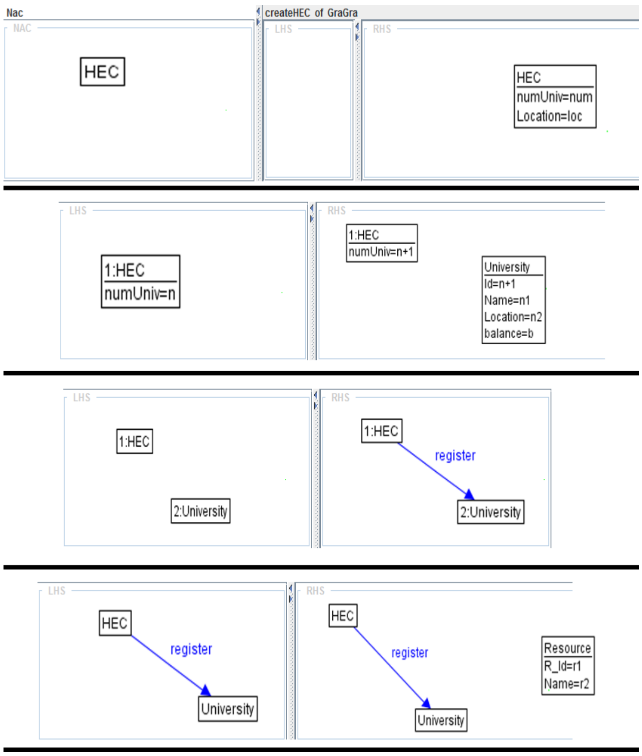

FIGURE 6. Visual-contracts for renting-out resources (part-1).

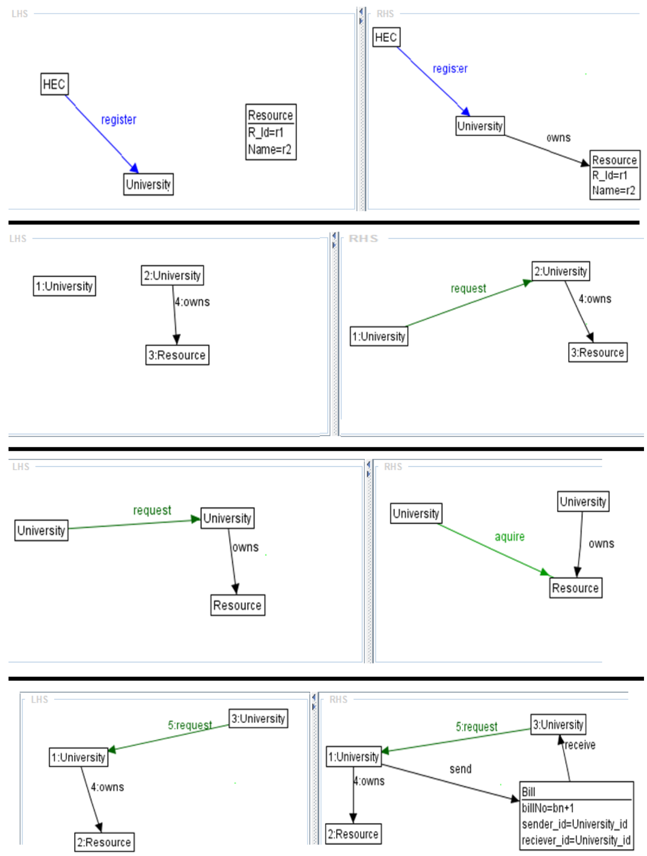

FIGURE 7. Visual-contracts for renting-out resources (part-2).

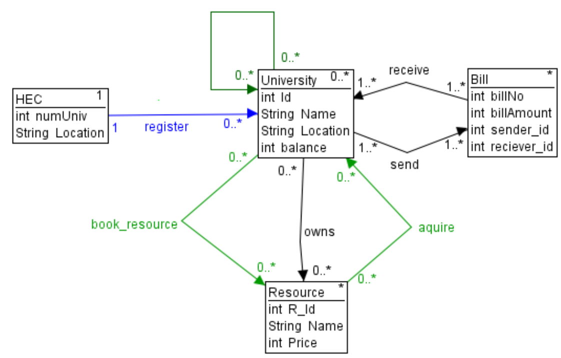

FIGURE 8. Type-graph of visual-contracts for resource renting.

the workflows and business processes. Aspect-oriented modeling may be used to separate concerns among various stakeholders. These models will provide a base to the application layer modeling. Howeverasome cases the business process layer may be eliminated shifting the logic from this layer to the application, virtual entity and service layer.

Below business process layer is virtual entity layer. At this layer virtual entities are modeled. So, here we have virtual representation of the devices either objects or ambient and agents. The data collected from different sensors is represented in the form of virtual entities so that it can be used in an efficient way. A virtual representation of agents, ambient and objects as shown in Figure 11 may be here as, we may use agent-based, ambient-oriented and object-based modeling in combination. We may represent different sensors data in relation with creating virtual objects against each sensor. The data collected from every smart entity will encourage us to create virtual agent against it. However, data collected from the entities with mobility, narrowness and inclusion will encourage us to create virtual ambient against it. There will also data related to human, e.g. near which garbage unit the number of people is expected to increase at a particular time. So, when we have data related to human behavior then the most efficient way to model is fuzzy logic modeling. Hence, at this level we may use agent-based modeling, ambient-oriented modeling, object-based modeling and fuzzy-logic modeling in combination.

Below virtual entity layer is IoT service layer. At this layer services will be modeled. Figure 10 shows use of different micro-services i.e. Garbage Collection Vehicle, Smart-parking System, Smart-trash and Air-quality monitoring system. The difference of IoT services from software services is that IoT services are dependent on physical devices. So, service-oriented modeling, aspect-oriented modeling and fuzzy-logic modeling may used at this layer to model services.

Below service layer is communication layer where the communication protocols will be modeled. Fuzzy-logic modeling may be used for defining effective routing protocols. Network based modeling may be used for relations

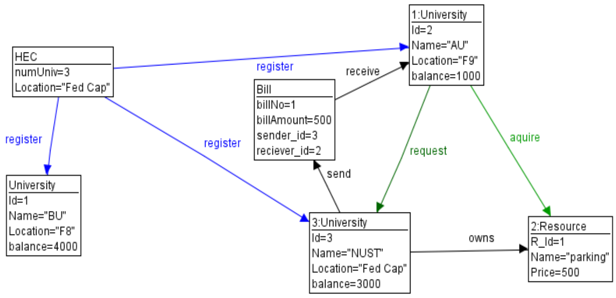

FIGURE 9. Start-graph of visual-contracts for renting-out resources.

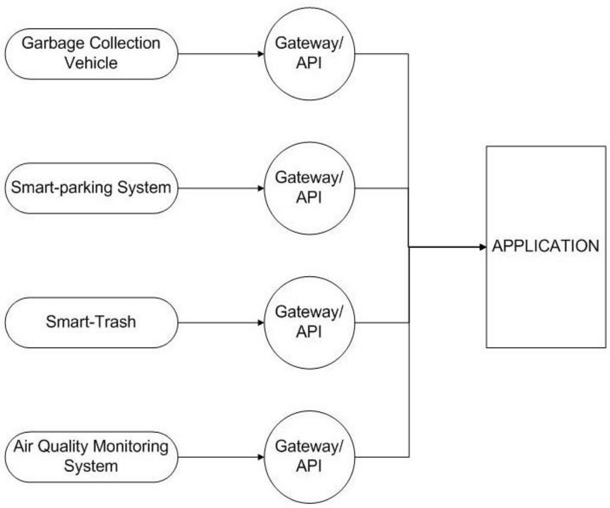

FIGURE 10. Modeling at service layer using different micro-services.

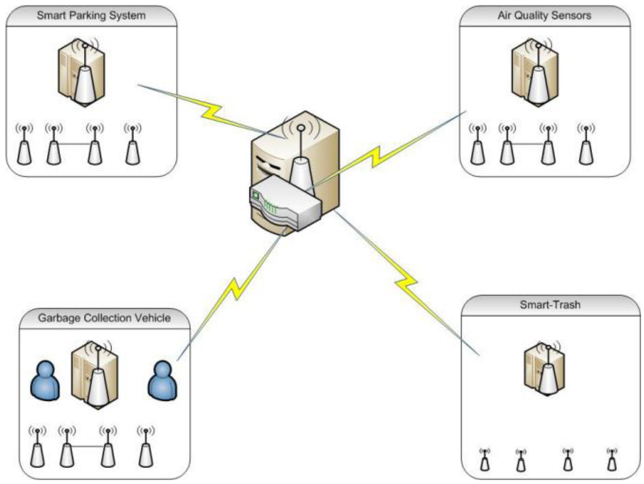

FIGURE 11. A use of agents and ambient as interacting resources.

among different objects, agents and ambient. So, modeling at this layer will use object-based modeling, agent-based modeling and ambient-oriented modeling in combination with network-based modeling and fuzzy-logic modeling. In [13], agent-based modeling has been used in combination with network based modeling for analyzing the energy consumption in IoT especially during the communication.

Below communication is device layer. As we categorized the devices earlier as ambient, agent and object so, here we place sensors as objects. Figure 11 shows a combination of agents and ambient for modeling at this level. A combination of related sensors which are grouped together to perform certain task compose an agent. And according to our definition of an ambient, all the physical entities which own the properties mobility, inclusion and narrowness are placed in the category of ambient. The objects may be Fill-level sensor, smart waste Flame Sensor and Humidity Sensor belonging to the agent smart trash. The agent smart parking has objects including In-ground sensor, surface-mount sensor and vehicle counting sensors. The agent indoor air quality control will have object Air quality sensors for indoor air. Now there is another smart device named as Garbage Collection Vehicle. This device will be placed in the category of ambient due to its properties. Garbage Collection Vehicle can move from one place to the other which shows its mobility. The movement of this vehicle is in a limited space i.e. collecting garbage from garbage units and throwing it in disposing units. So, at this level of the system object-based modeling, agent-based modeling and ambient-oriented modeling will be used in combination. The rules for agent-based simulation may include

- When smart-trash is full, it broadcasts a message to garbage collection vehicles.
- The nearest garbage-collection vehicle in "ideal state" corresponds to the message and changes its status from ideal to "task assigned".
- After collecting the trash the status of the smart-trash changes to "empty".
- If more than a certain number "n" vehicles are in "ideal state" then park the exceeding vehicles and driver may move out of the vehicle.
- If a vehicle in "ideal state" is moving near-by a smart-trash which is half filled then, the vehicle collects the trash from it and then move on.

V. CONCLUSION AND FUTURE DIRECTIONS

Internet of Things has an openness to integrate with different computing paradigms and other fields. Its uses in different domains will encourage different viewpoints about it. These differences of viewpoints, diversity in adoption and openness of integration makes it almost impossible for any single conceptual modeling approach to give coverage up to hundred percent. The coverage of different approaches varies depending on the viewpoint, adoption and use. This paper focuses on the possible coverage of different conceptual modeling approaches and appropriation of use of these approaches for IoT systems. Different terms are mixed, however this paper also provides definitions of the frequent terms being currently used while modeling IoT systems. This paper will provide a base for IoT researchers and engineers focusing on modeling and searching for appropriate modeling approach.

This research opens a way to formulate ontologies for IoT systems modeling. It also leads to a unified framework for modeling IoT systems which covers most of the aspects of modeling IoT systems.

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