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Developments in Cognitive Internet of Things and its Application in Smart Cities

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Abstract - The recent evolution of IoT being 'Cognitive Internet of Things' (CIoT), which is an intelligent automation applicable in a variety of domains. Developing IoT as CIoT can result in as self-reliant without human intervention to function in an intelligent way of decision making to optimize tasks is the sole objective of CIoT aim and purpose. Worldwide urban population is expanding that result in various resources crunch, which hampers sustainable living particularly for urban inhabitants. The urban resources are vital and also critical due to supply and demand mismatch and for sustainable inhabitation, application of IoT/CIoT is relevant as many resources like water, transportation, power, health, housing, education, etc., become scarce for sustainable inhabitation. The paper encompasses by briefing the development and advances of CIoT, specifically its significance in smart cities applications. The CIoT can be trained in taking decisions on par with humans in case of critical situations to find the remedial measures required, which makes the process smart, useful, cognitive for intelligent solution. The properties, characteristics and constraints of CIoT are briefed along with its business applications. Discussion and conclusions are drawn in highlighting the emerging innovation of CIoT, which can become a revolutionary concept in futuristic world of technological novelty in transforming the world as dynamic and smart for the benefit of all the stakeholders.

Keywords-CIoT, Smart Cities, WSN, Machine Learning, Automation, Data Analytics, RFID Technology.

I. INTRODUCTION

The 'Cognitive Internet of Things' (CIoT) is defined as the use of cognitive computing technology in combination with data generated by connected devices and the tasks that the devices can perform. [1]. Cognition means the activities of thinking, understanding, learning and remembering, which is normally done by a human and these characteristics to be incorporated in CIoT devices for various applications. The function of cognition involves three key elements viz., understanding, reasoning and learning. In a computer system understanding means, able to derive meaning from the voluminous volumes of both structured and unstructured data in establishing a model of concepts, entities and relationships. Reasoning involve with using the relevant model to derive solutions to the related problems. Learning refers to automatically infer new knowledge from the data, which is the key component in understanding at scale. Building or developing complex models of concepts and relationships at scale can be very time consuming and expensive. As many relationships are not known in advance, the only viable path is to use a computer, which can automatically analyze huge datasets to evolve patterns by means of cognitive computing in conjunction with IoT, which is named as CIoT. The use of CIoT improves the accuracy and efficiency of complex sensor driven systems through learning and infusing more awareness into the devices and environment among the humans. Cognitive computing is vital to the IoT for critical reasons such as [1]:

- Rate and scale of data generation: Application of 'Machine Learning' (ML) is essential to analyze the huge data generated by sensors in terms of rate and scale of data.
- Computing' movement into the physical world: The 'CIoT' would infuse intelligent functioning of IoT devices in augmenting human centric interface towards automation.
- Integration of multiple data sources and types: Use of CIoT can provide better decision making in analyzing the data from many sources of different types such as digital sensor data, audio, video, unstructured textural data, location data, etc., to derive correlations and patterns among these types of data, which are vital in terms reasoning and decision making that can be improved integrating multiple different data sources (For instance correlating sensor data with acoustic data).

End to end IoT deployment by creating reference architecture to activate inter-operability in connecting the edge and the cloud, which have applications in smart buildings, drone based delivery services, real-time subsurface imaging, traffic congestion management and video surveillance.

Cloud Computing in conjunction with fog computing becomes a hybrid approach in many automation operations such as connecting vehicles by cellular networks, equipped with advanced (LIDAR), image processing, autonomous vehicle operation, pedestrian smart infrastructure and an array of cloud based services to support in-car entertainment, predictive maintenance, remote diagnostics, etc. [2].

II. EMERGING DEVELOPMENTS IN CIoT

The CIoT activate IoT with characteristics of human brain for a high level intelligence in its cognitive tasks such as [3]:

- Perception action cycle
- Massive data analytics
- Semantic derivation and knowledge discovery
- Intelligent decision making
- On-demand service provisioning

The use of CIoT for smart city applications can link the physical world viz., objects, resources, etc., and the social with human needs and social behavior etc. In automatic network operations, smart resource allocation and facilitating provision for intelligent services. The CIoT facilitates IoT with high level intelligence as smart and dynamic enabling techniques. The CIoT can be described with a couple of application scenarios as given below:

- CIoT provides with automation if a human wants comfort condition based on his deeds such as want to relax by sleeping in a living room of his house, then the sensors off light fixtures dims, AC adjusts its temperature, TV turns off the audio, sofa on which the person rests changes to bed, etc., all by automation of CIoT.
- In case of traffic jam the CIoT assist in suggesting an alternative route may be more distance, but saving in travel time in case of personalized vehicle with intelligent transportation system (ITS) with advanced information system facilitated by automation using CIoT.

The CIoT is an emerging network paradigm, where (‘Physical-virtual’) things or objects are interconnected that act as agents with minimum human intervention. Things interact with each other following a context-aware, perception-action cycle, use the methodology of understanding-by-building to learn from both the physical environment and social networks, store the learned semantic or knowledge in kinds of data bases and adapt themselves to the changes or uncertainties via resource-decision making mechanism, with two primary objectives in mind:

a. Bridging the physical world with object resources, etc., and the social world with human demand, social behavior, etc., together with themselves to form an intelligent physical-cyber-social (IPCS) systems.

b. Enabling smart resource allocation automatic network operation and intelligent service provisioning.

III. CIoT AFAR FROM AUTOMATION

The CIoT is developed with an aim at improving performance and intelligence of IoT through coordinated mechanism of cognitive computing. The conventional IoT devices generally sense its surroundings and perform accordingly and the end tasks are based on pre-programmed models. The IoT devices are not totally autonomous systems in decision making and to incorporate this aspect in IoT devices, cognitive computing is enabled to interact dynamically with other connected objects and also to make continuous learning of the devices based on the environment or conditions or situations. Cognitive computing enabled IoT observe, filter and recognize as similar to humans and also assimilate the gathered information to extract for actionable knowledge and meaningful patterns [4]. The cognitive computing can be implemented in three aspects of IoT as described.

a. Networking aspect
b. Behavioral aspect
c. Data analytics aspect

a. Networking Aspect

This aspect of CIoT is basically an extended concept of cognitive radio (a radio that can be programmed and configured dynamically to use the best wireless channels in its vicinity to avoid user interference and congestion) and cognitive networks. The cognitive networks optimize performance by adapting to present conditions of the network. The CIoT can make intelligent decisions by using cognitive networks by comprehending the current network conditions and analyzing the perceived knowledge in arriving at optimal network performance and to minimize latency. Cognitive networks increase the network capacity through intelligent multi-domain interaction, which is beneficial as the volume of IoT data is expanding exponentially [5].

b. Behavioral Aspect

The embedded cognitive technologies in IoT devices are intended to sense the inputs in the form of visions, sound, taste, smell and touch, which make them intelligent and mimics the human cognitive capability and also capable of learning, thinking and comprehending by themselves of both physical and social worlds [6]. The cognitive things can take actions on their own and interact directly with human by understanding their communication language [7]. The cognitive devices can recognize different users by a variety identification attributes viz., face, finger prints or touch, voice and usage pattern [4]. Based on previous interaction experience they adjust the future interaction. The CIoT can sense with time the different emotions and respond accordingly as per the mood and varying emotions of other systems interaction with [4].

c. Data Analytics Aspect

Processing and channelizing voluminous data generated by IoT devices and utilize the data objectively has become monumental task and in such case 'Big Data' platforms viz., 'Hadoop' are used to store the data. The probabilistic concept of cognitive systems enables in generating huge complex and unpredictable IoT data. The IoT data can be converted into intelligent data by cognitive techniques in automating tasks and designing better products and in providing innovative customer centric services [8]. Also CIoT recognize the organizational goals, accumulate, integrate and analyze pertaining data in achieving the goals of the business organizations, firms, etc.

IV. PROPERTIES AND DISTINCTIVENESS OF CIoT

The CIoT is a distributed and pervasive in its function and the desirable characteristics of CIoT are as described below [9]:

- **a.** Self-learning: The CIoT can continuously learn from the environment, they dealing with other entities, from the events and continuously improve its performance. Cognitive computing works based on continual hypothesis formation and every time CIoT learns something new it obtains approval from the existing hypothesis.
- **b.** Probabilistic: CIoT interprets the input and the context probabilistically and it does not follow any preset pattern as the case of deterministic systems. It sets out with a hypothesis learns continually and adapts statistical methods to find a correlation between the new findings and its hypothesis. Based on the results, changes the previous hypothesis and infer with a new way of operation.
- **c.** Adaptive: The CIoT must adapt itself to varied conditions both physically and logically. It should learn to adjust itself as information changes and also to new objectives and requirements developed and update the acquired knowledge in view of any up gradations.
- **d.** Flexible: The CIoT should have self-learning and adaptive capabilities to have flexibility in absorbing and processing input data. CIoT, while processing data any variable in data it adjusts its processing model to incorporate the deviation, whereas in the case of IoT the program should be rewritten.
- **e.** Dynamic: The CIoT can handle real time data and should possess dynamic capability to process and analyze data without interruption of program running. Any ambiguity should be resolved dynamically and also to take care of unpredictability.
- **f.** Interactive: The CIoT is designed to be interactive with users, machines and other automated services and possess conducive, interactive capacity using natural language of the users.
- **g.** Iterative: The CIoT has self-learning, which is an iterative process, that comprising of making a hypothesis, further learning and updating the hypothesis.
- **h.** Stateful: The CIoT with adequate memory to register every transaction it carries out and capable of retrieval is possible if need arises.
- **i.** Conducive to unstructured data processing: The CIoT capable of handling unstructured data types that can be integrated with a majority of the data sources in the world, which enhances its scalability and the scope of knowledge acquisition.
- **j.** Highly integrated: In CIoT each individual device works autonomously (sense and learn), but team up to contribute to a central learning system by continuous, sharing information and updating own knowledge in a vis-à-vis condition or accordingly.
- **k.** Scalable: The CIoT working range can be within a room or over a whole city area to append/removing of mobile devices to the system dynamically.
- **l.** Context and situation sensibility: Validation of IoT data and informal knowledge depends on parameters viz., time, location, application and administrative domain, regulations, then user's profile, process tasks and goal. The CIoT can identify, read and extract this information and use it appropriately [9].
- **m.** Self-management: The extraordinary scale of CIoT makes it as a self-managed thing and different elements are as listed below:
  - i. Diagnosis, trouble shooting and maintenance.
  - ii. Fault tolerance.
  - iii. Performance management.
  - iv. Configuration management.
  - v. Security management.

V.CHARACTERISTICS OF CIoT

The emergence of CIoT is beneficial towards achieving automation with intelligence, but it has following constraints in its applications and use, which may be solved with advances and developments as the case with any innovation or product development. The listed constraints pertaining to CIoT is experienced as of now is given below:

- **a.** **Limited longevity of battery life:** The CIoT devices consumes more power as these devices have to carry out cognitive functions, which needed more power compared to conventional IoT devices.
- **b.** **Data Diversity:** The voluminous and unstructured data is to be processed generated from different sensors that include visual, audio, gesture, text, etc., by CIoT devices makes the tasks as very challenging in addition as the data is heterogeneous [9].
- **c.** **Privacy and security:** In general network data is susceptible to hacking unless the security safeguards are fool-proof. In case of CIoT cognitive data may reveal valuable insights that may be vulnerable for hacking, when data related to business, financial, security, etc. In such a situation different encryption algorithms are essential, which can be addressed by the measures such as:

- Adapting decentralized authentication and security model for CIoT applications.
- Use of data protection algorithms and technologies that are efficient in terms of resources, less runtime and energy consumption are preferred.

d. Training" In CIoT, continuous iterative training, cognitive of things becomes better in its functions with greater autonomy in evolving creativity based common sense in handling critical situations. The CIoT learn from past interactions based on success and failures, and then it determines the best options in solving a new problem situation and improves further for future interactions.

e. Device organization and data flow management: The IoT devices generate data in continuous time series pattern and the data must processed and analyzed time to time. The results or outcomes of one device may be required to be fed to origin device or to another device.

f. Challenges with network and communication: The CIoT network can dynamically modify evolves and discovers or explores self and other networks. The network should be adaptable to new things to its existing topology. The automated discovery of things and mapping capability is a great challenge but essential for its accuracy and efficient management of network in terms of operation and scalability.

g. Software and algorithms: The software is integrated into 'Things' at different network levels to communicate and access the network data. Software is executed in indifferent environments with heterogeneous type of 'Things' that communicates using different protocols. Developing CIoT applications, which integrates different software modules is the tough task that operates at different environments, logically and in well organized way that warrants the following factors:

- Distributed self-adaptive software viable for self-management, self-optimizing, self-configuring and self-healing.
- Open and energy efficient software platform capable to integrate the distributed software modules as coherent application in abstracting the network resources and communication.

VI. BUSINESS ENTERPRISE OF CIoT

Applications of CIoT in industries, organizations, establishments, etc., would improve the operations in several directions to achieve greater efficiency, output, up gradation, advancements and developments in the relevant domains as listed [11]:

i. Improved business process
ii. Enhances business opportunities
iii. Agile business environment
iv. Magnified productivity
v. Optimized operational efficiency
vi. Optimal asset utilization
vii. Quicker decision making
viii. Cost saving effectiveness.

VII. CIoT/IoT APPLICATIONS FOR SMART CITIES

The objective of smart cities being how ICT solutions can be implemented in order to develop the cities as 'smart cities' in terms of various parameters that make cities to be conducive for living, meeting needs of various resources including safety, security, health, reduction in pollution and carbon footprint, optimal energy utilization, etc., for sustainable living. The following factors are briefed as a part of smart cities components in achieving the overall objectives:

a. Structural Adequacy of Monuments or Iconic Structures: This can be achieved by the following measures.

- Continuous monitoring of health or structural stability of such buildings.
- Identification of structures, which require repairs and maintenance for their durability.
- The WSNs can be embedded to monitor the radio signals, which indicate distress, damages, deterioration of structures for remedial measures to prolong its service life.

b. Environmental Monitoring: The WSNs can process and analyze and disseminate information or data about various environmental parameters that are listed below [12]:

- Water level of water bodies viz., lakes, rivers, streams, reservoirs, etc.
- Gas supply by pipe network and their maintenance.
- Soil humidity and other characteristics.
- Any natural calamities such as landslides sink holes, earthquakes, etc.
- Smart street lightings management to conserve energy.
- Use of infrared radiation for fire hazards, etc.

c. Waste Management: It is one of the challenging tasks in urban in habitat and concern to hygiene and environmental sustainability. The use IoT can assist in informing the concerned for its disposal. Using LPWAN technology garbage can be classified as biodegradable or non-biodegradable.

d. Smart Parking: Parking bay vacancy can be communicated to drivers by smart phones, displays at the parking lots or by 'Human Machine Interface' (HMI) and RFID technology is very useful in this case. On board unit fitted in dash board of cars using VANETs (Vehicle Adhoc Wireless Networks) are effective in the identification of parking vacancy.

e. Smart Health: A 'Wireless Body Area Network' (WBAN) is effective in monitoring a patient's health condition in hospitals. The miniature sensors can be embedded inside the body or Urban Bus Navigation (UBN) System: The UBN system used in Spain comprises of three key systems:

- The network enabled urban bus system with Wi-Fi connectivity.
- Navigation details for commuters with UBN.
- Bus occupancy/crowd information, stop to stop buses in all routes.

f. Smart Grid: It uses new technologies as intelligent and autonomous controllers using latest software for data management informing power utilization by the consumers.

g. Autonomous Driving: A combination of radar, cameras and ultrasonic sensors located around an autonomous car can detect critical or dangerous situations and would trigger an alert that automatically activates emergency brakes to prevent collisions and accidents. The ITS (Intelligent Transportation System) enables to find best route in real-time conditions to save time and to minimize the carbon emissions.

VIII. DISCUSSION

There is no iota of doubt in implementing CIoT for smart cities initiatives as Government of India already launched for 100 cities in India to make urban in habitats as sustainable. The various resources availability, optimal utility, waste reduction, etc., are paramount concern in conservation of resources and its meticulous utilization. Application of IoT/CIoT can be effective in monitoring and implementing the measures and objectives of smart cities initiatives. As cities are expanding due industries and peoples are migrating to urban areas for employment, managing urban needs becomes complicated and unmanageable. In such situation use of automation by implementing IoT/CIoT technologies would be helpful as these technologies lead to automation without human intervention in managing the voluminous tasks. The emergence of CIoT and its use in smart cities as well as in many domains can lead to sustainable solutions in managing critical and huge tasks.

IX. CONCLUSIONS

9.1 The recent innovation of CIoT that infuse cognition in conventional IoT, which is advancement in IoT capability that derives intelligent automation on par with human thinking. The CIoT can be trained in arriving an appropriate and judicious decision making in case of critical problems as replicating human's role in such situations.

9.2 The CIoT technology plays an expert human role smartly and dynamically using human natural language instructions/commands in achieving automation in a smart way that lead to automation in complicated issues.

9.3 In networking, where CIoT can be perceived in the following three conditions to optimize the communication performance such as:

a. Behavioral, when CIoT data aims to learn, think, cognize on its own.

b. The network where IoT adapts itself according to the conditions to maximize the communication performance.

c. Data analytics, where CIoT executes its functions dynamically, intelligently and cognitively.

9.4 The CIoT is self-trained, self-learned and self-managed system by supplementing properties such as probabilistic, flexible, dynamic, and interactive to offer smart decision making for any problem.

9.5 CIoT based smart systems are not easy to develop and various associated problems such as limited battery life, diverse data types can train system accurately and any ethical concern involved in using it a care should be exercised.

9.6 The CIoT learns from the prevailing problems processed and ideally the future CIoT can generate a problem statement on its own based on artificial cognition, it can be handled using 'Artificial Intelligent Quotient'.

9.7 The CIoT is if misused for wrong implementation, it can cause negative utility of it.

9.8 The CIoT derives better business analysis and decision making using 'augmented business operations' for customer satisfaction and enhance revenues of a venture.

9.9 The complicated issues connected with 'smart cities' of all parameters can efficiently and effectively integrated in arriving smart solutions for all the parameters associated with smart cities initiatives , which is based on WSN system and can be effective if CIoT is used in tackling the complicated issues related to it.

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Authors Profile

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