A Novel Energy Optimization Approach for Artificial Intelligence-enabled Massive Internet of Things

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***Abstract*—Emerging trends in Internet of things (IoT) has caught the attention of every domain e.g., industrial, business, and healthcare etc. Sensor-embedded IoT devices are the key drivers for collecting large amount of data. Managing these large datasets is one of the critical challenges to be tackled. Continuous huge information collection through sensor-enabled devices is known as the massive IoT (mIoT). Thus, there is a need of self-adaptive artificial intelligence (AI)-based strategies to effectively cluster, examine and interpret the entire entities in the system. With increased data volumes and power hungry natured IoT devices it is a dire need to manage their power wisely. To fairly allot the power levels to the tiny portable devices it is important to integrate mIoT with AI-based techniques. To remedy these issues this paper proposes a novel cross-layer based energy optimization algorithm (CEOA) in mIoT system by examining the detailed features and data patterns. Experimental analysis reveals that proposed CEOA outperforms its competing counterpart i.e., Baseline in terms of efficient power management and monitoring.**

Keywords— Energy optimization, Massive IoT, AI, CEOA, Performance Evaluation

I. Introduction

With the increasing number of portable devices in this digital world, data is gathered in massive amount which is famously known as, massive IoT (mIoT). On the one hand capacity of the network is increased while on the other hand complexity increases with large number of devices and huge data volume. Moreover, portable device platform empowers the concept of mIoT with large scope and integrity to other existing technologies. Critical mIoT implementation puts restrictions on network capacity, coverage, battery lifetime and cost of both device and connection. The mIoT comprises billions and trillions of machines, handheld devices with smart and ubiquitous interconnection despite of the location and cost. Even after putting the sensors in depth of the ground they will sense and report the contents to the cloud/server on timely basis. The massive data level is defined by third generation partnership project (3GPP) from one million devices deployed per kilometer, and can be monitored by the nine mobile networks for efficient communication /transforming by enhancing battery lifetime up to more than ten years. In addition, 3GPP has focused on the involvement of the cheaper devices/machines with less power drain, high capacity and scalability [10-12]. Numerous innovative technologies for example, narrow-band Internet of things (NB-IoT) and Sigfox can be considered as appropriate options for the optimized and sustainable connectivity over joint AI and mIoT platforms. One of the prominent candidates for addressing the upcoming density challenge is 5G. With a streamlined signaling protocol and a lean air interface, 5G aims to connect millions of devices per square kilometer. In addition, network slicing will provide cellular networks with the much-needed flexibility to address specific Quality of Service (QoS) requirements of enterprises. In the broader sense, IoT applications can be classified into critical and massive classes. The later describes the large number of devices/machines and their voluminous data amount, low power drain, high coverage, high data rates etc, while the former merely supports the high reliability, availability, throughput and lower delay enabled platforms. The proliferation of long-range technologies like NB-IoT or long range (LoRa) can provide better backbone connectivity for mesh networks to reach wider areas. Similarly, non-cellular technologies like mesh is attracting more industries and enterprises to adopt IoT, which in turn will promote smart and sustainable connectivity [13-14]. The mIoT has been lapsed by several fields for example, healthcare, smart transportation, higher education, smart cities, and farms, among others. AI is one of the active and emerging paradigms to revolutionize the mIoT, applications, use-cases and trends. Three specific technological trends and practices in mIoT and AI are highlighted by the Gartner [4]. In order to follow those trend, wireless networks must fulfill quality of service (QoS) requirements with better end-user perception in densely enriched wearable platform.

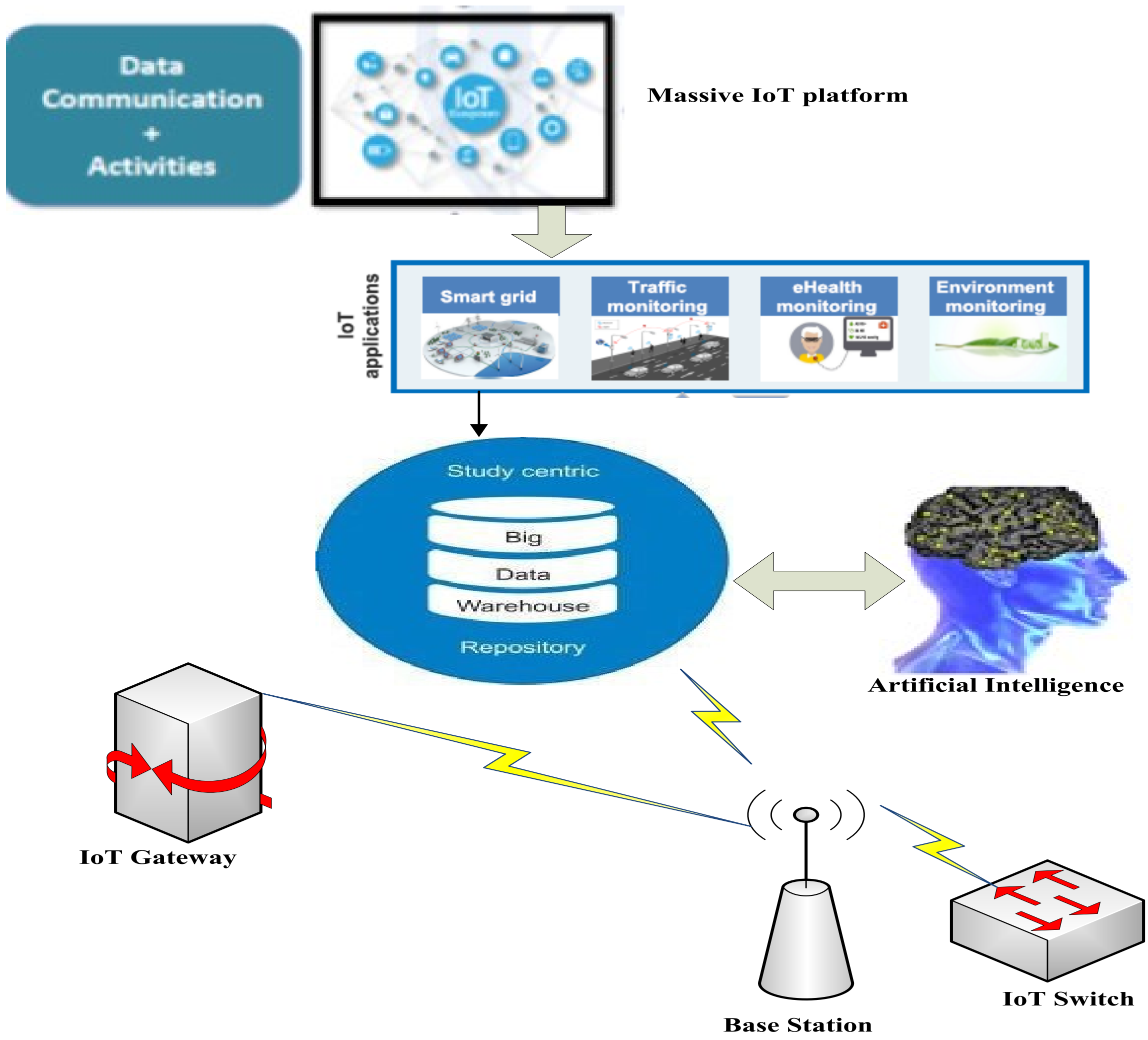

Fig. 1. Proposed framework of joint AI and massive IoT

AI based techniques concern the massive data classification patterns, pattern recognition and observed outcomes.

The key idea behind all the developed learning methods is to discover structures or latent variables that would exploit the data in the compact form by sustaining the functionality. Therefore, there is a vital and emerging role of the AI in the study and design of main capabilities of mIoT. Although some research attempts have been made towards understanding theoretical and practical potential of these disruptive AI solutions, the challenging and breakthrough objective of this research is to leverage the potential of using AI strategies to mIoT. One of the objectives of this research is to adopt emerging AI methods to extract massive amounts of data that might be generated from wireless channel measurements and sensor readings in mIoT. Besides, examining how transmitter and receiver are functioning while managing the complex data. Moreover, we aimed at learning and understanding the behavior of end-users while adapting new wireless networks for evaluating their perception about entire system performance [15]. In short, we can say though mIoT require much less bandwidth than the mobile broadband (MBB) services, the network may need to handle a higher number of concurrent access in densely populated geo-locations.

The paper contributes in three-ways. First, a novel cross-layer based energy optimization algorithm (CEOA) for massive IoT is proposed. Second, joint AI and mIoT framework is developed. Third, an AI and mIoT-based use-case is suggested.

The rest of the paper is arranged as follows. Extensive review of existing research is presented in section 2. Section 3, proposes the novel CEOA. Joint role of AI and massive IoT (mIoT) based use-case is suggested in section 4. Section 5 presents the experimental results. Finally, the paper is concluded in section 6.

II. EXISTING WORKS

In this emerging innovative technological trend there is a strong bond between IoT and AI. As IoT enabled devices generate large volume of data, which is synchronized, processed and transmitted in an efficient pattern with state-of-the-art tools and techniques. In this regard, AI plays the promising role in classification, monitoring and management of the voluminous data from wearable sensor devices [1-3]. Besides, AI-based intelligent algorithms adopt large datasets mostly in zeta-bytes, classifying, examining, and analyzing distinct patterns by optimizing highly likely desired value. As the name massive IoT (mIoT), portrays the large volume of data from interconnected machines, objects, and humans to reshape the various fields such as, agricultural farms, transportation, smart cities, healthcare, and enterprises with regular contact to the central cost-effective and efficient clouds. Besides, it is vital that the devices/machines which form the notions of mIoT must be less power hungry, sustainable, flexible, scalable and with wide coverage capabilities [4-7]. Currently, an interesting and emerging buzzword titled mIoT is formed by the industry, which is basically interconnection between large number of tiny low power and intelligent devices and machines to transform and exchange the information among each other and neighboring networks. There is another category of the IoT applications with strict requirement of high availability, scalability, and low delay lies under the umbrella of critical IoT and could be monitored by long term evolution (LTE) and 5G technologies [8-10]. Furthermore, mIoT usually comprises tiny, cost-effective, high coverage and lightweight sensor devices with regular connection to the remote centers. Low Power Wide Area (LPWA) is the building block for mIoT to meet the market demands by providing smart and sustainable healthcare solutions [11-14]. The notion of smart homes, smart medical cities and smart transportation is the main purpose to be considered and practiced for efficient and sustainable healthcare system. In third generation partnership project (3GPP), IoT device categories include category 1(Cat-1), category machine 1(Cat-M1) and Cat-Narrowband 1 (NB1). There multiple enhancements related to IoT and the 3GPP standards since last couple of years [15]. Power management in smart grids is the emerging research topic for smart and pervasive environment. Authors in [16], design the secure and cost-effective method for IoT driven home automation system. Unmanned aerial vehicles are cornerstones to establish hassle-free and convenient applications such as, healthcare, military, and industry [17]. QoS optimization in ad-hoc networks is the dire need be provided for the accurate system examination [18]. Green and battery-aware wearable platform plays remarkable role in IoT based pervasive healthcare [19-20].

III. Proposed Cross-layer based Energy Optimization Algorithm

Our proposed CEOA works on the physical as well as medium access control (MAC) layers. However, the proposed cross-layer approach efficiently and intelligently monitors each layer accordingly. For instance, the channel is entirely characterized in terms of QoS optimization, transmission power control route scheduling/selection at network, physical and link layers accordingly. Besides, duty-cycle of all IoT devices and customer demands are monitored and managed at the MAC and application layers respectively. Similarly, data rate and energy drain are computed at the physical layer with features of wireless link. Because small and light-weight sensor devices restricts the fair resource allocation process in most of the ad-hoc networks. Static nature of conventional short and long-haul wireless networks cover long ranges, but with more delay, inflexible deployment, high power drain, and more complexity at each layer of the OSI model. On the contrary, emerging proliferation in smart and sensor driven techniques have entirely revolutionize most of networks with high scalability, high speed, flexibility, high data rate and low delay. mIoT is one of them, which comprises sensor based portable nodes with high acceptable reliability and transmission range. Moreover, due to the heterogeneous nature of the mIoT networks, it is important to deal with the large pool of the involved entities to efficiently allocate the desired resources. In this regard a novel optimal cross-layer approach is developed by considering four application, network, physical and MAC layers with specific tuning parameters. A wireless channel is adopted, which connects the transmitting and receiving paths. It is assumed that an on-body sensor node has deadline time T to transmit W bits. At MAC layer, sensor nodes monitor the duty-cycle $T_{act} \leq T$ by transmitting the data to receiver node where the entire duty-cycle is computed as $D_C = T_{act} / T_{total}$. Similarly, at the network and physical layer, transmit and receive power, and data rate are adopted accordignly in order to achieve more reliable sustainable mIoT platform. The total power dissipation P_{total} for the AI-enabled massive system is represented in (1) and (2).

$$P_{total} = P_{act} + P_{slp} = \frac{E_{act}}{T_{act}} + \frac{E_{slp}}{T_{slp}} + \frac{E_{tran}}{T_{tran}} \tag{1}$$

Power drain problem is represented in (1) and (2) accordingly. Here we need to optimize *P* Subject to:

$$\begin{aligned} &0 \leq D_C \leq 1 \\ &0.1\, m \leq d \leq 1\, m \end{aligned} \tag{2}$$

Most important task is to optimize the energy dissipation and reliability by properly choosing/tuning the performance indicators at the application, network, physical and MAC layers. Sensor, nodes in the mIoT perform the various tasks i.e, sensing, processing, and transmission by following the proposed CEOA for smart and pervasive healthcare. The main purpose of the proposed CEOA is build an energy efficient, sustainable and reliable healthcare platform with the main slogan ‘healthcare for all’. Because it will promote both the adaptive and massive data generation and management methods. Besides, M-QAM modulation technique empowers large and error-free healthcare data transmission and analysis. Furthermore, the duty-cycle optimization D_{C_opt} at MAC layer remarkably reduces the energy drain at the physical layer with more reliability.

IV. Joint Artificial Intelligence and Massive IoT based Use-case

Massive IoT and AI are the key enablers to promote the machine to machine communication in an independent and accurate manner. Their flexible and computationally simple nature attracts other innovative technologies for instance, ZiBee, LoRa, body sensor networks to reform the healthcare industry for elderly patients with high sustainability, reliability and pervasiveness.

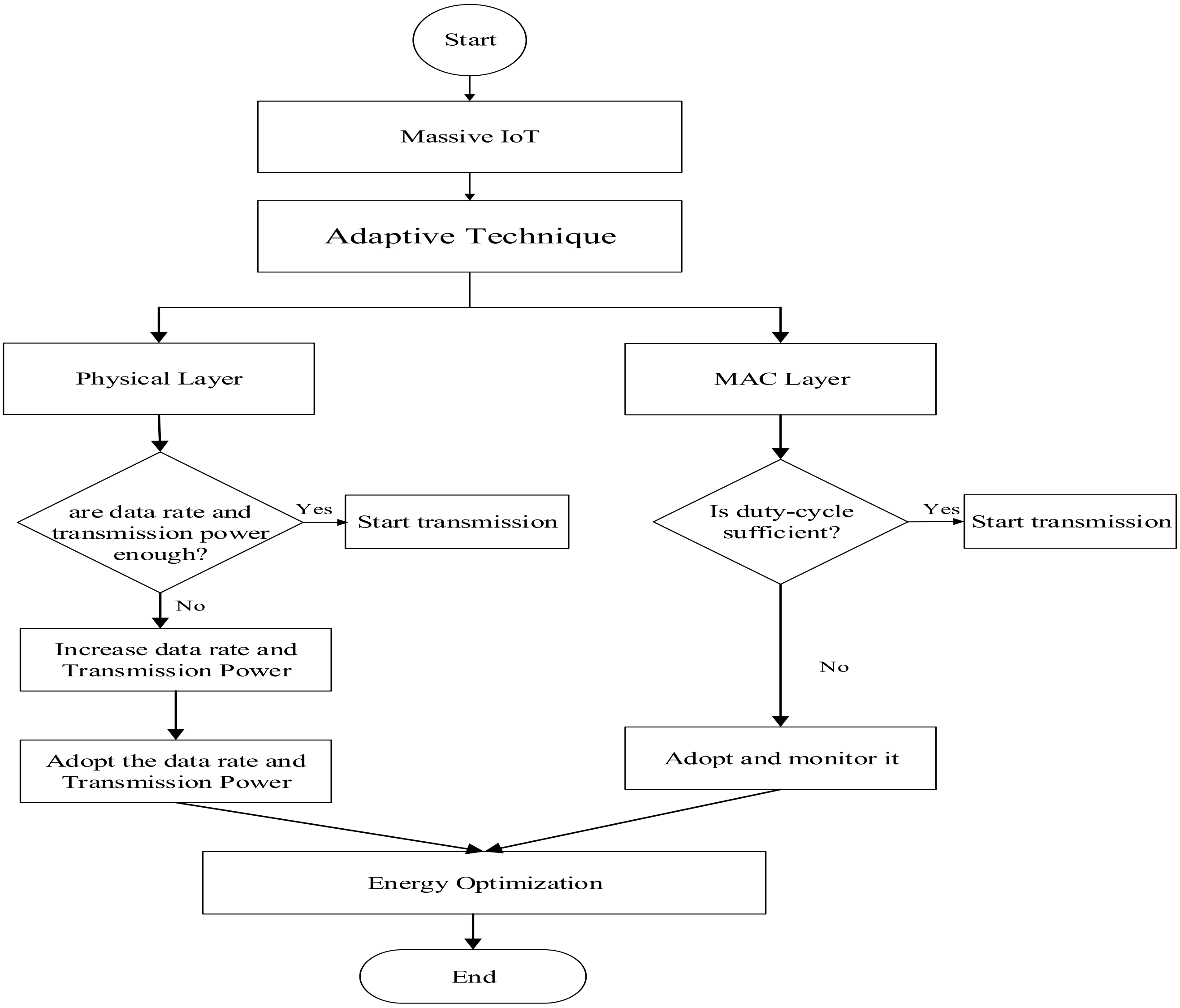

Fig. 2. Flowchart of propsoed cross-layer based energy optimization algorithm in AI-based massive IoT

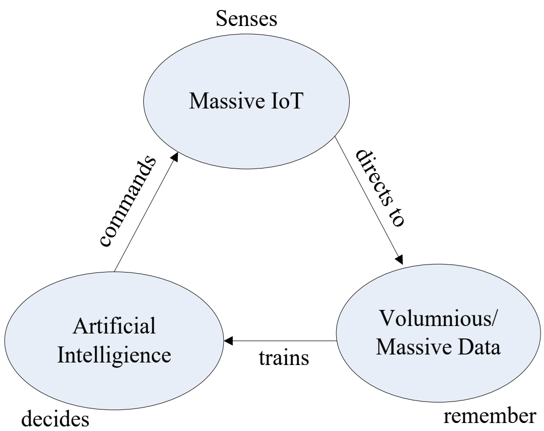

Fig. 3. Use-case of joint AI and massive IoT

It is widely accepted that joint mIoT and AI platform is the paradigm shift for several domains such as, healthcare, business, enterprises and autonomous systems. In mIoT M2M communication is the key integral part where devices/machines interact by sharing and transmitting information in an efficient way [2]. These features open the doors for critical challenges for instance, high power drain, heterogeneity, high battery charge drain in mIoT. And heterogeneous AI and mIoT platform and large data amount will create the synchronization problem between devices while sensing, processing and transmitting data among each other and towards intended destinations. Other challenging problem is the large overhead during synchronization among devices to deal with the rapid and fast convergence with other devices and neighboring networks. Moreover, it is crucial to cope-up with the short battery lifetime and more power drain while transmitting the data over joint AI and mIoT system. Key source of big data is the mIoT with its highly effective features in classifying, categorizing and recognizing the patterns. Large number of devices and their data management need self-driven and intelligent methods in various landscapes for example, industries, enterprises and academic sectors [15]. Recognizing, extracting and examining the appropriate classes of data in mIoT is performed exceptionally by AI technology for better and accurate insight and decision making in the entire system. Therefore, analyzing the importance of collected data information from mIoT is important for numerous firms and factories. Moreover, AI and mIoT help to form/shape the sustainable medical smart cities by transforming conventional concepts. For smart cities software and radio access networks in cooperation with typical LTE set-up are can be the key drivers. Proper selection of the self-adaptive technologies i.e., category machine, EC-GSM and NB-IoT works in the licensed bandwidth series thirteen with better performance unlike typical LTE networks. The first wave of emerging IoT revolution is accepted by most of the key enablers to promote the notion of mIoT [9]. Furthermore, dynamic and distributed architectures are the most promising parameters to achieve the appropriate and user-friendly system.

V. Results and Discussion

Experimental setup is developed in the MATLAB with the support of convex optimization tool and then the performance of the proposed CEOA (i.e.,with cross-layer) and Baseline (i.e., without cross layer) over joint AI and mIoT platform is assessed by adopting Physical and MAC layer parameters. Besides, performance of proposed CEOA is examined by adopting energy dissipation, packet delivery ratio (PDR), modulation level/data rate and lifetime of sensor nodes. Duty cycle monitoring/scheduling, and data rate/modulation level adaptation are done at MAC and PHY layers respectively for mIoT devices.

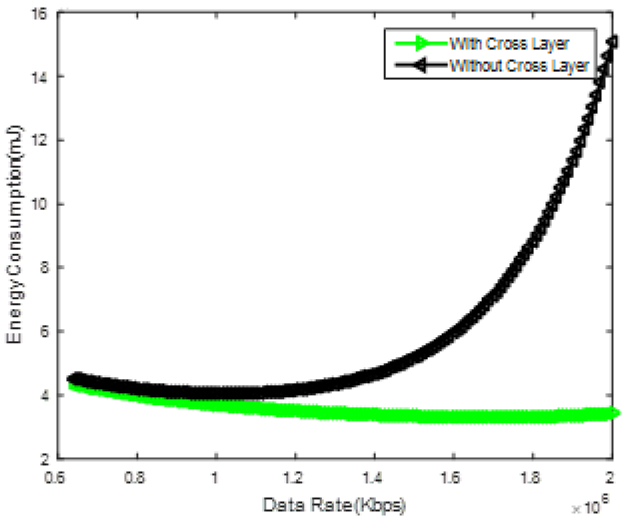

Fig. 4. Data rate vs. energy dissipation in mIoT

Due to the close ties and strong knot between all open systems Interconnection (OSI) layers, it is easy to integrate, exchange and transfer the information from one layer to another. Hence, by keeping this notion into mind we develop the Physical, and MAC based energy optimization algorithm over joint AI and mIoT system. Fig. 4, presents trade-off between data rate and energy drain. It is observed that more and less power is depleted by without cross layer and with cross layer methods accordingly.

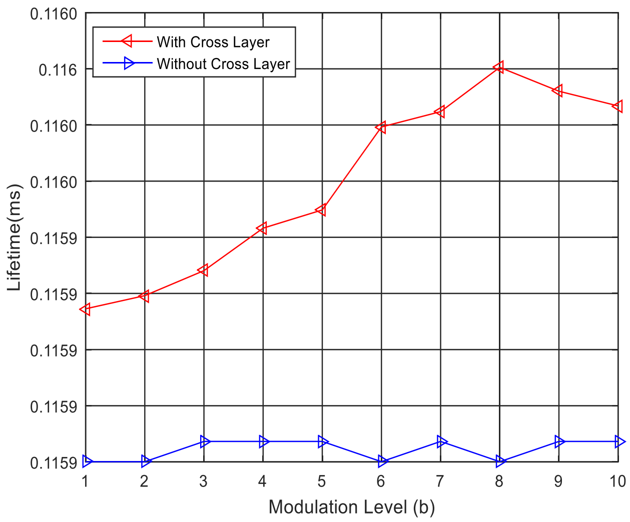

Fig. 5. Relationship between Modulation level and Lifetime in mIoT

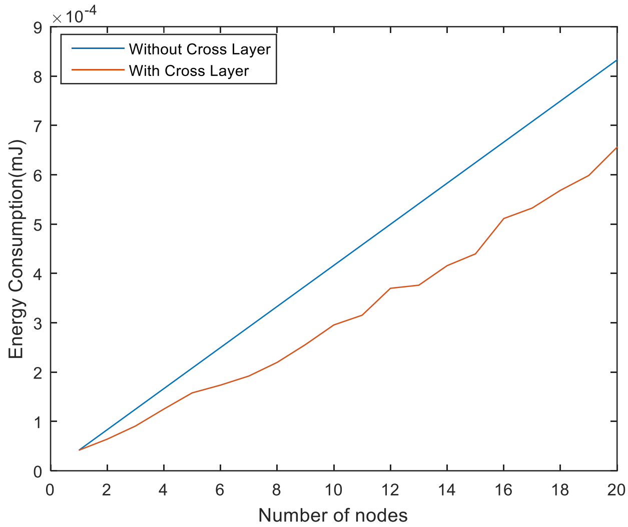

Fig.6 Tradeoff number of nodes and energy drain

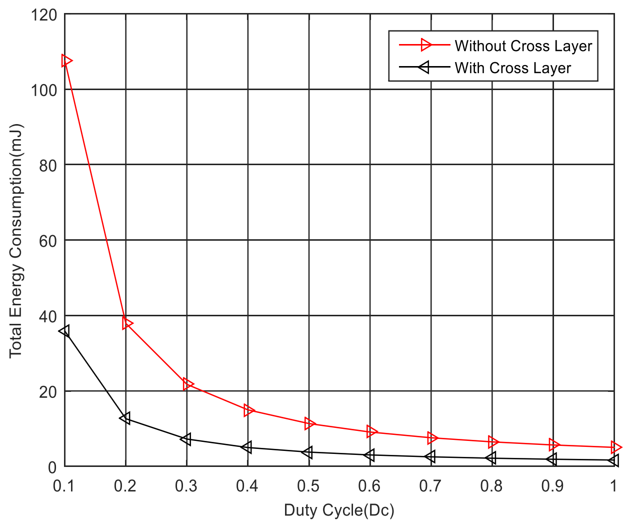

Fig. 7 Relationship between duty-cycle and total energy drain in mIoT

Similarly, the relationship between a lifetime of mIoT devices and date rate (Kbps) is revealed in Fig. 5. It is observed that with the increase of data rate more energy will be dissipated which shortens the lifetime of mIoT nodes, but with cross layer the lifetime of entire mIoT system is extended by reducing the power drain unlike the

Baseline method. Relationship between number of nodes and energy dissipation is revealed in Fig. 6 by considering with and without cross layer scenarios. It is interpreted that with the increase of sensor nodes energy will be dissipated more and less by without and with cross layer, respectively.

TABLE 1. Simulation Parameters

S.No	Entity	Value
1	Data rate	1-100 Kbps
2	E2E delay	600sec
3	Mobility	0-4km/h
4	Buffer size	130 Bytes
5	Carrier Frequency	3.5 GHz
6	Bandwidth	2500 KHz
7	Number of nodes	20
8	Receiver TP	46dBm
9	Transmitter TP	54dBm
10	Simulation time	400 sec

In addition, large number of sensor nodes increases complexity and hence more resources (i.e., energy and storage space) are needed for transmitting and exchanging information among intended entities. In Fig.7, we establish the relationship between duty-cycle and total energy drain for the mIoT system then assess the performance with and without cross layer approach. In addition, former outperforms the latter by showing proper energy optimization, because high and continuous duty-cycle keeps the data transmission/exchange process longer unlike the short duty-cycle period in mIoT devices. In other words, it can be claimed that cross layer approach provides more energy efficiency, reliable and robust performance over joint AI and mIoT system.

VI. CONCLUSION AND FUTURE WORK

This paper presents the emerging and revolutionary trends between AI and mIoT. How AI has widely transformed the conventional energy hungry and data management approaches into energy efficient, innovative, organized, clustered and well-prepared platform. The main challenge with the IoT-based devices is their tiny and resource-constrained nature with high energy dissipation and short battery lifetime. Therefore, to remedy these issues this research proposes a novel CEOA over joint AI and mIoT platform. Besides, a framework of AI-based mIoT is proposed with additional use-case for future smart healthcare applications. Finally, extensive experimental test-bed is developed by adopting convex optimization tool in MATLAB to enhance the energy efficiency and battery lifetime of mIoT system. In near future, we will consider the energy harvesting and big data issues in massive medical smart cities.

REFERENCES

[1] H.Hejazi, H.Rajab, Survey of platforms for massive IoT, 2018 IEEE International Conference on Future IoT Technologies, Eger, Hungary, 18-19 Jan, 2018, pp.1-8

[2] T.T. Brooks, An Artificial Intelligence Perspective on Ensuring: Chapter-Cyber Assurance for the IoT, pp.520, Wiley-IEEE Press,2017

[3] A..H.Sodhro, S.Pirbhulal "Artificial Intelligence Driven Mechanism for Edge Computing based Industrial Applications", IEEE Transaction on Industrial Informatics, March 6, 2019 (Early Access), DoI: 10.1109/TII.2019.2902878.

[4] M.Mohammadi,et al, Deep Learning for IoT Big Data and Streaming Analytics: A Survey, IEEE Communication Surveys & Tutorials, Vol. X, No. X, pp.1-40, 2018.

[5] M. Mohammadi, "Enabling Cognitive Smart Cities Using Big Data and Machine Learning: Approaches and Challenges," IEEE Communications Magazine, vol. 56, no. 2, pp. 94–101, 2018.

[6] J.Park ; H.Park ; Y-J Choi, Data compression and prediction using machine learning for industrial IoT, 2018 International Conference on Information Networking (ICOIN), pp. 10-12, 2018.

[7] A.H.Sodhro, S.Pirbhulal,G.H.Sodhro, A.Gurtov, "A Joint Transmission Power Control and Duty-Cycle Approach for Smart Healthcare System", IEEE Sensor Journal,Vol.PP, No.99, 2018

[8] X-W.Chen, X. Lin, "Big data deep learning: challenges and perspectives," IEEE Access, vol. 2, pp. 514–525, 2014.

[9] R.Li, Z. Zhao, X. Zhou, G. Ding, Y. Chen, Z. Wang, "Intelligent 5G: When cellular networks meet artificial intelligence,"IEEE Wireless Communications, vol. 24, no. 5, pp. 175–183, 2017.

[10] Kashif Sultan, ,Hazrat Ali , Zhongshan Zhang, Big Data Perspective and Challenges in Next Generation Networks, Future Internet , MDPI, Vol.10, No.4, pp.1-20, 2018

[11] Kun Guo, Yueming Lu, Hui Gao, and Ruohan Cao, Artificial Intelligence-Based Semantic Internet of Things in a User-Centric Smart City, Sensors, Vol.18, No.5, pp.1-22, 2018

[12] A.H.Sodhro, Y.Li, M.A.Shah,"Energy-efficient Adaptive Transmission Power Control in Wireless Body Area Networks", IET Communications, Vol.10, No.1, pp.81-90, Jan.2016.

[13] M.Taha Yazici , Shadi Basurra and Mohamed Medhat Gaber , Edge Machine Learning: Enabling Smart Internet of Things Applications , Big data and cognitive computing, Vol.2, No.3, pp.1-17, 2018.

[14] A.H.Sodhro, Z.Luo, "Towards an Optimal Resource Management for IoT based Green and Sustainable Smart Cities", Journal of Cleaner Production, Vol.220, No. 2019, pp.1167-1179, 2019, Elsevier, 2019.

[15] Obaidat, Mohammad S., Issa Traore, and Isaac Woungang. Biometric-Based Physical and Cybersecurity Systems. Springer International Publishing, 2019.

[16] Misra, Sudip, Sankar Narayan Das, and Mohammad S. Obaidat. "Context-aware quality of service in wireless sensor networks." IEEE Communications Magazine, Vol. 52, no. 6, pp. 16-23, 2014.

[17] Bera, Samaresh, Sudip Misra, Sanku Kumar Roy, and Mohammad S. Obaidat. "Soft-WSN: Software-defined WSN management system for IoT applications." IEEE Systems Journal, Vol. 12, no. 3, pp. 2074-2081, 2018.

[18] Mukherjee, Anandarup, Sudip Misra, Vadde Santosha Pradeep Chandra, and Mohammad S. Obaidat. "Resource-Optimized Multi-Armed Bandit Based Offload Path Selection in Edge UAV Swarms." IEEE Internet of Things Journal, 2018.

[19] A.H.Sodhro, L.Zongwei, A.S.Malokani, 'An Adaptive QoS Computation for Medical Data Processing in Intelligent Healthcare Applications', Neural Computing And Application (NCAA), Springer,Vol.30, No.3, pp.1-12, 2019

[20] H.Magsi, A.H.Sodhro, "Evolution of 5G in Internet of medical things", IEEE International Conference on Computing, Mathematics and Engineering Technologies (iCoMET) , pp. 1-7, Sukkur, Sindh, Pakistan, Jan1-2, 2018.

[21] A.H.Sodhro, G.H.Sodhro, L.Zongwei, "Artificial Intelligence based QoS optimization for multimedia communication in IoV systems", Future Generation Computer Systems, Elsevier, Vol.95, No.2019, pp. 667-680,2019

[22] M.M Lodro, A.H Sodhro, Statistical channel modelling of 5G mmWave MIMO wireless communication, International Conference on Computing, Engineering and Mathematics (iCoMET), 2018, pp.1-5,

[23] A.H.Sodhro, M.A.Shah, "Medical-QoS Telemedicine Service Selection using Analytic Hierarchy Process", Handbook on Smart Healthcare, Springer , Handbook of Large-Scale Distributed Computing in Smart Healthcare pp 589-609, 2017

[24] A.A Chandio, D.Zhu, A.H Sodhro, Integration of inter-connectivity of information system (i3) using web services, pp.1-8 - arXiv preprint arXiv:1405.3724, 2014