Green Internet of Things Using Mobile Cloud Computing: Architecture, Applications, and Future Directions

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1 Introduction

In the last few decades, the number of mobile users has increased drastically and the mobile devices have become popular medium for accessing Internet services. Various mobile applications have been introduced for learning purpose, video conferencing, chatting, health monitoring, playing games, listening music, editing photos and videos, accessing social networking sites and professional sites, etc. However, the handheld mobile devices suffer from various drawbacks such as limited storage capacity, limited processing capability, limited battery life, etc. Due to these constraints the execution of exhaustive applications and storage of high-volume data inside the mobile devices may not be possible. In such a scenario, MCC has come that permits to store data and execute applications outside the

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mobile device and into the cloud [1–3]. Nowadays, the use of edge/fog computing can provide the facility to perform processing in the intermediate device and can bring the resources at the network edge [4–6]. With the rapid advancement in different technological aspects, people are seeking smart solutions for their daily lives such as smart home, smart transportation, smart education, smart banking, smart retail, smart healthcare, smart agriculture, etc. To provide smart solutions IoT comes into the picture, where the uniquely identified embedded devices are connected within an Internet infrastructure to build a computing environment [6–7]. In IoT, the sensors and actuators are used, and the objects' status information collected by the sensors are transmitted to the servers for storage and processing. The use of cloud computing in IoT provides the facility of processing and storing huge volume of sensory information inside the cloud. The integration of IoT with MCC can be referred as *Internet of Things using Mobile Cloud Computing* (IoT-MCC). In IoT-MCC, the sensory information collected by the sensor nodes are transmitted to the cloud through the mobile device. The mobile device is connected to the network either through a cellular base station or through a Wi-Fi access point. In both the cases, the data processing and storage happen inside the cloud. After the introduction of fog computing the intermediate devices such as switch, router, gateway, etc. also participate in data processing [5–6]. The edge computing has brought the resources at the edge of the network [4–5]. In edge computing, the edge server is attached with the base station in case of the cellular network [4–5]. In case of Wireless Local Area Network (WLAN)/Wireless Metropolitan Area Network (WMAN), the cloudlet is used in case of edge computing [4–5]. The edge server/cloudlet is used for providing the facilities to offload data and computation inside the edge server/cloudlet. In case of edge-fog-cloud-based IoT framework, the intermediate fog devices or the edge server or cloudlet can participate in the processing and storage of the sensory information. An overview of the IoT-MCC architecture is presented in Fig. 1.

The mobile device can be used for data collection and accumulation purposes before forwarding to the next hop. Nowadays, various sensors are attached with mobile devices. Various mobile applications (apps) are also available to collect the number of footsteps went, acceleration, temperature, humidity, etc. Camera and GPS are also available inside the smartphones. The preliminary processing on the collected sensor data can be performed inside the mobile device itself. This in turn can reduce the unnecessary data transmission over the network. The use of edge/fog devices for data processing also reduces the amount of data transmission to the cloud. In [8–9], the edge/fog devices have been used for preliminary data processing in IoT-based healthcare. In [8–9], only if abnormal health condition has been predicted, the data transmission takes place to the cloud. This in turn provides faster health care service and reduces unnecessary data transmission over the network [8–9].

Mobile devices especially smartphones have become an important part of our life. The use of smartphones in IoT has brought several advantages to the users also, for example, using body area network and smartphone, the health parameter

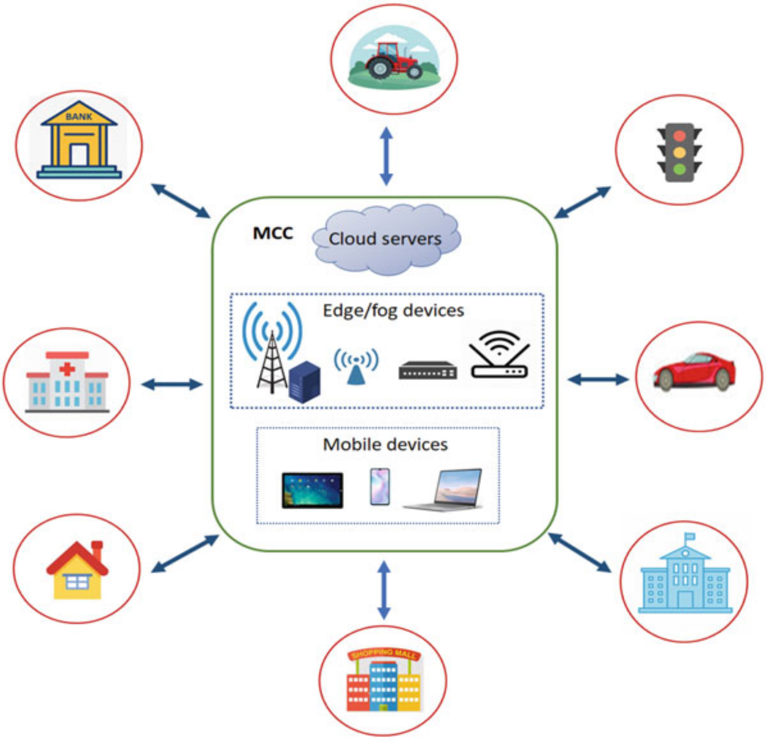

Fig. 1 Overview of IoT-MCC architecture

values, location, and movement information are collected and processed inside the smartphone/edge device/fog device/cloud to predict the current health condition of individual [8–9]. In case of abnormal health conditions, health care advice is provided to the user through the mobile phone. In the case of smart home, smart retailing, the smartphone acts as a medium of interaction. Augmented Reality (AR) provides a virtual environment to the users through which the users see the real world with virtual objects composited with the real world [10]. In IoT-MCC-based AR, a virtual reality can be provided to the user even at home to view the virtual objects superimposed with the real world. The IoT is largely used in smart agriculture. Various mobile apps related to agriculture are nowadays available.

In this chapter, we discuss on the architecture, applications, and research scopes of IoT-MCC. The rest of the chapter is organized as: Sect. 2 discusses the architecture of IoT-MCC. Section 3 illustrates the delay and power consumption in IoT-MCC, Sect. 4 briefly describes the IoT-MCC Convergence, and Sect. 5 describes various applications of IoT-MCC. Section 6 briefly illustrates enabling technologies for Green IoT-MCC, Sect. 7 summarizes different energy harvesting techniques for Green IoT, Sect. 8 investigates various research challenges of Green IoT-MCC, and finally, Sect. 9 concludes the chapter.

2 Architecture of MCC

Nowadays, due to the massive use of IoT devices in variety of application an enormous volume of data is generated. These large scales of data demand new architectures and technologies for data management both for capturing and processing. The IoT-MCC architecture serves the purpose. The IoT-MCC architecture consists of four layers as presented in Fig. 2. The principle components of IoT-MCC are:

- Sensors and actuators
- Mobile devices
- Edge/fog devices
  Cloud servers.

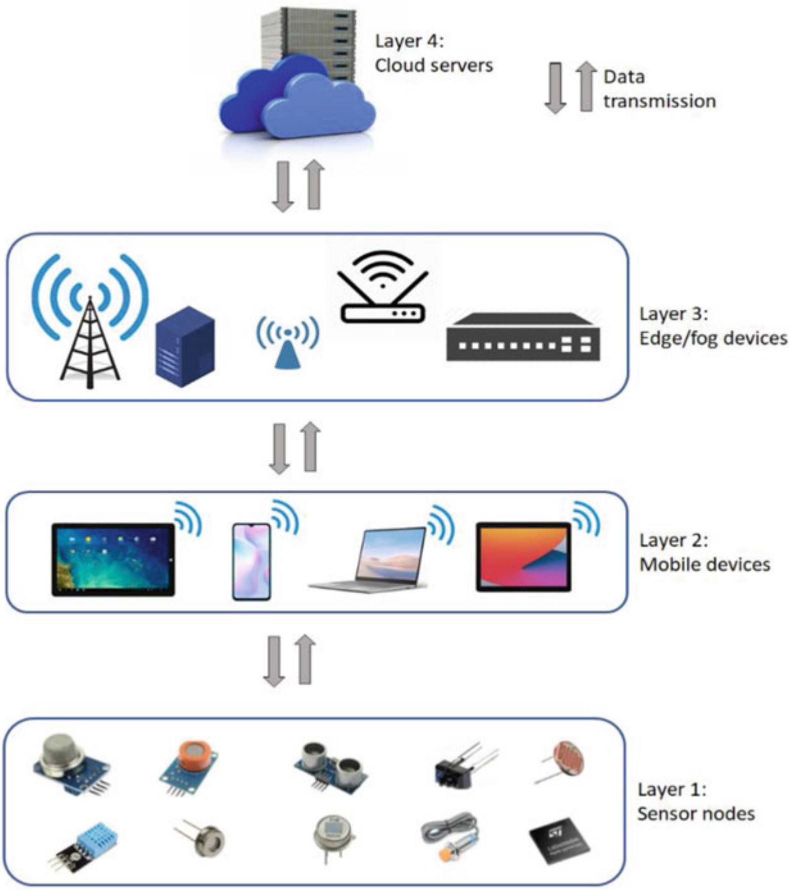

Fig. 2 Four-layer Architecture of MCC

The working model of IoT-MCC is described as follows.

- The layer 1 consists of sensor nodes and actuators. The sensor nodes are attached with the objects to collect their status. The collected sensor data is transmitted to the mobile device at layer 2.
- The mobile devices such as smartphone, tablet, laptop, etc. are present at layer 2. The mobile device receives sensor information from the sensor nodes. The mobile device performs preliminary processing on the data and then sends it to the connecting edge/fog device at layer 3. However, the mobile device can send the raw data also to the connecting edge/fog device at layer 3.
- At layer 3 the devices which connect the mobile device with the network are present. In case of cellular network, the base station, and in case of WLAN/WMAN, the Wi-Fi access point connects the mobile device with the network [4–5]. The access point is connected with the network through switch, router, etc. In cellular network, small cells exist [11–12]. In case of fog computing, the intermediate devices such as switches, routers and small cells participate in data processing before forwarding to the cloud. In case of edge computing, the edge server attached with the base station or the cloudlet participates in data processing. The data storage can happen inside the edge/fog devices after processing, or the data can be transmitted to the cloud at layer 4 according to the requirement.
- The cloud servers are present at layer 4. Usually, the data storage happens inside the cloud. The cloud can process the data, usually, for exhaustive computation cloud is used. If required the cloud can send the processed data or result after processing to the connected edge/fog device from which the user can receive the data or access the data using his/her mobile device.

3 Delay and Power Consumption of IoT-MCC Based Network

To calculate the delay, we have considered the data collection, transmission, and processing delays. The power consumption by the devices of IoT-MCC during these periods is calculated [5, 8–9] (Table 1).

The time period in data transmission from layer 1 to layer 2 is given as,

$$T_{sm} = (1 + f_{sm}) \frac{Data_{sm}}{R_{sm}} \tag{1}$$

The time period in data processing at layer 2 is given as,

$$T_m = \frac{Data_m}{S_m} \tag{2}$$

Table 1 Parameters used in delay and power consumption model

Parameter	Definition
T_s	Data collection period by sensors at layer 1
$Data_{sm}$	Amount of data transmitted from sensors at layer 1 to the connected mobile device at layer 2
R_{sm}	Data transmission rate from layer 1 to layer 2
f_{sm}	Link failure rate from layer 1 to layer 2
$Data_m$	Amount of data processed inside the mobile device at layer 2
S_m	Data processing speed of the mobile device
$Data_{me}$	Amount of data transmitted from the mobile device at layer 2 to the connected edge/fog device at layer 3
R_{me}	Data transmission rate from layer 2 to layer 3
f_{me}	Link failure rate from layer 2 to layer 3
$Data_e$	Amount of data processed by the participating edge/fog device at layer 3
S_e	Data processing speed of the edge/fog device participating in data processing
$Data_{ec}$	Amount of data transmitted from the edge/fog device at layer 3 to the cloud at layer 4
R_{ec}	Data transmission rate from layer 3 to layer 4
f_{ec}	Link failure rate from layer 3 to layer 4
$Data_c$	Amount of data processed inside the cloud at layer 4
S_c	Data processing speed of the cloud
P_s	Power consumption of a sensor node during data collection period T_s
N	Number of sensor nodes at layer 1
P_{st}	Power consumption of a sensor node per unit time during data transmission
P_{mr}	Power consumption of a mobile device per unit time during data reception
P_{mp}	Power consumption of a mobile device per unit time during data processing
P_{mt}	Power consumption of a mobile device per unit time during data transmission
P_{er}	Power consumption of an edge/fog device per unit time during data reception
P_{ep}	Power consumption of an edge/fog device per unit time during data processing
P_{et}	Power consumption of an edge/fog device per unit time during data transmission
P_{cr}	Power consumption of the cloud per unit time during data reception
P_{cp}	Power consumption of the cloud per unit time during data processing

The time period in data transmission from layer 2 to layer 3 is given as,

$$T_{me} = (1 + f_{me}) \frac{Data_{me}}{R_{me}} \tag{3}$$

The time period in data processing at layer 3 is given as,

$$T_e = \frac{Data_e}{S_e} \tag{4}$$

The time period in data transmission from layer 3 to layer 4 is given as,

$$T_{ec} = (1 + f_{ec}) \frac{Data_{ec}}{R_{ec}} \tag{5}$$

The time period in data processing at layer 4 is given as,

$$T_c = \frac{Data_c}{S_c} \tag{6}$$

Therefore, the total delay in data collection, processing, and transmission in the IoT-MCC framework is given as,

$$T_{tot} = T_s + T_{sm} + T_m + T_{me} + T_e + T_{ec} + T_c \tag{7}$$

The power consumption of the sensor nodes at layer 1 for data collection and transmission is given as,

$$P_{sct} = \sum\nolimits_N P_s + \sum\nolimits_N (P_{st} \bullet T_{sm}) \tag{8}$$

The power consumption of the mobile device at layer 2 for data reception, processing, and transmission is given as,

$$P_{mrpt} = (P_{mr} \bullet T_{sm}) + \left(P_{mp} \bullet T_m\right) + (P_{mt} \bullet T_{me}) \tag{9}$$

The power consumption of the edge/fog device at layer 3 for data reception, processing, and transmission is given as,

$$P_{erpt} = (P_{er} \bullet T_{me}) + \left(P_{ep} \bullet T_e\right) + (P_{et} \bullet T_{ec}) \tag{10}$$

The power consumption of the cloud at layer 4 for data reception and processing is given as,

$$P_{crp} = (P_{cr} \bullet T_{ec}) + \left(P_{cp} \bullet T_c\right) \tag{11}$$

Therefore, the total power consumption of the devices of the IoT-MCC framework is given as,

$$P_{tot} = P_{sct} + P_{mrpt} + P_{erpt} + P_{crp} \tag{12}$$

In the IoT-MCC framework, the intermediate mobile device and edge/fog device participate in data processing, therefore, the amount of data transmission from the end node to the cloud is reduced, which reduces the amount of data traffic, delay, and consequently, power consumption of the entire framework. In Table 2 and Fig. 4, we have presented the total delay and power consumption of the IoT-MCC framework for data collection, processing, and transmission.

Table 2 Delay in Edge/fog-based-IoT-MCC framework and Cloud-only IoT framework

	Delay (sec)	
Collected sensor data (MB)	Edge/fog-based IoT-MCC framework	Cloud-only IoT framework
100	3.8992	5.0717
200	7.8217	10.1867
300	11.7675	15.3450
400	15.7367	20.5467
500	19.7292	25.7917
600	23.7450	31.0800

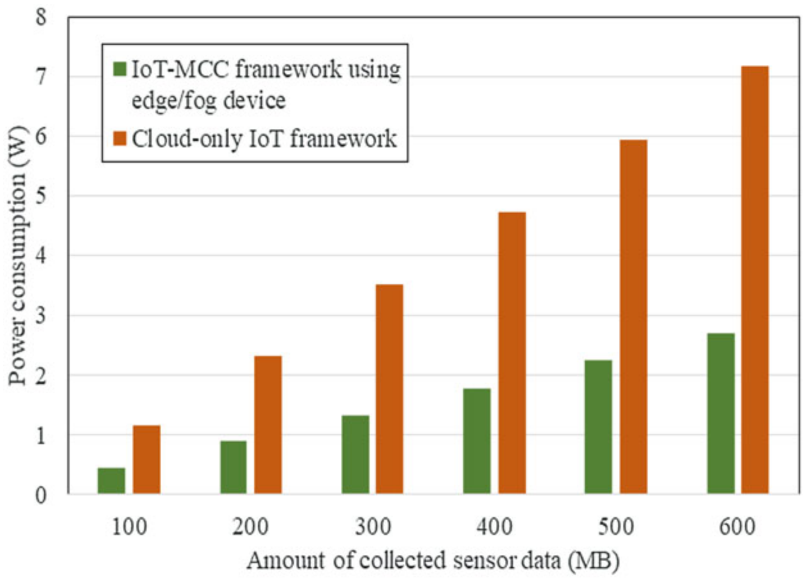

Fig. 3 Power consumption in Edge/fog-based IoT-MCC framework and Cloud-only IoT framework

We observe that the use of mobile device and edge/fog device in data processing reduces the delay and power consumption than transmission and processing of the entire collected sensor data inside the cloud. Table 2 shows that the use of edge/fog device in IoT-MCC reduces the delay ~23% than the cloud-only IoT framework. We observe from Fig. 3 that using the edge/fog device in the IoT-MCC framework the power consumption is reduced ~62% than the cloud-only IoT framework.

4 Contribution of IoT- MCC Convergence

The fruitfulness of IoT mainly depends on high performance, reliability, pervasiveness, and scalability. In recent days, it becomes possible through the integration of IoT with MCC which enables "everything as a service" model [13–15]. The integration of IoT with MCC provides several advantages mentioned as follows:

- Flexible and efficient architecture: Integration of IoT and MCC provides a flexible and efficient architecture.
- Unlimited data storage capacity: Convergence of IoT and MCC provides a solution towards the storage limitation of mobile device. It provides unlimited data storage capacity on cloud.
- Extending battery lifetime: One of the major limitations of the mobile device is its limited battery lifetime. IoT-MCC integration provides the facility of offloading. In order to reduce power consumption of mobile devices, large computation can be offloaded to the powerful cloud server.
- On-demand service: IoT-MCC integration extends various services of cloud computing to the edge of the network. Through MCC it is possible to distribute data in such a way that it will be easily accessible to the end users. Every IoT device is uniquely identifiable. Through IoT-MCC integration the request of users along with the ID and location are transmitted to the central processors of the cloud. After processing requested services are provided to the mobile users.

5 Applications of IoT- MCC

Integration of IoT and MCC technologies creates exciting opportunities in variety of real world applications [6–34] in which energy management [6, 16], environment monitoring, agriculture[17–19], healthcare [9, 12, 20–24], smart city [25–32], and Industrial automation [33–34] are worth mentioning. Table 3 presents recent IoT-MCC-based publications in various application domains. Here, we have considered the applications of sensor-mobile-cloud also.

6 Enabling Technologies for Green IoT-MCC

Green IoT means it should be environment-friendly and energy-efficient. Initially IoT devices remained switched on even when not required. In recent days, the main focus is on smart operation of devices to achieve green IoT [35–45]. It is achievable by enforcing that the devices will be only on when it is required otherwise it will remain idle or off. Green IoT-MCC is achievable through the collaboration of several enabling technologies [35] as shown in Fig. 4.

Table 3 List of recent IoT-MCC based publications in various application domains

Application domain	Papers	Journal/Conference/Book Chapter name	Author name	Year of publication	Publication type
Energy management	[6]	*The Journal of Supercomputing*	Mukherjee, A., Deb, P., De D.and Buyya, R.	2019	Journal
	[16]	*International Journal of Energy Research*	Hashmi, S.A., Ali, C.F. and Zafar, S.	2021	Journal
Agriculture	[17]	*IEEE Wireless Communications*	J. Ruan et al.	2019	Journal
	[18]	*IEEE access*	Ferrag, M.A., Shu, L., Yang, X., Derhab, A. and Maglaras, L.	2020	Journal
	[19]	*Materials Today: Proceedings.*	Kiran, S., Kanumalli, S.S., Krishna, K.V.S.S.R. and Chandra, N.	2021	Journal
Healthcare Application	[9]	*Journal of Ambient Intelligence and Humanized Computing*	Mukherjee, A., Ghosh, S., Behere, A., Ghosh, S.K. and Buyya, R.	2020	Journal
	[12]	*Journal of Medical Imaging and Health Informatics*	De, D. and Mukherjee, A.	2015	Journal
	[20]	*Journal of medical systems*	Suciu, G., Suciu, V., Martian, A., Craciunescu, R., Vulpe, A., Marcu, I., Halunga, S. and Fratu, O.	2015	Journal
	[21]	*International Journal of Smart Home*	Nandyala, C.S. and Kim, H.K.	2016	Journal
	[22]	*IEEE Access*	Islam, M.M., Razzaque, M.A., Hassan, M.M., Ismail, W.N. and Song, B.	2017	Journal
	[23]	*Sensors*	Oueida, S., Kotb, Y., Aloqaily, M., Jararweh, Y. and Baker, T.	2018	Journal

Table 3 (continued)

	[24]	*Electronics*	Ijaz, M., Li, G., Lin, L., Cheikhrouhou, O., Hamam, H. and Noor, A.	2021	Journal
Smart City	[25]	*Computer Communications.*	Jiang, D et al.	2020	Journal
	[26]	*Multimedia Tools and Applications*	Kumar, M., Raju, K.S., Kumar, D., Goyal, N., Verma, S. and Singh, A.	2021	Journal
	[27]	*IEEE Wireless Communications*	Chen, N., Qiu, T., Zhao, L., Zhou, X. and Ning, H.	2021	Journal
	[28]	*Sustainable Cities and Society*	Haseeb, K., Din, I.U., Almogren, A., Ahmed, I. and Guizani, M.	2021	Journal
	[29]	*Handbook of Green Engineering Technologies for Sustainable Smart Cities*	Kumar, K.S., Kumar, T.A., Sundaresan, S. and Kumar, V.K.	2021	Book chapter
	[30]	*Green Computing in Smart Cities: Simulation and Techniques*	Sarkar, N.I. and Gul, S.	2021	Conference paper
	[31]	*Towards Smart World*	Jokanović, V.	2020	Book chapter
	[32]	*2018 International symposium on networks, computers and communications (ISNCC)*	Rajab, H. and Cinkelr, T.	2018	Conference paper
Industrial Automation	[33]	*Materials Today: Proceedings*	Sundari, V.K., Nithyashri, J., Kuzhaloli, S., Subburaj, J., Vijayakumar, P. and Jose, P.S.H.	2021	Journal
	[34]	*Procedia Computer Science*	Xenakis, A., Karageorgos, A., Lallas, E., Chis, A.E. and González-Vélez, H.	2019	Journal

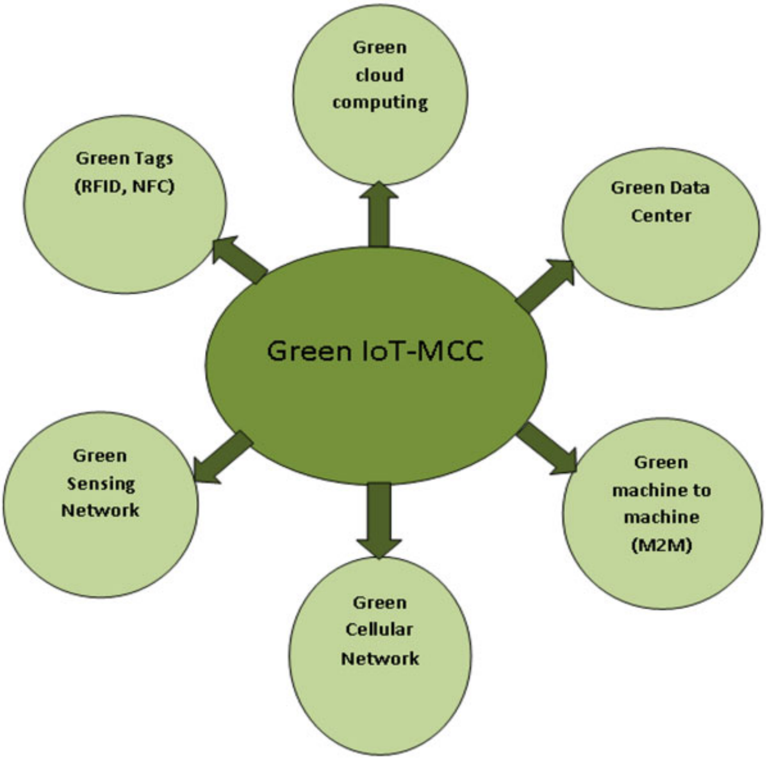

Fig. 4 Green IoT-MCC Enablers

Green tags are one of the important enabling technologies which include RFID (Radio Frequency Identification). It is a promising wireless system to enable green IoT. Near Field Communications (NFC) is one of the most recent short-range wireless system which is similar to RFID and more customer-oriented [35].Due to the tiny size, low cost, and reduced energy consumption these green tags are nowadays integrated in every device. In addition, several clustering algorithms including bio-inspired algorithms are playing important role for making green sensor network which is the main component of green IoT [39–42]. Energy-efficient cloud computing, data management, machine-to-machine communication, and green cellular network are also vital for Green IoT-MCC.

7 Energy Harvesting Techniques for Green IoT

Energy harvesting also plays a significant role in successful implementation of green IoT. Energy harvesting receives considerable research attention both from Industry

Table 4 Summary of energy efficient solutions for IoT

Papers	Contribution	Type
[44]	Energy harvesting architecture for IoT	Hardware
[45]	Energy-efficiency using virtual object reconfiguration	Software
[46]	Energy optimization using smart ant colony algorithm	Software
[47]	Energy-efficiency using fog computing model	Software
[48]	Energy-efficiency through data compression	Software
[49]	Energy-efficient system on chip (Soc) design.	Hardware
[50]	Green RFID tags and sensing network	Software
[51]	Smart location-based energy control in buildings	Hardware
[52]	Smart energy harvesting framework for IoT networks supported by femtocell access points (FAPs)	Hardware
[53]	Street illumination system and emergency e-vehicle charging	Hardware
[54]	An energy management scheme which includes reduction of data volume	Software

and Academia [44–56]. In addition, the role of other energy-efficient techniques is also important [57–60]. Table 4 summarizes various energy efficient solutions and their contribution towards green IoT [60].

8 Future Research Directions of IoT-MCC

Although IoT-MCC integration can overcome several limitations of IoT and provide several advantages, still there are a lot of research challenges need to be addressed, which we mention as follows:

- Security and privacy: Most of the real world IoT-MCC application requires communication between huge numbers of heterogeneous IoT devices which challenges the data security and privacy of individual users [36–38].
- Energy harvesting: The functioning of IoT devices mainly depends on the continuous power supply which becomes difficult in remote deployment. In this respect energy harvesting using ambient energy source can play an important role [52–56]. However, usefulness of this type of ambient energy mainly depends on the location of the devices and compromises the mobility of the device [60]. In addition, minimizing energy consumption of IoT devices, energy-efficient data aggregation and transmission from sensor nodes plays important role in implementing green IoT-MCC [57–63].
- Reusability: Due to the vast use of IoT devices, percentage of carbon foot print is also increasing rapidly. Therefore, reusability of IoT devices is becoming necessary for successful implementation of sustainable green IoT-MCC [64].
- Heterogeneity: The services offered by the IoT-MCC require communication between heterogeneous devices. Most of the IoT data which are coming from

dispersed sources are either unstructured or semi structured. Hence, the real time data processing and service provisioning are becoming major challenges [65–66].

- Interoperability: Interoperability among various heterogeneous IoT devices as well as between IoT/Cloud infrastructures is one of the main challenges of green IoT-MCC [67–70].
- Scalability: Scalability of the IoT device is one of the crucial design challenges which need to be addressed for fruitful implementation of green IoT-MCC [71–72].

9 Conclusion

IoT and MCC are two emerging areas of smart computing. In this chapter, we have illustrated the integration of IoT and MCC, and discussed the architecture and applications of IoT-MCC. We have mathematically formulated the delay and power consumption model for the IoT-MCC framework. We have discussed on the enabling technologies and applications of IoT-MCC. Green i.e. power-efficiency is a major concern for an eco-friendly system. The aspect of power-efficiency we have also highlighted in this chapter. Accordingly, the use of energy-harvesting in IoT has been also discussed. Finally, this chapter covers the future research directions of IoT-MCC.

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