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Energy Characterization for Data Collection and Transmission in Participatory Mobile Crowdsensing Environment

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Abstract: Energy consumption is a major issue for data collection in the Mobile crowdsensing(MCS) environment as it incurs a significant amount of power/energy consumption for data sensing, data collection, and further data transmission to the cloud platform using various data transmission modes such as Bluetooth, Wi-Fi, and cellular network. Due to this, user participation in the crowdsensing process has been affected. Therefore, it is highly essential to estimate and minimize power/energy consumption made for data collection and transmission from the user's side to encourage them for participation in the crowdsensing process. In the proposed work, an energy efficient dynamic data transmission model has been proposed using Bluetooth, Wi-Fi, and Long-Term Evolution(LTE) network for minimization of user's side power/energy consumption made for data transmission to cloud platform in the participatory MCS environment. It has been implemented using the CrowdSenSim simulator, and its performance is compared with the energy consumption for different transmission modes. The number of data contributors plays a vital role in the statistical analysis for energy characterization in various data transmission modes. It impacts the size of data transmitted and also the equivalent energy consumed. It has been observed that energy consumed using Bluetooth is minimum in comparison to Wi-Fi and LTE. It has been observed that energy consumption mostly depends on the transmission mode apart from the size of the data transmitted. It also depends on the size of data transmitted in every data transmission mode.

Keywords: Mobile Crowdsensing, Long-Term Evolution(LTE), Wi-Fi, Bluetooth, Energy consumption, Transmission mode.

1. INTRODUCTION

Smartphones emerged as essential and unavoidable things for human beings due to their vast services and ease of use. The smartphone can also be used for collecting and sharing information about the surroundings with or without users' knowledge by using many sensors, such as a global positioning system (GPS), accelerometer, humidity, temperature, proximity, etc., attached to it. It is one of the best tools for real-time data collection and data sharing to cloud or other devices using various data transmission modes such as Wi-Fi, Cellular networks, and Bluetooth that will provide better scope for information retrieval [1].
Mobile Crowdsensing(MCS) [2], [3] is a mechanism for collecting and integrating heterogeneous types of vast data from a variety of sources such as smartphones, laptops, tablets, palmtops, smart vehicles, smart buildings, smart wearable devices, and from humans in the knowledge of the user in case of participatory sensing or without knowledge of the user in opportunistic sensing. Further, this vast data will be transmitted to the cloud for storage using various data transmission modes such as Bluetooth, Wi-Fi, or cellular network, or it can be stored locally for analysis to get fruitful information from the dataset that will be used for the betterment of human beings. Various analytical models embedded with various advanced data management tools and analytical graphing methods for visualization related to Big-data, the Internet of Things(IoT), and cloud computing are generally used for data analysis. It has been analyzed to provide better solutions to manage various operations in the city, like traffic, vehicles, roads, infrastructure, etc., and also to improve the social and personal lifestyle of human beings.
In MCS, data will be collected from the environments through various devices like smartphones and IoT-enabled devices embedded with various sensors like temperature, proximity, accelerometer, GPS, pressure, etc., used for various applications[4]. Further, This data will be integrated and transmitted to the cloud or local system for storage and analysis to get fruitful information for the developer and the end-users. Data can be transmitted to the cloud platform for storage and analysis through dedicated and continuous internet connectivity. Internet connectivity can be obtained by using a cellular network like 3G, Long-Term Evolution(LTE), and 5G that incurs data charges

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from own pocket or by connecting through available Wi-Fi based network, or by using Bluetooth based network through Bluetooth tethering or Wi-Fi router in which data charges can be omitted. Bluetooth tethering is a mechanism in which the internet is available on a device that can be shared with another device connected through Bluetooth. It is an example of sensing as a service model[5] whose effectiveness can be estimated using the benefits in terms of obtained information and the cost of data collection. The cost of data collection includes energy consumption for data sensing and data transmission to the cloud or local system using various data transmission modes like Bluetooth, Cellular Network, or Wi-Fi[3].

a) Problem Statement and Motivation of Proposed Work

Power/Energy consumption is a major factor for data collection in the MCS environment. Smartphones, smart devices, laptops, etc., are generally used for data collection in the MCS environment that runs using batteries. In the MCS environment, a huge amount of data has been collected continuously from the environment with the help of sensors, with or without the knowledge of users. It incurs a significant amount of power/energy consumption for data sensing, data collection, and further data transmission to the cloud platform using various data transmission modes such as Bluetooth, Wi-Fi, and Cellular network. Due to the limited power capacity of devices used for crowdsensing, they exhaust the available energy faster; as a result, frequent recharging or replacement of the battery is required. Due to this, user participation in the crowdsensing process has been affected. Therefore, it is highly essential to estimate and minimize power/energy consumption made for data collection and transmission from the user's side to encourage them for participation in the crowdsensing process.

In order to solve this issue, a dynamic energy-efficient data transmission model for the participatory MCS environment through Bluetooth, Wi-Fi, and LTE data transmission modes has been presented. It is focused on data transmission to the cloud platform with minimum energy consumption. Data transmission mode will be selected automatically and dynamically among Bluetooth, Wi-Fi, and LTE as per the availability of the network to minimize power/energy consumption. Bluetooth and Wi-Fi based network has been considered in the proposed work to reduce energy consumption. Short-range wireless communication mechanism like Bluetooth, Wi-Fi, ZigBee, etc., has been considered to create small local area network for data communication, and the internet can be shared through Hotspot, and Bluetooth tethering that can be used for minimization of energy/power consumption [5], [6]. Bluetooth is an integral part of various devices like laptops, palmtops, Personal digital assistants (PDAs), and smartphones due to its energy-efficient mechanism. Zigbee, Bluetooth, Impulse Radio Ultra Wide Band (IR-UWB), etc., can be used as an energy-efficient data transmission mode in wireless media due to ultra-low power consumption, the low transmission time for the Internet of Things(IoT) Based application in mobile wireless sensor network [7], [8]. The proposed work has been implemented through the CrowdSenSim simulator to judge its efficiency. It estimates the order of data transmission modes in terms of energy consumption. It also highlights the impacts of the number of data contributors on the size of data transmitted and the equivalent energy consumed. Finally, it establishes a relationship among the size of data transmitted, energy consumed, and data transmission modes for energy characterization.

The rest of the paper is organized as follows. The background and related work are discussed in section 2, followed by the discussion on the proposed methodology in section 3. Section 4 analyses the experimental result, and conclusions and future scope are discussed in section 5.

2. Background

Data collection, transmission, and analysis are the major phases in mobile crowdsensing(MCS). Distributed data collection framework(DCF) has been discussed in [3] for minimization of reporting and sensing costs and also to boost the data collection process in an opportunistic cloud-based MCS environment. A different mechanism for enhancement of usage of data contributed by the user as well as minimization of sensing and reporting cost in DCF has been proposed in [9]. Authors in [10] suggested that in comparison to the probabilistic data reporting mechanism in DCF, nonstop and automatic data reporting is good for efficient energy utilization. Deterministic and stochastic mobility models have been discussed in [11] to obtain an optimized solution for minimizing energy consumption and predicting the locality of various users in an opportunistic MCS environment.

Authors in [12] presented a cooperative environment among devices through the cellular network to provide a correct position for executing various crowdsensing-related tasks in an energy-efficient manner in an MCS environment. Authors in [13] proposed a coalition formation algorithm-based device-to-device chain that will allow a user to upload data with proper assistance from other users using a cellular network to optimize resource consumption. Authors in [14] suggested that energy consumption for data transmission is more than data reception in smartphones using Network Simulator 3. Sensed data through a smartphone can be sent to a cloud platform either by using a cellular network, i.e., prepaid or postpaid, in which the user will pay for the data consumed for transmission or by using a Wi-Fi or Bluetooth network in which the user can transmit for free of cost manner [15].

Energy profiler, an android application, has been developed in [16] to characterize smartphone energy consumption for user interaction to perform various operations through 3G, 4G, and Wi-Fi modes. Authors in [17] proposed a Lyapunov optimization framework based data communication mechanism which dynamically selects energy-efficient data transmission mode among different approaches such as Wi-Fi, Cellular networks, or both for data transmission on wearable devices using the queue used for data transmission, device rolling speed and network conditions. Authors in [18] developed a control system for the management of energy consumption of household appliances using Wi-Fi for data transmission in an indoor mode for short-range communication and LORAWAN for outdoor use in long-range communication. FAN and Washing machines are used for experiments to judge the behavior of consumers and reduction of energy usage.

Authors in [6] suggested that Bluetooth is more memory efficient than Wi-Fi for data transmission in an MCS environment through a mathematical model designed for energy characterization. Authors in [5] discussed the energy and power consumption using Bluetooth transmission mode in an MCS environment in idle as well as the connected state. BMADS[19] a dynamic scanning mode can be implemented in Bluetooth devices in the BLE mesh network that will reduce power consumption by 98%. BLE can be used as an energy-efficient method for data collection for in-door tracking of humans as well as objects in beacon mode[20]. BLE sensors can be used for data collection and transmission in MCS environment[21], [22]. BLE is also implemented as low power data transmission mode Capacitive Electrocardiogram (ECG) that provides better health information for humans compared to gel-type ECG electrodes, and 16.4 mW power consumed by the whole system as reflected in [23]. BLE can be used as a solution for a low power system with an electroencephalogram(EEG) sensor attached to epilepsy patients for automatic and continuous recording and transmission of EEG data for long-term monitoring of seizure events, and it achieves 80% efficiency in seizure detection [24]. Similarly, it can be used for various sectors like Human activity recognition, biometrics and health care applications, a wearable device for health monitoring, etc. [25], [26].

a) *Technical Contributions*

Energy consumption for data collection and transmission is a major issue in mobile crowdsensing. From the above studies, it has been observed that various work has been done using Bluetooth, Wi-Fi, and cellular network to minimize energy consumption for data transmission in the MCS environment. In the proposed work, an energy efficient dynamic data transmission model based on Bluetooth, Wi-Fi, and LTE network has been proposed to minimize the user's side power/energy consumption made for data transmission to the cloud platform in a participatory MCS environment. In this model, a scenario has been formed in which automatically and dynamically energy efficient data transmission mode will be selected as per the availability of the network for data transmission among Bluetooth, Wi-Fi, and LTE. The efficiency of the model has been judged through energy characterization. The review data collection mechanism discussed in[27], [28] for ensuring data integrity in the MCS environment has been extended in the proposed work by uploading the review data to cloud platform through the proposed Bluetooth, Wi-Fi, and LTE based dynamic energy efficient model for energy consumption estimation. It has been implemented through the CrowdSenSim simulator, in which various users will move to different locations and provide feedback/review for the location, and review data will be transmitted to the cloud platform by using energy efficient local area network through Bluetooth or Wi-Fi mode if available in that location, otherwise through LTE network. The mode of data transmission will be selected automatically and dynamically among Bluetooth, Wi-Fi, and LTE modes in such a way that data will be transmitted with minimum energy consumption. Simulation data has been recorded and analyzed to estimate the size of data and the amount of energy incurred for data transmission to the cloud platform using Bluetooth, Wi-Fi and LTE data transmission modes. It highlights the order of data transmission mode in terms of energy efficiency. It establishes a relationship between the size of the data transmitted and the data transmission mode with the incurred energy for data transmission. It also highlights the impact of the number of data contributors in energy characterization.

3. Methodology

A. *Proposed Model*

The prime focus of the proposed work is to provide a dynamic energy efficient data transmission model for the participatory MCS environment through Bluetooth, Wi-Fi, and LTE. It is mainly focused on the selection of automatic and dynamic data transmission modes among Bluetooth, Wi-Fi, and LTE to transmit data to the cloud platform with minimal energy consumption and efficient use of available resources. CrowdSenSim Simulator has been used for simulation in the proposed work. During the simulation process, review data has been generated for various users and transmitted to the cloud for storage and analysis using mobile and web-based applications through various electronic gadgets such as smartphones, laptops, tablets, etc., and various transmission modes such as Bluetooth, Wi-Fi, and LTE in the mobile crowdsensing environment. The proposed system is focused on achieving the following objectives.

1) Generation of review data for a location using sensors such as GPS and accelerometer for a user after visiting the location during simulation. It will be transmitted to the cloud platform for storage and analysis with minimal energy consumption.
2) Estimation of the size of review data as well as the amount of energy consumed for transmission of review data to cloud platform using dynamically selected energy efficient data transmission mode among Bluetooth, Wi-Fi, and LTE modes of data transmission. Energy equations for data transmission to the cloud platform through Bluetooth, Wi-Fi, and LTE mode has been implemented through the CrowdSenSim simulator.
3) Transmission of review data to cloud platform for

storage and analysis through proposed dynamic energy efficient data transmission model with minimal energy consumption. Review data contains information like user info, review info, size of data, and consumed energy for data transmission.

4) Judge the efficiency of the proposed model through proper analysis of the received dataset using the proposed mathematical model for energy characterization in terms of data transmission mode, size of data transmitted, and the number of data contributors.

B. Proposed Architecture

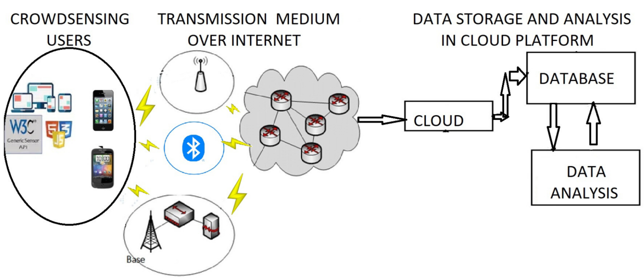

Figure 1. Architecture of Proposed Dynamic Energy Efficient Data Transmission Model through Mobile Crowdsensing

The proposed work has been implemented using a descriptive discrete event-based CrowdSenSim simulator[29] mostly used to provide a simulation environment for mobile crowdsensing. Various MCS related tasks can be successfully executed in urban spaces during simulation for the development of a novel solution for various areas like event observations, collection of data, management of resources, and activity assignments, and these events can be recorded to generate a vast dataset for analysis. During simulation, users will move through various locations randomly, and detection of the user's current location and their movement has been controlled using GPS and accelerometer sensors. Users will deliver reviews/feedback for their visited location during the simulation. Various users will transmit review data to the cloud platform through the dynamically selected energy efficient data transmission mode among Bluetooth, Wi-Fi, or LTE data transmission modes. The mathematical equations for data transmission using various data transmission modes such as Bluetooth, Wi-Fi, and LTE have been implemented using the CrowdSenSim simulator for the estimation of energy consumption and the size of data transmission of users. These events will be recorded in CSV format in text files during simulation for data analysis. Two thousand users and 897 distinct locations have been considered in the proposed work for review data collection and transmission. Bluetooth based network, Wi-Fi based network, or both, or none of them capable of providing internet connectivity to other users for data sharing, is available in all 897 locations. As per the availability of the network, energy efficient data transmission mode will be selected automatically in a dynamic manner in the desired location. Simulation has been performed for 25 rounds to generate a vast dataset for better analysis. The proposed architecture has been reflected in Figure 1, and it has been discussed as follows.

1) Crowdsensing Users

In the proposed work, during the simulation period in each round, 2000 users have been considered for the generation and transmission of reviews of various selected locations among 897 considered locations. Smartphones, laptops, desktops, tablets, etc., electronic gadgets can be used by users to deliver reviews/feedback for their visited location as per their experience through an android application or web-based application. Review/feedback data contains various information about the desired location, such as positional coordinates in terms of latitude and longitude obtained using GPS and accelerometer sensor, rating in the range of 1 to 5, the communicative language used in the location, constant feedback in terms of like, dislike, average, and rectification required, any message for the location to highlight its positive and negative remark and also for improvement. During simulation, this review data has been automatically generated for the user for their random visit to location among 897 considered locations. GPS and accelerometer sensors have been used to control the movement of users and for extraction of positional coordinates in terms of latitude and longitude of the current location of user. Further, this review data will be transmitted to the cloud platform through various electronic gadgets using various data transmission modes such as Bluetooth, Wi-Fi, and LTE.

2) Data Transmission from Users to Cloud Platform

After having a review/feedback data for the desired location, it will be transmitted to the cloud platform for storage and analysis using various data transmission modes such as Bluetooth, Wi-Fi, and LTE. For review data transmission to the cloud platform, after clicking on submit button, dynamically energy efficient data transmission mode has been selected as per the availability of network in the desired location among Bluetooth, Wi-Fi, or LTE data transmission modes as reflected in the algorithm 1, 2, and 3. After clicking on submit button for review transmission, initially, it will turn on Bluetooth and look for any Bluetooth based network in that location; if available, then pair with the randomly selected device among all nearby available devices for connection, and review data will be transmitted to the cloud platform. In the case of unavailability of Bluetooth based network, it will turn on Wi-Fi and look for available Wi-Fi based networks in the desired location, if detected then connect with the randomly selected available Wi-Fi based network among all available Wi-Fi based networks for connection and data will be transmitted to cloud platform. If both Bluetooth and Wi-Fi based network are not available in the desired location, then review data will be transmitted to the cloud platform using LTE mode. The mathematical equation for data transmission modes such as Bluetooth, Wi-Fi, and LTE has been implemented using the CrowdSenSim simulator for the estimation of energy consumption as well the size of data transmitted for review submitted by the user. These events will be recorded during simulation to generate a dataset for analysis.

3) *Data Storage and Analysis in Cloud Platform*

Review data received from users using Bluetooth, Wi-Fi, or LTE data transmission modes have been stored in the cloud platform for analysis. It has been analyzed using MATLAB software to estimate the energy consumption made by various users for data transmission, the size of data transmitted, number of data contributors during simulation. A relationship has been established between the size of data transmitted and equivalent energy consumption with data transmission mode for energy characterization. Also, the effect of the number of data contributors on energy consumption, size of data transmitted, and data transmission mode has been observed for energy characterization.

C. Data Collection Framework

Various activities for review generation and transmission of reviews using various data transmission modes such as Bluetooth, Wi-Fi, and LTE by various users through the android application or web-based application have been performed during each simulation using Crowdsensim Simulator in Mobile Crowdsensing environment [2]. A mathematical equation for energy consumption in various transmission modes such as Bluetooth, Wi-Fi, and LTE has been implemented in Crowdsensim Simulator to estimate energy consumption for each review submission by the user. Review data, size of review data, and estimated energy consumed for each review submission have been recorded during the simulation for the dataset. Every activity performed during simulation, from review generation to review transmission, has been observed and recorded to generate the dataset. Simulation has been performed for 25 rounds using 2000 users and 897 locations for review data generation. Simulation statistics have been reflected in Table I.

Item	Value
No. of Users	2000
No. of locations	897
No. of Simulations/Rounds(n)	25
No. of data transmission modes	3
No. of Reviews obtained	6100000
Size of generated dataset	600 Mb

TABLE I. Simulation Statistics

D. Data Pre-processing and Analysis

Review data generated using the CrowdSenSim simulator has been extracted, and it will be converted to comma-separated value(CSV) format and stored in the text file for analysis. Further, this dataset has been analyzed using MATLAB for energy characterization.

Algorithm 1 Case 1:- energy efficient Data Transmission mode selection process for review data transmission from user to cloud platform

Require: User(U) wants to submit a review(R) for the Location(L).
Ensure: Device of User(D_u) supports Bluetooth(B), Wi-Fi(W), and LTE(L) data transmission mode.

```
A_d ← {}    ▷ Array that contains list of available nearby Bluetooth or Wi-Fi based devices
while U trying to submit R for L do
    if D_u supports B then
        Turned ON B
        A_d ← Scanning for available nearby Bluetooth based networked devices capable of sharing internet connection
        N_d ← len(A_d) ▷ No. of available Bluetooth based networked devices
        if N_d ≥ 0 then
            L ← 0                           ▷ Lower limit
            U ← N_d                         ▷ Upper limit
            P ← (rand()%(U − L + 1)) + L ▷ Position of selected Bluetooth based networked device
            S_d ← A_d[P]    ▷ connect user's device with selected Bluetooth based networked device for internet connection through Bluetooth tethering
            transmit R to cloud platform for storage and analysis
        else if D_u supports W then
            Turned ON W
            A_d ← Scanning for available nearby Wi-Fi networks
            N_d ← len(A_d) ▷ No. of available Wi-Fi based hotspot devices
            if N_d ≥ 0 then
                L ← 0                       ▷ Lower limit
                U ← N_d                     ▷ Upper limit
                P ← (rand()%(U − L + 1)) + L ▷ Position of Wi-Fi based hotspot device
                S_d ← A_d[P]    ▷ connect user's device with selected Wi-Fi based hotspot device for internet connection
                transmit R to cloud platform for storage and analysis
            else
                Turned ON L
                A_d ← 0     ▷ Bluetooth based and Wi-Fi based networked devices not available those are capable of sharing internet connection then data will be transmitted to cloud through LTE mode
                transmit R to cloud platform for storage and analysis
            end if
        end if
    end if
end while
```

Algorithm 2 Case 2:- energy efficient Data Transmission mode selection process for review data transmission from user to cloud platform

Require: User(U) wants to submit a review(R) for the Location(L).
Ensure: Device of User(D_u) supports either Wi-Fi(W), or LTE(L) not Bluetooth data transmission mode.
$A_d \leftarrow \{\}$ ▷ Array that contains list of available nearby Wi-Fi based devices
while U trying to submit R for L **do**
  if D_u supports W **then**
    Turned ON W
    $A_d \leftarrow$ Scanning for available nearby Wi-Fi networks
    $N_d \leftarrow len(A_d)$ ▷ No. of available Wi-Fi based hotspot devices
    if $N_d \geq 0$ **then**
      $L \leftarrow 0$ ▷ Lower limit
      $U \leftarrow N_d$ ▷ Upper limit
      $P \leftarrow (rand()\%(U - L + 1)) + L$ ▷ Position of Wi-Fi based hotspot device
      $S_d \leftarrow A_d[P]$ ▷ connect user's device with selected Wi-Fi based hotspot device for internet connection
      transmit R to cloud platform for storage and analysis
    else
      Turned ON L
      $A_d \leftarrow 0$ ▷ Bluetooth based and Wi-Fi based networked devices not available those are capable of sharing internet connection then data will be transmitted to cloud through LTE mode
      transmit R to cloud platform for storage and analysis
    end if
  else
    Turned ON L
    $A_d \leftarrow 0$ ▷ Bluetooth based and Wi-Fi based networked devices not available those are capable of sharing internet connection then data will be transmitted to cloud through LTE mode
    transmit R to cloud platform for storage and analysis
  end if
end while

Algorithm 3 Case 3:- energy efficient Data Transmission mode selection process for review data transmission from user to cloud platform

Require: User(U) wants to submit a review(R) for the Location(L).
Ensure: Device of User(D_u) supports only LTE(L) data transmission mode.
while U trying to submit R for L **do**
  Turned ON L and connect with internet
  transmit R to cloud platform for storage and analysis
end while

E. Review Data Generation During Simulation

Two thousand users and 897 location has been considered during the simulation in the CrowdSenSim simulator. Users will randomly visit various locations, and for the location, the review will be generated and uploaded to the cloud collector through various data transmission modes such as Bluetooth, Wi-Fi, and LTE. Accelerometer and GPS sensors have been used to detect user movement and the current location visited by the user in terms of latitude and longitude of the location. After getting latitude and longitude from the GPS sensor, a rating in the range of 1 to 5, a few comments, communicative language, and feedback such as like, dislike, average, and rectification required for the selected location have been assigned to generate review data. The size of the review data has been estimated. Finally, this review data has been sent to a cloud collector using various transmission modes, and the consumed energy for data transmission has been computed. Review data, size of data, transmission mode, energy consumed, and the round number has been stored for each and every review for analysis. Simulation has been performed for n=25 rounds to generate a vast dataset. Specification of sensors like sample rate in Hertz, the Sample size in Bits, and Current drawn in microampere has been shown in Table II.

Sensor	Sample Rate(in Hz)	Sample Size(in Bits)	Current drawn(in μA)
Accerometer	10	48	450
GPS	0.1	192	22000

TABLE II. Parameters of sensors used during simulation

F. Estimation of Size of Review Data

Review data will be obtained using an accelerometer and GPS sensor for user movement detection and location estimation and textural information about the location. Therefore, it will be the sum of the size of the accelerometer data, the size of the GPS data, and the size of the textual data. The size of accelerometer sensor data can be estimated using Eq.-1 and Eq.-2. Similarly, Eq.-3 and Eq.-4 are used to compute the size of GPS sensor data.

$$A_{ns} = A_{sf} * 60 * A_{ti} \quad (1)$$

In Eq-1, the number of samples generated by the accelerometer sensor represented A_{ns} has been computed using the sample frequency of the accelerometer sensor as observed in Table II as represented by A_{sf} and time interval between two samples represented by A_{ti}.

$$A_{ds} = A_{ns} * A_{sz} \tag{2}$$

In Eq-2, A_{ds} represents the data size of the accelerometer sensor, and it is computed using the total no. of samples generated represented by A_{ns} and the sample size of the accelerometer sensor as observed in Table II.

$$G_{ns} = G_{sf} * 60 * G_{ti} \tag{3}$$

In Eq-3, the number of samples generated by the GPS sensor represented G_{ns} has been computed using the sample frequency of the GPS sensor as observed in Table II as represented by G_{sf} and time interval between two samples represented by G_{ti}.

$$G_{ds} = G_{ns} * G_{sz} \tag{4}$$

In Eq-4, G_{ds} represents the data size of the GPS sensor, and it is computed using the total no. of samples generated represented by G_{ns} and the sample size of GPS sensor as observed in Table II. The size of the review data has been computed using the following equation.

$$R_{ds} = A_{ds} + G_{ds} + T_{ds} \tag{5}$$

in Eq-5, T_{ds} represents the size of textual data of review, including rating, feedback, comments, communicative language, latitude, and longitude of the location. The size of review data reflected using R_{ds} has been computed using the size of accelerometer sensor data, GPS sensor data, and textual data of review.

G. Estimation of Energy Consumption

Review data will be collected by various users for the desired location, and it will be transmitted to the cloud collector in various data transmission modes. Energy consumption for data collection, as well as data transmission in various data transmission modes, has been computed for energy characterization.

Total energy consumption for a review submission is a summation of energy consumption for data collection as well as data transmission as reflected in Eq.-6 [2], [3].

$$E_t = E_{dc} + E_{dt} \tag{6}$$

in Eq.-6, E_{dc}, E_{dt}, and E_t represent energy consumption during data collection, data transmission, and total energy consumed, respectively. If the required sensor of the device has been used for data collection, then E_{dc} will be determined as per the following equations [2], [3].

$$S_u = \begin{cases} 1, & \text{if the attached sensor has been used for data collection} \\ 0, & \text{otherwise.} \end{cases} \tag{7}$$

$$E_{dc} = E_{dc} * S_u \tag{8}$$

In Eq.-7, S_u represents the sensor used or not. If the attached sensor has been exclusively used for data collection purposes, then S_u is 1; otherwise, it is 0. Energy consumption for data collection(E_{dc}) totally depends on use of attached sensors as reflected in Eq-8.

After having the review data, it will be transmitted to the cloud collector using the various data transmission modes such as Bluetooth, Wi-Fi, and LTE, and the energy consumed for data transmission(E_{dt}) for various modes will be determined. Energy consumption for data transmission in various modes has been reflected using the following equation.

$$E_{dt} = \begin{cases} E_w, & \text{if Wi-Fi or Wi-Fi, LTE or Bluetooth enabled and Wi-Fi c} \\ E_{li}, & \text{if Wi-Fi disabled,LTE is in idle state} \\ E_{lc}, & \text{if Wi-Fi disabled,LTE is in connected state} \\ E_{bi}, & \text{if Wi-Fi disabled,LTE idle, Bluetooth idle} \\ E_{bc1}, & \text{if Wi-Fi disabled, LTE idle, Bluetooth is in connected sta} \\ E_{bc2}, & \text{if Wi-Fi disabled, LTE disabled, Bluetooth in connected s} \end{cases} \tag{9}$$

1) Energy Consumption for Data Transmission in Wi-Fi Transmission Mode

Wi-Fi transmission mode is a popular mode for data transmission. Using Wi-Fi transmission mode, data can be uploaded without any data charges of their own. The amount of energy consumed for data transmission in Wi-Fi mode has been computed using the following equation[2].

$$E_w = \int_0^{ts} P_{tx}^w dx \tag{10}$$

$$P_{tx}^w = P_s^w + P_t^w * T_{ts}^w + C_e * R_g \tag{11}$$

In Eq.-10, E_w represents the energy consumed for data transmission in Wi-Fi mode, whereas ts represents transmission time. P_{tx}^w represents power consumption for transmission of Wi-Fi data packets computed in Eq.-11. P_s^w, P_t^w, T_{ts}^w, R_g and C_e represent transmission power of Wi-Fi in sleep mode, Transmission Power required to transmit a packet, Transmission time required to transmit a packet, Rate of generation of packets and cost in terms of energy to elaborate a packet respectively.

2) Energy consumption for Data Transmission in LTE Transmission Mode

Data packets can be transmitted to the cloud using cellular data using LTE mode, but it incurs data charges and for this user need to pay money from his pocket. Various power consumption levels in LTE mode have been discussed in [30] in the initial states those are connected, idle and tail using the implementation of radio resources control states. Idle and connected state has been used in the proposed work as an idle state has been taken as the worst case of tail state. If the smartphone is in the idle state, then for data transmission, it switches from the idle state to the connected state and moves to the tail state after data transmission before returning to the ideal state. During data transmission in the idle state, energy consumption in LTE mode has been determined using the following equation [3].

$$E_{li} = D^l_p * D^l_t + T s^l_p * T s^l_t + T s^l_p * DRX^l_{it} + DRX_p * RRCit^l \quad (12)$$

In Eq-12, Energy consumption in idle state (E_{li}) depends on promotional delay in terms of power(D^l_p), promotional delay in terms of time(D^l_t), power consumption for transmission($T s^l_p$) of an LTE packet, transmission time ($T s^l_t$) for transmission of an LTE packet, Discontinuous Reception Inactivity Timer (DRX^l_{it}), power consumption(DRX_p) while the smartphone is in one of the 2 DRX modes and RRC inactivity time($RRCit^l$). But the smartphone is in the connected state; then energy consumption can be determined using signal transmission data only as per the following equations.

$$E_{lc} = \int_0^{ts} P^l_{tx} dx \quad (13)$$

$$P^l_{tx} = P^l_s * T_u + P^l_b \quad (14)$$

In Eq.13 and Eq.14, E_{lc} represents energy spent for data transmission if the smartphone is already available in the connected state. It depends on power consumption (P^l_{tx}) and transmission time to transmit an LTE packet. Power consumed for transmitting an LTE packet depends on power spent(P^l_s) during data transmission, uplink throughput(T_u), and base power(P^l_b) of LTE mode of data transmission.

3) *Energy consumption for Data Transmission in Bluetooth Transmission Mode*

The Master/Slave model has been used by Bluetooth-based networks, particularly known as piconets, for data transmission. In this model, one master device can control up to seven slave devices. One slave device can be connected to only one master device. Data transmission can be performed between master and slave devices in the piconet, but a slave to slave communication is not possible. Communication steps begin by looking for a nearby Bluetooth device; if the desired device is found, then pair it to be connected. Energy consumption for data transmission when Wi-Fi and LTE are both in a disabled state and Bluetooth is in a connected state has been determined using the following equations.

$$E_{bc2} = \int_0^{ts} P^b_{tx} dx \quad (15)$$

$$P^b_{tx} = P^b_s + P^b_t * T^b_{ts} + C_e * R^b_g \quad (16)$$

In Eq.-15, E_{bc2} represents the energy consumed for data transmission in Bluetooth mode when LTE and Wi-Fi are disabled, whereas ts represents transmission time. P^b_{tx} represents power consumption for transmission of Bluetooth data packets computed in Eq.-16. P^b_s, P^b_t, T^b_{ts}, R^b_g, and C_e represent transmission power of Bluetooth in sleep mode, transmission power required to transmit a packet, transmission time required to transmit a packet, Rate of generation of packets and cost in terms of energy to elaborate a packet respectively.

during data transmission, if Wi-Fi is in a disabled state, LTE is in an idle state, and Bluetooth is in the connected state, then energy consumption can be estimated using energy consumption for LTE mode in an idle state and power consumed and transmission time required to transmit a Bluetooth packet as per following equations. Value of $T s^l_p$ and $T s^l_t$ is zero in E_{li} as LTE is in an idle state, and the packet will be sent using Bluetooth instead of LTE mode.

$$E_{bc1} = E_{li} + P^b_t * T^b_{ts} \quad (17)$$

While if Wi-Fi is disabled and Both LTE and Bluetooth are in an idle state, then energy consumption can be estimated by the promotional delay of Bluetooth in terms of power(D^b_p) and time(D^b_t) to the energy consumed during the connected state.

$$E_{bi} = E_{bc1} + D^b_p * D^b_t \quad (18)$$

Parameter	Description	Value	Unit
P^b_s	Power in sleep mode of Bluetooth	0.006	W
P^b_t	Transmission Power of Bluetooth	0.11	W
D^b_p	Promotional delay in terms of Power in Bluetooth	0.01	W
D^b_t	Promotional delay in terms of Time in Bluetooth	0.007	Second
R^b_g	Rate of generation of packets in Bluetooth mode	30	Fps
D^l_p	Promotional delay in terms of Power in LTE	0.0011	W
D^l_t	Promotional delay in terms of Time in LTE	0.0001	Second
DRX^l_{it}	Discontinuous Reception inactivity Timer	0.1	Second
DRX_p	Power consumption in DRX Mode	0.0001	W
$RRCit$	RRC Inactivity Timer	0.0012	Second
P^l_s	LTE power in transmission	0.43839	W
P^l_b	LTE base power	1.28804;	W
P^w_t	WiFi power in transmission	0.28317	W
P^w_s	WiFi power in sleep mode	0.13286;	W
R_g	Rate of generation of packets	1000	Fps
C_e	Energy cost to elaborate a generated packet	0.11*10-3	J

TABLE III. Parameters in Energy Equations and their values used during simulation

H. *Estimation of Transmission Time Required to Transmit Data*

Transmission time is the time required to transmit a packet using any transmission mode. It can be calculated using the size of data transmitted and the up-link data rate of various modes using the following equation.

$$T_{ts} = \frac{R_{ds} * 8.0}{D^m_u} \quad (19)$$

In Eq.19, Transmission Time has been represented by T_{ts}. R_{ds} is the total size of review data computed using Eq.5, and D^m_u represents the uplink data rate of various transmission modes. In the proposed work, LTE, Bluetooth, and Wi-Fi transmission mode have been considered, and their respective uplink data rate has been reflected in Table IV.

Transmission mode	Uplink Data Rate(in Mbs)
Wi-Fi	1
Bluetooth	1
LTE	1

TABLE IV. Uplink data rate of various transmission mode

I. *Analysis of Review Data Received from Various Users*

Simulation has been performed for n=25 rounds. In each round, 2000 users provide reviews for 897 locations as per their movement through various data transmission modes such as Bluetooth, Wi-Fi, and LTE. A total of 61 lakh data has been received, and its size is 606 MB. Received data has been stored in a text file in CSV format for better analysis and also to reduce the size of the data. Matlab software has been used for the analysis of data. Each data in the dataset contains information such as sl. no., round no., day, hour, minute, transmission mode, user ID, latitude, longitude, communicative language, message, rating, feedback, data size, and energy consumed. Important parameter and their symbols used in the equations have been reflected in Table V.

Review Data Elements	Symbol	Description
Transmission mode	$tmode_r$	Round-wise transmission mode
User ID	UID_r	User Id in numeric values
Data Size	DS_r	Round-wise size of data uploaded
Energy Consumed	EC_r	Round-wise Energy consumed
No. of Rounds	n	No. of rounds simulation has been performed

TABLE V. Symbols used in equation for data analysis

The round-wise dataset has been analyzed using Matlab software. Transmission mode(T_r) of each data in the dataset has been determined if it is transmitted using Bluetooth then B_r, the mode is Wi-Fi then W_r and in the case of LTE mode, it is L_r as reflected in the following equation.

$$T_r = \begin{cases} B_r, & \text{if } tmode_r \text{ is Bluetooth} \\ W_r, & \text{if } tmode_r \text{ is Wi-Fi} \\ L_r, & \text{if } tmode_r \text{ is LTE} \end{cases} \tag{20}$$

1) *Statistical Analysis of Bluetooth Transmission Mode*

If T_r is B_r, then no. of data contributions(NDU_r^b) will be incremented by 1, user id (UID_r) of the current user will be appended to the list of Bluetooth Users(U_r^b) where r represents round ranges from 1 to n, and b represents data transmission mode Bluetooth.

$$UN_r^b = \begin{cases} 1, & \text{if user id } (UID_r) \text{ not available in } U_r^b \\ 0, & \text{otherwise.} \end{cases} \tag{21}$$

In Eq.21, if UN_r^b =1, then the current user is new. Hence No. of Bluetooth users(NU_r^b) will be increased by 1.
The round-wise total size of data transmitted(TDS_r^b) and round-wise total energy consumed(TEC_r^b) using Bluetooth transmission mode has been determined using the following equations with initial value zero, and it will be updated as per review data.

$$TDS_r^b + = DS_r \tag{22}$$

$$TEC_r^b + = EC_r \tag{23}$$

The round-wise average size of data transmitted(MDS_r^b) and round-wise average energy consumed(MEC_r^b) using Bluetooth transmission mode have been determined using the following equations.

$$MDS_r^b = \frac{TDS_r^b}{NDU_r^b} \tag{24}$$

$$MEC_r^b = \frac{TEC_r^b}{NDU_r^b} \tag{25}$$

The total size of data transmitted(TDS^b) and total energy consumed(TEC^b) in all n no. of rounds using Bluetooth transmission mode has been determined using the following equations.

$$TDS^b = \sum_{r=1}^{n} TDS_r^b \tag{26}$$

$$TEC_r^b = \sum_{r=1}^{n} TEC_r^b \tag{27}$$

The average size of data transmitted(MDS^b) and average energy consumed(MEC^b) per round in all n no. of rounds using Bluetooth transmission mode has been determined using the following equations. Total n no. of rounds has been considered during simulation.

$$MDS^b = \frac{TDS^b}{n} \tag{28}$$

$$MEC^b = \frac{TEC^b}{n} \tag{29}$$

Total no. of data contributors($TNDU^b$) and total no. of unique Bluetooth users(TNU^b) in all n no. of rounds those transmitted review data using Bluetooth transmission mode can be determined using the following equations.

$$TNDU^b = \sum_{r=1}^{n} NDU_r^b \tag{30}$$

$$TNU^b = \sum_{r=1}^{n} NU_r^b \tag{31}$$

Average no. of data contributors($MNDU^b$) and average no. of unique Bluetooth users(MNU^b) per round in all n no. of rounds those transmitted review data using Bluetooth transmission mode can be determined using the following equations.

$$MNDU^b = \frac{TNDU^b}{n} \tag{32}$$

$$MNU^b = \frac{TNU^b}{n} \tag{33}$$

2) Statistical Analysis of Wi-Fi Transmission Mode

If T_r is W_r, then no. of data contributions(NDU_r^w) will be incremented by 1, user id (UID_r) of the current user will be appended to the list of Wi-Fi Users(U_r^w) where r represents round ranges from 1 to n, and w represents data transmission mode Wi-Fi.

$$UN_r^w = \begin{cases} 1, & \text{if user id } (UID_r) \text{ not available in } U_r^w \\ 0, & \text{otherwise.} \end{cases} \tag{34}$$

In Eq.34, if UN_r^w =1, then the current user is new. Hence No. of Wi-Fi users(NU_r^w) will be increased by 1.
The round-wise total size of data transmitted(TDS_r^w) and round-wise total energy consumed(TEC_r^w) using Wi-Fi transmission mode has been determined using the following equations with initial value zero, and it will be updated as per review data.

$$TDS_r^w + = DS_r \tag{35}$$

$$TEC_r^w + = EC_r \tag{36}$$

The round-wise average size of data transmitted(MDS_r^w) and round-wise average energy consumed(MEC_r^w) using Wi-Fi transmission mode has been determined using the following equations.

$$MDS_r^w = \frac{TDS_r^w}{NDU_r^w} \tag{37}$$

$$MEC_r^w = \frac{TEC_r^w}{NDU_r^w} \tag{38}$$

The total size of data transmitted(TDS^w) and total energy consumed(TEC^w) in all n no. of rounds using Wi-Fi Transmission has been determined using the following equations.

$$TDS^w = \sum_{r=1}^{n} TDS_r^w \tag{39}$$

$$TEC_r^w = \sum_{r=1}^{n} TEC_r^w \tag{40}$$

The average size of data transmitted(MDS^w) and average energy consumed(MEC^w) per round in all n no. of rounds using Wi-Fi transmission mode has been determined using the following equations. Total n no. of rounds has been considered during simulation.

$$MDS^w = \frac{TDS^w}{n} \tag{41}$$

$$MEC^w = \frac{TEC^w}{n} \tag{42}$$

Total no. of data contributors($TNDU^w$) and total no. of unique Wi-Fi users(TNU^w) in all n no. of rounds those transmitted review data using Wi-Fi transmission mode can be determined using the following equations.

$$TNDU^w = \sum_{r=1}^{n} NDU_r^w \tag{43}$$

$$TNU^w = \sum_{r=1}^{n} NU_r^w \tag{44}$$

Average no. of data contributors($MNDU^w$) and average no. of unique Wi-Fi users(MNU^w) per round in all n no. of rounds those transmitted review data using Wi-Fi transmission mode can be determined using the following equations.

$$MNDU^w = \frac{TNDU^w}{n} \tag{45}$$

$$MNU^w = \frac{TNU^w}{n} \tag{46}$$

3) Statistical Analysis of LTE Transmission Mode

If T_r is L_r, then no. of data contributions(NDU_r^l) will be incremented by 1, user id (UID_r) of the current user will be appended to the list of LTE Users(U_r^l) where r represents round ranges from 1 to n, and l represents data transmission mode LTE.

$$UN_r^l = \begin{cases} 1, & \text{if user id } (UID_r) \text{ not available in } U_r^l \\ 0, & \text{otherwise.} \end{cases} \tag{47}$$

In Eq.47, if UN_r^l =1, then the current user is new. Hence No. of LTE users(NU_r^l) will be increased by 1.
The round-wise total size of data transmitted(TDS_r^l) and round-wise total energy consumed(TEC_r^l) using LTE transmission mode has been determined using the following equations with initial value zero, and it will be updated as per review data.

$$TDS_r^l + = DS_r \tag{48}$$

$$TEC_r^l + = Eng_r \tag{49}$$

The round-wise average size of data transmitted(MDS_r^l) and round-wise average energy consumed(MEC_r^l) using LTE transmission mode have been determined using the following equations.

$$MDS_r^l = \frac{TDS_r^l}{NDU_r^l} \tag{50}$$

$$MEC_r^l = \frac{TEC_r^l}{NDU_r^l} \tag{51}$$

The total size of data transmitted(TDS^l) and total energy consumed(TEC^l) in all n no. of rounds using LTE transmission mode has been determined using the following equations.

$$TDS^l = \sum_{r=1}^{n} TDS_r^l \tag{52}$$

$$TEC_r^l = \sum_{r=1}^{n} TEC_r^l \tag{53}$$

The average size of data transmitted(MDS^l) and average energy consumed(MEC^l) per round in all n no. of rounds using LTE transmission mode has been determined using the following equations. Total n no. of rounds has been considered during simulation.

$$MDS^l = \frac{TDS^l}{n} \tag{54}$$

$$MEC^l = \frac{TEC^l}{n} \tag{55}$$

Total no. of data contributors($TNDU^l$) and total no. of unique LTE users(TNU^l) in all n no. of rounds those transmitted review data using LTE transmission mode can be determined using the following equations.

$$TNDU^l = \sum_{r=1}^{n} NDU_r^l \tag{56}$$

$$TNU^l = \sum_{r=1}^{n} NU_r^l \tag{57}$$

Average no. of data contributors($MNDU^l$) and average no. of unique LTE users(MNU^l) per round in all n no. of rounds those transmitted review data using LTE transmission mode can be determined using the following equations.

$$MNDU^l = \frac{TNDU^l}{n} \tag{58}$$

$$MNU^l = \frac{TNU^l}{n} \tag{59}$$

4. Experimental Results and Discussions

In this section, it has been discussed the results and analysis. The proposed dynamic energy efficient data transmission model has been implemented using the CrowdSenSim simulator; a discrete event based simulator particularly used for providing a simulation environment for research activities in the MCS environment. In the proposed work, a simulation environment has been designed using the CrowdSenSim simulator with 2000 users and 897 distinct locations in urban spaces in which different users will move to different locations randomly, and for every visited location, feedback/review has been received from users for their visited locations as per their experience through smartphone or web based applications. Review/feedback data provides various information about the location, like its geographical position obtained using an accelerometer and GPS sensor, rating, communicative language, message, etc. In the proposed work, data will be transmitted to the cloud platform for storage and analysis using the proposed dynamic energy efficient data transmission model in which energy efficient data transmission mode, among considered Bluetooth, Wi-Fi, and LTE modes, will be selected automatically as per availability of network in the desired location. Mathematical equations for estimation of the size of data transmitted and equivalent energy consumption using selected data transmission modes among Bluetooth, Wi-Fi, and LTE have been implemented using CrowdSenSim Simulator. Simulation has been performed for 25 rounds. In this section, the number of data contributors, the average and total size of data transmitted, and energy consumption made for data transmission in various data transmission modes in each round and all rounds have been discussed. The relationship between the number of data contributors, the size of data transmitted, and equivalent energy consumption in various data transmission modes on an average round basis and total basis has been estimated for energy characterization in the MCS environment.

A. *Estimation of Order of Data Transmission Mode in terms of Energy Consumption*

Initially, 1000 kb of data has been transmitted through Bluetooth, Wi-Fi, and LTE in each round. It has been performed 25 times to send a total of 25000 kb of data in all rounds. Energy consumption made by Bluetooth, Wi-Fi and LTE mode has been estimated on a total basis as well as on an average basis for estimation of energy efficient data transmission mode and its order of preference for dynamic and automatic selection of data transmission mode during simulation. It has been presented in Figure 2 and 3.

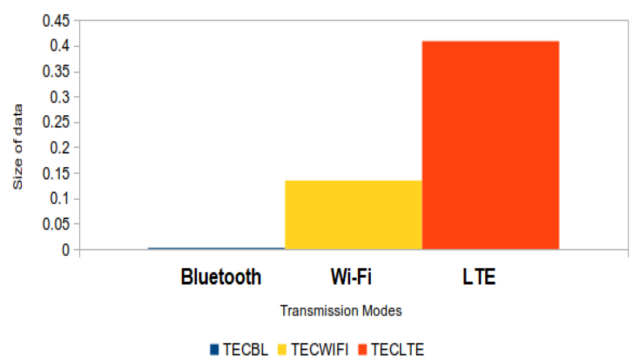

Figure 2. Total energy consumed for transmission of 25000kb of data in 25 rounds in 3 different modes

Figure 2 Provides a comparative result of total energy consumption in all rounds for transmission of 25000 kb of data in 25 rounds through 3 different modes of data transmission such as Bluetooth, Wi-Fi, and LTE mode by TECBL for Bluetooth mode, TECWIFI for Wi-Fi mode and TECLTE for LTE Mode. It is observed that TECLTE is maximum, as well as TECBL is minimum, whereas TECWIFI is placed in between Bluetooth and LTE mode for the transmission of 25000 kb of data. For data transmission of 25000kb size of data through Bluetooth mode consumes a minimum or a negligible amount of energy, and LTE incurs the highest amount of energy, whereas, through Wi-Fi, energy consumption is higher than Bluetooth but mostly lower than LTE mode. Bluetooth mode is more energy efficient than Wi-Fi or LTE mode of data transmission in terms of total energy consumed in all 25 rounds.

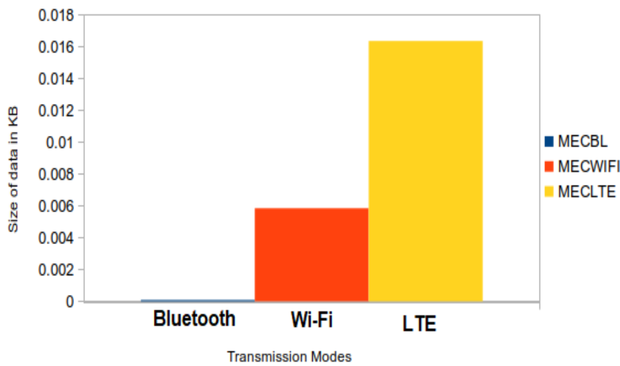

Figure 3. Average of total energy consumed for transmission of 1000kb of data per rounds in 3 different modes

Figure 3 provides a comparative study of the average amount of energy consumed per round for transmitting 1000 kb of data in each round using three different transmission mode such as Bluetooth, Wi-Fi, and LTE. The average energy consumed for data transmission of 1000 kb of the size of data through Bluetooth, Wi-Fi, and LTE modes is represented by MECBL, MECWIFI, and MECLTE, respectively. It is observed that TECLTE is maximum and TECBL is minimum, whereas TECWIFI is placed between Bluetooth and LTE mode for the transmission of 1000 kb of data per round in 25 rounds. Therefore, on an average basis also, it is observed that data transmission through Bluetooth mode is energy efficient as energy consumption is lowest in Bluetooth. Energy consumption using LTE mode is highest, whereas energy consumption through Wi-Fi mode is higher than Bluetooth mode but lower than LTE mode.

From Figure 2 and 3, it is observed that energy consumption in Bluetooth mode is minimum and it is maximum in LTE mode. Therefore, the order of data transmission mode should be Bluetooth, Wi-Fi, and LTE as per the energy consumption. This order has been used for automatic and dynamic selection of data transmission mode during review data transmission to the cloud platform through the proposed dynamic energy efficient data transmission model in the participatory MCS environment.

B. Establish a Relationship Between Data Transmission Mode With the Size of Data Transmitted and equivalent Energy Consumption for Energy Characterization

The proposed dynamic energy efficient data transmission model has been implemented using the CrowdSenSim simulator. During the simulation, 2000 users will move randomly to various locations and provide feedback for the location after the visit. The location may have a Bluetooth network, Wi-Fi based network, both, or none for providing internet connectivity to users for review data transmission. Review data will be transmitted to the cloud platform for storage analysis through the proposed dynamic energy efficient data transmission model in the MCS environment. The proposed dynamic energy efficient data transmission model will choose the energy efficient data transmission mode among Bluetooth, Wi-Fi, and LTE modes as per the availability of network provider in the desired location in a dynamic manner, and the user will be connected with the selected network, and review data will be transmitted to cloud platform automatically using dynamically selected energy efficient data transmission mode. The energy equation for Bluetooth, LTE, and Wi-Fi has been implemented using CrowdSensim Simulator. The proposed mathematical model has been used to estimate the size of data transmitted and the amount of energy consumed in the selected mode. Simulation has been performed for 25 rounds to generate a vast dataset for analysis. Further, it has been analyzed to establish a relationship between data transmission mode with the size of data transmitted and equivalent energy consumption for Energy Characterization.

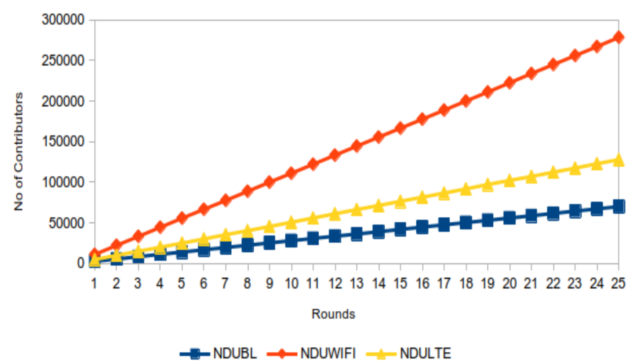

Figure 4. Total No. of Contributors in 3 different modes in various Rounds

Figure 4 represents the total number of contributors in various rounds in 3 different modes, such as Bluetooth, Wi-Fi, and LTE for transmission of data. In the proposed work, 25 rounds have been taken for simulation. The total no. of data contributors using three different transmission modes, Bluetooth, Wi-Fi, and LTE, are represented as NDUBL, NDUWIFI, and NDULTE, respectively. It is observed that no. of contributors is minimum in Bluetooth modes, whereas maximum in Wi-Fi mode. More no. of users consider Wi-Fi for data transmission rather than Bluetooth or LTE. It will be very as per the network provider available in the location and dynamically selected energy efficient data transmission mode by the proposed model for data transmission. The number of data contributors plays an important role in data analysis based on the size of data transmitted and consumed energy. If no. of contributors increases, then the total size of data and the total energy consumed will increase and vice versa. If no. of contributors is more, then the average size of data and average energy consumed will be fewer, whereas the average size of data and energy consumed will be more in the case of less no. of contributors. It may influence the average and total size of data and also the average and total energy consumption analysis as per data. Therefore it plays an important role in statistical analysis.

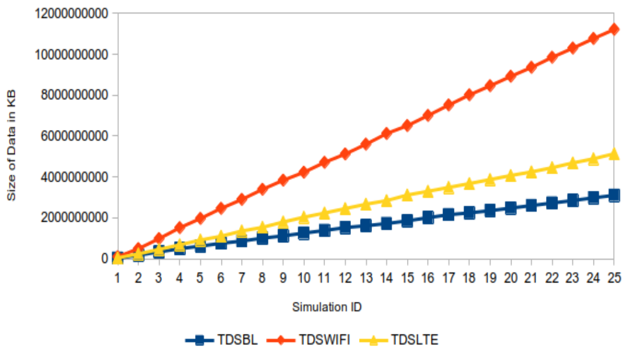

Figure 5. Total Size of Data Transmitted in 3 different modes in various Rounds

Figure 5 reflects the total amount of data in Kb transmitted in various rounds ranging from 1 to 25 in three different modes of data transmission such as Bluetooth, Wi-Fi' and LTE. The total size of data transmitted using three modes of transmission in each round has been computed, and it is demonstrated as TDSBL for Bluetooth mode, TDSWIFI for Wi-Fi mode, and TDSLTE for LTE mode in this graph for analysis. The size of data increases as the number of rounds increases sequentially in all three modes of transmission. The size of data transmitted using Bluetooth mode is lowest, whereas highest in the case of Wi-Fi mode because no. of contributors of Bluetooth is less than Wi-Fi and LTE, and WI-Fi has the highest no. of contributors as observed in Figure 4. As no. of contributors in LTE mode is in between Wi-Fi and Bluetooth modes, Hence the size of data transmitted using LTE modes is in between Bluetooth and Wi-Fi modes. Therefore no. of contributors plays an important role in the size of data transmitted through various modes of data transmission.

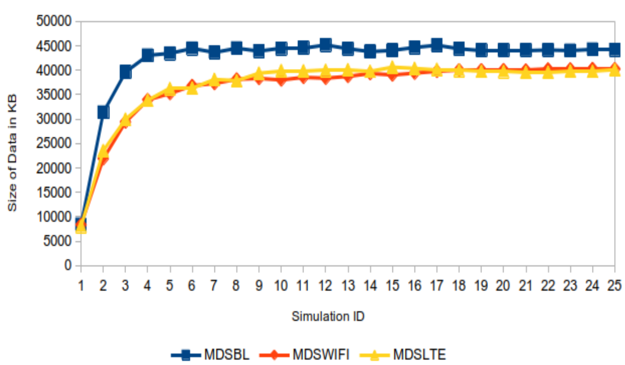

Figure 6. Average Size of Data Transmitted in 3 different modes in each Round

An average amount of data in Kb transmitted using three different modes of transmission, such as Bluetooth, Wi-Fi', and LTE has been presented in Figure 6. The average amount of data transmitted using three modes of transmission in each round has been determined, and it is demonstrated as MDSBL for Bluetooth mode, MDSWIFI for Wi-Fi mode, and MDSLTE for LTE mode in Y-axis and X-axis represents round no. from 1 to 25. It is observed that the maximum average amount of data has been transmitted using Bluetooth mode and the average amount of data transmitted using LTE and Wi-Fi are nearly the same. But, as we observed in Figure 5, the total amount of data transmitted in Bluetooth is minimal, whereas Wi-Fi has maximum, and Using LTE mode is in between Wi-Fi and Bluetooth. In the case of the total size of data transmitted, Bluetooth is minimum, but it is maximum in the case of the average amount of data transmitted. It might happen because no. of contributors in Bluetooth mode for transmission is less as compared to LTE and Wi-Fi modes, as observed in Figure 4. Due to less no. of contributors in each round, the average size of data transmitted is more and vice versa.

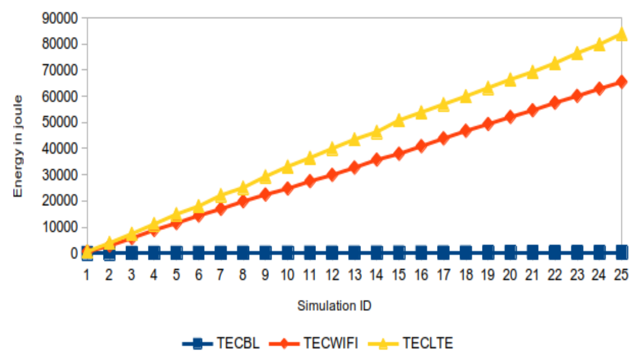

Figure 7. Total Energy Consumed in 3 different modes in various Rounds

Figure 7 reflects the total amount of energy consumed in Joule for data transmission in various rounds ranging from 1 to 25 in three different modes of data transmission such as Bluetooth, Wi-Fi' and LTE. The total energy consumed for data transmission using three modes of transmission in each round has been computed, and it is reflected as TECBL for Bluetooth mode, TECWIFI for Wi-Fi mode, and TECLTE for LTE mode by Y-axis and X-axis represents round no. Amount of energy consumption increase with increasing order of round no. in all three modes of transmission. Total energy consumed in Bluetooth mode is minimum as compared to LTE and Wi-Fi and is maximum in the case of LTE mode of data transmission. Therefore Bluetooth mode of data transmission is more energy-efficient than Wi-Fi and LTE modes. Energy consumption depends on the size of the data transmitted and the mode of data transmission. As observed in Figure 5, the total size of data transmitted per round in Bluetooth mode is minimum and maximum in Wi-

Fi mode and, for LTE mode of transmission, it is in between Bluetooth and Wi-Fi. But Total energy consumption in LTE mode is more than in Wi-Fi mode, but the total size of data transmitted is less than in Wi-Fi mode. Therefore energy consumption highly depends on the mode of transmission. Total Energy consumption is minimum in the case of Bluetooth and maximum in LTE mode, and it is in between in Wi-Fi mode for each round.

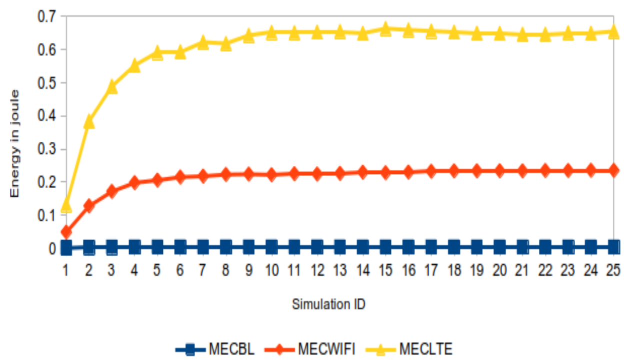

Figure 8. Average Energy consumed in 3 different modes in each Round

Figure 8 reflects round-wise average amount of energy consumed in Joule for data transmission in three different modes of transmission such as Bluetooth, Wi-Fi' and LTE. For each round, the average energy consumed for data transmission using three modes of transmission has been computed, and it is reflected as MECBL for Bluetooth mode, MECWIFI for Wi-Fi mode, and MECLTE for LTE mode by Y-axis and X-axis represents round no ranges from 1 to 25. The average amount of energy consumption for data transmission increases with the increasing order of round no. in all three modes of data transmission. For each round, the average amount of energy consumed in Bluetooth mode is minimum as compared to LTE and Wi-Fi modes and is maximum in the case of LTE mode of data transmission. Therefore Bluetooth mode of data transmission is more energy efficient than Wi-Fi and LTE modes per round on an average basis. Energy consumption generally depends on the size of the data transmitted and the mode of data transmission. As observed in Figure 6, the average amount of data transmitted per round in Bluetooth mode is maximum and nearly the same in Wi-Fi and LTE modes. But the average amount of energy consumption per round in Bluetooth mode is less than in Wi-Fi and LTE modes. Therefore the mode of data transmission is highly important for energy consumption. In each and every round, the average amount of energy consumption is minimum in the case of Bluetooth mode, whereas the maximum is in LTE mode, and it is in between in Wi-Fi mode. From Figure 7 and 8, it is observed that Bluetooth is more energy-efficient and it consumes less energy as compared to Wi-Fi and LTE modes for data transmission in terms round wise total and average energy consumption.

From the above Figures and through analysis, it has been observed that the use of Bluetooth and Wi-Fi for data transmission will minimize energy consumption. Also, it has been estimated that Bluetooth is more energy efficient than Wi-Fi and LTE, whereas Wi-Fi is more energy efficient than LTE. But due to the high range of Wi-Fi, it is mostly used for data transmission rather than Bluetooth. It has been concluded that the size of the data transmitted influences energy consumption, but it mostly depends on the data transmission mode rather than the size of the data transmitted. Therefore more data can be transmitted with minimum energy consumption if it has been transmitted using energy efficient data transmission modes like Bluetooth and Wi-Fi. No. of data contributors also plays an important role for the estimation of the size of data transmitted. In a further section, it has been analyzed using bar graphs to provide more clarity on this.

C. Effect of Number of Contributors on size of data transmitted and equivalent energy consumption for Energy Characterization

In this section, the Result has been analyzed using bar graphs for better clarity over concepts. Primarily it has been focused on the role of the number of data contributors, the number of users on the size of data transmitted and equivalent energy consumed for data transmission through Bluetooth, Wi-Fi, and LTE data transmission modes.

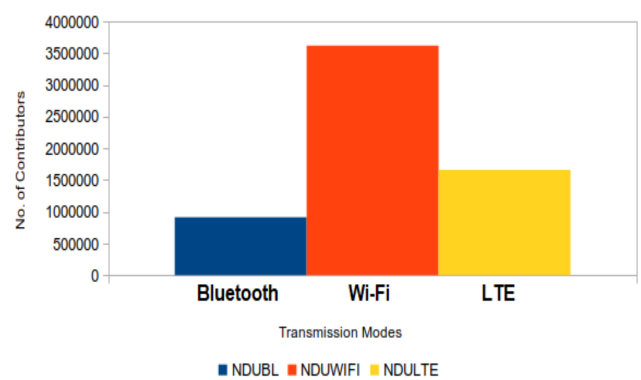

Figure 9. Total No. of Contributors in 25 rounds in 3 different modes

Figure 9 Provides a comparative idea of the total number of data contributors in 25 rounds in three different modes of data transmission such as Bluetooth, Wi-Fi, and LTE mode by NDUBL for Bluetooth, NDUWIFI for Wi-Fi and NDULTE for LTE mode of data transmission. It is observed that NDUWIFI is the highest and NDUBL is the lowest, whereas NDULTE is in between NDUBL and NDUWIFI. Mostly data has been transmitted through Wi-Fi mode instead of Bluetooth and LTE modes. The number of contributors using Bluetooth mode is the lowest, and no. of contributors in LTE mode is more than in Bluetooth and less than in Wi-Fi mode. It depends on the selection of energy efficient data transmission mode among all the available networks in the desired location.

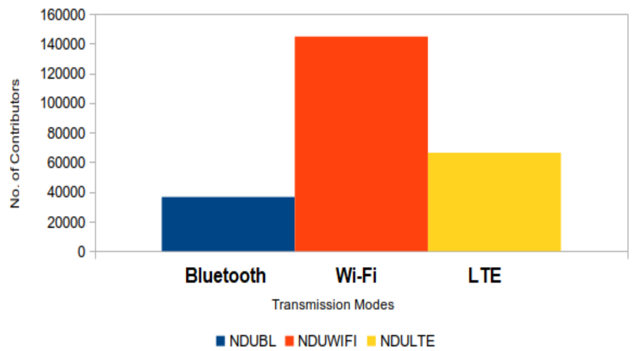

Figure 10. Average No. of Contributors in 25 rounds in 3 different modes

Figure 10 Provides a comparative idea of the average number of data contributors per round in 25 rounds in three different modes of data transmission such as Bluetooth, Wi-Fi, and LTE mode by NDUBL for Bluetooth, NDUWIFI for Wi-Fi and NDULTE for LTE mode of data transmission. It is observed that on an average basis also, NDUWIFI is highest and NDUBL is lowest, whereas NDULTE is higher than NDUBL and lower than NDUWIFI. On an average basis also, Most of the time, Wi-Fi data transmission mode has been used for data transmission rather than Bluetooth and LTE. From Figure 9 and Figure 10, it has been concluded that the Wi-Fi transmission mode is mostly preferred for data transmission rather than Bluetooth and LTE, even if Bluetooth is more energy efficient than Wi-Fi. It is possible because of the higher range of Wi-Fi than Bluetooth, so most of the time, it has been detected and used for data transmission.

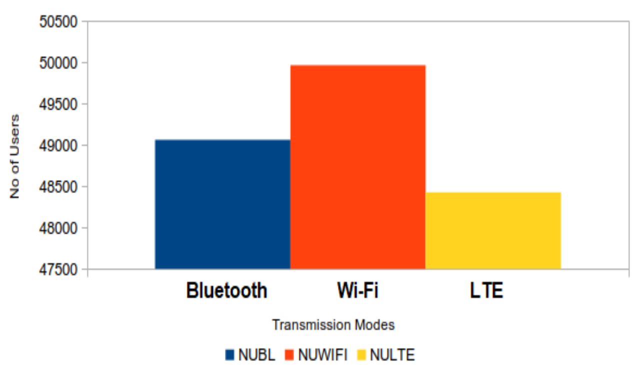

Figure 11. Total No. of Users in 3 different modes in 25 Rounds

Figure 11 reflects the total number of users whose reviews have been transmitted through Bluetooth, Wi-Fi, and LTE data transmission modes for data Transmission in 25 rounds. NUBL, NUWIFI, and NULTE represent the number of users whose reviews have been transmitted through Bluetooth, Wi-Fi, and LTE data transmission modes, respectively. Wi-Fi mode has been selected for the maximum number of users, LTE for the minimum number of users, whereas the use of Bluetooth for data transmission is in between Wi-Fi and LTE, and it is closer to LTE. Most of the time, Wi-Fi has been picked up for data transmission as compared to Bluetooth and Wi-Fi.

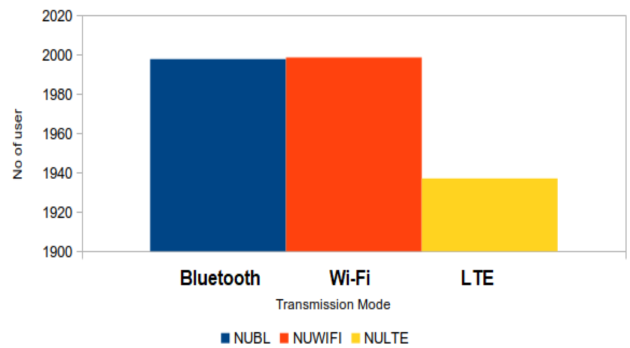

Figure 12. Average No. of Users per Round in 3 different modes

Figure 12 reflects the average number of users per round whose review data has been transmitted through Bluetooth, Wi-Fi, and LTE data transmission modes for data Transmission in 25 rounds. The average no. of users per round whose review data has been transmitted through Bluetooth, Wi-Fi, and LTE data transmission modes are represented as NUBL, NUWIFI, and NULTE, respectively, in Figure 12. Wi-Fi mode has been selected for the maximum number of users, LTE for the minimum number of users, whereas the use of Bluetooth for data transmission is in between Wi-Fi and LTE, and it is closer to LTE. Approximately on an average basis, Wi-Fi and Bluetooth modes have been used nearly the same number of times for data transmission per round. In Figure 11 and 12, it is observed that most of the time, Wi-Fi has been picked up for data transmission as compared to Bluetooth and Wi-Fi. But in the case of Bluetooth range is smaller than Wi-Fi; therefore, the use of Bluetooth for data transmission is less as compared to Wi-Fi. In Figure 11 and 12, It has been observed that No. Bluetooth, Wi-Fi, and LTE users differ from each other even in the simulation environment. It is possible because it depends on the data transmission mode selected for data transmission to the cloud platform by the proposed model. In the proposed model, the data transmission mode will be selected automatically and dynamically as per the available network provider and minimum energy consumption for data transmission. Each location may have a Bluetooth based network, Wi-Fi based network, or both, or none of them.

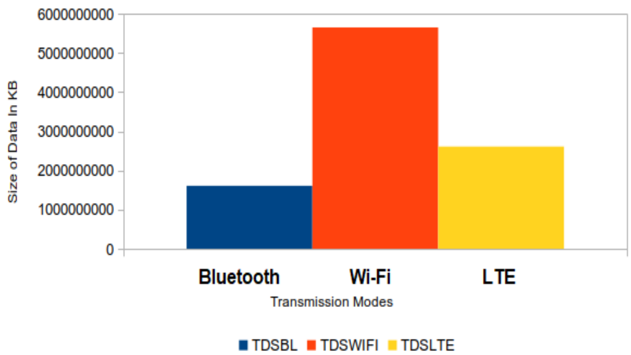

Figure 13. Average of total Size of Data Transmitted per round in 3 different modes

The average of the total size of data transmitted per round using three different data transmission modes, such as Bluetooth, Wi-Fi, and LTE, has been presented in Figure 13. The average of the total size of data transmitted per round has been determined using the total size of data transmitted per round, and the total no. of rounds in 3 different transmission modes, such as Bluetooth, Wi-Fi, and LTE, has been represented as TDSBL, TDSWIFI, and TDSLTE respectively in Figure 13. It is observed that TDSWIFI is maximum, whereas TDSBL is minimum, and TDSLTE has been placed in between TDSWIFI and TDSBL. On average, in each round average of the total size of data transmitted per round using Wi-Fi is more as compared to Bluetooth and LTE. It might be possible due to the higher no. of users and contributors per round in Wi-Fi Transmission mode as compared to Bluetooth and LTE, as observed in Figure 11 and 9. The number of data contributors influences the size of the data in a positive manner.

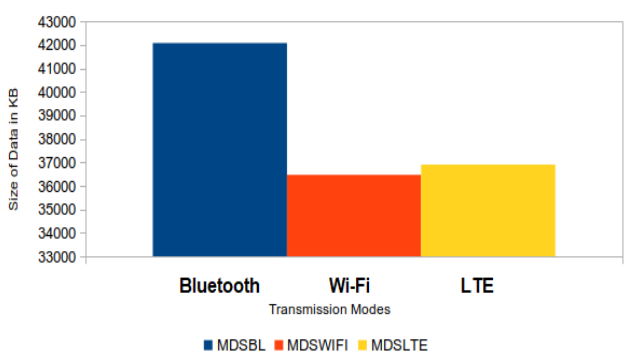

Figure 14. Average of Average Size of Data Transmitted per Round in 3 different modes

Average of the average size of data transmitted per round using Bluetooth, Wi-Fi, and LTE data transmission modes have been presented in Figure 14. Average of the average size of data transmitted per round has been determined using the total average size of data transmitted per round, and the total no. of rounds in Bluetooth, Wi-Fi, and LTE data transmission modes have been represented as MDSBL, MDSWIFI, and MDSLTE, respectively in Figure 13. It is observed that MDSBL is maximum whereas MDSWIFI is minimum, and MDS is slightly higher than MDSWIFI. On average, in each round average of the average size of data transmitted per round using Bluetooth is more as compared to Wi-Fi and LTE. It might be possible due to the higher no. of users and contributors per round as well as lower total size of data transmitted in Bluetooth transmission mode as compared to Wi-Fi and LTE, as observed in Figure 12, 10 and 13.

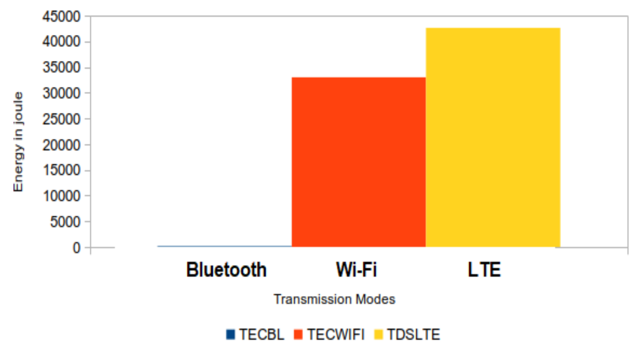

Figure 15. Average of total energy consumed per round in 3 different modes

Figure 15 reflects the average amount of total energy consumed per round in Bluetooth, Wi-Fi, and LTE data transmission modes. The average of total energy consumed has been computed using total energy consumed per round and total no. of rounds in three different transmission modes and represented as TECBL for Bluetooth, TECWIFI for Wi-Fi, and TECLTE for LTE mode of data transmission in Figure 15. It is observed that TECLTE is maximum and TECBL is minimum, whereas TECWIFI is lower than TECLTE but higher than TECBL. Data transmission using Bluetooth mode consumes a negligible amount of energy per round as compared to Wi-Fi and LTE modes of data Transmission. Therefore Bluetooth is more energy-efficient than Wi-Fi and LTE modes in terms of the average of total energy consumed per round.

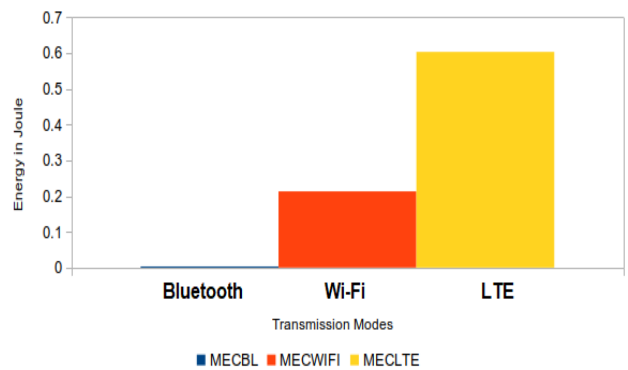

Figure 16. Average of average energy consumed per Round in 3 different modes

Figure 16 reflects the average amount of average energy consumed per round in Bluetooth, Wi-Fi, and LTE data transmission modes. Average of average energy consumed has been determined using average energy consumed per round and total no. of rounds in 3 different transmission modes and represented as MECBL for Bluetooth, MECWIFI for Wi-Fi, and MECLTE for LTE mode of data transmission in Figure 16. It is observed that MECLTE is maximum and MECBL is minimum, whereas MECWIFI is a little bit higher than MECBL. As observed in Figure 14, average of the average size of data transmitted per round using Bluetooth mode is higher than Wi-Fi and LTE modes, but it consumes less energy for transmitting data as compared to Wi-Fi and LTE. Data transmission using Bluetooth mode consumes a negligible amount of average of average energy per round as compared to Wi-Fi and LTE modes of data Transmission. Therefore Bluetooth is more energy-efficient than Wi-Fi and LTE modes in terms of average of average energy consumed per round. From Figure 15 and 16, it is observed that Bluetooth mode for data transmission incurs less energy whereas, LTE mode consumes more energy and Wi-Fi mode of data transmission has been placed in the middle of both LTE and Bluetooth.

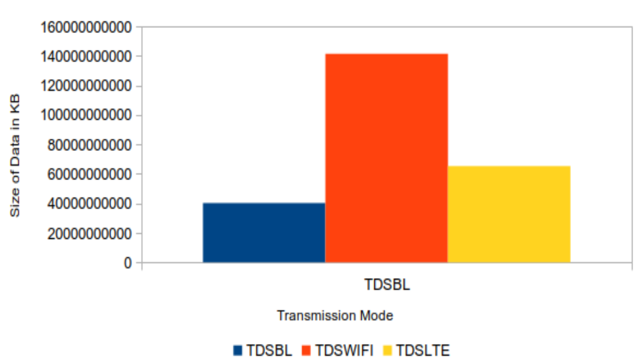

Figure 17. Total Size of Data Transmitted in 25 rounds in 3 different modes

Figure 17 represents the total size of data in KB transmitted in 25 rounds using Bluetooth, Wi-Fi, and LTEdata transmission modes, and it is represented as TDSBL for Bluetooth, TDSWIFI for Wi-Fi and TDSLTE for LTE mode of data transmission. It is observed that the highest amount of data is transmitted using Wi-Fi mode and the lowest in Bluetooth mode. In contrast, the size of data transmitted using LTE mode is larger than in Bluetooth mode and lower than in Wi-Fi mode of data transmission. It might be possible because the total no. of the user and data contributors are more in Wi-Fi as compared to Bluetooth and LTE, as observed in Figure 9 and 11.

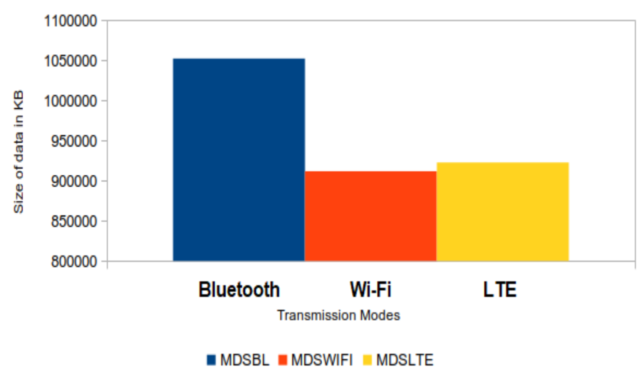

Figure 18. Average of total Size of Data Transmitted in 25 Round in 3 different modes

Figure 18 reflects the average amount of size of data transmitted in 25 rounds using Bluetooth, Wi-Fi, and LTE data transmission modes, and it is reflected by MDSBL for Bluetooth, MDSWIFI for Wi-Fi and MDSLTE for LTE mode of data transmission in the Figure. MDSBL is the highest, and MDSWIFI is the lowest.MDSLTE is slightly higher than MDSWIFI. On an average basis, the size of data transmitted in all rounds is more in Bluetooth mode and less in LTE mode. It might be possible because the total size of data transmitted using Bluetooth mode is lowest as compared to Wi-Fi and LTE as well as no. of users and no. of data contributors are nearly equal to Wi-Fi and higher than LTE mode as observed in Figure 13, 9 and 11.

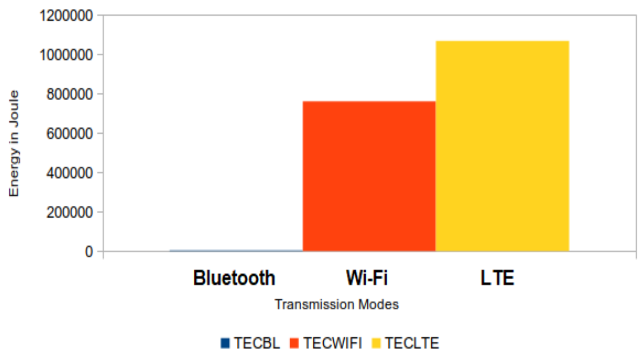

Figure 19. Total energy consumed in 25 rounds in 3 different modes

Figure 19 provides a comparative view of total energy consumed in 25 rounds using three different modes of data transmission such as Bluetooth, Wi-Fi, and LTE by TECBL for Bluetooth, TECWIFI for Wi-Fi, and TECLTE for LTE mode. It is observed that TECBL is minimum and TECLTE is maximum, whereas TECWIFI is lower than TECLTE but higher than TECBL. The total size of data transmitted using Bluetooth mode is minimum, and through Wi-Fi mode is maximum, whereas LTE is in the middle as observed in Figure 17. Therefore energy consumption depends on the transmission mode as well as the size of the data. Energy consumption using Bluetooth mode is lowest and negligible in comparison to LTE and WI-Fi. Hence Bluetooth is energy efficient in terms of total energy consumed in 25 rounds.

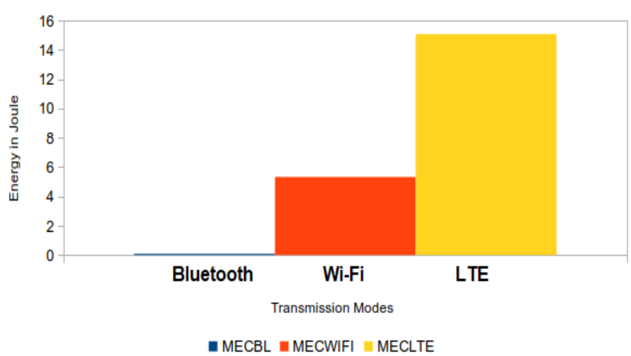

Figure 20. Average of total energy consumed in 25 Round in 3 different modes

Figure 20 Provides a comparative view of the average amount of energy consumed per round in all 25 rounds using three different transmission modes such as Bluetooth, Wi-Fi, and LTE mode by MECBL for Bluetooth, MECWIFI for Wi-Fi and MECLTE for LTE mode. It is observed that MECLTE is maximum and MECBL is minimum, whereas MECWIFI is higher than MECBL and lower than MECLTE. Energy consumption using Bluetooth mode is the lowest and negligible, and it is highest for LTE mode. But in Figure 18, it is observed that on an average basis, the size of data transmitted using Bluetooth mode is maximum whereas, through Wi-Fi and LTE modes are closer to each other. Hence, energy consumption mostly depends on the transmission mode rather than the data size. In Figure 19 and 20, it is observed that energy consumption for data transmission using Bluetooth mode is lowest as well as highest in LTE mode whereas Through Wi-Fi mode has been placed in between Bluetooth and LTE. Hence Bluetooth is energy efficient.

From the above Figures, it has been concluded that the number of data contributors and the number of users play a significant role in statistical analysis for energy characterization. It impacts the size of data transmitted and equivalent energy consumption for data transmission using the selected data transmission mode. It is also confirmed that Bluetooth is more energy efficient than Wi-Fi and LTE, but it is less preferred for data transmission than Wi-Fi because of its lower range than Wi-Fi. It cannot be detected and used. Therefore, Wi-Fi mode is mostly picked up by the proposed model for data transmission than Bluetooth and LTE in the MCS environment. It is also observed that energy consumption mostly depends on the data transmission mode rather than the size of the data transmitted. So More data can be transmitted with minimal energy consumption using Bluetooth and Wi-Fi data transmission modes.

5. Conclusions And Future Scope

In the proposed work, a dynamic energy efficient data transmission model has been presented that will dynamically and automatically select the energy efficient data transmission mode among Bluetooth, Wi-Fi, and LTE modes as per the availability of the network in the desired location in the MCS environment. Further, the data will be transmitted to the cloud platform for storage and analysis using the selected data transmission mode with minimal energy consumption. This model has been implemented using the CrowdSenSim simulator. Two thousand users provide reviews for 897 locations during the simulation for 25 rounds. One user can provide multiple reviews for the same location. Each and every location may contain Bluetooth, or Wi-Fi based network, or both, or none of them to provide network connectivity to users for review data transmission. For each review activity, the energy consumed for data transmission and the size of data transmitted has been estimated as per the selected data transmission mode. It is concluded that energy consumption in Bluetooth mode is minimum and it is maximum in LTE mode by sending 1000 kb of data in each round 25 times through all transmission modes. Therefore, the order of data transmission mode should be Bluetooth, Wi-Fi, and LTE as per the energy consumption. This order has been used for automatic and dynamic selection of data transmission mode during review data transmission to the cloud platform through the proposed dynamic energy efficient data transmission model in the participatory MCS environment. On an average basis, in each round, the total no. of Bluetooth and Wi-Fi users is nearly the same, whereas no. of LTE users is minimum. The total number of Bluetooth, Wi-Fi, and LTE users differs

from each other, even in the simulation environment. It is possible because of the dynamic and automatic selection of data transmission mode among Bluetooth, Wi-Fi, and LTE modes by the proposed model as per the available network in the desired location and the minimum energy consumption. The number of reviews obtained from Wi-Fi transmission mode is maximum, whereas minimum in the case of Bluetooth transmission mode in all rounds as well as on an average per-round basis. The total size of data transmitted using Wi-Fi is maximum and minimum in Bluetooth in all rounds, whereas on an average basis, the per-round average size of data transmitted is maximum in Bluetooth and minimum in Wi-Fi, and it is possible because the total size of data transmitted and total no. of reviews obtained using Bluetooth is minimum. Therefore, the number of data contributors and the number of users play a significant role in statistical analysis for energy characterization in terms of the size of data transmitted and equivalent energy consumption for data transmission using the selected data transmission mode. It has been observed that the use of Bluetooth and Wi-Fi for data transmission will minimize energy consumption. Also, it has been estimated that Bluetooth is more energy efficient than Wi-Fi and LTE, whereas Wi-Fi is more energy efficient than LTE. But, it is less preferred for data transmission than Wi-Fi because of the lower range than Wi-Fi. Therefore, Wi-Fi mode is mostly picked up by the proposed model for data transmission than Bluetooth and LTE in the MCS environment. Energy consumption depends on the size of data transmitted in every transmission mode. But energy consumption mostly depends on the transmission mode apart from the size of data transmitted because the total size of data transmitted is maximum in Wi-Fi mode whereas minimum in Bluetooth mode, but total energy consumed is maximum in LTE and minimum in Bluetooth mode. So More data can be transmitted with minimal energy consumption using Bluetooth and Wi-Fi data transmission modes. Bluetooth mode is more energy efficient than Wi-Fi and LTE.
In the future, we will try to eliminate the need for continuous and dedicated internet connectivity for data transmission to cloud platform using small local area networks and clustering.

6. Declarations

A. Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

B. Funding

No funding was received to assist with the preparation of this manuscript.

C. Authors' Contributions

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Ramesh Kumar Sahoo under the guidance of Dr. Sateesh Kumar Pradhan, Dr. Srinivas Sethi, and Dr. Siba K. Udgata. The problem is formulated by Dr. Siba K Udgata and he also contributed to draft the response to the reviewer comments. All authors have contributed to the writing, and review of the paper.

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