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Hybrid backscatter communication for IoT devices in remote areas

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ABSTRACT

The IoT devices placed in remote locations require a battery replacement very often, which is not a convenient option. Backscatter communication can resolve this problem, as backscatter communication is a data transmission in which an RF signal incident from the gateway is used for energy harvesting, and this energy will be employed for data transmission. In this paper, a hybrid contention-based TDMA scheme is proposed, which provides slots to devices by dividing them into groups, and then contention is employed in groups to acquire a slot; if a device is not able to transmit during harvest, then transmit (HTT) period, then it can transmit in variable sub frame and the devices which are not able to completely transmit during HTT period can reserve sub-frames. The proposed hybrid scheme is compared with the TDMA scheme for average transmission delay.The proposed scheme provides scalability. The difference between the average transmission delay of TDMA and the proposed hybrid scheme is from 6 to 20 s, depending on the number of devices added and when traffic is generated.

1. Introduction

Recently, the Internet of Things (IoT) is commonly used in networks, including mobile, computer, and satellite communications. The IoT, or in other words, IoT devices, are used in smart cities for smart applications like traffic, waste management, factories, etc [1–3]. Intelligent services and options are provided to users with the use of intelligent devices IoT devices used are mainly battery-powered. For the expansion of applications where these devices can be utilised, these devices must provide information frequently. These IoT devices have a limitation as they are battery driven [4–6]. Sometimes even in smart cities there are places where it's impossible to replace the battery very often; the IoT device might be on high-rise buildings or at very remote locations [7]. This limitation can be overcome by utilizing backscatter communication for the applications to provide stable services. The expansion of IoT device data collection in smart cities makes it possible to set up a backscatter network that uses backscatter communication. This will lead to enable smart services flexibly for energy-limited devices. Another technology that can be used here is Radio frequency energy harvesting (RFEH), an energy conversion technique employed for converting energy from the electromagnetic field into the electrical form (i.e., into voltages and currents). In particular, RFEH is a very appealing solution for backscatter as it allows low-power sensors and systems to be wirelessly powered in various application scenarios [8]. RFEH is employed in Cognitive Radio Networks (CRN) scenario with a mobile secondary transmitter which performs energy harvesting [9].

The backscatter communication is for devices not connected to the power source or without batteries. Using backscatter communication methodology, the data transmission is twofold: energy harvesting followed by transmission. In the first step, an RF signal is received by a device from a power source and the device harvests energy from the received signal for transmission. Then this

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harvested energy is used for transmission in 2nd step. The devices used for the backscatter communication cannot transmit data without performing energy harvesting. Thus, backscatter devices and an RF source form a backscatter network [10–12]. The backscatter devices work as a sender and receiver.

An incident RF signal is generated by an RF source generates an incident RF signal [13]. An IoT device is mainly used as a backscatter sender, while different devices can be used as a backscatter receiver. A backscatter receiver, a gateway, or an RF source can receive data from a backscatter sender. The backscatter systems are classified into two types depending on the backscatter receiver type [14]. In a monostatic backscatter system, the sender transmits data to the RF source, which generates the incident signal. In contrast, in a bistatic backscatter system, the sender transmits data to other devices, excluding the RF source that generated it. These systems or network architectures are utilised to expand IoT networks [15].

Like in any wireless transmission, multiple data transmission is possible from multiple devices. For a successful transmission, media access control is utilised. The media access control used for any wireless medium is classified as contention-based and guaranteed media access control [16]. In guaranteed media access control, devices transmit data only during the time slot allotted to them, the data transmission is stable. However, this suffers from problem of overhead in managing the allocation of time slots and deciding the master node. In the contention-based media access control, the devices compete with each other to obtain time slot for data transmission. This leads to collisions even though devices transmit data after acquiring a time slot.

In any network, a number of devices try to transmit at any instant in time. The request of transmission originating from these devices is random. The backscatter devices are required to do energy harvesting, too. Due to this, these devices use an algorithm for media access, which has defined energy harvesting periods. The algorithm must provide scalability, too.

Backscatter communication is a constructive method used for data transmission by energy-limited IoT devices. Using energy-harvesting IoT devices that are battery-less can also transmit data as these devices can only transmit data after energy harvesting. From the transmission power model given in Ref. [17].

$$SNR = P_T - P_L(d) - P_N \tag{1}$$

where SNR denotes signal to noise ratio, $P_L(d)$ is path loss power at distance d and P_N is noise power. Using the bit error model in IEEE Standard 802.15.4 [15], the packet reception rate is given as

$$PRR = (1 - e)^s \tag{2}$$

where s denotes the size of the frame transmitted in bits.

The authors in Ref. [18] use the example of a wireless digital TV signal that a sensor can sustain wireless communication without using batteries. The authors of [19,20], merged Backscatter communication (BackCom) with WPCN and proposed a backscatter-assisted wireless powered communication network (BAWPCN), which is extended by the authors of [21] to multimode backscatter communication and use of HTT, a resource allocation scheme is also proposed which maximizes link capacity using time slots. The work in Ref. [22], maximizes the throughput of EH, backscatter, and wireless transmission using optimal time allocation. In Ref. [23], a resource allocation scheme is proposed that optimizes the transmission time, throughput, reflection coefficient, and transmit power of full-duplex BackCom. The work in Ref. [24], using NOMA, maximizes the throughput by optimizing both the backscatter time and reflection coefficient, with limitations in the form of SNR and energy collection. In Ref. [25], the authors maximize the user energy efficiency (EE) for BAWPCNs.

Different multiple access schemes are available for the media access control. The multiple access schemes possible are frequency division multiple access (FDMA), space division multiple access (SDMA), and code division multiple access (CDMA), however, they suffer from the problem of higher complexity [8]. Due to limited computing resources available with backscatter devices, they cannot handle higher complexity access schemes. The possible candidate multiple access schemes are time division multiple access (TDMA) and carrier sense multiple access (CSMA). The schemes that use TDMA are simple in design, and energy harvesting is easily possible with the advantage of stable data transmission in a particular time slot. The work in Ref. [11], proposes a TDMA-based data transmission scheme in which they constructed several time slots, and each time slot constitutes two modes: the harvest-then-transmit (HTT) mode and the backscatter mode.

The work in Ref. [26], uses three multiple access schemes: TDMA, FDMA, and non-orthogonal multiple access (NOMA). NOMA [27–29] looks a promising candidate for backscatter communication; however, it suffers from the problem of complexity of no control on each device's transmission power due to interference and noise level. In Ref. [30], a task offloading resource allocation is proposed, which review energy consumption for a backscatter network, the work in Ref. [31] proposes a resource allocation scheme that confirms throughput with fairness and enhance the data rate.

The work has been done to ways of decoding signals in backscatter communication [32–34], parallel decoding of signals of all backscatter devices is one option, the disadvantage associated with it is higher complexity on receiever side and is not supported by receivers in existing form. The work in Ref. [35], selects one backscatter device from active devices for backscattering its own signal, this work considers that there no direct link between source and destination due to deep shadowing will have higher transmission delays.Work has been done on avoiding multiuser interference among backscatter devices withour compromising receiver complexity. In Refs. [36,37], different frequency bands are assigned to backscatter devices. This give rise to fairness problem among devices. The time division multiple access (TDMA) based scheme can be used to address these problems, which find its feet in different applications like CR [38], wireless powered communications [10] and secure communications [39]. The TDMA has been used by Ref. [40] for the maximization of total energy efficiency.

The data transmission scheme which uses TDMA are simple but are not scalable. The devices have to wait for the allocation of time slots from the gateway, which means they have to wait until a time slot is available to start data transmission [41]. The backscatter devices usually have limited resources and many devices utilize the network for transmission. The arrival and departure of devices is random in any network; when a device is substituted, the frame structure must be changed, too, reducing transmission efficiency. In addition to this, the backscatter devices have provision of energy harvesting and scalability. A possible solution is the use of contention-based transmission, which increases scalability even when different combinations of devices are activated. In this paper, a hybrid contention-based data transmission is proposed, which is focused on capacity improvement. The arrival and departure of calls that are activated are random in network. The use of a contention-based scheme even provides scalability when activated devices are changed.

The proposed work in this paper uses all these parameters in the algorithm. The work is suitable for smart city applications for cities with load shedding problems.

The remainder of this paper is organised as follows. In section 2, the proposed scheme with its algorithm is explained. Results and simulations are discussed in section 3, and finally, the paper is concluded in section 4.

2. Proposed work

The paper uses a hybrid contention-based scheme for TDMA, in which the channel time is divided into frames. The number of backscatter devices is divided into groups. The frame is comprised of reservation subframe, fixed subframe and variable subframe [42]. The group can put their demands for data transmission in the reservation subframe. A group is allotted a slot in a fixed subframe

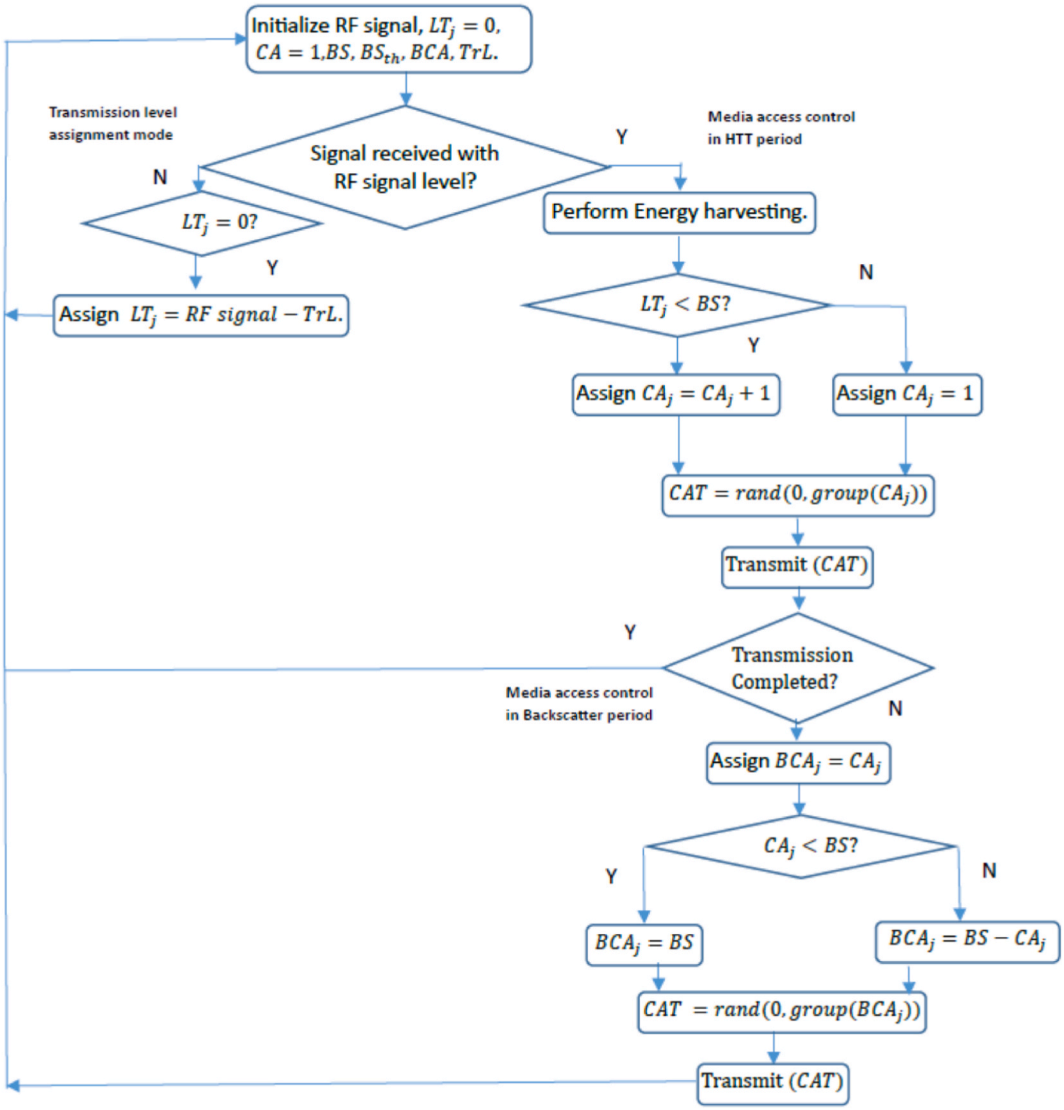

Fig. 1. Flow Chart of the proposed work.

allocated to devices in that group based on contention. In a fixed subframe, every group will be allotted one slot for data transmission. The devices in the group use contention for access; if more than two devices try to use the slot, the data transmission results in collision. When the transmission results in a collision or when a device manages to complete a data transmission during a fixed subframe and has more packets to be transmitted. Those devices will use the variable subframe. The devices in a group attempt for transmission in an ideal medium. Compared to the work in the literature, the work uses a fixed subframe as a contention-based transmit and a variable subframe as a backscatter period.

The gateway (*GW*) broadcasts a beacon signal periodically. The beacon signal is used for the sharing of the main frame structure with devices looking for access. The power level of RF signal is initialised. The level of transmission (*LT*) is initialised with the help of RF signal power level sent to the device by *G*. The GW also controls the energy harvesting among backscatter devices. Depending upon the distance of the device from GW, the RF signal will be assigned to the device, where transmission level (*TrL*) is used to adjust the RF signal with respect to distance in the flow chart shown in Fig. 1. For media access control, if a device receives a beacon signal (*BS*). Energy harvesting (EH) is performed before transmission in HTT period. When *LT* is less than *BS*, change the level of device channel access (*CA*) i.e. group in which they belong. When the beacon signal level reaches the threshold (BS_{th}), initialise *CA* and media channel access time is randomly selected, and the device uses this time to transmit the data. When the transmission is not completed in HTT period due to collision or because the device has more data to transmit, then backscatter period is used for transmission. CAT and BCA denote the channel access time, which denotes channel access level of the backscatter period.

This work divides the mainframe into the following periods: beacon, EH, contention-based transmission, and backscatter. The frame structure information is shared in the beacon period used by the backscatter devices for data transmission. If beacon period is $T\,ms$, the EH and backscatter period will be $\frac{3T}{2}ms$ and $2T\,ms$, respectively. Considering all these periods, the main frame period(size) will be $6T\,ms$.

In the event of a collision, a backoff time of $\frac{T}{10}ms$ is used, which is a binary exponential random backoff. In this work, retransmission is allowed for two times only. The result leads to less collision. During backscatter period, the device that have been waiting long will be given the chance.

The flow chart is given in Fig. 1.

3. Results and simulations

The simulation environment is created on MATLAB 2022. The simulation time is 10 min. Three groups are used for the simulations, and each group randomly uses a media access time of 2 ms, with intervals from 0 to 4 ms. The packet size of data transmission is 125 Bytes. The beacon period used is $T= 20\,ms$. The activated backscatter devices at a time determine the number of TDMA time slots, a TDMA time slot used is of 5 ms.

The number of backscatter IoT devices used is 25,35 and 45. The average transmission delays of the proposed hybrid scheme are compared with TDMA-based scheme applied on the same simulating network. The interference in signals will bring low throughput rate and reduce transmission reliability. Therefore, interference must be avoided or minimized. The contention error [43,44] in a wireless link is given by

$$p= 1-\left(1 - \frac{p_a}{N+1}\right)^N \tag{3}$$

Where p_a is the probability of the number of active devices out of N nodes.

The TDMA scheme is influential by all means but lacks scalability. A gateway is used for scheduling of devices during time slots, and

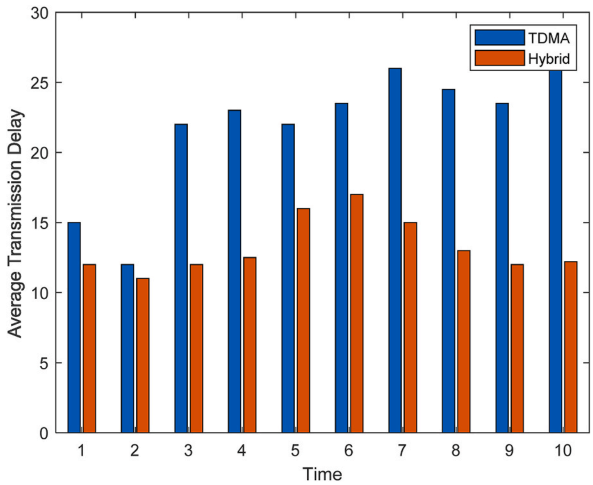

Fig. 2. Plot of average transmission delays(ms) against time in minutes when traffic generated after every 25 ms for 25 devices.

devices wait for the next schedule in case it does not have time slot [41].To improve transmission reliability. In Figs. 2 and 3, Hybrid and TDMA schemes are compared when traffic is generated every 25 ms and 15 ms, respectively for 25 devices. In Figs. 4 and 5, Hybrid and TDMA schemes are compared when traffic is generated every 25 ms and 15 ms, respectively for 35 devices. In Fig. 6, Hybrid and TDMA schemes are compared when traffic is generated every 25 ms for 45 devices. In all the simulations, the proposed hybrid scheme has a lower average transmission delay as compared to TDMA based scheme. When the number of activated backscatter devices increases, the provision of scalability is seen in hybrid scheme.

Along with it, the proposed scheme has a provision of providing transmission for the devices that are not able to transmit during HTT period and devices that have more data to transmit which they are not able to complete their transmission. In Fig. 2, the maximum transmission delay difference between the Hybrid and TDMA scheme is 13 ms. In Fig. 3, the maximum transmission delay difference between the Hybrid and TDMA scheme is 8 ms. In Figs. 4–6, however, as the number of devices increases, the difference in average transmission delay reduces. In Fig. 5, the TDMA-based method outperforms the hybrid scheme due to the delay caused by the creation of available timeslots. In TDMA, slots are provided to a user for transmission, this leads to a delay until the next frame for a newly added device. In a hybrid method based on backscatter, the devices can leave and join randomly. The problem associated with the proposed method is retransmission or, in other words, overhead generated due to retransmission, which resulted in better performance of the TDMA method in the results of Figs. 4 and 5 in the initial phase.

The average transmitted packets when 25 devices are activated is plotted in Fig. 7. The hybrid scheme outperforms conventional TDMA in transmitting packets, as conventional TDMA transmits when the sensor or device gets a slot as compared to hybrid, which can transmit in both HTT and backscatter period.

The energy consumed (mJ) per device TDMA, Hybrid scheme, and probing backscattering energy recycling (PBER) [40] are compared in Fig. 8, the hybrid scheme consumes less energy as there is no delay when a device leave or join the network until next frame, while in TDMA the device(s) have wait till next frame for assignment of a slot. The PBER scheme consumed minimum energy at the cost of capacity performance.

4. Conclusion

The IoT devices in the backscatter network are a key communication technology for the devices in remote areas connected to satellites. The replacement of a battery is not a convenient option; therefore, energy needs to be harvested for communication through some other means. Backscatter communication is a candidate that can resolve this problem, as energy harvesting is employed in it before transmission. However, it has problems associated with the random behaviour of devices that simultaneously participate in communication. The IoT devices participating in backscatter communication do energy harvesting from RF signals they received. IoT networks harvest energy from other RF signals. The work in this paper uses hybrid contention based TDMA for allocating slots to the devices for data transmission. The average transmission delay difference between proposed method and TDMA method is between 6 and 20 ms. The proposed method performs better than the TDMA method for different number of devices and time of new generated traffic.

In the hybrid method, a collision can exist, which is supported using retransmission, while in the case of the TDMA method, the number of activated devices decides the number of time slots and there is a delay associated with increase or decrease of slots as it due to reflection in next frame. Proposed method, contention-based transmission is used. Collision can occur and retransmission is supported for collision. The TDMA-based method generates transmission slots according to the number of activated devices. The next data frame reflects increasing or decreasing the number of transmission slots. The work clearly demonstrates that the average transmission delay of the hybrid method is mostly lesser as compared to TDMA method and hybrid method provides scalability too. Use of

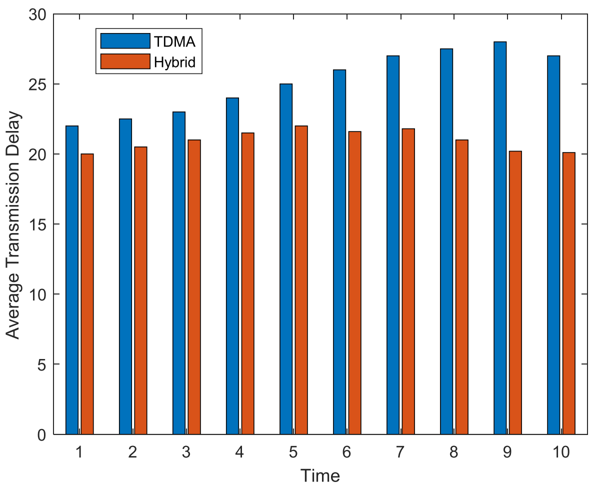

Fig. 3. Plot of average transmission delays(ms) against time in minutes when traffic generated after every 15 ms for 25 devices.

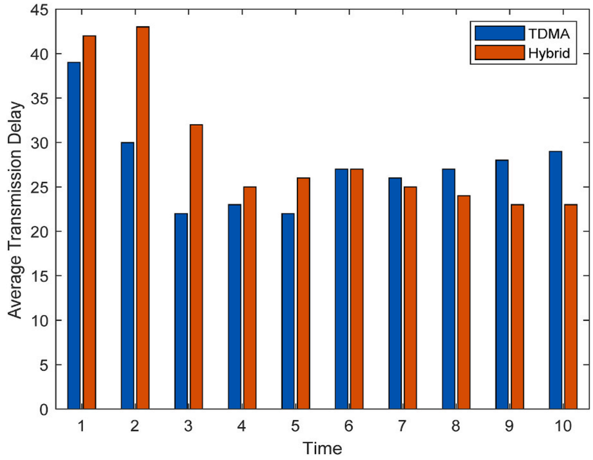

Fig. 4. Plot of average transmission delays(ms) against time in minutes when traffic generated after every 25 ms for 35 devices.

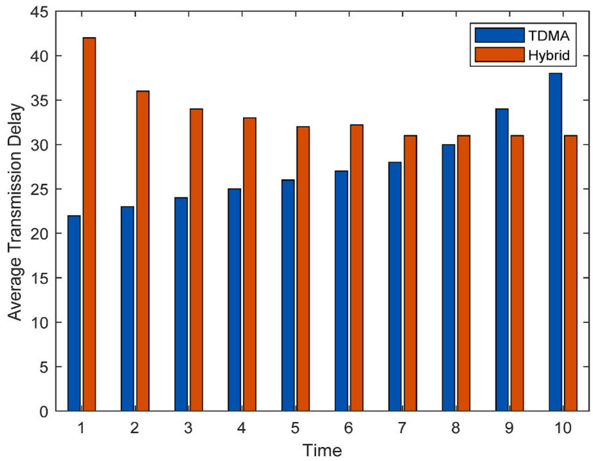

Fig. 5. Plot of average transmission delays(ms) against time in minutes when traffic generated after every 15 ms for 35 devices.

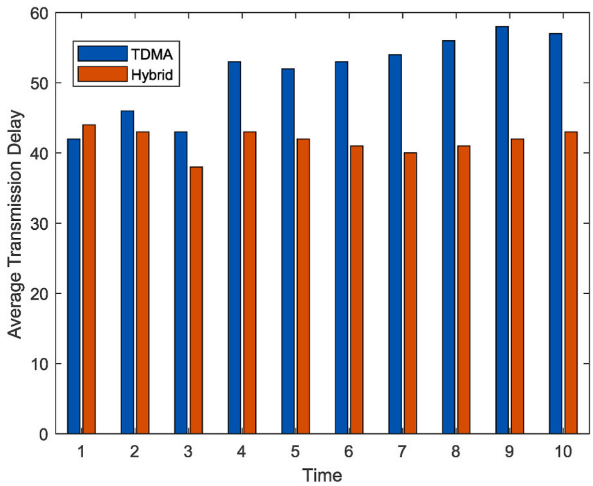

Fig. 6. Plot of average transmission delays(ms) against time in minutes when traffic generated after every 25 ms for 45 devices.

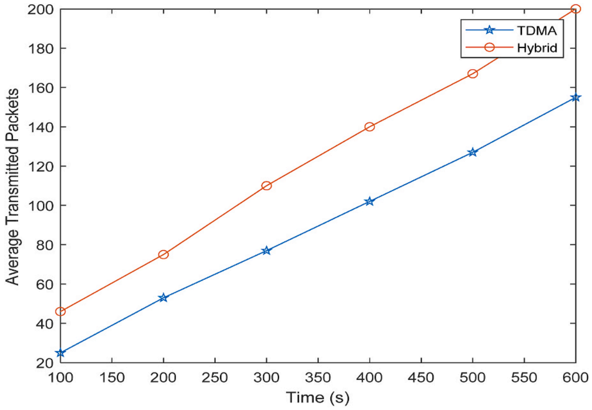

Fig. 7. Plot of average transmitted packets against time in seconds when 25 devices are activated.

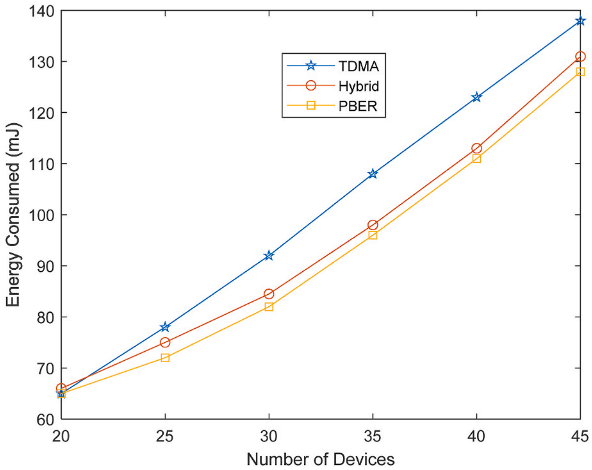

Fig. 8. Plot for Energy consumed versus number of devices activated in the network.

contention allows flexibility to devices for transmission. Also, a device not able to transmit during HTT period can do so in backscatter period. In TDMA based method, a device must wait for next frame after joining, as slots are increased or decreased in next frame only. The proposed work is a test work which will be used in future for satellite network which will employ backscatter communication in LoRa nodes.

CRediT authorship contribution statement

Gunjan Gupta: Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis, Data curation, Conceptualization. **Vipin Balyan:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Vipin balyan reports article publishing charges was provided by Cape Peninsula University of Technology - Bellville Campus. None.

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