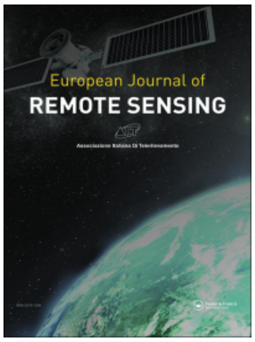

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Neighbourhood oriented TDMA scheme for the internet of things-enabled remote sensing

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ABSTRACT
Throughout the world, Internet of Things (IoT) have been used in different application areas to assist human beings in numerous activities such as smart buildings and cities via remote sensing-enabled techniques. However, simultaneous transmission of packet(s) by multiple devices C_i, which are interested to start a communication session with a common receiver device, is one of the challenging issues associated with these networks. In the literature, various mechanisms have been presented to resolve the aforementioned issue without changing the technological infrastructures; however, neighbourhood information of sensor nodes is not considered yet. In IoT-enabled remote sensing, neighbourhood information of various devices plays a vital role in developing a reliable communication mechanism specifically for scenarios where multiple devices C_i are interested to start communication with a common destination module. In this paper, a neighbourhood-enabled TDMA scheme is presented for the IoT to ensure the concurrent communication of multiple devices C_i with a common destination device S_j preferably with a minimum possible packet collision ratio (if avoidance is not possible). The proposed scheme bounds each and every member device Ci to assign a dedicated time slot to its neighbouring devices in the operational IoT network. Furthermore, neighbouring devices Ci are forced to communicate within the assigned time slot. Simulation results have verified that the proposed scheme is ideal solution compared to the existing schemes for the IoT and other resource-limited networks particularly in scenarios where the deployment process is random.

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Internet of things; remote sensing; TDMA; devices neighbourhood; time slot

Introduction

Recent advancements in Information and Communication Technology (ICT) have attracted researchers to a naive research domain that is Internet of Things (IoT)-enabled remote sensing for smart cities and buildings (Nguyen et al., 2020). IoT has a direct correlation with almost every activity of human beings. Generally, IoT is defined as a network of ”things” where a thing is any physical object—with embedded sensors, actuators, software, microprocessor and transceiver—and these objects have the capability to form an operational network without human intervention (Naeem et al., 2021; Savaglio et al., 2020; Tran et al., 2021). Due to the self-organizing nature of member devices Ci, these networks are either deployed randomly or manually in the vicinity of the underlying phenomenon. Usually, IoT are deployed to probe an underlying environment or activity periodically and are bounded to send the collected data to a centralized location via gateway(s) using a reliable wireless communication mechanism (Azarhava et al., 2020).

Due to the limited transmission power capacity of member devices Ci, direct communication of every device with the gateway or server Sj module is not always possible (Fu et al., 2020; N-T. Nguyen & Liu, 2019). Therefore, the multi-hop communication mechanism is adopted in these networks where every member device Ci, specifically relaying device(s), is bounded to transmit collected data of the neighbouring device(s) in addition to its own (Nguyen et al., 2019). Additionally, hierarchical networking infrastructures were proposed in the literature to resolve the limited transmission problem associated with the resource-limited networks such as IoT, wireless sensor networks and ad hoc networksNori & Sharifian, 2020). In these networks, ordinary nodes are bounded to transmit their collected data to the concerned CH, which is responsible for its transmission to the intended base station through either direction communication or other CH (N-T. Nguyen et al., 2016). In both cases, communication is many to one (m: 1), i.e. multiple source nodes Ci are sending data to a single point. A common problem associated with these scenarios is the simultaneous communication, i.e. destination device has a single receiver and is able to communicate with one device only at a particular time. This issue becomes more complex when two or more nodes Ci communicate simultaneously with a common base station or CH. Additionally, the scarcity of available power of the devices imposes further

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restrictions on the networking infrastructures in general and on the transmission modules in particular (Do et al.,).

Numerous wireless communication schemes were presented in the literature to address the concurrent communication problem particularly in the IoT networks (Do et al.,). In Carrier sense multiple access with collision avoidance (CSMA/CA), a device should sense the channel twice, i.e. for authentication and association, respectively (Doost-Mohammady et al., 2016). This mechanism results in collision among multiple competing devices and requires an excessive time to complete the registration process of sensor nodes Ci in an operational network. Similarly, various mechanisms were presented in parallel such as distributed authentication control (DAC) (Bankov et al., 2016) and combined authentication/association (CAA) (Shahin et al., 2016) to address the aforementioned issue associated with resource-limited networks such as WSNs and IoT. However, some of the challenging issues associated with these schemes are excessive registration time, transmission delay and packet collision ratio.

The time-division multiple access (TDMA) scheme was presented to enable a reliable wireless communication among multiple operational devices over a shared medium (Faruque, 2019). For this purpose, the transmission time is divided into slots of equal sizes and a proper scheduling policy is used to assign these slots to the requesting devices. These devices are bounded to communicate within their allotted time slots to avoid packet collision and achieve maximum bandwidth or channel utilization as shown in Figure. 1. A multi-channel variable TDMA- and FDMA (frequency domain multiple access)-based scheduling approach was presented to develop a reliable communication infrastructure for the wearable devices (Ramachandran et al., 2021). Likewise, a topological ordering-based TDMA approach was presented where every member device Ci has the prior knowledge about its waiting time for a particular time slot and is helpful in reducing collisions and competition among neighbouring devices (Nguyen et al.,). A hybrid TDMA- and CSMA/CA-enabled MAC protocol is proposed to address energy efficiency issue that is tightly coupled with IoT. Moreover, sleep and wake-up periods of various devices are subjected to the variance in operational network loads (Al-Janabi et al., 2019). TDMA-based optimal co-operative ad hoc MAC protocol was proposed to use multiple cooperative devices for forwarding data. Selection criteria of these cooperative nodes are subjected to communication range, successful transmission probability between source and destination devices and available time slot in the operational resource-limited network (Hadded et al., 2015). However, overhearing, excessive slot waiting time and bandwidth wastage are among the critical issues with the existing TDMA approaches. To the best of our knowledge, neighbourhood information of numerous member devices C_i has not been considered in developing TDMA-based approaches specifically in the IoT. Furthermore, to the best of our knowledge, the neighbourhood-based TDMA approach is not presented in the literature.

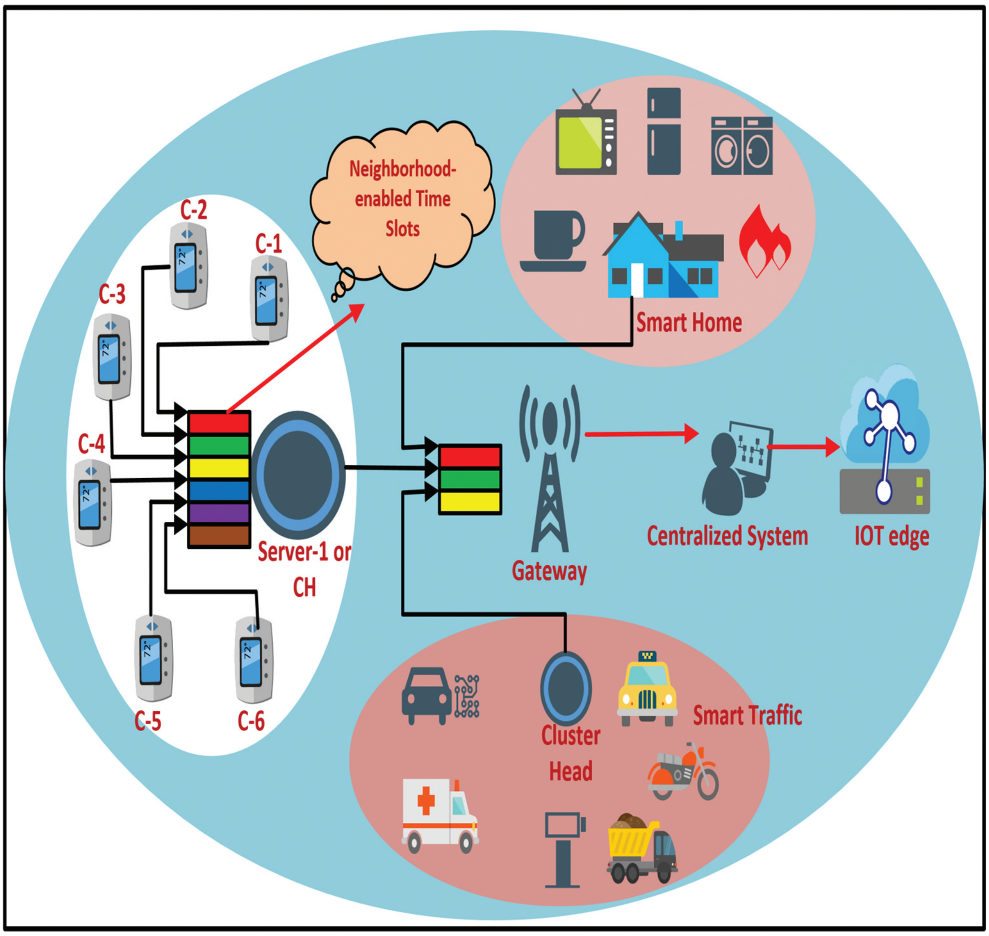

Figure.1. Neighbourhood-Enabled Time Division Multiple Access (TDMA) in the IoT.

In this paper, a device C_i (preferably CH) neighbourhood-enabled TDMA scheme is presented to ensure simultaneous transmission of multiple requesting devices. The proposed scheme is an ideal solution for the IoT networks where formation of a balanced clustering mechanism is not feasible. Furthermore, the proposed technique (a) should be more energy efficient, (b) should be collision free and (c) requires minimum possible communication overheads. The main contributions can be summarized as follows:

1. Neighbourhood-enabled TDMA algorithm for the IoT networks
2. A scheduling algorithm with a minimum possible average collision ratio and waiting time of a device C_i for a particular time slot
3. Infrastructure-free TDMA Scheme

In Section 2, a comprehensive literature review is presented with most relevant approaches discussed. In Section 3, we elaborate on the problem statement. The proposed mechanism is enlightened in Section 4. Section 5 presents a comparative analysis of the proposed and existing schemes in terms of various performance metrics and finally concluding remarks are given.

Literature review

Medium access control (MAC) sub-layer schemes are used to enable simultaneous communication among multiple device Ci, i.e. sensor nodes in this case, over a shared medium. Various mechanisms have been presented in the literature to resolve this issue. A brief review of those techniques, which are relevant to the proposed work, is presented as complete survey is beyond the scope of this research work. A four way-enabled contention-based handshake mechanism entitled Carrier sense multiple access with collision avoidance (CSMA/CA) was presented to address the concurrent communication problems where every device CI interested in communication is bounded to access the shared medium twice, initially, to send authentication request messages and then to send the association messages (Doost-Mohammady et al., 2016), Adame et al., 2014). However, packet collisions and excessive registration time are among the main problems associated with the CSMA/CA scheme. To address these issues and enhance the operational capabilities of the resource-limited networks, centralized authentication control (CAC) (Pawlowski et al., 2014), distributed authentication control (DAC) (Bankov et al., 2016) and combined authentication/association (CAA) (Shahin et al., 2016) were presented in the literature. Although these techniques resolve some of the aforementioned issues, transmission delay and packet collision ratio are still there. Request to send (RTS) and clear to send (CTS) handshake were presented to resolve the hidden terminal scenario, which is a common problem associated with devices C_i deployed in closed proximity, and communicate via a shared medium (Chen et al., 2018). However, a sensor node deployed in the vicinity of either source or destination module should wait for the completion of an ongoing communication session, i.e. expose terminal scenario. Time-division multiple access (TDMA) is a MAC-sublayer mechanism that was developed to enable a reliable communication among multiple devices over a shared medium preferably with a common destination module (Faruque, 2019). For this purpose, the transmission time T is divided into slots of equal sizes and a proper scheduling policy is used to assign available slots to the requesting devices Ci. Every device Ci is bounded to transmit the collected data within its allotted time slot and wait if slots are fully utilized. A proper scheduling policy is helpful to avoid collision among the transmitted packets and utilize bandwidth or channel up to its maximum capacity. However, various limitations of TDMA-based schemes are (i) bandwidth wastage, i.e. when the devices Ci with allotted time slots are not communicating, (ii) excessive waiting time experienced by the devices Ci for their assigned slots and (iii) overhearing. A hybrid of hierarchical structure and time-based MAC was proposed by Lee et al (Lee & Cho, 2017) to enhance the operational capabilities of the TDMA scheme particularly in resolving overhearing and funnelling problems. However, the hierarchical tree-based networks have their own limitations. For example, they experience excessive transmission delay because the child devices communicate with the gateways or their intended cluster heads (CHs) via their immediate parents. Moreover, failure of a parent device results in disconnection of an entire branch from WSNs.

In (Shahin et al., 2018), a slotted-CSMA/CA-TDMA scheme was presented to address the concurrent communication and excessive registration issues that are common when multiple devices Ci are transmitting in an IoT network. In this approach, CSMA/CA is used by devices Ci to broadcast authentication requests simultaneously, whereas TDMA is dedicated to send or receive the association request messages. Although this scheme has resolved the registration issue successfully, however, other TDMA issues such as excessive waiting time, bandwidth consumption and latency are not dealt with. A contention-free MAC protocol was presented by Zhai et al (Zhai et al., 2016) to enable a schedule-oriented packets transmission, in both the frequency domain and the time domain, with an optional automatic repeat request mechanism. This approach is limited to a particular IoT hardware infrastructure and is not suitable for other platforms. A distributed token-based adaptive MAC scheme was proposed to resolve the hidden terminal problem specifically with IoT-enabled Mobile Ad Hoc Networks (MANET) (Ye & Zhuang, 2017). Concurrent communication, latency and a single point of failure are among the main issues associated with this approach.

A distributed TDMA scheduling scheme was proposed for the resource-limited networks (Li et al., 2017). The prioritized slot allocation mechanism was used to guarantee a proper time slot allocation.

However, it does not guarantee simultaneous communication among multiple devices Ci. A multi-channel variable TDMA- and FDMA (frequency domain multiple access)-based scheduling approach was presented to streamline a reliable communication infrastructure for the wearable devices (Ramachandran et al., 2021). Although this hybrid approach is quite convincing, complexity and energy efficiency are among the common issues associated with it. Likewise, a topological ordering-based TDMA approach was presented in (Nguyen et al.,) where every node knows how much time it has to wait for a particular time slot. This mechanism is helpful in reducing collisions and competition among neighbouring devices of the operational networks. However, a device will have to wait a longer time if the deployment is dense in the networks with limited resource. To resolve the collision issue associated with resource-limited networks, a distributed TDMA-enabled scheduling scheme, which is specifically designed for the correlated contentions, is presented (Bhatia & Hansdah, 2013). However, a tightly coupled issue with this approach is the synchronization of various neighbouring devices, which is not always possible particularly if devices are resource limited. Batta et al (Batta et al., 2019) proposed the distributed TDMA scheduling scheme for improving latency in IoT.

Problem Statement

In the literature, various TDMA-based wireless communication mechanisms (both static and dynamic) were presented and used to enable the resource-limited networks, i.e. IoT and WSNs, to transmit data collected by various devices C_i with minimum possible overheads such as control messages, waiting time and packet collisions. Although these schemes were quite convincing in resolving the aforementioned issues, these mechanisms were either application specific or overlay complex. Furthermore, a majority of the existing TDMA-based schemes were focused on efficient utilization of the available power without considering other valuable parameters such as average packet delivery ratio, waiting time (specifically during slot allocation), starvation (in some cases), most importantly, slot availability, etc.

In both flat and hierarchical networks, existing TDMA-based schemes either use static or dynamic slot allocation mechanisms to various devices C_i, which is not realistic particularly if the deployment process is random. Moreover, these schemes impose an unrealistic restriction on ordinary nodes C_i belonging to a particular cluster, that is, the number of these devices in any cluster should be the same, which is not always possible if devices are deployed randomly. Additionally, in resource-limited networks, a common issue that is tightly coupled particularly with hierarchical networks is the criticality of heavy loaded CH, which will consume their residual energy E_r more rapidly than other CH. Selection and join procedure of an alternative CH is resource harvesting and time-consuming process. This research work will be focused on the development of Two-Tire Neighbourhood-Oriented and TDMA-enabled Energy Efficient Wireless Communication Mechanisms specifically for the hierarchical Resource-Limited Networks such as IoT.

Usually, in IoT network, every member server S_j has a unique set of neighbours as shown in Figure. 1. In the case of the traditional TDMA scheme (either static or dynamic), a uniform scheduling policy is implemented throughout the network irrespective of the devices' neighbourhood. However, if this policy is fine-tuned according to the neighbourhood of a particular server S_j, then it is quite likely that most of the issues associated with existing TDMA-enabled schemes will be addressed. For example, if a device has two neighbours, then its TDMA must be adjusted accordingly, i.e. two slots only.

Proposed methodology: neighbourhood-enabled TDMA scheme for the IoT

A Two-Tyre neighbourhood-oriented and TDMA-enabled energy efficient wireless communication mechanism is presented to resolve the aforementioned issues such as maximum average delivery ratio, minimum possible end-to-end delay, minimum possible waiting time for slot, minimum collision ratio and enhanced networks' lifetime. Initially, in the neighbours' discovery phase, a control packet, Msghd, is broadcasted by each and every server module or cluster head (CH) Sj, with a value of JoinReq = 0, which is received by devices Ci deployed in closed proximity, which is defined by equation. 1.

$$\left\{ \begin{array}{c} {}_{i=0\ldots n}C_i \in \sigma(C_i) iff \sqrt{(x_i - S_j)^2 + (y_i - S_{j+1})^2} < \delta \\ {}_{i=0\ldots n}C_i \in \sigma(C_i) iff \sqrt{(x_i - S_j)^2 + (y_i - S_{j+1})^2} == \delta \\ whereSrepresentsservermodule. \end{array} \right. \tag{1}$$

Parameters σ and δ are used to represent neighbourhood and threshold values, respectively. A neighbouring device Ci that is interested to join a particular CH or server Sj sends an updated version of message Msghd, i.e. with the value of JoinReq = 1, after its back-off time expires. The back-off time of a device Ci is computed using equation. 2

$$Back - offTimer(C_i) = rand(0 - 100) microseconds. \tag{2}$$

The back-off timer is the time needed to receive such types of messages from various CH S_j, which are deployed in closed proximity of a particular device C_i. Usually, a device C_i prefers to join that cluster, which is associated with a CH or server module Sj from which it has received a message with the maximum value of Received Signal Strength Indicator (RSSI), which is computed using equation. 3 (preferably for RSSI) and .4 (for path loss), respectively,

$$RSSI = P_t - P_{loss}(d), \tag{3}$$

$$P_{d=}P_{d0} - 10log\frac{d}{d0} - X_{\sigma.} \tag{4}$$

Thus, every device C_i (preferably those reside in closed communication range of CH) generates a request message (REQ) and sends it to the concerned server S_j, which contain request to join information. Thus, every CH or server S_j module has a defined list of member devices, which is not necessarily the same as assumed in the majority of the existing models.

In the next phase, every CH or server module S_j develops a TDMA-enabled communication strategy for its member devices C_i, where the number of slot in TDMA is directly proportional to the neighbouring member devices Ci preferably those that are interested to join this cluster. A server module S_j receives cluster join request messages from the neighbouring devices only. Thus, the slots generation ratio is directly proportional to these request messages, i.e. if a server S_j receives ten (10) message, then it is bounded to divide its sliding window (time) into 10 slots. Furthermore, these slots are assigned or allocated to the requesting member devices Ci in first come first sever (FCFS) bases (as described in Equation. 5 using a non-preemptive strategy where a member device Ci can hold an assigned slot as long as needed,

$$Max(C_i) = WaitingTime. \tag{5}$$

Apart from it, a server module or CH S_j is allowed to assign membership to every requesting device Ci irrespective where other server S_j or CH has minimum member devices, which is usually the case if a random deployment strategy is adopted for the IoT networks. Furthermore, the slots assignment strategy is performed once as soon as the underlined IoT networks are deployed. The proposed approach is a static approach where each and every CH or server S_j has different numbers of member devices Ci. Let us assume that an IoT network has three (3) CH or servers S_j, which are S1, S2 and S3 with 8, 15 and 20 member devices Ci, respectively. In this network, server S3 generates 20 time slots and are assigned accordingly, whereas S1 and S2 have 8 (eight) and 15 (fifteen) time slots, respectively. Additionally, a member device Ci is assigned multiple slots (not necessarily adjacent), which is possible only if other member devices Ci are not interested to send data in the respective time slot. However, additional slots are assigned temporarily, i.e. if the concerned device Ci is interested to communicate in another session, then it can communicate within the assigned time slot. For this purpose, a query message ”MSGQ” is broadcasted by the concerned server module Sj prior to the slot beginning (preferably first). Thus, every member device Ci is interested to send data during its upcoming slot and send a response message ”MSG” with value of slots, which could be set either to S or M where S means that the device Ci is intended to send data in its own time slot only, while M is for multiple time slots. However, if a response message is not received from a particular member device Ci, then it is assumed that the concerned device is not interested in communication in coming session and thus, its time slot is assigned to another member device preferably with slot value being M for the response message. It is noted that the assignment of the additional free slots is assigned to the requesting devices Ci based on the shift probability (pshif) distribution according to the equation. 6.

$$p_{shift}(C_i) = \frac{(1-\gamma)\gamma^k}{(1-\gamma^k)}.\gamma^s, \tag{6}$$

where s = 1,2,3 . . . .k and k is the number of free slots. $\gamma = C_{1\ldots m\frac{-1}{k-1}}$ and 0 < γ < 1, where $C_{1\,\ldots\,m}$ represents the number of contestant member devices Ci. Multiple slot assignment strategy presented in equation. 6 is used if and only if two or more than two member devices C_i are interested in multiple free slots. However, if each and every member device Ci is interested to send data in its assigned time slot, then multiple slots requests are ignored by the concerned server or CH module S_j.

In addition to it, each and every CH or server S_j module is bounded to reserve time slots for other servers, which are not able to communicate directly with the base station modules, which is based on equation. 7.

Additionally, slots are also reserved for those sever modules Sj that are deployed on the edge of maximum possible distance measure, i.e. range of the communication module, according to equation. 8, that is

$$_{j=0\ldots m}S_j \in \sigma(S_{j+1}) iff \sqrt{(S_{xj}-BS_j)^2+(S_{yj}-BS_j)^2} < \delta, \tag{7}$$

$$\exists_{j=0\ldots m}S_j \in \sigma(S_{j+1}) iff \sqrt{(S_{xj}-BS_j)^2+(S_{yj}-BS_j)^2} == \delta, \tag{8}$$

where δ represents the capacity of the concerned wireless communication module of Sj. As opposed to the member device Ci empty slot temporary assignment strategy, slot assigned to another CH or server module Sj is not assigned to any other device or server Sj+1.

Consider a scenario presented in Figure. 1 where server-1 has six members or neighbouring devices. Server-1 initiates member or neighbour discovery process by broad-casting a control message ”MSGhd”, which is received by these neighbouring devices, i.e., C1,C2 . . . . C6. These devices respond with an updated version of the received message where value of parameter "Join –Request: 1", which is based on the RSSI value as described above. However, each and every member device Ci is bounded to wait a certain time interval (preferably random as described in equation. 2) prior to sending revised version of the received message. Random waiting time is introduced to reduce the collision probability of packets specifically in scenarios where multiple devices Ci are eager to send their packets simultaneously. When server-1 receives these response messages and its waiting period is expired, then it generates slots according to the number of requesting devices Ci, which is 6 (six) in this case as shown in Figure. 1. We have developed a neighbourhood-enabled TDMA algorithm, which is presented below where every device Ci is forced to waiting a defined time interval (which is 25 ms in case) to receive join-request message from various server modules S_j residing in closed proximity. Furthermore, every server S_j must ensure to allot a dedicated time slot to each and every requesting device Ci.

Algorithm 1 Proposed Neighborhood-enabled TDMA Algorithm for the IoT Networks

Require: Neighborhood-enabled TDMA

Ensure: Time Slots Assignment to the Member Devices C_i

```
$Class - Member$ ← Zero
$Class - NonMember$ ← Zero
4← 25 ms
$i$ ← Devices $C_i$ in the IoT
$j$ ← Server $S_j$ in the IoT
for every $S_j \in IoT$ do
    Generate "$MSG_{hd}$"
    Set value "$Join - Requet$: 0"
    Broad-Cast "$MSG_{hd}$"
endfor
for every $C_i \in IoT$ do
    if RSSI ($S_j > S_{j+1\,\ldots\,m}$) & (4:0) then
        Update "$MSG_{hd}$"
        Set value "$Join - Requet$: 1"
        Set Destination "$S_j$"
        Backoff Timer = rand(0–100 millisec)
        Broad-Cast "$MSG_{hd}$"
    endif
endfor
for every $S_j \in IoT$ do
    if ($Join - Request$: 1) then
        add $C_i$ to $Class - Member$
        Create a Time Slot for $C_i$
    else
        add $C_i$ to $Class - NonMember$
    end if
end for
return Neighborhood-enabled Static Time Slots
```

Performance evaluation metrics

In this section, a detailed analysis and verification (in terms numerous performance metrics) of the proposed neighbourhood-enabled TDMA and existing schemes is presented where various algorithms (such as opportunistic cooperative TDMA (Batta et al.,), Cooperative TDMA (Son & Jeong, 2020), Prioritized TDMA (Shahin et al., 2018) and Cooperative MAC (Tiwari et al., 2021) were implemented in OMNET++, which is an open source simulation tool for the IoT and other resource-limited networks. A random topological network is generated such that every device Ci has an embedded delay (both processing and communication) and other parameters as shown in Table 1.

Empty slot utilization

Generally, a TDMA-based scheme where a minimum possible slot waiting time is required for a particular member device C_i is preferred over other schemes (where the slot waiting time is maximum or longer) if other performance metrics are not compromised. A graphical description of the proposed approach and different existing approaches' comparative analysis in terms of slot waiting time (preferably its own) is presented in Figure. 2, which clearly shows that the proposed neighbourhood-enabled TDMA scheme requires a minimum slot waiting time specifically in situations where IoT deployment is random and cluster formation mechanism is not matched, which is usually the case in the IoT resource-constraint networks.

Table 1. Simulation parameters of the IoTs.

Parameters	values
IoTs Deployment Area	1000 m * 1000 m
Devices C_i	50, 100, 500, 1000
Server Modules S_j	One
Physical Headers and Preamble S_j	20us
Beacon Length S_j	70 to 100 bytes
Backoff Timer S_j	random
IFG & Gaurd Time S_j	50us
Duration of Slot S_j	65us
Signal to Noise Ratio p	10 dB
Feed back bits	8 Bits
Initial Energy (E_s)	52,000 mAh
Residual Energy (E_r)	*Ei-Ec*
Transmission Power Consumption (P_{Tx})	91.4 mW
Channel Delay (Ch_{delay})	10 milliseconds
Receiving Power Consumption (P_{Rx})	59.1 mW
Idle Mode Power Consumption	1.27 mW
Sleep Mode Power Consumption	15.4 μW
Transceiver Energy (T_i)	1 mW
Transmission Range (T_r)	500 m
Receiving Power Threshold (RTS_n)	1024 bits
Packet Size (P_{size})	128 bytes
Distance between devices	300 m
Sampling Rate	10 seconds
Topological Infrastructure	Static and Random

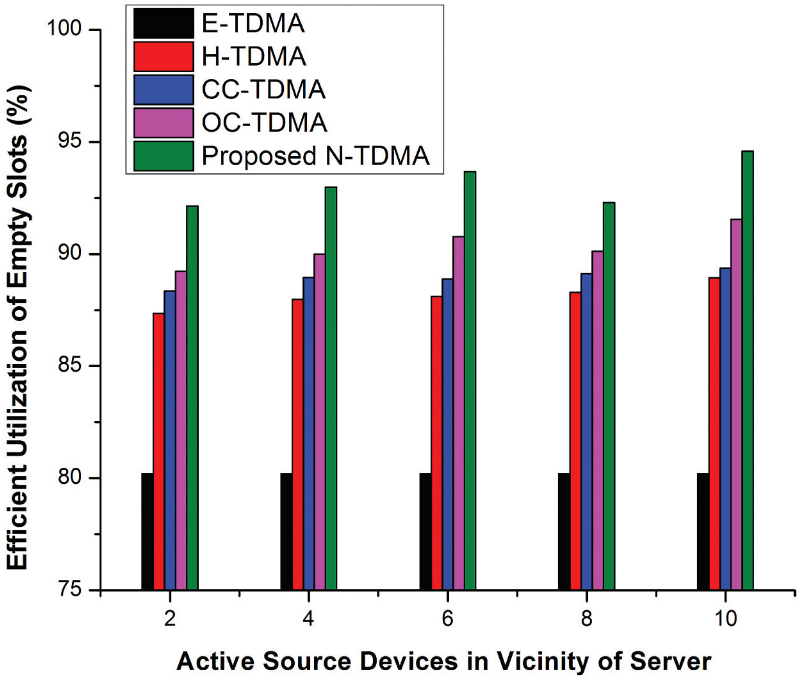

Figure.2. Efficient Utilization of Empty Slots in the IoT where Maximum Devices in a Cluster are Less than or Equal to Ten (10).

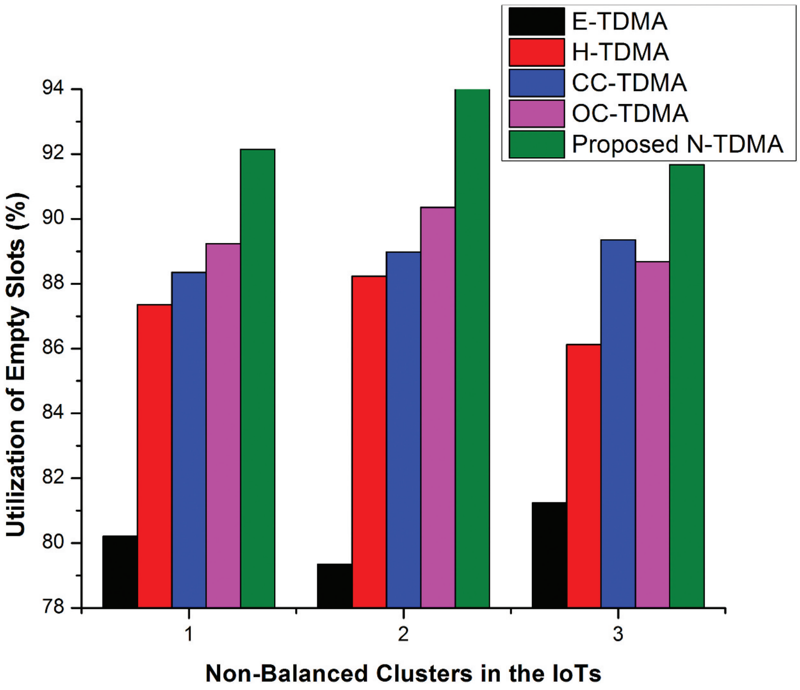

Figure.3. Efficient Utilization of Empty Slots in the IoT where Maximum Devices in a Cluster are Less than or Equal to Ten (20).

Furthermore, IoT networks are used in automatic event-driven application environments to assist a network administrator in controlling numerous critical events. For this purpose, the proposed neighbourhood-enabled TDMA scheme is designed such that it is equally applicable in different application areas specifically event driven. Figure. 3 shows that the proposed scheme has maximum utilization of the empty slots where different numbers of member devices are active in a particular cluster. The proposed scheme ensures that an active device is assigned the maximum possible empty slots ratio (if available) in every round of the operational IoT network.

Slot waiting time of a device in the IoT

Slot waiting time is defined as the time that a device should wait before its assigned time slot is encountered and it is directly proportional to the number of slots in a particular window. Usually, a TDMA approach with a minimum possible slot waiting time is preferred over complex procedures **if** it does not compromise on other performance metrics. A graphical representation of the exceptional performance of the proposed neighbourhood-enabled TDMA scheme is presented in Figure. 4 where it is ensured that each and every cluster has a maximum of ten (10) member devices, which may or may not be less. Likewise, a graphical representation of the proposed and existing TDMA approaches in terms of average slots waiting time is shown in Figure. 5 where member devices of a particular server or CH should be less than or equal to twenty (20). In both case, the average slot waiting time of the particular device using the proposed TDMA approach is less than the field-proven approaches.

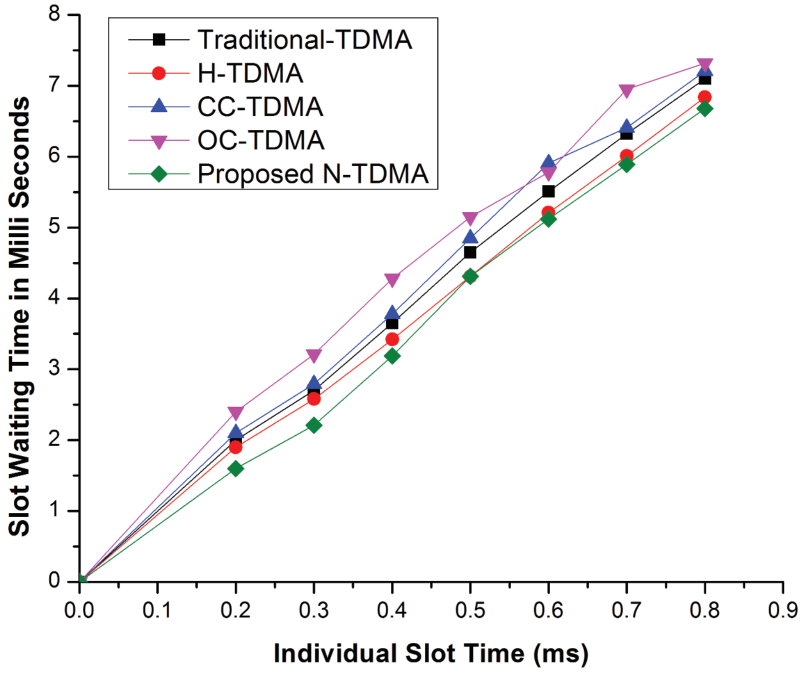

Figure.4. Slot Waiting Time (ms) where Member Devices are Less than or Equal to Ten (10).

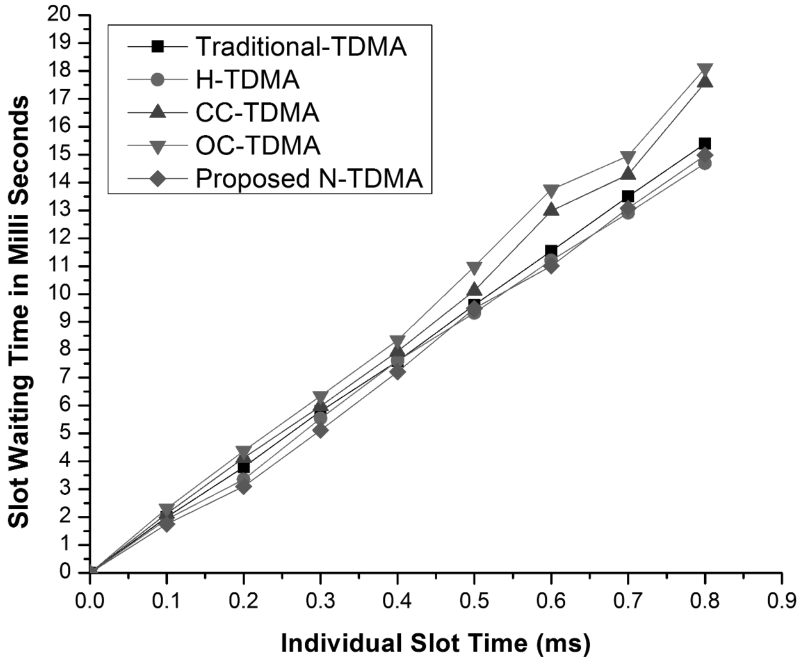

Figure.5. Slot Waiting Time (ms) where Member Devices are Less than or Equal to Ten (10).

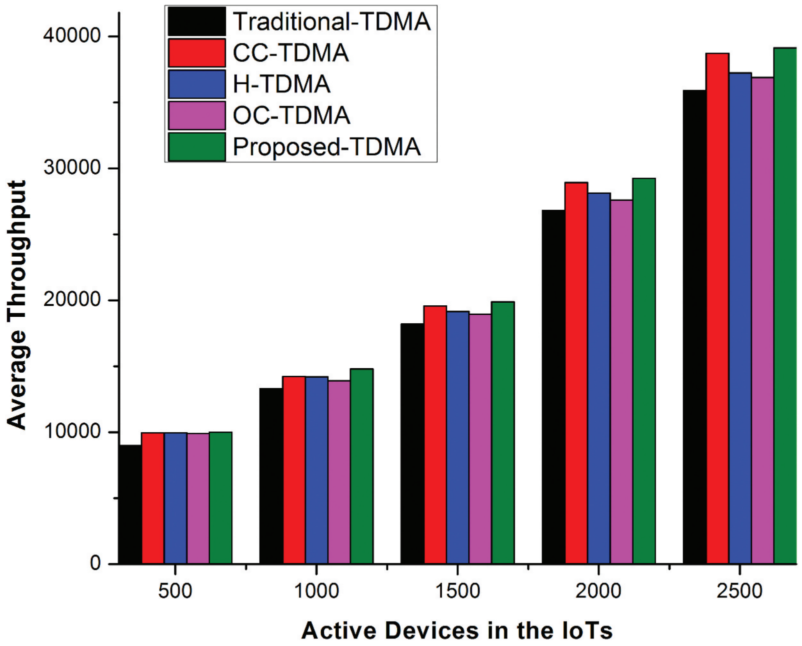

Figure.6. Average Throughput Analysis of the Proposed Neighbourhood-enabled and Existing TDMA Approaches.

Average throughput analysis

Average throughput is defined as the number of frames (packets) received successfully by the destination device (server S_j in this case) and it is one of the important performance measures to evaluate a newly developed approach preferably in scenarios where the devices are resources limited and their deployment methodology is random. In Figure.6, a comparative analysis of the average throughput performance metric of the proposed and existing approaches is shown, which depicts that the former approach is an ideal solution for the resource-limited networks as maximum average throughput is achieved with various network densities. Furthermore, these results were obtained using different network topologies and non-balanced clustering approaches, which is common in the resource-limited networks such as IoT. We have observed that the performance of the proposed scheme is not affected if the number of member devices in a cluster is increased or decreased, whereas existing schemes have a direct correlation with these measures. Furthermore, unlike the existing approaches, the ratio of active devices in a particular cluster does not affect the performance of the proposed approach, i.e. average throughput in this case.

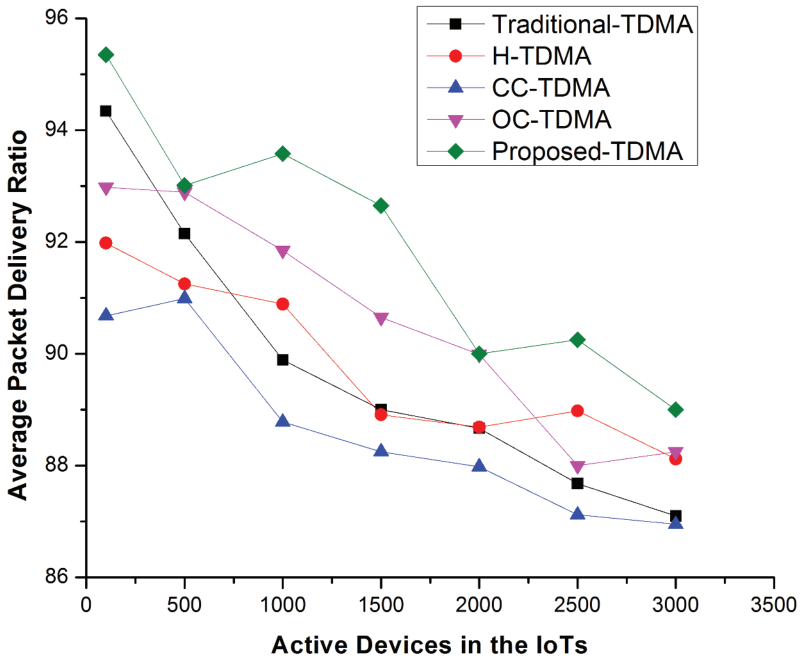

Figure.7. Comparative Analysis of the Proposed and Existing Approaches in Terms of APDR Performance Evaluation Metric.

Average Packet Delivery Ratio (APDR)

Average packet delivery ratio is defined as the ratio of the packets that are received successfully by the concerned destination device, i.e. base station in this, to that of the transmitted packets and it has a direct correlation with the throughput of the underlined IoT network. A comparative analysis (preferably in terms of average packet delivery ratio) of the proposed and existing schemes is presented in Figure. 7, which shows that an IoT network with the proposed scheme has a better APDR ratio than its rival schemes. It becomes possible due to the efficient utilization of empty slots and allowing active devices C_i to avail additional empty slots, which is preferably need based. Furthermore, every server or cluster module S_j is bounded to generate time slots based on its neighbourhood or member devices in an un-balance cluster environment of the IoT networks that is not possible with the approaches available in the literature.

Conclusion and future work

Although Internet of Things (IoT) are used to assist human beings in various monitoring- and controlling-related activities, i.e. smart buildings & cities, one of the challenging issues with these networking infrastructures is the simultaneous transmission of multiple devices C_i (preferably neighbours) and a common destination device S_j. To address this, various approaches were presented in the literature to ensure simultaneous transmission of multiple devices such as time division multiple access (TDMA), frequency division multiple access (FDMA) and carrier sense multiple access (CSMA). Although these approaches have resolved this issue successfully, neighbourhood information of a device or CH or server is not considered by these approaches, which plays a vital role in developing a reliable communication mechanism equally for simultaneous transmission of multiple devices $C - i$ to common destination devices. In this paper, a neighbourhood-enabled TDMA approach was designed and developed to ensure simultaneous transmission of multiple devices C_i to a common destination module S_j preferably with a minimum possible ratio of collision (as avoidance is not possible in each and every case). The proposed scheme bounds each and every server or CH module S_j to assign a dedicated time slot to its member devices C_i in the IoT network. Additionally, empty slots are assigned to the requesting devices based on need-based strategy (preferably in event-driven application areas). Simulation results have verified that the proposed neighbourhood-enabled TDMA scheme is better than the existing schemes in terms of various performance metrics such as slots waiting time, empty slots utilization, throughput and APDR ratio particularly in scenarios where deployment of the underlined IoT network is random.

In the future, we are eager to extend the proposed neighbourhood-enabled scheme for other networking infrastructures. Moreover, the proposed scheme could be extended for IoT networks where communication is multi-hop.

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Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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