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Controlled Redundancy Schemes in Collaborative IoT by Smartphones

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Abstract—Internet of Things (IoT) operators tend to utilize smartphones in establishing reliable and sustainable communication links for their services. Collaborative IoT (CIoT) is a concept where the smartphones are utilized as a mobile gateway (GW) that connects sensors to the cloud. CIoT scheme has many challenges including the redundancy in transmissions of sensor readings. As the same sensor data is sent by many uncoordinated users, this leads to consuming network resources and degrading Quality of Services (QoS) for primary users. This paper has three main contributions: First, four metrics for evaluating redundancy and its effects in CIoT network are defined and explained. Second, a novel redundancy control scheme (Fresh-List redundancy control) is proposed and evaluated against well-known probabilistic transmission schemes using the proposed metrics. Finally, a simulation setup for CIoT environment is implemented using a computer equipped with Bluetooth network card. The setup simulates many CIoT users with different scenarios of random entry, departure, and dwelling times. Results show the ability of Fresh-List method to reduce redundancy order and increase efficiency compared to non-controlled redundancy. It is also shown that a mix between probabilistic transmission and Fresh-List methods provide even more better redundancy control at an acceptable increase at the average packet delivery delay.

Index Terms—Controlled redundancy, opportunistic network, end-to-end, collaborative IoT

I. INTRODUCTION

Smartphones are devices with ubiquitous coverage, incredible processing power and multiple sensing and connectivity features. Due its widespread, Internet of Things (IoT) operators are stimulated to utilize smartphones in establishing E2E links for their IoT services. In particular, collaborative IoT (CIoT) is a concept where the smartphones are utilized as a mobile gateway (GW) that connects sensors to the cloud [1]. Several advantages of this arrangement include preserving sensor battery and fast deployment in zones without dedicated IoT networks. Nevertheless, CIoT scheme has many challenges including the redundancy in transmissions of broadcasted sensor data. As the same sensor is reachable by many users with no coordination, same reading is transmitted many times by many users to the cloud server, causing high degree of redundancy, which in turn consumes network resources and degrades QoS.

Many IoT systems in smart cities and Ambient Assisted Living applications are fitted with unlicensed wireless short-range radio connectivity technologies, including HaLow, Bluetooth Low Energy (BLE), Smart Utility Networks (SUNs), and ZigBee [2].

The scope of the paper is to address the concept of CIoT in collecting sensor node(s) data. The CIoT topology is a WSN with opportunistic gateways. In the case of opportunistic networks, nodes are not to gain or develop any knowledge of the network topology that is required for conventional WSN routing protocols. Routes are dynamically designed, when messages are on the route between the sender and the destination, and any potential mobile node can be used as the next hop if the message is likely to be sent to the final destination. Thus, the mobile node is functioning as an opportunistic gateway. No inference is made as to the nature of a full path between the Origin and destination wanting to connect. Source and destination can cannot be linked to the same network at the same time. Opportunistic networking strategies allow these nodes to share messages between them. Typically, this occurs at the cost of extra redundancy and delay in the transmission of communications, as messages are often buffered on the network waiting for a route to the destination to be accessible [3].

The CIoT gateway device can be deployed using any general purpose and commonly used device with WSN compliant communication interface(s) and acceptable communication interfaces to the remote server. In CIoT Topology, user-associated devices such as smartphones serve as mobile gateways [4]. The feasibility of this setup consists of a huge number of distributed and mobile gateways (user devices) that could access almost all types of sensors owing to the extensive use of devices, especially smartphones. The sensors are employed to relay their data through a short distance to the passing gateway and hence the required power is usually considerably less than in the fixed gateway configurations. Nevertheless, several challenges are associated with this concept including authenticity and data security, latency in data upload, and data redundancy problem.

Using smartphones as a highly redundant mobile infrastructure to provide connectivity in sensor networks and IoT networks will, in general, solve a range of problems in IoT networking. The difficulty of a sensor node's lifespan is simplified as the spectrum to be protected by its RF front end is significantly decreased and thus the needed Tx capacity is reduced. In addition, the

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power source gateway issue has been removed as mobile users already recharge their devices batteries. Smartphones have many networking techniques available that can be used to communicate with sensor nodes, such as Bluetooth and BLE. However, sensor nodes can also use technology that are not supported by smartphones such as Zigbee. In comparison, the usual routing problems of sensor nodes may also be important when using smartphones in sensor networks, based on communication techniques (e.g., if the sensor node has Zigbee, not BLE, it should send its data to another gateway that has the same communication technique).

Smartphones may have certain sensing features, but are not usually equipped with sensors that measure their surroundings. Smartphones may precisely calculate their location using either GPS or network knowledge. Smartphones may incorporate network positioning information since smartphones can predict the location of the sensor nodes by any appropriate localization algorithm. Smartphones are used to provide a small amount of additional redundancy, as several separate smartphones can communicate with a node instead of a single communication connection between two or more sensor nodes[5].

To demonstrate the usability of smartphones in environmental sensing a prototype, a desktop application was designed, implemented, and tested in a test-bed. Parts of the design have also been tested using a simulator. The prototype application was able to:

- Communicate to the sensor nodes via BLE.
- Receive sensor data and share the sensor data.
- Visualize the aggregated sensor data (in the application).
- Upload the data to the external server.

Furthermore, a backend was developed to support the upload of data and visualizing the uploaded results.

The prototype demonstrated the feasibility of using smartphones in environmental sensing as it was able to act as a communication link between sensor nodes and the external server. Besides, the prototype provided additional functionality to the system like reducing the redundancy on mobile network traffic by using redundancy-control schemes. The need of controlling redundancy is illustrated in Section II. Finally, simulation setup and implementation are presented to discuss the impact of reducing the number of redundant re-transmissions while diffusing a broadcast message in the network.

II. BASICS INTERRELATED TO BROADCASTING IN CIOT

A. *Running Broadcasting in CIoT*

In typical WSN, there is Wireless Sensor nodes that get readings from surrounding environment and broadcast them to its neighbors at the same hop. Then every node broadcasts every incoming packet to its neighbor, at the same hop, to end at static gateway as shown in Fig. 1. This matter causes data redundancy at the server. So, it is needed to control this redundancy to save network resources.

On the other hand, In CIoT, where smartphone works as a mobile gateway as shown in Fig. 2, it receives the incoming packets from surrounding sensor nodes and sends this data to the server while, the sensor node reads the surrounding phenomena and then broadcasts this data. There is only one hop is applied, if more than a smartphone passes on the same sensor node in the same time slot or different time slot, they will receive its data as the sensor node broadcasts its reading always. Then every mobile sends this data to the server, the redundancy impacts the backend server since it must receive and process the data. The mobile or smartphone can send the received data by 4G or Wi-Fi connection.

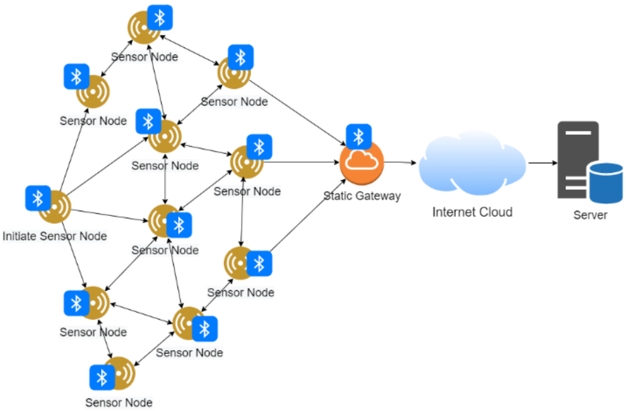


Fig. 1. Broadcasting in WSN and WSN architecture

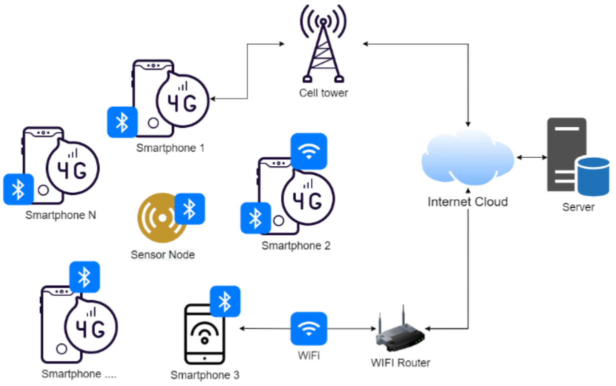


Fig. 2. Broadcasting in CIoT and CIoT architecture

Because of the similarities between WSN and CIoT from an architecture point of view, some redundancy schemes of WSN can be used in CIoT. The differences between the two systems:

- In WSN, redundancy controlling criteria are made by the sensor node itself. But in CIoT, the smartphone is responsible for controlling redundancy.
- WSN is multi-hop but CIoT reduces the hop number to one hop. So, the delay is reduced and power too since any node doesn't send neighbors data. Taking into account the waiting delay of the smartphone in case of CIoT.
    i. ***The drawbacks of broadcasting:*** *Broadcasting is a data dissemination technique, where a node transmits or forwards a packet to all of its*

neighbors[6]. *It is the simplest data forwarding technique, and its generic form exhibits several drawbacks:*

- Implosion: Duplicated packets are delivered to the destination because multiple copies of a packet travel via different paths.
- Broadcast storm: Broadcasting produces extreme amounts of redundant traffic since the number of packets in the network grows exponentially after every hop.
- Endless packet wandering: Due to lack of propagation directivity, a packet may circulate around the network for a long time, thus occupying precious network resources.
- Resource blindness: This shortcoming refers to the excessive consumption of traffic resources and energy.

ii. ***Potential benefits of broadcasting**:*

  - The main benefit of broadcasting is its utter simplicity.
  - There is no need for exchanging control messages between the nodes.
  - Node failures require no reaction from the network layer, so there exists a smooth transition to the new constellation.
  - The data is delivered via multiple paths, enhancing redundancy and reliability.
  - The routing exchange info. in broadcasting is virtually non-existent, which leaves more traffic capacity open for the actual data traffic.

The key is to limit the physical scope of forwarding and find the delicate balance between the traffic load, speed, and reliability of delivery.

B. Using Smartphones Opportunistically with BLE Sensor

Human-centric ubiquitous technologies, such as crowdsourcing and participatory sensing implementations, are often correlated with opportunistic sensing and opportunistic networking [7] and [8]. The authors of [9] demonstrated an approach to use Bluetooth for sharing sensor data between a sensor node and a smartphone; however, it was designed only for a single phone to measure temperature and humidity. The paper **Error! Reference source not found.** [10] was published by the same author and extended the previous paper by using multiple Bluetooth sensors. The approach however it still uses only one smartphone. When using more than a smartphone, the data redundancy problem will appear sense the same message will be delivered by more than smartphone.

C. The Existing Broadcasting-Based Approaches for Conventional WSNs

In [11], In advanced manufacturing contexts, the authors outlined an IoT-based infrastructure to allow collaborations among remote parties. A general IoT-based cyber physical framework was developed, which included software modules, supervising apps and agents, along with interfaces to physical resources; a suite of IoT sensors and cameras, in conjunction with networks, play an important role in sharing and communicating vital data/information among distributed resources and users. This broad framework was then refined into a more specific collaborative framework for the assembly of microdevices. Using the engineering Enterprise Modeling Language (eEML), an enterprise model of the collaborative use of cyber physical components was built; this information-centric model served as the foundation for designing a cloud-based approach using the Next Internet as part of the GENI initiative. This IoT framework was used to construct a cyber-physical test bed for the assembly of micro devices; this test bed is the first major implementation of an IoT-based framework involving cyber physical components for an advanced manufacturing application.

This concept is at the heart of many IoT-based frameworks, both commercial and open source. Cumulocity [12], AllJoyn [13], Xively [14] and ThingWorx [15] all fall into this category. Such solutions are powerful when it comes to managing all of the entities that are implemented within them, but they act as IoT islands with little or no interoperability with others. When dealing with environmental monitoring, this can result in data redundancy and lack of availability, i.e. when data is interesting for the general benefit.

Gossiping [16] is an attempt to address the redundancy overhead problem at the expense of increased delay. The forwarding node will pass the packet to a randomly selected subset of neighbors. Gossiping shows bi-modal behavior, meaning that, for forwarding probabilities below a certain threshold, the gossiping dies out. Li et al. [8] claim that this threshold is between 0.6 and 0.8, for a sufficiently large network. It claims that gossiping sets up routes that are 10-15% longer than the ones found by flooding, for different gossip probabilities.

In [17] Flossip proposed to achieve a zero-overhead resource-aware routing. It operates in two modes. In the gossiping mode, the sending node randomly selects a neighbor to deliver its packet to. Other neighbors receive the packet as well, and they all generate a random value, which, when compared to a predefined threshold in the packet header, will decide whether they will retransmit the packet or discard it. These neighbors are said to be in broadcasting mode. By adjusting the threshold value between 0 and 1, Flossiping can scale to either single-branch gossiping or flooding. The main advantage is its scalability and the compromise between the power efficiency of gossiping and reduced delay of flooding.

Graded Back-off Flooding [18] is a distance-based flooding strategy. It is a cross-layer solution; where the smaller forwarding back-off times (i.e. MAC priority) are given to the packets coming from senders further away. If the same message is heard by a node more than once, it is discarded. The distance is determined by measuring the RSS, which is not a reliable indicator, due to its intensive variations in an industrial environment.

Wang *et al.* in [19] find the best re-transmission candidate as the one whose retransmission would cover the largest, yet uncovered, area. This is a time-consuming procedure with high latency, and it is not converged cast, but broadcast in nature. Most importantly, it is blind - there are no guarantees that there will be any nodes in the new footprint.

Jeong *et al.* [20] proposes a cross-layer counter-based flooding modification, where the distance between sender and receiver is found from the received signal strength and then used to calculate the re-transmission back-off time, which is inversely proportional to the signal strength. This way, the priority is given to the transmissions that reach farthest from the source. A counter is used for duplicates of received packets and the back-off time will be directly proportional to it. One drawback of this scheme is the lack of synchronization because the MAC layer of WirelessHART is TDMA-based and only a few slots are up for grabs. Furthermore, as previously mentioned, RSS is an unreliable measure due to its fast variation, which can result in an inaccurate relative location estimate. Finally, this is a broadcast protocol and duplicate transmissions to the same node do not t well with the strict timing requirements.

SenSquare[21], Such platform possesses the capabilities to achieve the task of environmental monitoring for Smart Cities with a significantly fine granularity, joining the concepts of open data sources and crowd sensing, therefore exploiting the devices owned by the end users in order to produce valuable services. The paper proposed an architecture open to extensions in several ways and still allowing the coexistence of diverse data gathering methods. In order to give unique interpretability to heterogeneous data author designed a common data structure which he rendered in a relational database.

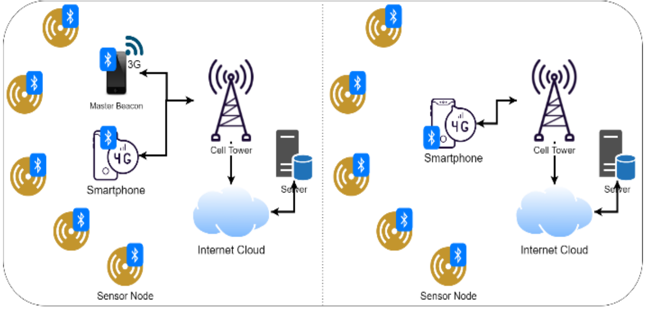
III. THE PROPOSED SOLUTION TO CONTROL REDUNDANCY

The proposed lightweight solution has virtually no control routing infrastructure, nor message exchange, to minimize the traffic overhead and increase the efficiency of traffic resources. Furthermore, there is no heavy burden of path recalculation triggered by link failures. The algorithm of the proposed solution is shown below, preceded by its formal description. The key features of the proposed solution are:

- A distributed routing algorithm: each mobile phone independently decides whether to re-transmit or discard the received packet. The content of data packets contains all of the information required to make a forwarding decision.
- Handling of outdated packets: a deadline equal to the sensor refresh rate is introduced. Each mobile phone compares the age of the incoming packet with the deadline, and if the packet is outdated, it is discarded. This feature is introduced to free up traffic resources from old packets.
- Reduce Redundancy in the system: at the server, the incoming message rate will be reduced due to a controlled redundancy scheme.

A. The Proposed Schemes

- Basic probabilistic (BP): where a uniform probability distribution is chosen to receive a given message or not. Based on the result of this function, the smartphone may choose not to receive the message at all.
- Fresh-list (FL): The scheme is that, once the server receives the message, it generates a FL of sensors MAC addresses to 'heal' the smartphones after they get the message. The server 'cures' the forwarder that passed the message to it by sending a FL to master beacons. The master beacons broadcast FL to smartphones as shown in Fig. 3 a.
- Mixed scheme: The final scheme, or optimization, if the message isn't in the FL the smartphones decide to forward the message or not.



a) Mixed and FL schemes b) None Redundancy and BP schemes

Fig. 3. Schemes of the control redundancy algorithm

B. The Forwarding Criteria

Non-controlled redundancy Scheme (NCR): Any incoming packet will be forwarded with no restriction.

```
Algorithm 1:
    Receive a packet
    Forward the packet
    Go to the waiting mode
```

Basic probabilistic scheme: A received packet will be rebroadcast depends solely on the two forwarding conditions. The pseudo-code of the proposed approach is shown below, followed by the definition of all two forwarding conditions in Table I.

```
Algorithm 2:
    Receive a packet
    If ($C1 \cap C2$ = True) then
    Forward the packet
    Else
    Discard the packet
    End if
    Go to the waiting mode
```

Fresh-List scheme: A received packet will be rebroadcast depends solely on the one forwarding condition, which must hold for the re-transmission to take place. The pseudo-code of the proposed approach is shown below, followed by the definition of the forwarding condition in Table I.

```
Algorithm 3:
    Receive a packet
    If ($C1$ = True) then
    Forward the packet
    Else
```

```
        Discard the packet
        End if
        Go to the waiting mode
```

Mixed scheme: A received packet will be rebroadcast depends solely on the three forwarding conditions, which all must hold for the re-transmission to take place. The pseudo-code of the proposed approach is shown below, followed by the definition of all forwarding conditions in Table I.

```
Algorithm 4:
        Receive a packet
        If (C1 ∩ C2 ∩ C3 = True) then
        Forward the packet
        Else
        Discard the packet
        End if
        Go to the waiting mode
```

TABLE I: SCHEMES CONDITIONS

C_i	Basic Probabilistic	Fresh-Data	Mixed
C_1	Is true if the BP function returns a forward signal.	Is true if the smartphone didn't receive an FL or the sensor isn't in the FL.	Is true if the BP function returns a forward signal.
C_2	Is true if the RSSI between sensor and mobile is smaller than the adopted value of threshold: RSSI < threshold.	-	Is true if the RSSI between sensor and mobile is smaller than the adopted value of threshold: RSSI < threshold.
C_3	-	-	Is true if the smartphone didn't receive an FL or the sensor isn't in the FL.

IV. PERFORMANCE MEASUREMENT AND SIMULATION SETUP

This section defines performance metrics of redundancy in CIoT network, and how they are measured. It also describes environment emulation of CIoT system using a mixed setup of computer simulation and physical components.

A. *Evaluation Metrics*

Four metrics are considered for evaluating the proposed controlled redundancy schemes:

1) *Network efficiency*

Network Efficiency is measured by how a system can decrease the redundant packets. So, the Network Efficiency is one minus the ratio of a total number of messages sent by all nodes to the backend, including the overhead of FL update when applying redundancy control mechanism to the total number of messages when not applying any redundancy control. This is represented as:

$$\eta = \left(1 - \frac{N_{rc,Traffic} + N_{fresh\ list}}{N_{Traffic}}\right) \times 100\ \% \qquad (1)$$

where $N_{rc,Traffic}$ is the number of packets sent when applying redundancy control algorithm, N_{fresh} list is the number of FL update packets sent from the server to master beacon, and $N_{Traffic}$ is the number of packets sent by CIOT users without applying any redundancy control, all evaluated during a specified evaluation period.

2) *Average E2E delay (seconds)*

Average E2E Delay is the average of the time difference between message availability at the sensor node and message arrival time to the back-end.

$$\bar{T}_d = \frac{1}{N_{rc,Traffic}} \sum_{i=1}^{N_{rc,Traffic}} (T_{Backend} - T_{sensor}) \qquad (2)$$

where $N_{rc,\ Traffic}$ is the number of packets sent when applying redundancy control algorithm, $T_{Backend}$ is the time of packet arrival at the backend, and T_{sensor} is the time of packet availability at the sensor node.

$$\bar{T}_d = T_{CIoT} + T_{Network} \quad \text{(Seconds)} \qquad (3)$$

where CIoT Delay T_{CIoT} is average CIoT system delay is taken by any reader to deliver each unique packet to the network. In this work, the CIoT Delay will be calculated instead of the E2E delay $\bar{T}_d$ because the network delay $T_{Network}$ is changeable from case to case.

3) *Packet delivery ratio Rd*

Packet delivery ratio Rd is the ratio of the number of distinct (i.e., unique) packets received by the backend to the total number of generated packets by the sensors. It should be noted that the redundancy order of the packets doesn't affect the packet delivery ratio. That is, the parameter measures every received distinct packet just once, regardless of the number of times it reached the backend due to imperfect redundancy control.

$$R_d = \frac{N_{Unique\ uploaded\ Packets}}{N_{Total\ Unique\ Packets}} \times 100\% \qquad (4)$$

where $N_{Unique\ uploaded\ Packets}$ is the number of unique packets sent to backend during applying redundancy control algorithm, $N_{Total\ Unique\ Packets}$ is the number of total unique packets broadcasted from all sensors, all evaluated during a specified evaluation period.

4) *Redundancy Order Ro*

Redundancy Order RO is the average number of repetitions for a packet at the backend.

$$RO = \frac{N_{Total\ uploaded\ Packets}}{N_{Unique\ uploaded\ Packets}} \qquad (5)$$

where $N_{Unique\ uploaded\ Packets}$ is the number of unique packets sent to backend during applying redundancy control algorithm, $N_{Total\ uploaded\ Packets}$ is the number of total packets sent to the backend, all evaluated during a specified evaluation period.

B. *Implementation*

In this section, CIoT emulation setup is described. A CIoT emulator has been built to emulate a large number of mobile users without the need to use actual handsets. Additionally, the random arrival, departure, and dwelling time of different users within the sensor area has been considered. The simulation depends on the existence of real sensor nodes and the backend server. The smartphones are emulated by a desktop application run by a laptop utilizing BLE peripheral. The master sensor is responsible for broadcasting FL of sensor nodes that send their data to server, it gets this list by 3G since it has a GSM module. The architecture of the system is shown in Fig. 4.

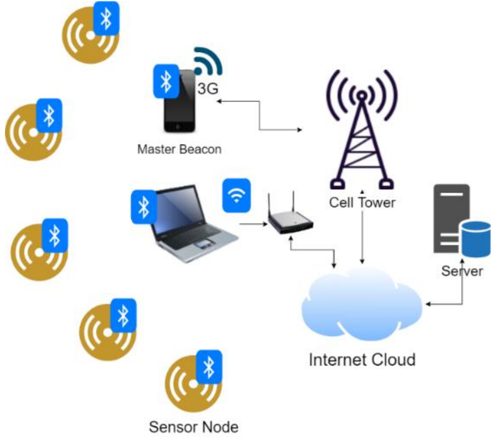


Fig. 4. Emulation setup for CIoT redundancy evaluation.

The reader application emulates multiple readers. When the simulation starts, it listens to the beacons in range, captures their data, and parses it to extract relevant data. After that it forwards the extracted data to currently present android readers, whose number will vary according to the current elapsed time of the simulation, the simulated android readers will apply the chosen redundancy control mechanism, and decide to send the received data to the backend or not. The parameters used in the simulation are summarized in Table II.

TABLE II: VALUE RANGES OF SIMULATION PARAMETERS

Parameter	Value
Number of Sensors	10
Simulated Time	1 hour
Range for reader arrival rate	5:10000 readers per hour
Range for reader leave ratio	5:10000 readers per hour
Reader Average Dwelling Time	1 minute: 1 hour
Transmission Range	60m
BLE RSSI rejection Threshold	-80 dBm

V. SIMULATION RESULTS AND DISCUSSION

This section presents the performance of all broadcasting-based schemes discussed earlier after applying the four evaluation criteria defined in Section III-B. It should be highlighted that the delay calculations at the following results refer to the delay of the first copy of each unique sensor reading. The delay for the subsequent replicas of the same reading doesn't influence delay calculations for this specific sensor reading. The various delays of unique packets representing individual readings are then averaged to get the delay for specific scheme.

It should also be highlighted that this study doesn't consider the delays related to the link between smartphones and backend server, as those delays are related to 3G/4G network, and is considered negligible compared to CIoT delays.

In the following setup, four different scenarios are targeted, depending on the average number of simultaneous active users and the average dwelling time. We believe that those four scenarios cover most of the potential environment where CIoT service could apply, e.g. large malls, big enterprise, small office, and rural areas.

A. Scenario A

1) Description

Scenario-A represents crowded environment with high mobility smartphone users, e.g. shopping malls and train stations. This is reflected by high entrance rate and short dwelling time. The CIoT system is configured with ten sensors. The Master beacon changed its FL every 1 minute. The simulation parameters are listed in Table III. The simulation is developed to accept min and max presence time so any presence of reader is a random number between max and min to emulate more realistic events. The system describes a crowded place like a small mall. And every user stays from 1 minute to 10 minutes around any sensor.

TABLE III: SIMULATION PARAMETERS SCENARIO A

Item	Value
Simulation period	1 hour
Entrance rate	1200 Readers/hour
Minimum presence	1 minute
Maximum presence	10 minutes
Probability of forwarding PF	0.1: 0.9
Number of Nodes	10
Fresh duration classes	4 (5, 10, 15, and 20 min)

2) Result

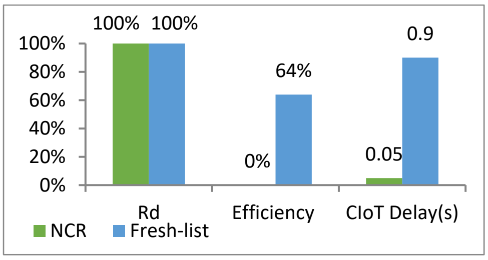


Fig. 5. Network parameters performance in case of NCR and FL for scenario A

The redundancy order of NCR is 11395 times while in case of the FL scheme is 4081 times, which indicates reduction in redundant packets by factor of 2.8. As expected, the delivery ratio of both the FL and NCR schemes are equal to 100%, since no unique packets are dropped in both schemes. The efficiency of FL is improved by 64% due to the reduction of transmitted packets, but at the expense of CIoT delay resulting from the fact that no sensor updates are allowed within the fresh-list period, which results in increase CIoT delay as defined earlier. These results are illustrated at Fig. 5. The delivery ratio of other schemes (BP, Mixed) is still 100% and this is a good sign to use controlled redundancy schemes instead of generic broadcasting in crowded environments.

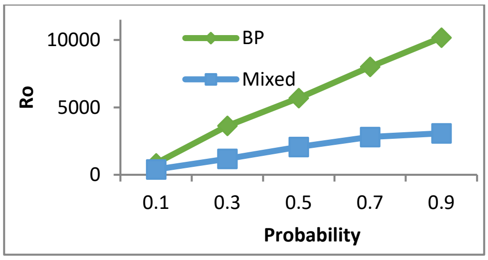


Fig. 6. Redundancy order performance versus probability in case of BP and mixed schemes for scenario A

Fig. 6 illustrates the effect of changing PF on RO. It should be highlighted that the delivery ratio for the whole range of evaluated PF was 100%, even at low PF values. The importance of this result is that it shows the positive effect of large number of users at CIoT area, as even at very low forwarding probability (and hence very low RO), the readings can still reach the server at very high delivery ratio. The Mixed scheme shows good results in terms of RO compared to the BP for crowded places at the expense of a little more time delay for delivery.

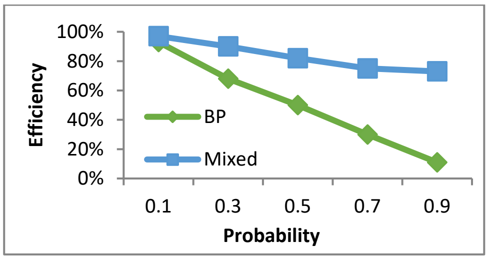


Fig. 7. Network efficiency performance versus probability in case of BP and mixed schemes for scenario A

The efficiency of saving network resources is increased with increased PF in both schemes (PB, Mixed) as shown in Fig. 7. Naturally, the efficiency decreases with PF. Moreover, at the same PF, the Mixed scheme gives higher efficiency, as some of the redundant packets are filtered by the FL algorithm.

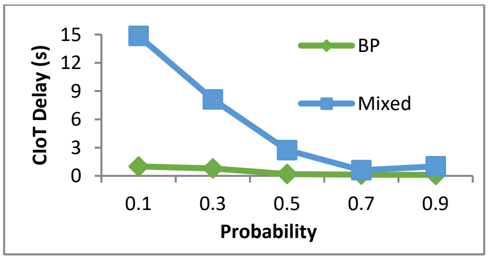


Fig. 8. CIoT delay performance versus probability in case of BP and mixed schemes for scenario A

B. Scenario B

1) Description

Scenario B represents moderate crowded environment with low mobility smartphone users, e.g. big enterprise. This is reflected by moderate entrance rate and high dwelling time, where entrance rate is decreased to be 600 Readers/hour and the maximum presence increased to equal simulation period where any reader stays random time from 1 minute to 1 hour in the simulation as described in Table IV.

TABLE IV: SIMULATION PARAMETERS SCENARIO B

Item	Value
Simulation period	1 hour
Entrance rate	600 Readers/hour
Minimum presence	1 minute
Maximum presence	60 minutes
Probability of forwarding PF	0.1: 0.9
Number of Nodes	10
Fresh duration classes	4 (5, 10, 15, and 20 min)

2) Results

Fig. 9, Fig. 10, Fig. 11, and Fig. 12 illustrate the performance of different schemes in scenario-B. It worth comparing the results in Fig. 9, Fig. 10, Fig. 11, and Fig. 12 with equivalent results for scenario A. While the delay and efficiency are almost the same, the redundancy order increases considerably at scenario B, although the entrance rate of CIoT users is halved. This is justified by the increase in dwelling time from 10 minutes to 1 hour. This increase is equivalent to large number of effective users at the same time duration accessing same group of sensors, which increases redundancy, and decreases efficiency. Therefore, static nature of the users tends to increase the effective number of CIoT users in a given area, even at low entrance/exit rate. This fact should be considered while dynamically selecting PF according to user statistics.

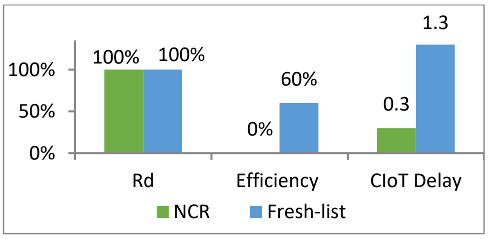


Fig. 9. Network parameters performance in case of NCR and FL for scenario B

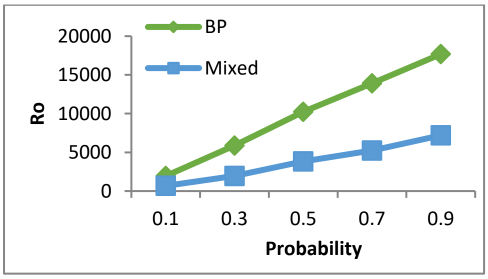


Fig. 10. Redundancy order performance versus probability in case of BP and mixed schemes for scenario B

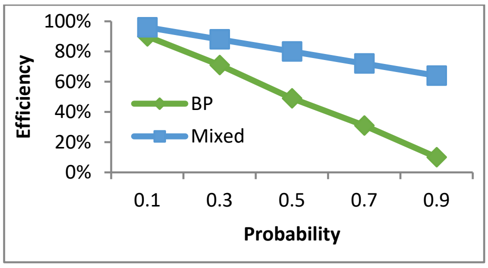


Fig. 11. Network efficiency performance versus probability in case of BP and mixed schemes for scenario B

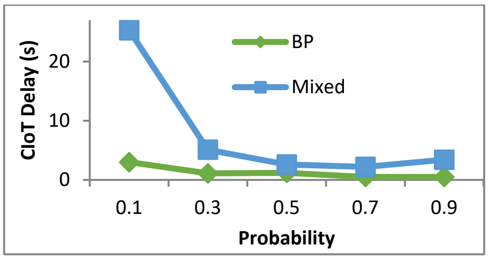


Fig. 12. CIoT delay performance versus probability in case of BP and mixed schemes for scenario B

C. *Scenario C*

1) *Description*

Scenario C represents low crowded environment with low mobility smartphone users, e.g. small office. This is reflected by low entrance rate and high dwelling time. Table V describes that the entrance rate of readers is decreased to be 60 readers per hour and the maximum presence is the same like the previous scenario.

TABLE V: SIMULATION PARAMETERS SCENARIO C

Item	Value
Simulation period	1 hour
Entrance rate	60 Readers/hour
Minimum presence	1 minute
Maximum presence	60 minutes
Probability of forwarding PF	0.1: 0.9
Number of Nodes	10
Fresh duration classes	4 (5, 10, 15, and 20 min)

2) *Result*

The delivery ratio is 100% for BP and is varying in case of Mixed scheme as shown in Fig. 14 because of the packet time and FL time. But it is in the acceptable range. The delivery ratio has been affected by the FL scheme, decreased by 4%, but the efficiency of the CIoT system is improved by 59% and the redundancy also improved. Fig. 15 and Fig. 16 shows the effect of the FL scheme on packets delivery ratio where a timing diagram for one sensor is drawn. In case of the time of packet is greater than FL time the redundancy order will increase due to the uploading time will increase and the delivery ratio will be 100% because no packet is dropped. On the other hand, the FL time is greater than the packet time more packet is dropped so we take the mid case where the packet time equals FL time.

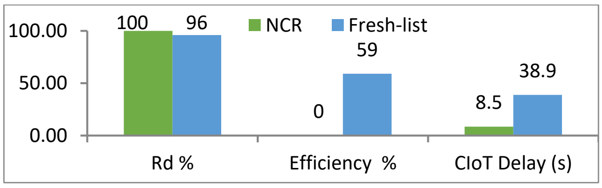


Fig. 13. Network parameters performance in case of NCR and FL for scenario C

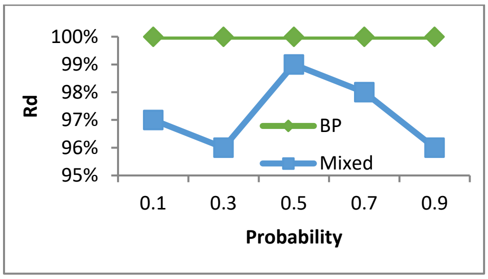


Fig. 14. Delivery ratio performance versus probability in case of BP and mixed schemes for scenario C

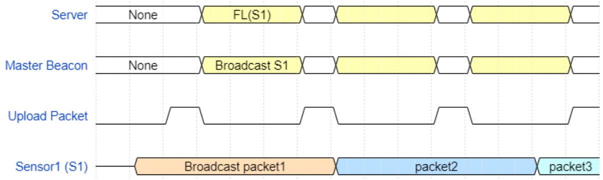


Fig. 15. Timing diagram for time of sensor packet is greater than FL time

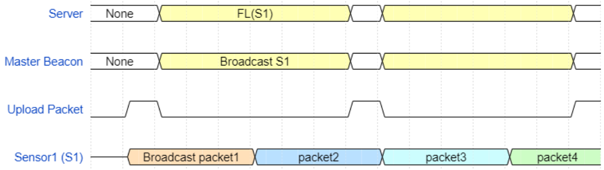


Fig. 16. Timing diagram for time of sensor packet is less than FL time

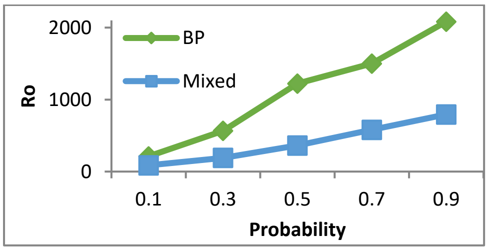


Fig. 17. Redundancy order performance versus probability in case of BP and mixed schemes for scenario C

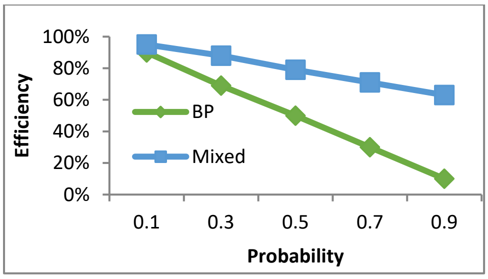


Fig. 18. Network efficiency performance versus probability in case of BP and mixed schemes for scenario C

Comparing the results of BP and mixed in this scenario with the previous one, scenario B, the RO is almost decreased by the same ratio between the entrance rates in both scenarios. The efficiency is almost the same in different values of PF. The CIoT delay is increased due to the decreasing of the existing smartphone users at any time. (See Fig. 17, Fig. 18, and Fig. 19)

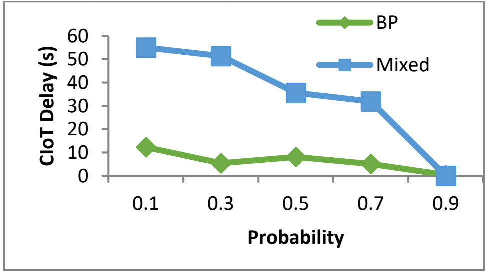


Fig. 19. CIoT delay performance versus probability in case of BP and mixed schemes for scenario C

D. *Scenario D*

1) *Description*

Scenario D represents rural environment with very low mobility smartphone users. This is reflected by very low entrance rate and high dwelling time, the entrance rate of readers is decreased to be 6 readers per hour as shown in Table VI.

TABLE VI: SIMULATION PARAMETERS SCENARIO D

Item	Value
Simulation period	1 hour
Entrance rate	6 Readers/hour
Minimum presence	1 minute
Maximum presence	60 minutes
Probability of forwarding PF	0.1: 0.9
Number of Nodes	10
Fresh duration classes	4 (5, 10, 15, and 20 min)

2) *Result*

The redundancy order of NCR is 164 times when the FL scheme records 147. The efficiency is improved by 51% in FL scheme than NCR scheme as shown in Fig. 20.

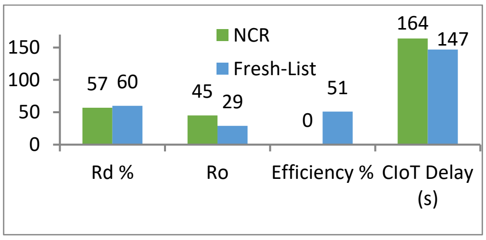


Fig. 20. Network parameters performance in case of NCR and FL for scenario D

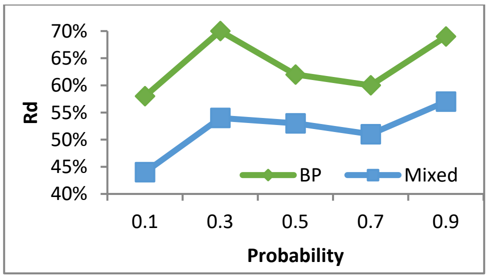


Fig. 21. Delivery ratio performance versus probability in case of BP and mixed schemes for scenario D

It is evident that the nature of scenario-D, which resembles rural places with very small potential CIoT users affects the delivery ratio and CIoT delays dramatically. This is clear at Fig. 21, Fig. 22, Fig. 23, and Fig. 24. This effect calls for assignment of higher PF and shorter fresh duration at those areas to increase the delivery ratio.

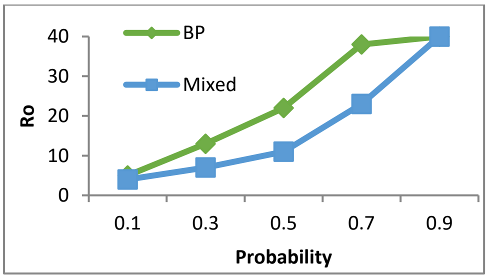


Fig. 22. Redundancy order performance versus probability in case of BP and mixed schemes for scenario D

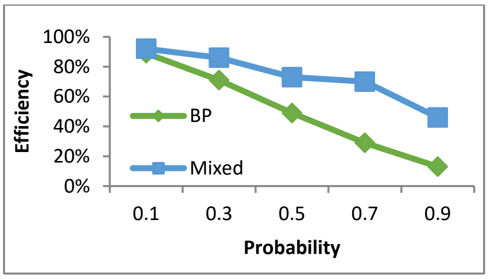


Fig. 23. Network efficiency performance versus probability in case of BP and mixed schemes for scenario D

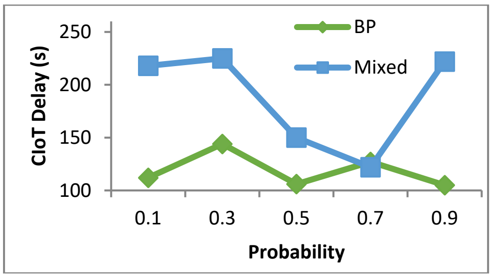


Fig. 24. CIoT delay performance versus probability in case of BP and mixed schemes for scenario D

The system here is preferred to use the Fresh-List scheme as it is better than others. Sometimes the Mixed schemes is the optimum scheme but in rare places the Fresh-List is the best to not filter the unique packets and the redundancy order is mostly low as seen in Fig. 20. In rare places, it is preferred to depend on the two metrics (Delivery ratio and Efficiency) because delivery of data is the important role in such cases and the delivery time or redundancy order is not matter.

VI. CONCLUSION

This work aims to test the schemes of redundancy control against the adequate evaluation criteria. Starting from the generic form of broadcasting, several modifications are introduced to reduce the traffic redundancy, while preserving the good properties of broadcasting, which were the initial motivation for considering it as a data dissemination technique in CIoT. The simulation result shows that the NCR scheme, the generic form of broadcasting, has drawbacks and unusable for the CIoT system. The drawback of a generic form of broadcasting is the excessive amount of traffic that it creates and the consequent network congestion.

The four scenarios have been introduced to clarify the idea of redundancy control mechanisms. The scenarios described some of the real places like the mall, market, building, and remote place. The result in scenarios A and B are similar to each other. The mixed scheme with probability 0.1 showed good results compared to other schemes. Although the CIoT delay is higher than the others, it is still within the acceptable range.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Under the supervision of Professor Abdelhalim Zekry and Associate Professor Ayman M. Hassan. Mohamed A. Marzouk has conducted and wrote the paper; all authors had approved the final version.

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