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E^2R-F^2N: Energy-efficient retailing using a femtolet-based fog network

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Summary

Energy-efficient smart retail system design is a challenging research area. In this paper, we propose an automated retail system using a femtolet-based fog network. A femtolet is an indoor base station providing computation and storage. Femtolets in our system work as indoor base stations and maintain databases of the products located in their respective coverage areas. The femtolets switch to active or idle mode according to the user's presence in its coverage. A smart trolley is proposed for our retailing system, which guides the user to the particular product type selected by the user. The user, after entering the shopping mall, carries the smart trolley. The customer selects and purchases products using this trolley. On the basis of product purchasing, the respective databases maintained inside the femtolets are updated. An Android application for the proposed retailing is developed. We compare the power consumption and delay of the proposed retail system with the existing retail system. Simulation analyses illustrate that the proposed approach reduces power by approximately 89% and 94%, respectively, in comparison to the local cloud server–based and remote cloud server–based retail systems. Thus, we refer to the proposed system as a green retail system. The performance of the proposed system through experimental analysis is also evaluated.

KEYWORDS

femtolet, power, retail, sensor, smart trolley

1 | INTRODUCTION

The explosive growth in the digital industry has made the people busier. Effective utilization of time is now vital for everyone. When a user visits a shopping mall for the first time, to select a product from a shop inside the mall, the customer has to take help from the personnel working in the shop. In few shopping malls nowadays, a large screen display is provided regarding the products in the shopping malls. However, this may not help the user locate the product type that he/she is looking for. People of today's world are familiar with a smart phone, which contains a Global Positioning System (GPS), which can guide the user to the product if a smart application is developed. An augmented reality (AR)–based smart retail system has been proposed.[1] An interactive smart retail system has been also discussed.[2] Although research studies have focused on smart city, smart room, smart health, etc, with energy efficiency, the design of green and smart retail systems has not yet been largely explored. This paper focuses on this area.

To provide seamless connectivity to the Internet, a shopping mall contains Wi-Fi access points. A user's smart phone is resource hungry; hence, to execute an application or to store large-volume data, a smart phone may be infeasible due to poor battery life or limited storage and computation power. As a solution, mobile cloud computing (MCC) offers data and application offloading to mobile devices.[3,4] In data offloading, the users store and access data outside their mobile devices but inside the cloud servers.[5,6] In application offloading, exhaustive applications execute inside the cloud servers, and users receive the result using their devices.[7,8] A remote cloud server is located far from the mobile device; access to the remote cloud servers may cause increase in propagation and communication delays and power consumption. A cloudlet, by working as an agent between the mobile device and cloud servers, solves this problem.[9-12] The femtolet has been proposed for providing both communication and computation to the mobile devices under its coverage.[13] It is an indoor base station containing large storage and having processing power. The femtolet contains the components of a femtocell[14] and a cloudlet, and it has the features of both. A femtocell is a home node base station (HNB) with low transmission power, and it is used for providing a good signal level at the indoor region.[15-17] For energy- and latency-aware offloading, fog computing has been introduced.[18-21] In a fog network, the intermediate devices between a mobile device and cloud servers are used to process data. We have used the femtolet as a fog device for data and computation offloading in a previous work.[22]

In a shopping mall, to maintain the product data private, cloud servers or work stations are used. The shopping mall administration may store the data inside the remote cloud servers; when the product list is updated, the data stored at the local servers are also updated. The user visiting the shopping mall either manually picks up products, puts the products into the trolley, and waits in the counter for billing or accesses the product data at the server side, picks the product, puts the product into the e-trolley, and makes payment digitally. However, in both cases, the user accesses the product data at the server side through either the access point or the base station. If a femtolet-based fog network (F^2N) is used, the users can directly access the product information inside the femtolet as it is an indoor base station. The femtolet provides data and application offloading to the registered users inside its coverage. In this paper, we propose a smart retail system by using the femtolet as a fog device. Femtolets are deployed at the floors of the shopping malls according to their coverage and capacities. A femtolet can cover an area of 10-20 m and serve up to 32 users at a time.[13,22] In our system, each femtolet maintains the databases of the products that are present under its coverage. These femtolets are connected with the local cloud servers.

Delay and energy are two important parameters in the field of computing. Customers of different geographical regions have different requirements. The shopping centers of different regions contain products according to the customers' requirement. Storing product database inside the remote cloud data center and access to the database according to product purchase enhance the delay and energy consumption. Our motivation is to propose a smart retail system that will reduce delay and power consumption.

The key contributions of this paper are as follows.

1. To provide retailing in a shopping mall without manual guidance, we propose a smart system for energy-efficient retailing using a femtolet-based fog network (E^2R-F^2N). In the proposed system, using a smart trolley, a customer can select and purchase a product after entering a shopping mall. An Android app for E^2R-F^2N is created, and the product selection through the app is illustrated.
2. For reducing delay and power consumption, a fog device is used instead of remote cloud servers. A femtolet is an indoor base station with computation ability and storage. It is used as a fog device. By maintaining the product database inside the fog device, access to remote cloud servers is avoided in order to save power and delay. Through simulation and experimental analyses, it is illustrated that the proposed system reduces power and delay to improve user experience.

The rest of this paper is organized as follows. Section 2 discusses related works. Section 3 proposes the architecture and working principle of E^2R-F^2N. Section 4 describes the app of E^2R-F^2N. Section 5 discusses the power and delay consumption of E^2R-F^2N. Section 6 presents the results and analyses. Section 7 provides future research directions, and Section 8 concludes this paper.

2 | RELATED WORK

Smart and automated system design has become an emerging research domain in the last few years.[23] Researchers have focused on smart home, smart city, smart health monitoring, intelligent surveillance systems,[24] etc. Nowadays, Internet of Things (IoT) is playing a vital role in developing smart systems.[25] The integration of IoT and cloud for smart city development has been discussed.[25] In such an integrated system, the IoT devices, ie, sensor nodes, collect object status, and data processing and storage occur inside the cloud servers. For energy efficiency and latency optimization, fog computing has been introduced.[18-21]

Electronic commerce (e-commerce) is very popular nowadays. However, smart retail system design has not yet been focused on to a large extent. Nowadays, people are familiar with online shopping. However, for the daily needed commodities, people still prefer to visit shopping centers. For the existing retail systems, the product-related data are stored and processed inside the local servers or remote cloud servers. The employees of shopping centers guide the customers, and product purchase and payment are made manually, especially in underdeveloped countries. If an automated retail system is developed, the customers' time can be saved. The customers' experience on smart technology in retail systems has been studied.[26-28] An AR-based smart retail system has been proposed[1]; here, the user is guided based on the product location and the route toward the product in the store, using deep learning. An interactive smart retail system has been discussed.[2] A machine-readable image and a user gesture–based retail system have been discussed.[29] The IoT-based business model has been discussed.[30] A retail shopping application has been discussed.[31] The future of retailing in relation to different issues, such as visual display, big data, data analytics, profitability, etc, has been illustrated.[32] The relation of retail with big data and data analytics has been discussed in another research work.[33] A service-oriented architecture for retail has been discussed.[34] In this system, data storage and processing occur inside the cloud instances. A smart vending machine based on IoT has been proposed.[35] The user can order products using a smart phone without interaction with the vending machine in this system.[35] For physically disabled users, an AR-based smart system has been discussed,[36] which allows the disabled user to shop independently.

Data offloading and application offloading are two vital areas of MCC with respect to energy and latency optimization.[3,4] The use of fog devices for latency- and energy-efficient code offloading has been discussed.[22] A simulation toolkit for fog computing, edge computing, and IoT has been proposed,[37] whereas for a cloud computing environment, a simulation toolkit has been proposed.[38] Privacy and security are important factors in networking. For privacy preservation in IoT, a dynamic protection model has been proposed.[39] A fully homomorphic encryption solution based on blend arithmetic over real numbers has been proposed.[40] For high-level-security transmission based on multichannel communications, a method has been proposed.[41] A smart city framework based on fog computing has been proposed.[42] An energy-efficient architecture for fog computing has been proposed.[43] A peer-to-peer network based on fog computing has been discussed.[44] A searching method has been also discussed to achieve efficiency with respect to delay and bandwidth.[44] A routing algorithm for a fog-based wireless sensor network has been proposed.[45] Reduction of latency improves the quality of service (QoS). For improving the QoS selection of a cloudlet in an energy-efficient way, a fifth-generation mobile network device femtolet has been proposed,[13] which has been used as a fog device in another work.[22] A femtolet is a device that possesses the features of a femtocell[14] and a cloudlet.[12] The cloudlet reduces energy and latency more than remote cloud servers, while offloading computation.[12] In this paper, we propose a smart retail system using F^2N, where retail data offloading occurs inside the fog device instead of the cloud servers, to reduce power and delay. A comparison of contributions in the proposed work and those in the existing retail systems is provided in Table 1. Through this comparison of existing works with ours, we observe that our proposed retail system is novel and useful than the existing retail systems.

3 | PROPOSED RETAIL SYSTEM

In this section, we discuss the three-tier architecture of E^2R-F^2N with its working principle. Mathematical modeling is also described.

3.1 | Architecture of E^2R-F^2N

The three-layer architecture is pictorially shown in Figure 1 and discussed as follows.

3.1.1 | Layer 1: Sensor-mobile layer with smart trolley and mobile device

Layer 1 is composed of a smart trolley equipped with sensor nodes, a microcontroller, a bulb, and a mobile device (smart phone). The customer takes a smart trolley after entering the shopping mall. As soon as the user touches the trolley, the sensor detects human touch and sends a signal to the microcontroller. The microcontroller then sends a message to the

TABLE 1 Comparison of contributions of the proposed work and of the existing retail systems

Features	**Retail Systems and Applications**				
	Augmented Reality–Based Retail[1]	**Smart Retail**[2]	**Retail Based on Machine-Readable Image and User Gesture**[29]	**Augmented Reality –Based Retail for Physically Disabled Users**[36]	**Proposed E^2R-F^2N**
Contributions	On the basis of augmented reality, a retail system is proposed. The user's location, along with his/her surrounding, is captured using the user's mobile device; using this image, the route toward the product required by the customer is provided through deep learning.	On the basis of the user's preferences, personalized contents are delivered through large display. In this work, digital content, visualization technologies are integrated with interactivity to improve customer experience.	On the basis of user gesture and a machine-readable image, a retail scheme is proposed. The machine-readable image is compared with user gesture to predict the association of the user with the product of the image.	This system is based on augmented reality and radio frequency identification. For physically disabled persons, a handheld device is provided, through which the user selects the product.	A fog computing–based retail system is proposed. A smart trolley is introduced, which contains sensor nodes and a microcontroller. The user using a smart phone and this trolley selects and purchases products. The route toward the required product is also provided to the user through the retail app. The product databases are maintained inside the femtolet with which the fog device, the smart phone, is connected. These databases are updated according to product purchase.
User interactive retail system	✓	✓	✓	✓	✓
Route toward the product from the user's location is provided	✓	×	×	✓	✓
Fog computing	×	×	×	×	✓
Access point/base station works as a fog device	×	×	×	×	✓
Power consumption by a smart phone is considered	×	×	×	×	✓
Delay is considered	×	×	×	×	✓

Abbreviation: E^2R-F^2N, energy-efficient retailing using a femtolet-based fog network.

mobile device. As soon as the message is received, an Android app is opened on the screen of the mobile device, showing a welcome note. Then, the app asks the user to enter his/her username and password. If the user has already an account, he/she logs in to the account. Otherwise, the user creates a new account, following user id and password creation. After a successful login, the product category list is opened by the app on the mobile screen, where the customer can easily find his/her needed commodity. When a user selects an item category, the GPS tracker in the mobile device tracks the location, and a route toward the selected item category is displayed on the mobile screen. Using this route, the user moves toward the item rack; after reaching the location, the user picks the item. If the user puts the item in the trolley, the weight measurement sensor detects a change in the weight and sends a signal to the microcontroller. The microcontroller sends

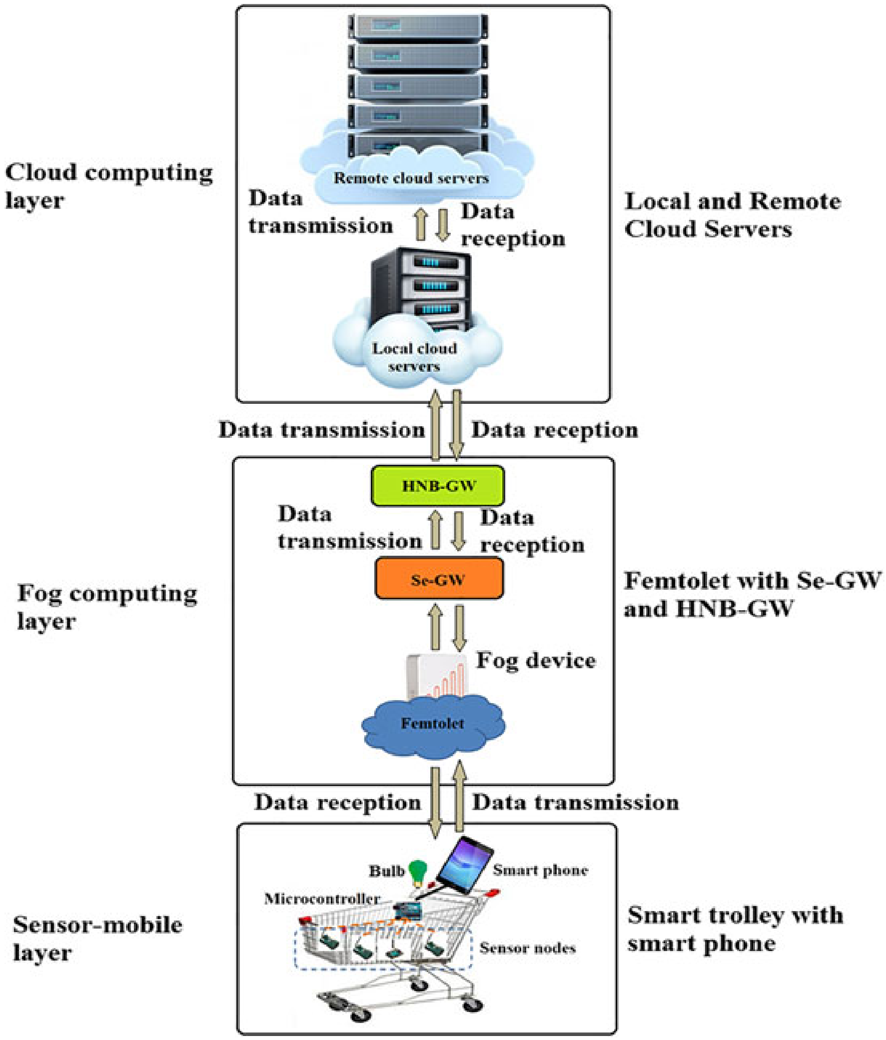


FIGURE 1 Three-layer architecture of energy-efficient retailing using a femtolet-based fog network. HNB-GW, home node base station–gateway; Se-GW, security-gateway [Colour figure can be viewed at wileyonlinelibrary.com]

a signal to the connected bulb and the mobile device; after receiving the signal, the bulb glows red, and an option appears on the mobile screen asking the user if he/she wants to buy the item. If the user clicks "yes," the user is asked to enter the barcode using the scanning device. After the correct barcode is entered, a screen will appear showing the option to make an online payment. The user makes the payment through a digital wallet, and after the successful payment, the mobile device sends a message to the microcontroller. The microcontroller sends a signal to the bulb, which then glows green. If the payment is not made successfully, the bulb remains red. If the user wants to buy more items, then the user has to continue in the same way.

3.1.2 | Layer 2: Fog computing layer with femtolet, security-gateway, and HNB-gateway

Layer 2 is composed of the femtolet, the security-gateway (Se-GW), and the HNB-gateway (HNB-GW). The mobile device is connected with the femtolet. The femtolet contains a database of the products located in its coverage area. The product database is updated based on purchase of the product. The quantity of each product is maintained in the database. When a product quantity reaches 0, the femtolet sends this information to the local cloud via Se-GW and HNB-GW. The updated product database is sent to the local cloud servers through Se-GW and HNB-GW at a time interval. As the database update takes place inside the intermediate device femtolet, it is referred to as a fog device. When the user makes a payment digitally, communication is performed through the use of the femtolet. The femtolet is connected with the network through Se-GW, which passes the information through a security tunnel. The security algorithms used for the femtolet and cloud servers are discussed in Section 3.3.

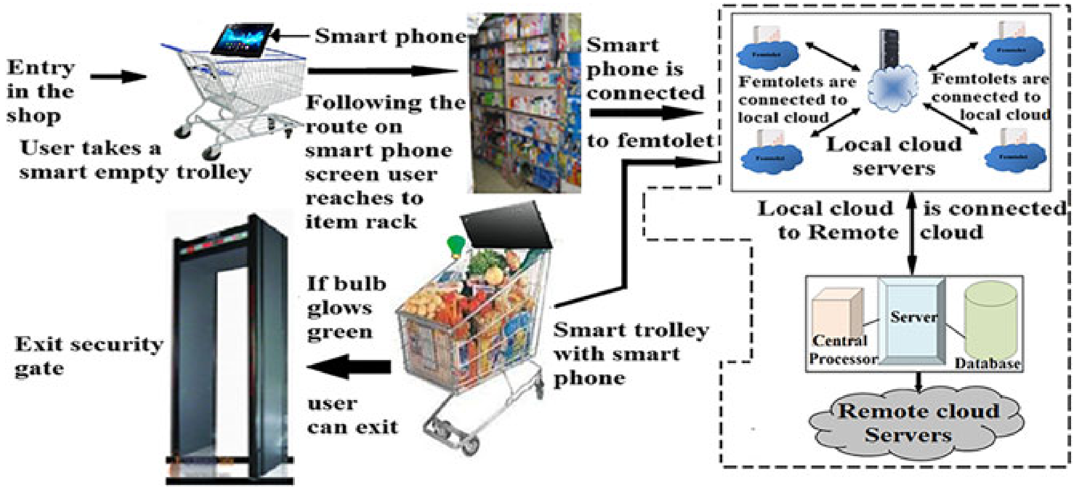


FIGURE 2 Proposed retail system using energy-efficient retailing using a femtolet-based fog network [Colour figure can be viewed at wileyonlinelibrary.com]

3.1.3 | Layer 3: Cloud computing layer with local and remote cloud servers

Layer 3 is composed of the local and remote cloud servers. The local cloud is connected with all the femtolets deployed in various floors of the shopping mall. These femtolets send their respective product databases to the local cloud at a time interval. Therefore, the local cloud has all the product databases for the shopping mall. The local cloud server is connected with the remote cloud servers. When the local cloud receives a message from a femtolet that a product quantity has reached 0, the local cloud sends an order message to the registered mobile device of the product vendor agency for sending the products. The shopping mall data, if the administration wishes, can be maintained inside the remote cloud servers. When any discount or similar offers are launched in the shopping mall, advertisements on the social networking sites about these offers are displayed.

3.2 | Working principle of E^2R-F^2N

Figure 2 shows the working model of the proposed E^2R-F^2N.

The user, after entering the shopping center, takes the smart trolley and places the smart phone. Using the proposed system, the user reaches the product location and picks the product from the rack. If the user purchases the product, a payment is made through a digital wallet, and the product databases maintained inside the femtolet covering that region of the center are updated. Whenever products are purchased by the customers, the corresponding product database maintained in the respective femtolets are updated. These femtolets, after a time interval, send the updated product databases to the local cloud servers of the shopping center. The local cloud servers are connected with remote cloud servers. When the user makes a payment for all the products placed in the trolley, the bulb glows green, and the user is allowed to exit the shopping center. The working model of E^2R-F^2N is illustrated in Algorithm 1.

If we consider N number of customers, then the procedure is performed for all these customers. Thus, the complexity of the algorithm will be $O(N)$. Section 5 discusses in detail the delay and power consumption of the proposed model.

3.3 | Security algorithms used in femtolet and local cloud servers

Private and public cryptographic methods are used in the femtolet and cloud servers. Table 2 presents the cryptographic algorithms used for securing data transmission and data storage in the femtolet.

The femtolet contains a dedicated chip, which contains a cryptographic processor such as a femtocell.[46] The femtolet is connected with the network through Se-GW. Data transmission takes place through a security tunnel. An Internet Protocol Security connection is used.[47,48] Using a hash function and key, authentication is performed; this is referred to as keyed-hash message authentication code/secure hash algorithm. Triple Data Encryption Standard–based cipher block chaining and Advanced Data Encryption Standard–based cipher block chaining are used.[49]

Algorithm 1 Working Model of E^2R-F^2N

Considerations:

D_{hm}: Data amount transmitted from human touch detecting sensor node to microcontroller
D_{wm}: Data amount transmitted from product weight detecting sensor node to microcontroller
D_{md}: Data amount transmitted from microcontroller to mobile device
U_{sm}: Data transmission rate from sensor node to microcontroller
U_{md}: Data transmission rate from microcontroller to mobile device
U_{dm}: Data transmission rate from mobile device to microcontroller

Input at layer 1: Sensor nodes in trolley, smart phone
Output from layer 1: Sensor data, product data, mobile device's ID

Input at layer 2: Sensor data, product data, mobile device's ID
Output from layer 2: Fog device's retail data

Input at layer 3: Fog device's retail data
Output from layer 3: Cloud servers' retail data

1. **Start**
2. **For 1:*N* customers**
3. Customer enters the shop with his/her smart phone
4. The customer touches an empty smart trolley and places his/her smart phone into the front space of the empty trolley
5. The sensor *S* attached with the trolley detects the event human touch and sends a signal to the microcontroller *M* with the delay calculated as

$$L_{hmi} = \frac{D_{hm}}{U_{sm}} \tag{1}$$

6. The microcontroller *M* sends a message to the smart phone *D* and the attached bulb
7. Retail app *A* is opened on the smart phone screen showing a Welcome note and the bulb glows green
8. A login page is opened on the screen and customer is asked to provide ID and password
9. **If** the customer is a new user,
10. He/she creates new ID and password
11. **Else**
12. The customer provides his/her ID and password
13. **End if**
14. **If** the customer successfully logs in,
15. The menu list for the product item categories available in the shopping center is opened by the app
16. The user selects the item category from the menu
17. The GPS tracker tracks the location of the user and the route toward the selected product category is displayed on the screen
18. Following the route, the customer reaches the product location
19. The user picks the product and puts it into the trolley
20. The sensor *S* attached with the trolley detects an increase in the trolley weight and sends a signal to the microcontroller *M* with the delay calculated as

$$L_{wmi} = \frac{D_{wm}}{U_{sm}} \tag{2}$$

21. The microcontroller *M* sends a signal to the bulb attached with the trolley
22. The microcontroller *M* sends a message to the smart phone *D* with the delay calculated as

$$L_{md} = \frac{D_{md}}{U_{md}} \tag{3}$$

23. A product purchase page is opened by the app A and the bulb glows red
24. The customer is asked to enter the barcode number of the product
25. After the correct barcode is entered, a payment page is opened
26. The user makes payment digitally and the smart phone D sends a message to the microcontroller M with the delay calculated as

$$L_{dm} = \frac{D_{dm}}{U_{dm}} \tag{4}$$

27. The microcontroller M sends a signal to the bulb, which then glows green
28. The product database maintained inside the femtolet F allocated inside the corresponding shopping region is updated
29. A page is opened on the smart phone screen with continue and exit buttons
30. **If** the user clicks on the continue button,
31. Repeat steps 15 to 29
32. **Else if** the user clicks on the exit button,
33. The app A gets closed by showing a Thank you note.
34. **End if**
35. **End if**
36. **End for**
37. The femtolets allocated in the shopping center send their respective product databases at a fixed time interval to the local cloud servers
38. **If** a femtolet F detects that any product quantity has reached 0,
39. The femtolet F sends a message to the local cloud servers
40. The local cloud server C sends a message to the mobile device of the product supplier mentioning the required quantity of the product to be delivered
41. The product-supplying agency then takes the required initiative to deliver products
42. **End if**
43. **If** the administration wishes, the product database is maintained inside the remote cloud servers
44. **End if**
45. When any discount or similar offers are launched in the shopping mall, advertisements on the social networking sites about these offers are displayed.
46. **End**

Among the public-key cryptographic algorithms, elliptic-curve cryptography is used for securing data storage inside the femtolet and cloud servers. In crypto cloud computing, Quantum Direct Key is used, which is based on a private- and public-key pair.[50] Hierarchical identity-based cryptography can also be used in cloud servers as a public-key cryptographic method.[51]

TABLE 2 Cryptographic algorithms used in the femtolet

Name of Cryptography Algorithm	Where to Provide Security	Advantage
HMAC-SHA	IPSec tunnel	
Triple DES-CBC	IPSec tunnel	Used for securing data transmission
AES-CBC	IPSec tunnel	
ECC	Femtolet, local cloud servers	Used for securing storage
HIBC	Femtolet, local cloud servers	Used for securing cloud computing services

Abbreviations: AES-CBC, Advanced Data Encryption Standard–based cipher block chaining; ECC, elliptic-curve cryptography; HIBC, hierarchical identity-based cryptography; HMAC-SHA, keyed-hash message authentication code/secure hash algorithm; IPSec, Internet Protocol Security; Triple DES-CBC, Triple Data Encryption Standard–based cipher block chaining.

3.4 | Use of bitcoin and blockchain

While making payment digitally, the bitcoin system is popular nowadays. This is a decentralized digital payment system where payment making is performed directly without the intervention of an intermediate such as a central bank. Bitcoin is a cryptocurrency approach. In cryptocurrency, encryption is used to control the currency unit generation and verify fund transfer; it operates independently without an intermediate. As we are using the femtolet that is connected with the network through Se-GW, a security tunnel is maintained during data transmission. In a bitcoin system, the network nodes are used to verify the transactions by using cryptography, and the records are maintained inside a blockchain. The blockchain is a chain of blocks where each block has a hash up to the genesis block of the chain. Using the bitcoin system, the user can make payment. A secure brokerage model has been discussed for retail banking services in a research work.[52] The secure brokerage model can be incorporated in the proposed E^2R-F^2N while making payment digitally.

3.5 | Mathematical model of E^2R-F^2N

The mathematical definitions of the components at different layers of E^2R-F^2N are provided in this section.

3.5.1 | Layer 1

Definition 1 (Sensor node).
A sensor node is denoted by S and defined as $S = (S_{id}, S_e)$, where S_{id} denotes the unique ID of a sensor node and S_e is the event sensed by the sensor node. Weight detection while an item is being put into the trolley, human touch detection when a person takes the trolley, etc, are different events sensed by the respective sensor nodes.

Definition 2 (Microcontroller).
A microcontroller is denoted by M and defined as $M = (M_{id}, M_e)$, where M_{id} denotes the unique ID of the microcontroller and M_e is the event set detected by the microcontroller from the connected sensor nodes; this depends on the sensor nodes with which the microcontroller is connected; M_e is denoted by a set $\{S_{e1}, S_{e2}, \ldots, S_{en}\}$, where S_{ei} denotes the event sensed by sensor node S_i, where $1 \leq i \leq n$ and n is the number of sensor nodes with which the microcontroller is connected.

Definition 3 (Mobile device).
A mobile device is denoted by D and defined as $D = (D_{id}, D_M, A_k, F_{in})$, where D_{id} denotes the unique ID of the mobile device, D_M is the message received from the microcontroller, A_k is the instance of the retail application executed inside the mobile phone, and F_{in} is the message received from the connected fog device femtolet.

Mapping in layer 1. The mapping from the sensor nodes to the microcontroller is a many-to-one mapping, and it is denoted as $M'(.) : S' \rightarrow M$.

Mapping from layer 1 to layer 2. The mapping from the mobile devices of layer 1 to the fog device femtolet of layer 2 is a many-to-one mapping, and it is denoted as $M'(.) : D' \rightarrow F$.

3.5.2 | Layer 2

Definition 4 (Fog device femtolet).
A fog device is denoted by F and defined as $F = (F_{id}, F_D, F_{sp}, F_c)$, where F_{id} denotes the unique ID of the fog device; F_D is a set denoting the message received from the connected mobile devices given as $\{F_{D1}, F_{D2}, \ldots, F_{Dm}\}$; F_{Dj} denotes the message received from mobile device D_j, where $1 \leq j \leq m$ and m is the number of mobile devices with which the femtolet is connected; F_{sp} is the amount of data stored and processed inside the femtolet; and F_c is the message received from the connected local cloud via Se-GW.

Definition 5 (Se-GW).
An Se-GW is denoted by SE and defined as $SE = (SE_{id}, SE_F, SE_c)$, where SE_{id} denotes the unique ID of the Se-GW; SE_F is a set denoting the message received from the connected femtolets given as $\{SE_{F1}, SE_{F2}, \ldots, SE_{Fq}\}$; SE_{Ft} denotes the message received from a femtolet F_t, where $1 \leq t \leq q$ and q is the number of femtolets with which the Se-GW is connected; and SE_c is the message received from the local cloud via HNB-GW.

Definition 6 (HNB-GW).
An HNB-GW is denoted by H and defined as $H = (H_{id}, H_{SE}, H_c)$, where H_{id} denotes the unique ID of the HNB-GW, H_{SE} denotes the message received from the connected Se-GW, and H_c is the message received from the local cloud.

Mapping from layer 2 to layer 3. The mapping from the fog devices of layer 2 to the local cloud of layer 3 is a many-to-one mapping, and it is denoted as $M'(.) : F' \rightarrow C$.

3.5.3 | Layer 3

Definition 7 (Local cloud instance).
A local cloud computing instance is mathematically defined as $C = (C_{id}, C[b])$, where C_{id} is the distinctive identity of the local cloud component, and $C\,[b]$ is the tuple, defined as a nonempty array of size b, which stores the processing unit IDs of all the essential local cloud servers.

Definition 8 (Remote cloud instance).
A remote cloud computing instance is mathematically defined as $R = (R_{id}, R[v])$, where R_{id} is the distinctive identity of the remote cloud component, and $R\,[v]$ is the tuple, defined as a nonempty array of size v, which stores the processing unit IDs of all the essential remote cloud servers.

Mapping in layer 3. The mapping from the local cloud to the remote cloud is a many-to-one mapping, and it is denoted as $M'(.) : C' \rightarrow R$.

In the next section, we develop an Android app for our proposed E^2R-F^2N.

4 | PROPOSED ANDROID APP FOR E^2R-F^2N

We design an Android app "RetailMyFriend" in this section. A user enters the shopping mall and takes a smart trolley. Using the Android app, the user selects and purchases an item. Figure 3 shows the designed Android app. In Figure 3A, the app shows a welcome note on the screen. Figure 3B shows the screen where the user is asked to enter the customer ID and password. If the user is new, he/she clicks on the sign up button. Otherwise, the user enters the customer ID and password. After a successful login, the item category list is displayed on the screen, as shown in Figure 3C. The user selects the desired item category and clicks on continue.

The subcategory of the item is displayed on the next page; the user selects the subcategory of the item he/she wants to buy and clicks on route (see Figure 3D). The route toward the selected subcategory of the item is displayed on the screen (see Figure 3E). On the basis of the customer's location captured by the GPS, the route toward the selected item subcategory is displayed on the screen, as shown in Figure 3E. Following this route, the user moves toward the item and takes it from the rack. If the user puts the item in the smart trolley, the user is asked to buy the item. If the user wishes to purchase the item, he/she clicks on the Buy button, as shown in Figure 3F. After the user clicks on Buy, the user is asked to enter the barcode. After the correct barcode is entered, using the digital wallet, the customer makes payment. If any offer is going on in the shopping center for purchase on any product, that advertisement is displayed on the mobile screen.

5 | DELAY AND POWER CONSUMPTION IN E^2R-F^2N

The parameters used for calculating power and delay are given in Table 3.

5.1 | Delay

The delay for sending data from a sensor node S_i to a microcontroller is given by $L_{smi} = \frac{D_{sm}}{U_{sm}}$.

If n is the number of sensor nodes connected with the microcontroller in a smart trolley and the delays for node 1 to n are $L_{sm1}, L_{sm2}, \ldots, L_{smn}$, respectively, the delay for receiving data at a microcontroller is given by

$$L_{sm} = L_{sm1} + L_{sm2} + \cdots + L_{smn} = \sum_{i=1}^{n} L_{smi}. \tag{5}$$

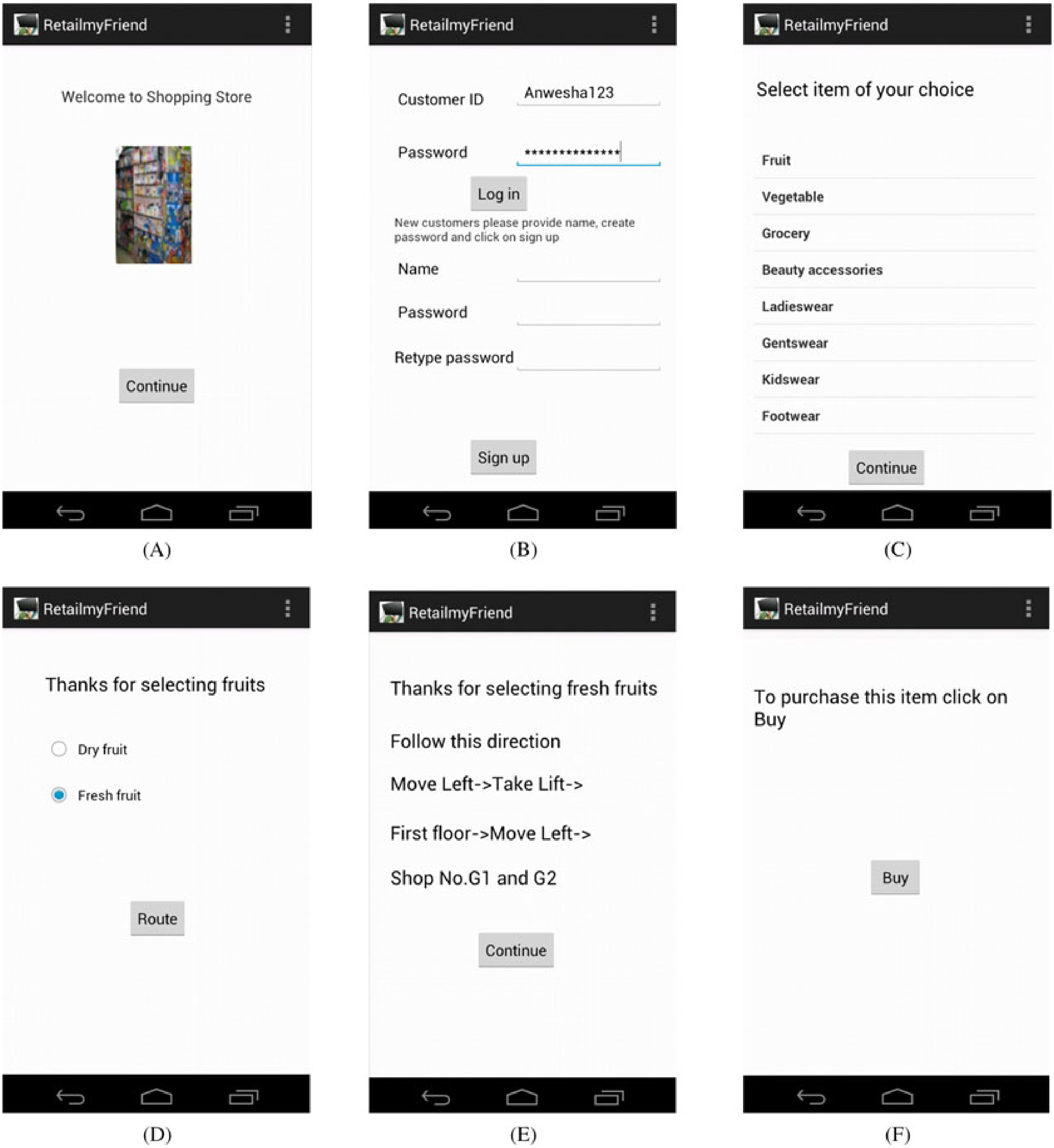


FIGURE 3 A, Welcome note is shown on the screen; B, Customer enters ID and password; C, User selects an item from the category list; D, User selects the subcategory of the item and clicks on route; E, Route toward the selected item category is displayed; F, User clicks on Buy to purchase the item [Colour figure can be viewed at wileyonlinelibrary.com]

The delay for sending data from a microcontroller to a mobile device is given by

$$L_{md} = \frac{D_{md}}{U_{md}}. \tag{6}$$

TABLE 3 Parameters used in calculating delay and power for energy-efficient retailing using a femtolet-based fog network

Parameter	Definition
D_{sm}	Amount of data transmission from a sensor node to a microcontroller
D_{md}	Amount of data transmission from a microcontroller to a mobile device
D_{df}	Amount of data transmission from a mobile device to a femtolet
D_{fc}	Amount of data transmission from a femtolet to the local cloud
D_{cr}	Amount of data transmission from the local cloud to the remote cloud
D_{fd}	Amount of data reception by a mobile device from a femtolet
D_{cf}	Amount of data reception by a femtolet from the local cloud
D_{rc}	Amount of data reception by the local cloud from the remote cloud
D_{spf}	Amount of processed and stored data inside a femtolet
D_{spc}	Amount of processed and stored data inside the local cloud
D_{spr}	Amount of processed and stored data inside the remote cloud
U_{sm}	Data amount sent from a sensor node to a microcontroller per unit time
U_{md}	Data amount sent from a microcontroller to a mobile device per unit time
U_{df}	Data amount sent from a mobile device to a femtolet per unit time
U_{fc}	Data amount sent from the femtolet to the local cloud per unit time
U_{cr}	Data amount sent from the local cloud to the remote cloud per unit time
U_{fd}	Data amount received by a mobile device from a femtolet per unit time
U_{cf}	Data amount received by a femtolet from the local cloud per unit time
U_{rc}	Data amount received by the local cloud from the remote cloud per unit time
p_{sm}	Power in sending unit amount data from a sensor node to a microcontroller
p_{md}	Power in sending unit amount data from a microcontroller to a mobile device
p_{df}	Power in sending unit amount data from a mobile device to a femtolet
p_{fc}	Power in sending unit amount data from a femtolet to the local cloud
p_{cr}	Power in sending unit amount data from the local cloud to the remote cloud
p_{fd}	Power in receiving unit amount data by a mobile device from a femtolet
p_{cf}	Power in receiving unit amount data by a femtolet from the local cloud
p_{rc}	Power in receiving unit amount data by the local cloud from the remote cloud
S_c	Data processing speed of th local cloud
S_r	Data processing speed of the remote cloud
S_f	Data processing speed of a femtolet
S_d	Number of instructions executed by a mobile device per unit time
I	Number of instructions executed inside a mobile device
p_{ds}	Mobile device's power consumption per unit time to transmit data
p_{dr}	Mobile device's power consumption per unit time to receive data
p_{di}	Mobile device's power consumption per unit time in idle mode
p_{da}	Mobile device's power consumption per unit time in active mode
p_{fa}	Femtolet's power consumption per unit time in active mode
p_c	Local cloud servers' power consumption per unit time
p_r	Remote cloud servers' power consumption per unit time

The delay for sending data from a mobile device to a femtolet is given by

$$L_{df} = \frac{D_{df}}{U_{df}}. \tag{7}$$

The retail application execution delay in a mobile device is given by

$$L_d = \frac{I}{S_d}. \tag{8}$$

The data processing delay in a femtolet is given by

$$L_f = \frac{D_{spf}}{S_f}. \tag{9}$$

The delay for receiving data by a mobile device from a femtolet is given by

$$L_{fd} = \frac{D_{fd}}{U_{fd}}. \tag{10}$$

Thus, the total delay for the customer while using the proposed $E^2R\text{-}F^2N$ is given by

$$L_{srs1} = L_{sm} + L_{md} + L_{df} + L_d + L_f + L_{fd}. \tag{11}$$

The delay for data transmission from a femtolet to the local cloud is given by

$$L_{fc} = \frac{D_{fc}}{U_{fc}}. \tag{12}$$

The delay for data reception by a femtolet from the local cloud is given by

$$L_{cf} = \frac{D_{cf}}{U_{cf}}. \tag{13}$$

The delay for data transmission from the local cloud to the remote cloud is given by

$$L_{cr} = \frac{D_{cr}}{U_{cr}}. \tag{14}$$

The delay for data reception by the local cloud from the remote cloud is given by

$$L_{rc} = \frac{D_{rc}}{U_{rc}}. \tag{15}$$

The data processing delay in the local cloud is given by

$$L_c = \frac{D_{spc}}{S_c}. \tag{16}$$

The data processing delay in the remote cloud is given by

$$L_r = \frac{D_{spr}}{S_r}. \tag{17}$$

Therefore, for a single femtolet, the total delay for data processing, data transmission, and reception from the local cloud is given by

$$L_{totf} = L_f + L_{fc} + L_{cf}. \tag{18}$$

For the local cloud, the total delay for data processing, data transmission, and reception from the remote cloud is given by

$$L_{totc} = L_c + L_{cr} + L_{rc}. \tag{19}$$

5.2 | Power consumption

The power consumed for sending data from the sensor nodes to a microcontroller is given by

$$P_{sm} = \sum_n D_{sm} \cdot p_{sm}, \tag{20}$$

where n is the number of sensor nodes connected with the microcontroller in a smart trolley.

The power consumed for sending data from a microcontroller to a mobile device is given by

$$P_{md} = D_{md} \cdot p_{md}. \tag{21}$$

The power consumed for sending data from a mobile device to a femtolet is given by

$$P_{df} = D_{df} \cdot p_{df}. \tag{22}$$

The power consumption for retail application execution in a mobile device is given by

$$P_d = L_d \cdot p_{da}. \tag{23}$$

The power consumption for data processing in a femtolet is given by

$$P_f = L_f \cdot p_{fa}. \tag{24}$$

The power consumed for receiving data by a mobile device from a femtolet is given by

$$P_{fd} = D_{fd} \cdot p_{fd}. \tag{25}$$

Thus, the total power consumed for the customer while using the proposed $E^2R\text{-}F^2N$ is given by

$$P_{srs1} = P_{sm} + P_{md} + P_{df} + P_d + P_f + P_{fd}. \tag{26}$$

The power consumed for data transmission from a femtolet to the local cloud is given by

$$P_{fc} = D_{fc} \cdot p_{fc}. \tag{27}$$

The power consumed for data reception by a femtolet from the local cloud is given by

$$P_{cf} = D_{cf} \cdot p_{cf}. \tag{28}$$

The power consumed for data transmission from the local cloud to the remote cloud is given by

$$P_{cr} = D_{cr} \cdot p_{cr}. \tag{29}$$

The power consumed for data reception by the local cloud from the remote cloud is given by

$$P_{rc} = D_{rc} \cdot p_{rc}. \tag{30}$$

The power consumption for data processing in the local cloud is given by

$$P_c = L_c \cdot p_c. \tag{31}$$

The power consumption for data processing in the remote cloud is given by

$$P_r = L_r \cdot p_r. \tag{32}$$

Therefore, for a single femtolet, the total power consumed for data processing, data transmission, and reception from the local cloud is given by

$$P_{totf} = P_f + P_{fc} + P_{cf}. \tag{33}$$

For the local cloud, the total power consumed for data processing, data transmission, and reception from the remote cloud is given by

$$P_{totc} = P_c + P_{cr} + P_{rc}. \tag{34}$$

The mobile device's, ie, the smart phone's, power consumption for data transmission, reception, and application execution is given by

$$P_{totd} = p_{da} \cdot L_d + p_{dr} \cdot L_{md} + p_{ds} \cdot L_{df} + p_{dr} \cdot L_{fd} + p_{di} \cdot L_{sm}. \tag{35}$$

In the next section, the delay and power consumption in E^2R-F^2N will be determined and compared with cloud server–based retail systems.

6 | PERFORMANCE EVALUATION

We evaluate the performance of our system through multiple approaches, namely, analytical, simulation, and experimentation, as discussed in this section.

6.1 | Analytical evaluation

In this section, we have calculated the delay and power consumption in the proposed E^2R-F^2N and compared the results with local cloud server–based and remote cloud server–based retail systems. These results are obtained based on the simulations performed in MATLAB R2015a. The data amount stored and accessed for the retail system, inside a femtolet and local cloud servers, is assumed to be 50-300 and 500-3000 GB, respectively. The data amount transmitted from a mobile device to a femtolet is assumed to be 0.5-3 MB, and this is the data amount accessed for a user, assumed in simulation. While a user selects and purchases items using the proposed E^2R-F^2N, the delay consumed is calculated and presented in Figure 4. The delay is measured in seconds (s). The results are compared with the retail systems where, instead of a femtolet, a Wi-Fi access point is used, and the data storage and access are performed inside the local or remote cloud servers.[36] During selection and purchase of items using the proposed E^2R-F^2N, the mobile device's, ie, smart phone's, power consumption is calculated. The obtained results are presented in Figure 5, along with the power consumption of the mobile device in the case of local cloud server–based or remote cloud server–based retail systems,[36] where, instead of a femtolet, a Wi-Fi access point is used, and the data storage and access are performed inside the local or remote cloud servers. The power is measured in watts (W). The results presented in Figure 4 illustrate that the proposed E^2R-F^2N reduces the delay by approximately 90% and 95%, respectively, compared to the local cloud server–based and remote cloud server–based retail systems.[36]

Figure 5 demonstrates that the proposed E^2R-F^2N reduces the mobile device's power consumption by approximately 89% and 94%, respectively, compared to the local cloud server–based and remote cloud server–based retail systems.[36]

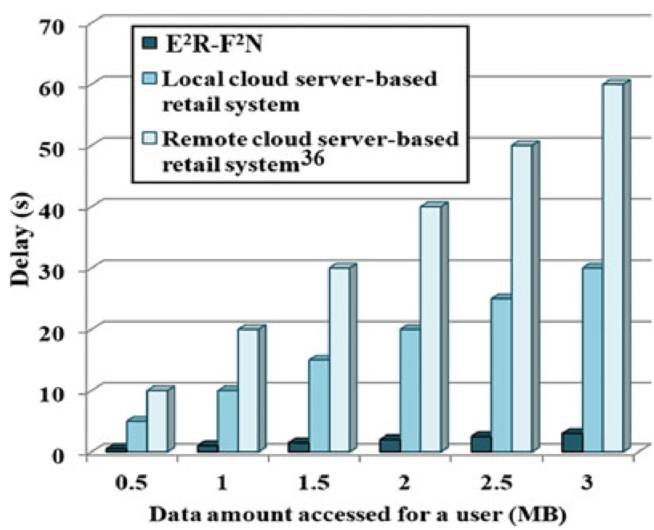


FIGURE 4 Delay for a user in the proposed energy-efficient retailing using a femtolet-based fog network (E^2R-F^2N) and existing cloud server–based retail systems [Colour figure can be viewed at wileyonlinelibrary.com]

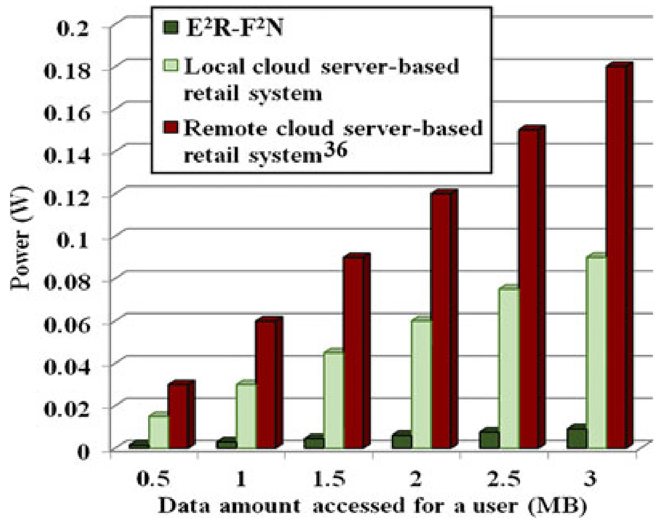


FIGURE 5 Smart phone's power consumption in the proposed energy-efficient retailing using a femtolet-based fog network (E^2R-F^2N) and existing cloud server–based retail systems [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Simulation parameters

Parameter	Value
Radio type	802.15.4 radio, 802.11b radio
Packet reception model	PHY 802.15.4 reception model, PHY 802.11b reception model
Energy model for sensor nodes and microcontroller	Mica-motes
MAC protocol	802.15.4, 802.11
Network protocol	IPV4
Routing protocol	AODV
Simulation time	300 sec

The results demonstrate that the proposed E^2R-F^2N is a green retail system. By reducing delay, the user's experience is improved. As power and delay are both reduced, the QoS of the retail system is enhanced.

6.2 | Simulation using QualNet 7

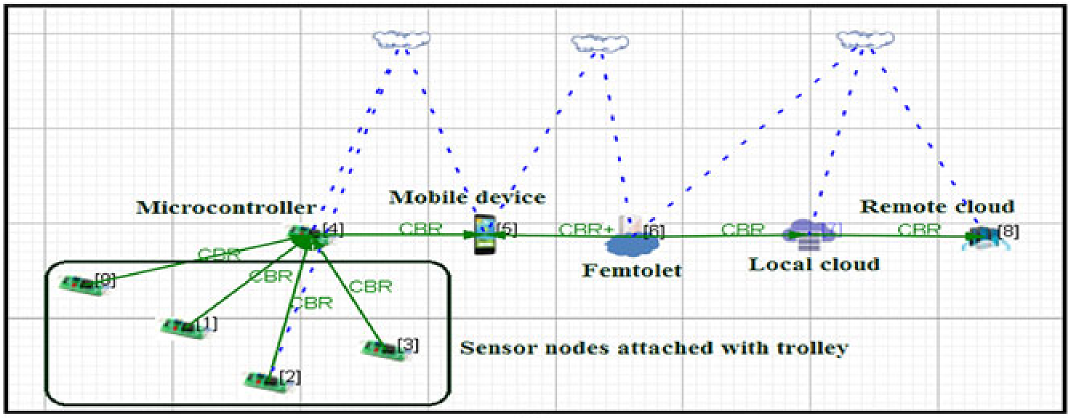
In QualNet 7, we have created the E^2R-F^2N scenario. Four sensor nodes are considered, which are attached with the trolley, and these sensor nodes are connected with the microcontroller attached with the trolley. The microcontroller is connected with the mobile phone of the user. The mobile phone is connected with the femtolet. On the basis of purchase, the product database is updated inside the femtolet. The femtolet sends the updated product database to the local cloud server twice a day. The local cloud is connected with the remote cloud servers. The parameters of simulation are given in Table 4, and the simulation scenario is presented in Figure 6. In Figure 6, sensor nodes (1, 2, 3, 9) are connected with the microcontroller (node 4). Node 4 is connected with the mobile device (node 5) of the user. The mobile device is connected with the femtolet (node 6). The femtolet is a base station with storage and computation ability; it works as the fog device in E^2R-F^2N. The femtolet holds the databases of the products present under its coverage. The femtolet is connected with the local cloud (node 7). The local cloud is connected with the remote cloud (node 8).

6.2.1 | Carried load

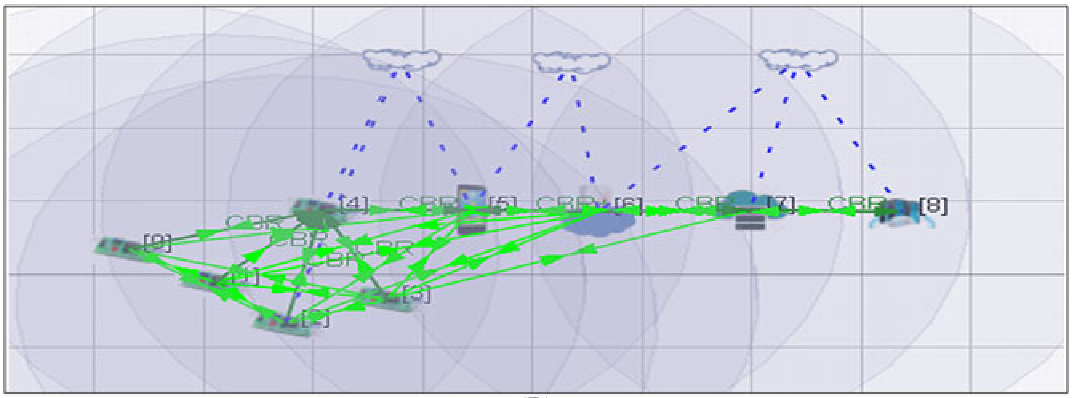
Figure 7 presents the carried load by the nodes in the proposed E^2R-F^2N with respect to the amount of transmitted data between two consecutive nodes. It is observed from the Figure that the carried load is approximately $< 1\,700\,000$ bits/s, for 100-1000 MB of data transmission between two consecutive nodes.

6.2.2 | Unicast received throughput

Figure 8 presents the unicast received throughput of the nodes in the proposed E^2R-F^2N with respect to the amount of transmitted data between two consecutive nodes.



(A)



(B)

FIGURE 6 A, Energy-efficient retailing using a femtolet-based fog network scenario created in QualNet 7; B, Simulation scenario during execution [Colour figure can be viewed at wileyonlinelibrary.com]

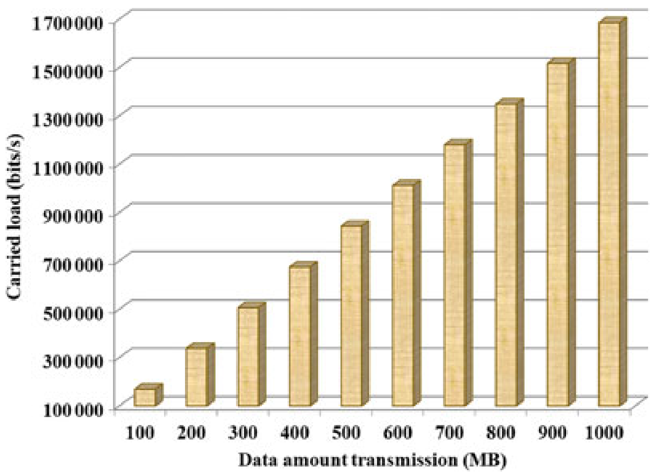


FIGURE 7 Carried load in energy-efficient retailing using a femtolet-based fog network [Colour figure can be viewed at wileyonlinelibrary.com]

It is observed from the Figure that the unicast received throughput is approximately $<300\,000\,000$ bits/s, for 100-1000 MB of data transmission between two consecutive nodes.

6.2.3 | Average delay

Figure 9 presents the average delays of the proposed E^2R-F^2N and the local cloud server–based and remote cloud server-based retail systems, with respect to the amount of transmitted data between two consecutive nodes.

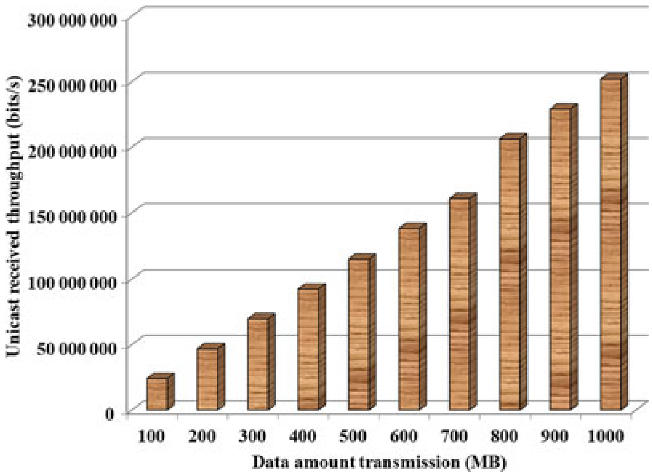


FIGURE 8 Unicast received throughput in energy-efficient retailing using a femtolet-based fog network [Colour figure can be viewed at wileyonlinelibrary.com]

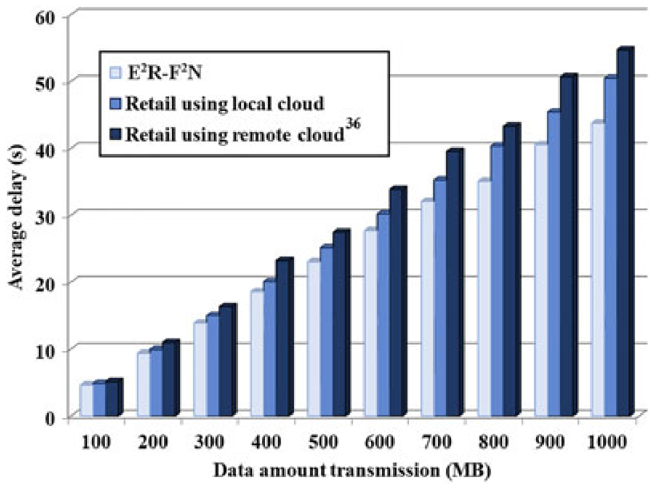


FIGURE 9 Average delay in energy-efficient retailing using a femtolet-based fog network (E^2R-F^2N) and local cloud–based and remote cloud–based retail systems [Colour figure can be viewed at wileyonlinelibrary.com]

Delay refers to the time between sending a packet by the sender node and receiving the same packet by the receiver node. The delay is measured in seconds (s). It is observed from the Figure that the average delays for E^2R-F^2N and the local cloud server–based and remote cloud server–based retail systems are approximately < 50 s, ≤ 50 s, and < 60 s, respectively, for 100-1000 MB of data transmission between two consecutive nodes. The simulation results demonstrate that E^2R-F^2N reduces the average delay by approximately 4%-12% and 10%-20%, compared to the local cloud–based and remote cloud–based retail systems,[36] respectively.

6.2.4 | Average jitter

Figure 10 presents the average jitters of the proposed E^2R-F^2N and the local cloud server–based and remote cloud server-based retail systems, with respect to the amount of transmitted data between two consecutive nodes. Jitter refers to the delay between receiving two consecutive packets by a node. It is observed from the Figure that the average jitters for E^2R-F^2N and the local cloud server–based and remote cloud server–based retail systems are approximately < 7 s, ≤ 8 s, and < 9 s, respectively, for 100-1000 MB of data transmission between two consecutive nodes. The simulation results demonstrate that E^2R-F^2N reduces the average jitter by approximately 3%-21% and 8%-25%, compared to the local cloud–based and remote cloud–based retail systems,[36] respectively.

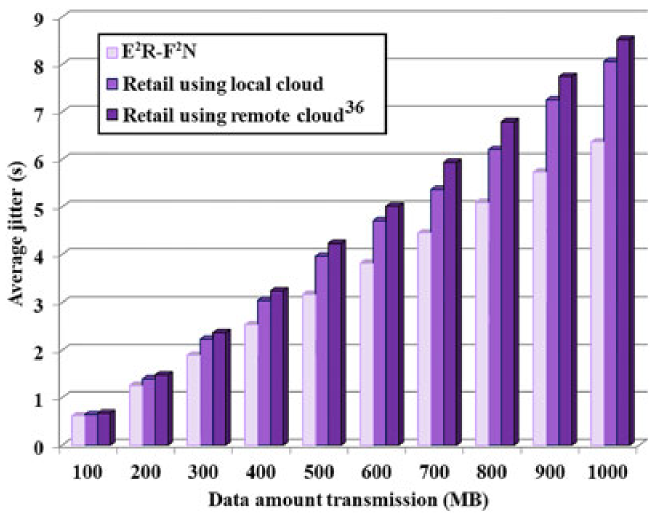


FIGURE 10 Average jitter in energy-efficient retailing using a femtolet-based fog network (E^2R-F^2N) and local cloud–based and remote cloud–based retail systems [Colour figure can be viewed at wileyonlinelibrary.com]

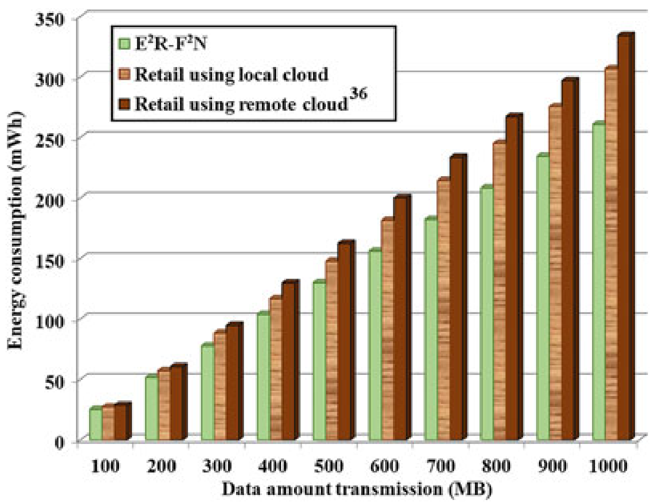


FIGURE 11 Energy consumption in energy-efficient retailing using a femtolet-based fog network (E^2R-F^2N) and the local cloud–based and remote cloud–based retail systems [Colour figure can be viewed at wileyonlinelibrary.com]

6.2.5 | Energy consumption

Figure 11 presents the energy consumed by the proposed E^2R-F^2N and the local cloud server–based and remote cloud server–based retail systems, with respect to the amount of transmitted data between two consecutive nodes.

It is observed from the Figure that the energy consumption values of E^2R-F^2N and the local cloud server–based and remote cloud server–based retail systems are approximately < 300 mWh, ≤ 300 mWh, and < 350 mWh, respectively, for 100-1000 MB of data transmission between two consecutive nodes. The energy consumption of the nodes in transmit and receive modes is summed up to calculate the energy consumption. The simulation results demonstrate that E^2R-F^2N reduces the energy consumption by approximately 6%-15% and 12%-22%, compared to the local cloud–based and remote cloud–based retail systems,[36] respectively.

From the simulation results, we observe that E^2R-F^2N reduces the average delay and jitter more than the local cloud server–based and remote cloud server–based retail systems. As delay and jitter are reduced, the QoS of the system is enhanced. According to the simulation results, the energy consumption is also lower in E^2R-F^2N than in the local cloud–based and remote cloud–based retail systems. Hence, we can refer to E^2R-F^2N as an energy-efficient, ie, green, retail system.

6.3 | Experimental analysis of product database update at the fog device

For experimental purposes, we consider the product database of a ladies beauty accessory lipstick maintained inside a shopping center. The configurations of the fog device, local cloud servers, and smart phones used in the experiment are noted in Table 5.

We consider the product database of a ladies beauty accessory lipstick maintained inside a shopping center. The first Table (Lipstick) contains the product_id, product_name, product_company, product_qty, and product_price. The data of lipstick of different companies are maintained. The second Table (Supplier) contains the product_company as a reference to the product_company of the first Table, supplier_name and supplier_ph. When a product quantity reaches 0, the supplier is informed. The lipstick database is maintained by fog device1. When a lipstick is purchased by a customer, the first Table is updated. If a product quantity reaches 0, ie, if product_qty = 0, then the second Table is accessed. From the second Table, the supplier mobile number is obtained from the field supplier_ph. The fog device sends a message to the local cloud servers along with the product_id, product_company, supplier_name, and supplier_ph, informing that the product quantity is 0. From the local cloud, a message is sent to the supplier's mobile number.

Tables 6A, 6B, and 6C show the first Table at 10:30 am on the 24th, 25th, and 26th of October, 2018, respectively.

On 26/10/2018, the quantity of product "LKL106" reaches 0 (see Table 6C); the fog device accesses the second table (see Table 7) and obtains the supplier's mobile number from the field supplier_ph.

The fog device sends a message to the local cloud servers along with the product_id (LKL106), the product_company (Lak_C), the supplier_name (Erinasupply), and the supplier_ph (97########), informing that the product quantity is 0.

TABLE 5 Configurations of smart phones, the fog device, and local cloud servers

Equipment	RAM	HDD	Processor	Operating System
Oppo A57	3 GB	32 GB	QualcommMSM8940 octa-core	Android V 6.0.1
Samsung Galaxy On8	3 GB	16 GB	1.6 GHz octa-core	Android V 6.0
Samsung Galaxy J2	1 GB	8 GB	1.3 GHz quad-core	Android 5.1.1
Fog device	16 GB	2 TB	Intel Xeon CPU ES-2667 0 @ 2.90 GHz	CentOS
Local cloud server 1	16 GB	1 TB	Intel Xeon CPU ES-2667 0 @ 2.90 GHz	CentOS
Local cloud server 2	16 GB	2 TB	Intel Xeon CPU ES-2667 0 @ 2.90 GHz	CentOS

TABLE 6A First Table at 10:30 am on 24/10/2018

product_id	product_name	product_company	product_qty	product_price
LKL 101	Lipstick_Violet_Lak	Lak_C	30	250
LKL 102	Lipstick_Red_Lak	Lak_C	40	220
LKL 103	Lipstick_Orange_Lak	Lak_C	35	220
LKL 104	Lipstick_Black_Lak	Lak_C	20	300
LKL 105	Lipstick_Pink_Lak	Lak_C	35	200
LKL 106	Lipstick_Brown_Lak	Lak_C	20	200
……..	……..	……..	……..	……..
……..	……..	……..	……..	……..
ELL 10001	Lipstick_Violet_EI18	EI18	25	350
ELL 10002	Lipstick_Red_EI18	EI18	50	300
ELL 10003	Lipstick_Brown_EI18	EI18	50	320

TABLE 6B First Table at 10:30 am on 25/10/2018

product_id	product_name	product_company	product_qty	product_price
LKL 101	Lipstick_Violet_Lak	Lak_C	30	250
LKL 102	Lipstick_Red_Lak	Lak_C	30	220
LKL 103	Lipstick_Orange_Lak	Lak_C	35	220
LKL 104	Lipstick_Black_Lak	Lak_C	20	300
LKL 105	Lipstick_Pink_Lak	Lak_C	35	200
LKL 106	Lipstick_Brown_Lak	Lak_C	10	200
……..	……..	……..	……..	……..
……..	……..	……..	……..	……..
ELL 10001	Lipstick_Violet_EI18	EI18	25	350
ELL 10002	Lipstick_Red_EI18	EI18	45	300
ELL 10003	Lipstick_Brown_EI18	EI18	45	320

TABLE 6C First Table at 10:30 am on 26/10/2018

product_id	product_name	product_company	product_qty	product_price
LKL 101	Lipstick_Violet_Lak	Lak_C	20	250
LKL 102	Lipstick_Red_Lak	Lak_C	30	220
LKL 103	Lipstick_Orange_Lak	Lak_C	30	220
LKL 104	Lipstick_Black_Lak	Lak_C	20	300
LKL 105	Lipstick_Pink_Lak	Lak_C	35	200
LKL 106	Lipstick_Brown_Lak	Lak_C	0	200
……..	……..	……..	……..	……..
……..	……..	……..	……..	……..
ELL 10001	Lipstick_Violet_EI18	EI18	25	350
ELL 10002	Lipstick_Red_EI18	EI18	40	300
ELL 10003	Lipstick_Brown_EI18	EI18	35	320

TABLE 7 Second Table at 10:30 am on 26/10/2018

product_company	supplier_name	supplier_ph
Lak_C	Erinasupply	97########
EI18	Beautyven	98########
Oriflm	Femicraz	98########
MACL	Queensup	97########
…… ..	…… ..	…… ..
…… ..	…… ..	…… ..
Riml	Rimsup	99########
Soml	Somsup	98########

The delay and power consumption in accessing these two tables based on the number of customers purchasing the products are provided in Table 8. The results are compared with the local cloud server–based and remote cloud server–based retail systems.

From the experimental results presented in Table 8, we observe that the proposed retail system reduces delay and power by approximately 23.77%-53.51% and 23.27%-53.28%, respectively, compared to the local cloud–based retail system. It is also observed from Table 8 that the proposed E^2R-F^2N reduces delay and power by approximately 33.19%-62.15% and 32.97%-61.98%, respectively, compared to the remote cloud–based retail system. Thus, we observe that the proposed retail system reduces delay and power by approximately 23%-62% and 23%-61%, respectively, compared to the existing systems. In E^2R-F^2N, the fog device maintains the product database of the respective region in which the fog device is deployed. As a result, the delay in accessing the product database is reduced, which, in turn, decreases the power consumption than with the local cloud–based and remote cloud–based retail systems. As delay and power are reduced, the QoS of the system is enhanced.

TABLE 8A Delay in accessing Lipstick in energy-efficient retailing using a femtolet-based fog network (E^2R-F^2N) and the local cloud server–based and remote cloud server–based retail systems

Number of Customers Purchasing Products	Delay,ms			Reduction in Delay (Approx) Using E^2R-F^2N Than	
	Local Cloud –Based Retail System	Remote Cloud–Based Retail System	Proposed E^2R-F^2N	Local Cloud –Based Retail System	Remote Cloud–Based Retail System
500	652	744	497	23.77%	33.19%
1000	960	1099	612	36.25%	44.31%
1500	1164	1436	660	43.29%	54.04%
2000	1385	1756	736	46.86%	58.09%
2500	1682	2066	782	53.51%	62.15%

TABLE 8B Power consumption in accessing Lipstick in energy-efficient retailing using a femtolet-based fog network (E^2R-F^2N) and the local cloud server–based and remote cloud server–based retail systems

Number of Customers Purchasing Products	Power Consumption, W			Reduction in Power (Approx) Using E^2R-F^2N Than	
	Local Cloud –Based Retail System	Remote Cloud–Based Retail System	Proposed E^2R-F^2N	Local Cloud –Based Retail System	Remote Cloud–Based Retail System
500	0.159	0.182	0.122	23.27%	32.97%
1000	0.235	0.269	0.149	36.59%	44.61%
1500	0.284	0.351	0.161	43.31%	54.13%
2000	0.339	0.429	0.181	46.61%	57.81%
2500	0.411	0.505	0.192	53.28%	61.98%

7 | FUTURE RESEARCH DIRECTIONS

Challenge 1: Online shopping using the femtolet

Nowadays, a huge number of people like to purchase products online. Generally, there are websites for online product purchase. As E^2R-F^2N is designed for shopping centers, the users can purchase the product while visiting the mall. If the shopping center provides an option for purchasing online the products of that shopping mall, the website of the shopping mall has to maintain an online shopping cart system and a secure payment mechanism. If the user accesses the Internet service through a femtolet, data transmission and reception take place through a security tunnel. The users residing at home can purchase the shopping mall's products online by accessing the Internet through a femtolet. To offer online purchase of the products of the shopping center, the product databases have to be maintained inside the remote cloud servers. The security in storage and access to product database will be crucial factors in that case.

Challenge 2: AR in E^2R-F^2N

AR provides a virtual environment to the users through which the users observe the real world with virtual objects.[36,53] Using AR, a user can work with real three-dimensional objects with the information received visually from a mobile device. In E^2R-F^2N, if AR is used, the user can view the products in the shopping center using his/her mobile device. This can help the user track the product he/she wants to purchase. For physically disabled users, AR-based shopping has been proposed in a research work.[36] If F^2N is integrated with AR-based retailing, energy efficiency can be achieved.

Challenge 3: Product location tracking using deep learning

In our system, based on the user location, the route toward the selected product category is displayed on the smart phone located in the trolley to guide the user. However, it may happen that under the same category of products, the user wishes to select a particular item, for example, while a user selects fresh fruits, different fruits are there. Not only that, under a specific fruit category, a user may like to select a particular one. In such a case, the system has to be made more user friendly. For product location tracking based on the user's gesture, deep learning[54] can be used in E^2R-F^2N.

Challenge 4: Dedoop-based energy-efficient femtolet for smart retail

Deduplication-based hadoop is called Dedoop[55]; it is used to handle big data[56] in a retail chain. As the shopping mall contains a huge amount of data inside the femtolets, a Dedoop-based femtolet has to be developed to remove the deduplication problem in a next-generation retail system. If online retailing is provided, then remote cloud servers also will contain big data for the shopping center. Dedoop for online retailing to handle huge data is a promising future scope.

Challenge 5: Light fidelity–based energy harvesting IoT using F^2N

In light fidelity (LiFi)–based retail, it is necessary to decrease the overall energy consumption of the IoT nodes.[57] An additional source of energy has become essential. Amidst crisis of the radio frequency spectrum, LiFi offers key benefits. The Energy Harvesting Retail model for future hybrid LiFi/F^2N may open a new horizon. Energy Harvesting Retail is capable of high-speed transmission by harvesting energy. Multidevice transmission is synchronized by multicolored light-emitting diodes.

Challenge 6: Software-defined femtolet-based blockchain cloud architecture for energy-efficient retail

Software-defined networking (SDN) offers network management in an easy manner and a programmatically efficient network configuration.[58] In SDN, the control plane is separated from the forwarding plane. If SDN is integrated with E^2R-F^2N, system management can be performed more efficiently. Blockchain cloud architecture using SDN and a femtolet as the controller of fog nodes at the edge of the network is a challenging research scope of E^2R-F^2N.

Challenge 7: Privacy preservation in an energy-efficient retail system

In E^2R-F^2N, the user himself/herself selects and purchases products with the help of a smart trolley. The payment is also performed digitally. Therefore, privacy preservation is an important factor in E^2R-F^2N, especially if online retailing is provided.

Challenge 8: Energy-efficient priority retailing

Different users visit shopping centers and purchase products. If the quantity of a product is less than its requirement, then priority has to be assigned to the customers. The priority can be on a "first come, first serve" basis or on the basis of how frequently the users visit the shopping mall. The users who visit the shopping mall frequently can be provided various offers regarding product purchase. Therefore, classification of the prioritized and nonprioritized customers is another future scope of E^2R-F^2N.

Challenge 9: Geospatial information analysis for customer demand prediction

Different geographical regions have different types of customers having various types of requirements. Analyzing the product database of different shopping centers of different regions, the customer demand in different areas can be predicted. In this case, mapping between the geospatial data[59,60] and product purchase data will be performed to analyze customer demand. The customer demand–based product storage and management by the shopping center based on geospatial information is also a challenging research scope.

Challenge 10: Performance and resource-aware orchestration in retailing

Resource allocation in a latency- and energy-optimized way is a vital factor in IoT based on fog computing and MCC.[61,62] Resource allocation and service function chaining are demanding research scopes in IoT.[63] Service function chaining orchestration in E^2R-F^2N is an interesting research domain, especially if online retailing is provided.

Challenge 11: Commitment and customer loyalty in E^2R-F^2N

Customer loyalty and commitment are important for commercial organizations.[64] E^2R-F^2N is a commercial model for purchasing products in a shopping mall. Security and privacy while purchasing products through a digital wallet and ease of providing service while guiding the user toward the product location through an Android app are important factors for customer satisfaction. Hence, for enhancing customer satisfaction, the development of a more user-friendly application, which will consider not only the GPS but also users' gesture, as well as a more secure environment especially in online retailing is a vital research area of E^2R-F^2N.

8 | SUMMARY AND CONCLUSIONS

The smart green retail system is an interesting domain of research. This paper has introduced E^2R-F^2N as a retail system using F^2N, where, in a shopping mall, the customer selects and purchases products using a smart trolley. This trolley guides the user toward the location of the selected product category. Sensor nodes are attached with the smart trolley to track the status of items put in the trolley. These sensors are connected with the microcontroller that sends information to the mobile device according to the items put into and picked from the trolley. Using a digital wallet, the user makes payment through the mobile device placed in the trolley. The femtolet is used as a fog device, which connects the user with the network. The femtolets in the shopping mall store the product data. The femtolets are connected with local cloud servers, which act as a data repository for the shopping mall. The mathematical model of E^2R-F^2N has been proposed, along with power and delay calculation. The simulation results depict that E^2R-F^2N reduces power and delay by approximately 89% and 90%, compared to the local cloud server–based retail system. The proposed system is simulated in QualNet 7. The average delay, average jitter, energy consumption, carried load, and unicast received throughput of the system are determined. An Android app for $E^2R\text{-}F^2N$ is developed. Experimental results demonstrate that the proposed fog-based retailing reduces delay and power by approximately 23%-62% and 23%-61%, respectively, compared to the cloud server–based system. Finally, the future research challenges of $E^2R\text{-}F^2N$ were highlighted in this paper.

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