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RESEARCH ARTICLE-COMPUTER ENGINEERING AND COMPUTER SCIENCE

Smart Utilities IoT-Based Data Collection Scheduling

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Abstract

The Internet of Things is an ecosystem that connects billions of smart devices, meters, and sensors. These devices and sensors collect and share data for use and evaluation by organizations in different industry sectors. Humans may use the IoT to live and work more intelligently and gain total control over their lives. Consequently, IoT can be used to connect devices and integrate them with new digital technologies for customers. On the other hand, smart utility companies in the electric, gas, and water sectors need to deliver services more efficiently and analyze their operations in a way that can help optimize performance, detect growing problems in real time, and initiate fixes to avoid unplanned service interruptions. Building actual smart metering networks is costly and time-consuming. Therefore, in this paper, a new Smart Utilities Traffic Scheduling Algorithm (SUTSA) is proposed. To minimize the system complexity, the model is based on narrowband power line communication, in which a wired hidden network sends data across power lines. A simulation is performed using OPNET Modeler 14.5 to evaluate the proposed model. The results proved that the proposed model is highly scalable and achieves full network-bandwidth utilization in different situations based on different application requirements.

Keywords Internet of Things · Power line communication · Scheduling · Smart meter · Smart utility

1 Introduction

1.1 Background

The Internet of Things (IoT) is considered to be the third revolution in information technology. According to researchers, over three million new devices are connected to the Internet every month [1–3].

Information and communication technology is rapidly converging at three levels of technical innovation: cloud, public infrastructure for processing and exploring streams (PIPE), and devices [4–6].

The cloud is an important component of IoT because it delivers essential services for a wide range of applications. It allows anyone to build content and applications for consumers worldwide, thus providing a global infrastructure to generate new services [7, 8]. Networks connect things globally and maintain their identity online. This worldwide infrastructure can be accessed through mobile devices at any time and location. As a result, there is a global network of objects, users, and consumers with the ability to launch enterprises, contribute content, and create and acquire new services [9].

PIPE is used by both industries and consumers through a variety of interconnected smart devices. It includes traditional telecommunications, cables, and internet data communication networks.

The devices represent the physical sensors of the IoT that aim to collect and process information. It includes personal devices, telecommunications premises, and home entertainment boxes.

Currently, smart utility companies face several challenges in expanding and deploying the smart grid (SG) to replace the old electrical infrastructure. SG provides two-way digital communication between the electricity plant and the consumer [10].

It is necessary to implement a low-cost real-time network to carry out all communication operations of the various

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components of the smart grid. The key challenges are grid infrastructure, communications, security, data management, stability concerns, and energy management [11, 12].

This paper focuses on two main concerns: data management and communication issues. Data management issues: SG integrates a massive number of meters, sensors, and controllers into the power network. The data from these devices were utilized to improve the operators' capabilities. A failure or damage might be prevented before it occurs through precise data analysis.

Consequently, an appropriate platform for IoT must be used in data management design in an Internet network, in which the concepts of communication, processes, and storage should be correctly defined, and it should provide flexibility, security, dominance, administration capabilities, and scalability [13].

Communication issues: A wide range of communication technologies for deployment can be used in SG; however, they all have their own limitations, which include bandwidth limitations, distance limitations, and higher packet loss. Technologies such as 3 G, ZigBee, PLC, GPRS, PLCC, GSM, and GPRS can be used. Although wired communication, such as power line communication, goes beyond the drawbacks of wireless communication, it still has to deal with the issue of shared media [14, 15].

1.2 Literature and Related Work

The smart grid is the future of the electrical industry, which uses upgraded power system components to replace the old electrical infrastructure. It provides two-way digital communication between the electricity plant and the consumer. In addition, it can provide multi-directional communications among all partners in electrical energy [16]. Smart meters are the most important part of the smart grid they record energy usage and send the data to the utility suppliers. Currently, these are the most prevalent methods for calculating, regulating, and monitoring electricity, gas, and water usage. A smart meter is a device that provides reliable real-time monitoring, automatic data gathering, user interaction, and power control [17, 18]. Many authors have suggested different scheduling methods trying to manage communication between smart grid components with high data traffic, meet business requirements, and reduce the probability of data packet loss. Each technique is effective in its own particular parameter set.

MAC layer scheduling with queue status information based on PLC was proposed in [19]. It satisfies the QoS requirements of real-time (RT) services and then uses the remaining resources for non-real-time (NRT) services; it lists users in decreasing order based on the utility function's value. Then allocate physical-layer resources for user scheduling based on this. This technique is effective only when large data rates are necessary. Also, it requires an expensive linear amplifier, which may suffer from Inter-carrier Interference between the subcarriers [20]. Therefore, our contribution is based on a narrowband PLC that overcomes this problem, minimizes system complexity, and avoids OFDM problems.

An optimal interference-aware TDMA-like data collection scheduling is proposed in [21]. A link-timeslot problem has been solved with interference constraints to avoid modifications to the CSMA MAC protocol.

Authors in [22] introduce a solution for intensive data collection for smart energy and smart building systems. The data were gathered using several parallel-running scripts for each subsystem and each Ethernet converter. Devices are polled accordingly inside each subsystem. The collected data are sent to the IoT platform using MQTT protocol. Although it can achieve an acceptable lifetime for battery-powered sensors, system complexity and cost are not considered in this approach. To overcome this, our proposal focuses on enhancing the use of the already existing network, with no need to add more stations to serve more areas.

[23] presents scheduling of data collection. It presents analytical models of data quality based on mismatch probability (mmPr). It uses three data access mechanisms: push, pull, and event-based to achieve different network QoS levels. This method lacks simultaneous interaction between the sensor and the controller, which is required for on-demand reading requests and alarm handling. Our proposal addresses this issue using the SUTSA hybrid model.

The work of [24] proposed a resource scheduling algorithm that helps each smart meter select a proper path to the access point. Meters cooperate to transmit using distributed decisions on their transmission path, every node acting as a gateway to the other nodes. In the proposed approach, a sink node is designed to collect data and/or alarms from a particular number of groups and deliver them to the headend. This minimizes the role of each node and reduces the delay.

A traffic scheduling algorithm based on time unit assignment in a floor network and wireless multi-channel was proposed in [25]. It offers a data transmission sequence for meters by using a random spanning tree. It assigns different priorities to the meters. The priority of the meter's data transmission increases with closeness to the floor gateway. This algorithm focuses on interference avoidance at the expense of data transmission latency.

In [26], a heterogeneous neighborhood area network (NAN) architecture was proposed for the smart grid. It comprises smart meters, routers, and concentrators. The smart meters are clustered together, and the corresponding router composes their data in the small cell. Routers then used the max–min fair data collection algorithm to send data to the concentrators. The problem with this solution is the infinite number of possible locations for placing a single gateway in a NAN. In our approach, a sink node is designed to collect data and/or alarms from a particular number of groups and deliver them to the headend regardless of its location.

The approaches presented in [26, 27] are based on wireless network design. Under certain circumstances, setting up a wireless network may cost up to four times as much as setting up a wired network. Wireless networks are highly vulnerable to interference, which causes them to malfunction.

Three data collection methods were suggested by authors in [27] to enhance TCP performance in IEEE 802.11 s-based wireless mesh AMI networks. The first one is based on the routing protocol of IEEE 802.11 s. The second is based on time division multiple access (TDMA), where each meter is given a separate slot. The last one is a hybrid of both previous mechanisms.

In [28], the scalability of smart grid advanced metering infrastructure (AMI) data collection was improved using a layer-2 path discovery protocol. After making modifying the hybrid wireless routing protocol (HWMP), the AMI network depends on the periodic operations of IEEE 802.11 s MAC-based routing such as establishing and maintaining peering between smart meters. Building the network topology may result in considerable congestion and interference, which may increase the data delay as well as the packet loss. In addition, the upper layer protocol operations should be reported using address resolution protocol (ARP), which increases contentions and eventually creates a broadcast storm, leading to network performance degradation [29].

In [30, 31], algorithms for scheduling load on demand that enable users to request more power at a lower price were proposed.

In [30], a fair delay energy-scheduling algorithm was proposed. Each customer's load has a defined upper limit, and each customer demands the energy required. If the power system can handle the load without entering the peak stage, it fulfills immediately. Otherwise, the customer's request is delayed for later consumption. To achieve fairness among all customers, the individual delays should be limited to a set threshold. Additionally, based on the current normalized delay and the average delay of all customers provided by the power supplier, if the energy consumption exceeds the boundary, a back-off or carry-on operation is used. The problem with this algorithm is that each customer must be aware of both the individual delay and the overall delay state of the NAN grid.

In [31], an iterative algorithm was proposed for utility companies and users, which can improve their welfare and enables a final balance between the power supply and demand. Users first select the utility provider offering the cheapest energy rates and then modify their energy needs in accordance with the pricing those utilities have established for energy. The algorithm can satisfy users' demands at lower prices; however, it does not handle the case of demand shifting.

1.3 Motivation and Contribution

The motivation behind this study can be summarized as follows:

- The expansion and deployment of SG to replace existing electrical infrastructure is a major challenge faced by smart utility companies.
- An algorithm is required to collect meters readings and alarms in near-real time. Therefore, we propose a scheduling algorithm that is capable of collecting smart utilities data.
- A suitable medium that is robust to interference, cost-effective, secure, and has low system complexity. Hence, we propose a robust model capable of leveraging the existing electricity infrastructure with minimal components added for smart utilities data collection.
- Delay issues in reading data processing, alarm handling queuing and transmission, and guaranteeing a certain quality of service. Because delay is critical in the case of alarms, our proposed model provides a near real-time solution for such situations.

The contributions of this study can be summarized as follows:

- A low-cost network architecture is proposed for smart grid to carry meters collected data and alarms from a large number of meters.
- The PLC is used as a data transmission medium to address and overcome many wireless issues and reduce system complexity.
- A scheduling model is proposed to overcome the problem of multi-access using a PLC-shared medium.
- Different models have been proposed for collecting meters readings data and alarms that are suitable for different practical cases.

1.4 Paper Organization

The remainder of this paper is organized as follows. Section 2 presents the proposed system model. The problem statement is introduced in Sect. 3, and the performance validation is described in Sect. 4. Finally, Sect. 5 presents the conclusions and future work.

2 System Model

The following section introduces the IoT architecture reference model, which specifies how all of these components and devices are connected. It also explains the benefits of using the PLC as a data transmission medium.

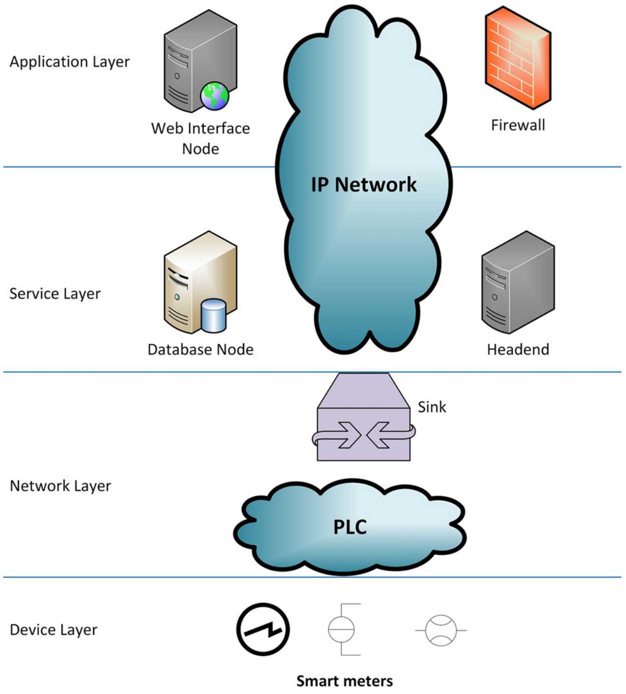


Fig. 1 Smart meter system architecture-based ITU-IoT

2.1 IoT Network Architecture

The IoT requires a flexible layered architecture to link billions or trillions of heterogeneous objects. The system model is adapted to our use case, as shown in Fig. 1. It is built on the Telecommunication Union (ITU) IoT reference model, which is a four-layer suite [32].

It comprises four layers as well as management and security capabilities. Application layer: This layer delivers the services requested by clients. This layer is crucial for the IoT because it can provide high-quality smart services to fulfill customers' needs. The application layer covers a wide range of vertical domains, including smart homes, transportation, and healthcare [2].

Service support layer: Data processing and storage are examples of generic support capabilities that can be used in various IoT applications. These capabilities may also be invoked by specific support capabilities, such as building other specific support capabilities. Specific support capabilities are particular capabilities that cater to the requirements of diversified applications [33].

Network layer: It provides appropriate network connectivity control functions, such as access and transport resource control, mobility management, and authentication [34].

Device layer: This layer includes sensors and actuators that can be used to measure weight, temperature, light intensity, motion, position, acceleration, and humidity. These devices can directly gather and upload information with or without the use of gateway capabilities and receive commands from the communication network [6]. In applications that require enhanced scalability and rapid deployment, devices may be able to build networks on their own. This may assist in energy-saving measures, such as sleeping and waking up [35].

2.2 Power line Communication (PLC)

Nowadays, PLC is the most intelligent and appropriate decision for future AMI [36]. AMI is deployed in many countries. It provides utility companies with a two-way communication system from the control node to the meter, additionally the ability to modify customers' service level parameters.

PLC systems can be divided into two categories: narrowband and broadband systems. Narrowband PLC (NB-PLC) is a type of low-bandwidth communication that uses a frequency spectrum below 500 kHz and provides data speeds in the range of tens of kbps [37]. Broadband PLC (BPL) uses a much larger frequency spectrum, usually between 2 and 30 MHz, and can handle data rates of hundreds of Mbps [38].

Because frequencies below 500 kHz have relatively little attenuation while frequencies over 1 MHz are considerably attenuated owing to capacitive coupling between power cables and ground, NB-PLC technologies have been widely used for smart metering worldwide [39].

These two types of PLC technologies have different modulation methods. Single-carrier modulation techniques such as amplitude-shift keying (ASK), frequency-shift keying (FSK), and phase-shift keying (PSK) are commonly used in narrowband systems [40], whereas multi-carrier techniques such as orthogonal frequency-division multiplexing (OFDM) are used in broadband systems [41].

This paper focuses on NB-PLC. The European Committee for Electrotechnical Standardization (CENELEC) standard reserves some frequencies and issued the standard EN 50065, which specifies four frequency bands for communications over PL networks. Power utilities were allotted to the A-band (3-95 kHz). The B-band (95-125 kHz) is a versatile frequency range that can be utilized in a variety of applications. The C-band (125-140 kHz) is reserved for in-home networking. The D band (140−148.5 kHz) has been used in security and alarm systems [42].

3 Problem Statement

The following section describes in detail the model parameters, the proposed network architecture, and different model scenarios.

The electrical meter is considered to be the home PLC gateway. It is connected to other meters inside the household and collects data from them. The connection between the electrical meter and other meters in the same household can be wired (serial connection, network connection) or wireless modules (WIFI, Bluetooth, or ZigBee). The electrical meter has a PLC modem to communicate with the sink node and send collected data on behalf of the other meters. Hence, only the electrical meter will be connected to the PLC network to simplify the infrastructure requirements for smart utilities data collection [43, 44].

3.1 Model Parameters

The model has the following characteristics:

- To minimize system complexity, the model is based on a narrowband PLC operating from 3 kHz to approximately 500 kHz. Band A (3-95 kHz) is reserved exclusively for power utilities [42, 45].
- The model is a bidirectional flow of information between the sink node, which acts as the gateway between the provider and consumer smart meters.
- The model uses a single-carrier BPSK modulation. Hence, the maximum data rate is 9.6 Kbps.
- The frequency range is divided into two bands of each 4.8 kHz, where the lower-frequency channels are for the uplink and the upper-frequency channels are for the downlink.
- For clarity, we assumed that “Sc” is the maximum sink capacity, “N” is the number of groups in each sink, and “M” is the number of meters per group. Then:

$$Sc \leq N * M \tag{1}$$

Only the minimum amount of information necessary from the smart meter is utilized in the suggested message format, as listed in Table 1 [26]. The “Timestamp” is utilized for alerts and reading logs, as well as for time reference between meters and gateways, whereas “Type” is four-bit code used to categorize the message type as illustrated in Table 2. “Meter Identifier (ID)”= 64 bits, with format “City code.District.Partition.Block.Building.Flat.Meter”. Finally, “Data” are the actual meter data values.

Using the suggested message length of 228 bits, the number of messages per second (mps) is given by the uplink rate/message size

$$\text{mps} = \frac{4800}{228} \approx 21\text{messages/second} \tag{2}$$

The used frame format is given in Fig. 2. The frame duration is one second, and it has 21 Time slots (Ts).

Table 1 Proposed message format

Timestamp	Type	ID	Data
32 bit	4 bit	64 bit	128 bit

Table 2 Proposed message types

Code	Type
0000	Read request
0001	Read response
0010	Lock
0011	Unlock
0100	Charging
0101	Warning
0111	Violation detected
1000	Violation check
1001	Channel reservation

3.2 Proposed Model Network Architecture

As shown in Fig. 3, the network consists of three main components:

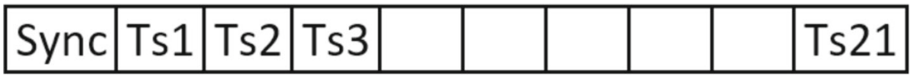
- A smart meter of any type (electricity, water, or gas).
- A sink node: is the network gateway for several smart meters in a specific district that manages, controls, and aggregates smart meters readings and alarms. It is responsible for collecting meter readings to be sent to the headend interfaced server to be saved in the dedicated database node [46].
- A headend server: is the database warehouse connected to different sink nodes and can be used for data query, analysis, and statistics.

3.3 SUTSA Sequential Access Model

Smart Utilities Traffic Scheduling Algorithm (SUTSA) is our proposed method for smart meter data collection, including readings and alarms. The meter readings are collected daily to monitor the usage difference between working days and weekends. The alarms are collected instantly upon occurrence. These data are used in the data analysis to provide valuable insight into consumers’ actions and desires. It also helps smart utility companies in load forecasting, upgrade planning decisions, scheduling, operations, pricing, customer satisfaction, and system security [47].

SUTSA Sequential Access Model can be divided into two parts, as illustrated in Fig. 4. Part one involved gathering

Fig. 2 Used frame format



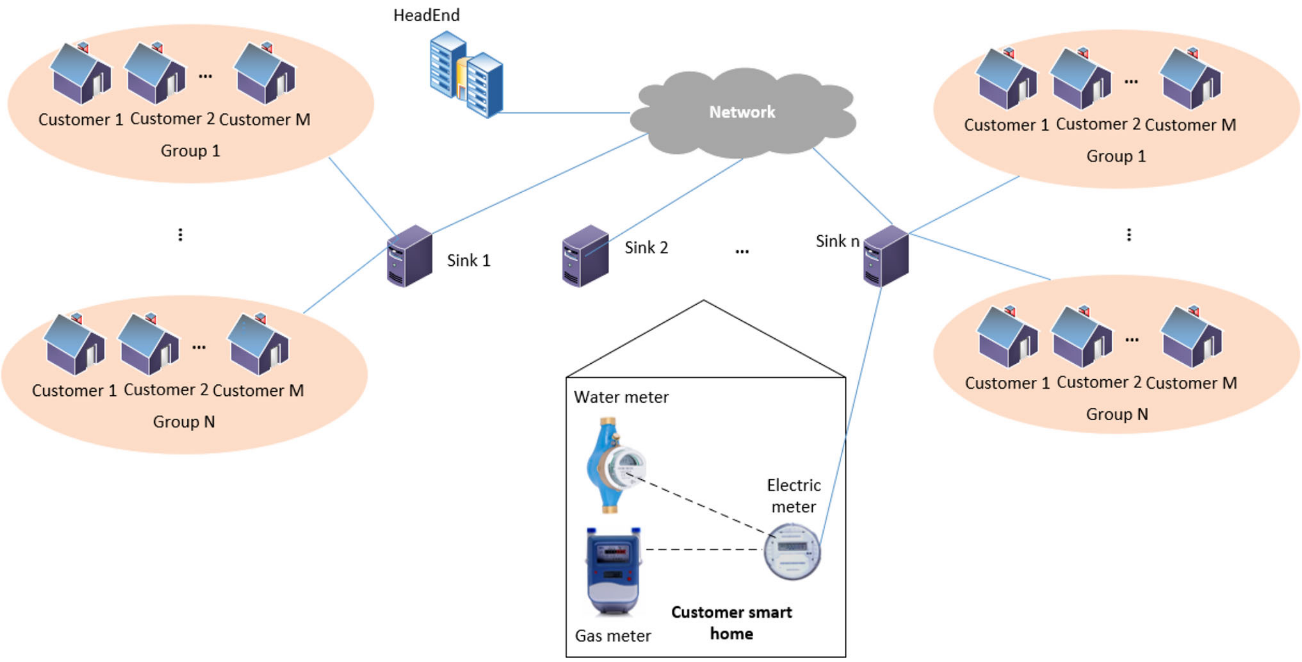


Fig. 3 Proposed network architecture

meters readings data. Part one flowchart is shown in Fig. 4a, where the meters readings data are collected daily. Starting with the first group, the sink sends data collect requests, and each meter is set to provide its reading at a specific time based on the meter ID. Then, meters respond to the reading request in sequence in ascending order. Finally, sink send the collected data to the headend. This method is then repeated for each of the N groups.

The collected data are used to generate customer bills, conduct analyses with appropriate big data tools, manage and even avoid outages, anticipate and build predictive models for demand-programmed planning, establish new rate plans and services for clients, and detect meter tampering.

The second part of the flowchart addresses warnings and alarms. As shown in Fig. 4b, this begins when a meter uses the type field in the frame to signal an alarm or warning. When the sink receives this flag, it schedules the collection of alarms at the end of each group based on the alarm severity level. While collecting meter readings, the sink provides a period for collecting alarms after collecting each group's readings. The sink then sends a request to get the group alarms, where odd ID meters send the alarm in the odd frames, and even ID meters send the alarm in the even frames. If only one meter sends an alarm per time slot (meter ID +alarm severity code), the sink receives the alarm successfully.

A collision may occur if two or more meters send alarms in the same time slot. The sink receives an undefined data format and detects a collision; therefore, it drops the request. If the meter does not receive a confirmation from the sink after a certain period, it will try to send its alarm again in the next frame. It is not typical to have a large number of alarms, and not all of them occur at the same time; thus, by dividing the meters' transmission into odd meters and even meters transmission, theoretically, the possibility of collision is decreased by half. After dealing with all the alarms in a specific group, the sink starts to collect the readings from the next group.

3.4 SUTSA Sequential Model Functional Workflow

- Reading data: Because there are multiple sinks collecting data to the headend, each sink should register and authenticate with it so that data transmission between them may be regulated. Figure 5 shows the reading message workflow, which starts with an authentication check between the headend and sink (1). The headend initiates data collection requests based on a predefined time in (2). The sink sends a "GET" request to the first group (3), and each meter is set to submit its reading at a specific time interval. The meters respond to the sink in order (4). The sink collects the data and sends them to the headend (5). The procedure is repeated within the next group.
- Alarm detection: An alarm detection module is embedded in the meter to alert the company of any unauthorized physical interaction using the devices [48].

As shown in Fig. 6, the alarm message workflow starts with an authentication check between the sink and meter using meter ID (1). The meter sends a "violation detect message" (2, 3). Headend sends a "warning message" and the meter displays it on its digital screen (4, 5), indicating that

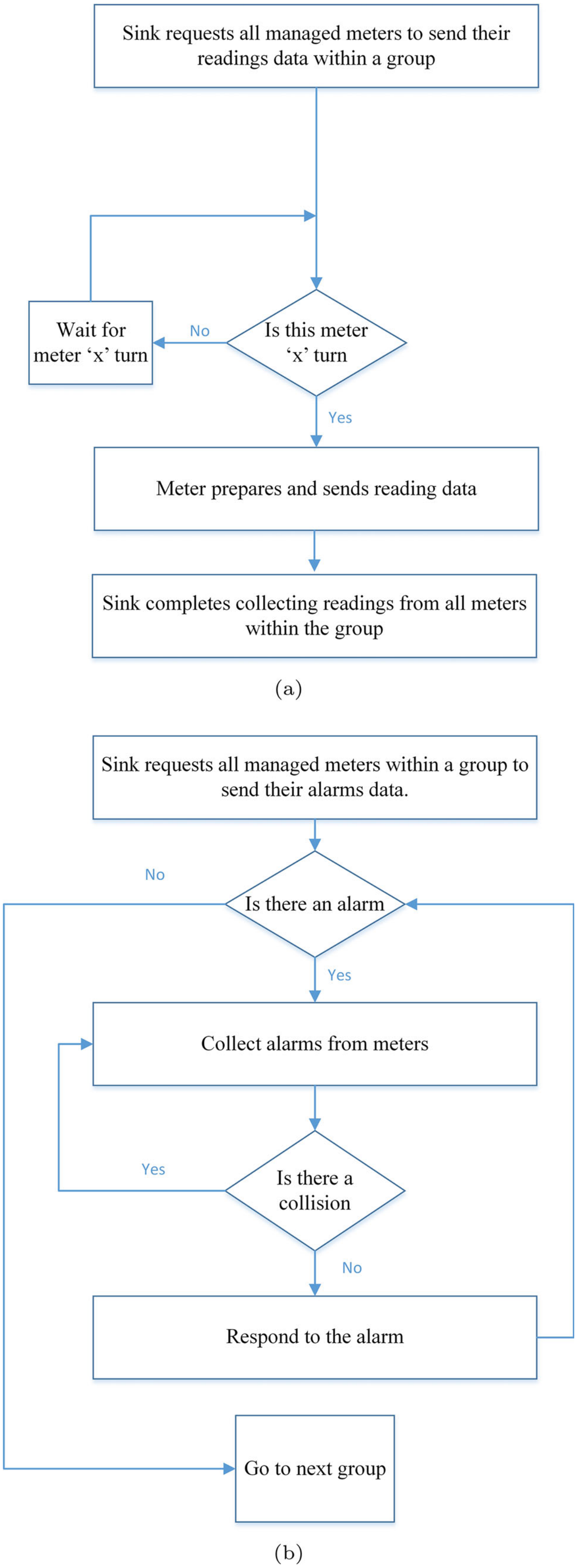


Fig. 4 **a** Collecting meters readings, **b** collecting meters alarms

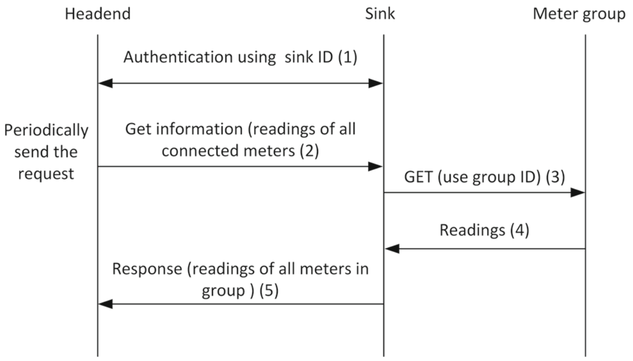


Fig. 5 Reading functional messages flow

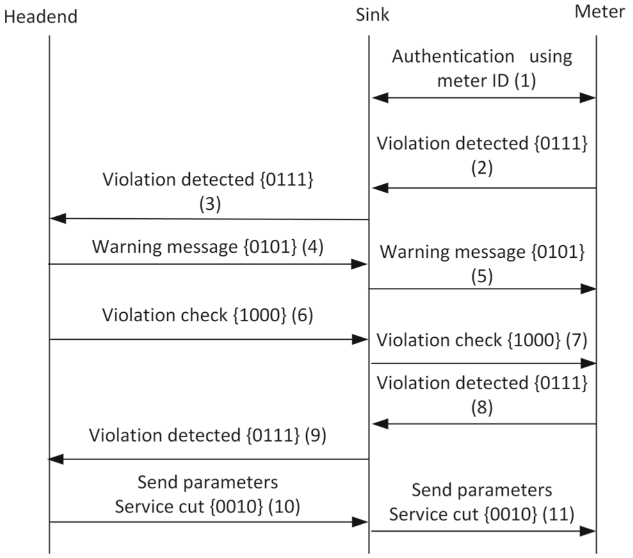


Fig. 6 Alarm example messages functional flow

it will check the usage again. If there is abnormal reading, action will be taken to cut the service. “Violation check” message will be sent again (6 to 9). If tampering still exists, the headend will cut the service by sending a “set parameters Service cut” message (10, 11) through the sink. Message codes used in the workflow are mentioned in Table 2.

- Set values: This is a communication method between the headend and meter. It is used to set parameters, display warnings, lock/unlock, display bill value or charge the meter. As shown in Fig. 7, this flow begins with a meter ID-based authentication check between the sink and meter (1). A lock message is used to disable the service after detecting tampering or no charging, and an unlock message is used to enable the service after the situation has been resolved (2, 3). The charging message is sent to display the amount to be paid (4, 5). If they are manipulated, a warning message is sent and shown on the digital screen of the meter, indicating that action will be taken (6, 7).

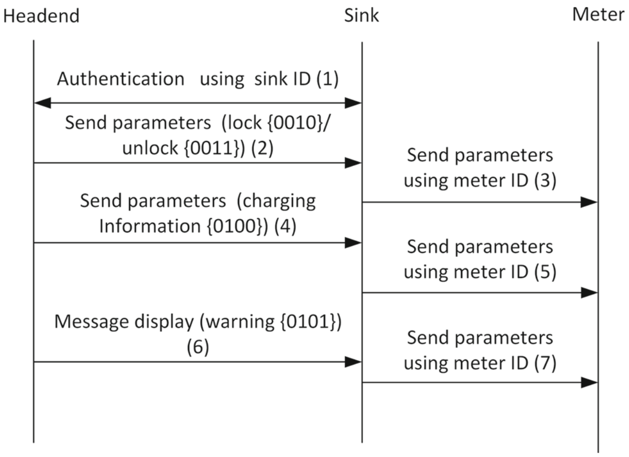


Fig. 7 Control messages functional flow

3.5 SUTSA Random Access Model

In the previous model for a large number of meters per group, the meters wait a long time to send data. On the other hand, there are several unused Ts for other groups with no data to be sent. To solve this issue and improve the frame utilization, there is no scheduled transmission time for a meter. The transmission is random among the meters that transmit their alarms. As shown in Fig. 8, the first ten time slots per frame are used for channel reservation (CR), and ten time slots are used for sending data. Figure 9 shows the flowchart of the proposed algorithm. This algorithm can be divided into two parts. Part one is channel reservation, and part two is sending data.

The first ten time slots of every frame are reserved by the sink for CR requests. If a meter needs to send data, it must first make a channel reservation through one of the predefined time slots, which includes the meter ID and its message-type code. The meter waits for sink acknowledgement. If the meter does not receive an acknowledgement, it waits for a random amount of time before sending the request again. Then, the sink assigns a Ts in the uplink frame for the entire communication duration after receiving the request. If a large number of meters send CR requests simultaneously, the sink prioritizes them. If two meters have the same priority alarms, the sink will serve requests based on a first-come, first-serve basis. If two meters attempt to submit CR requests simultaneously, a collision occurs, and the two must wait a random amount of time before re-sending the CR.

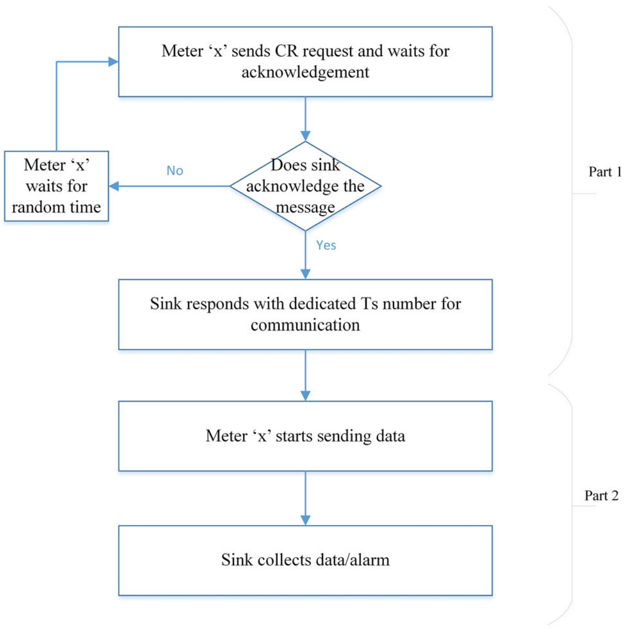


Fig. 9 Random access model flowchart

Part two starts with the data sent by meters. There are two types of data: reading and alarm data. The sink collects alarm data and then acknowledges receiving the data.

3.6 SUTSA Random Access Model Functional Workflow

The SUTSA random-access model message workflow is illustrated in Fig. 10. This starts when meter 'x' sends a request for the channel reservation (1). The sink then responds with one of the available time slots for sending data (2). Meter 'x' starts sending data (3). The same goes with meter 'y' (4, 5) and it starts sending the alarm information (6).

3.7 SUTSA Hybrid model

This model combines the benefits of the two previous models to prioritize alarm handling. The reading process is sequential among all groups, similar to the first model, whereas alarms are handled randomly at any time, as in the second model. The uplink frame is shown in Fig. 11, the first three time slots per frame are used for CR, eighteen time slots are used for sending data, three time slots of them for sending alarms data, and fifteen time slots for readings data. Figure 12 shows the flowchart of the algorithm.

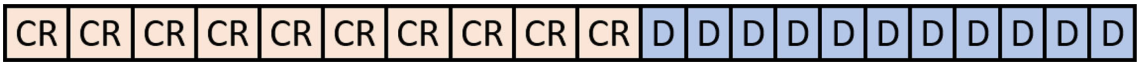


Fig. 8 SUTSA random access frame details

Initially, the sink checks the first three time slots of the frame. If a meter needs to send alarm data, the sink assigns one of the predefined time slots for the meter requested for alarm data sending. However, it starts sending reading requests to all managed groups. Starting with the first group, every meter is programmed to send its reading within a certain time slot. The meters respond to the sink in sequence. Sink collects readings data from fifteen meters of the group per frame then aggregates and sends them to the headend. The process is then repeated with all N groups. Any time a meter needs to send alarm data, it first requests channel reservation via one of the predefined time slots. The meter waits until an acknowledgement is received from the sink. If the meter does not receive acknowledgement, it waits for the next frame and then sends the request again. If a large number of meters send CR requests simultaneously, the sink first decides by priority. If two meters have alarms or data with the same priority, the sink uses first-come, first-serve data. If two meters try to send CR requests at the same time slot, a collision occurs, and the two should wait for a random time to resend CR again.

4 Performance Validation

The simulation is run using OPNET Modeler 14.5 [49], to evaluate the proposed model approaches. OPNET is a comprehensive network simulation tool with numerous features. This allows for the simulation of heterogeneous networks using a variety of protocols [50].

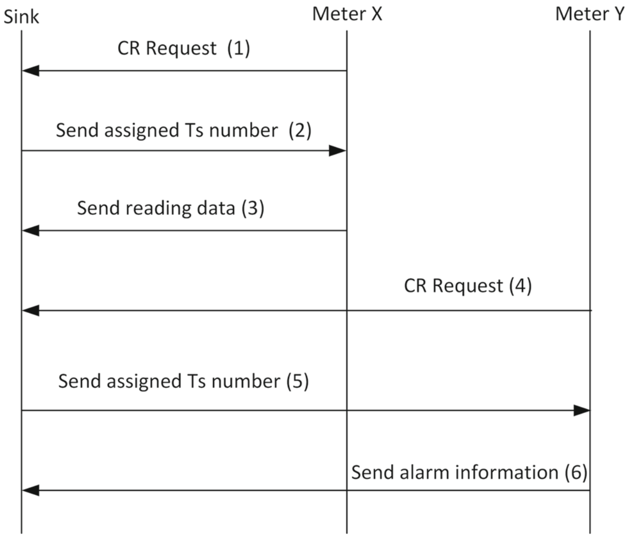


Fig. 10 Random access model messages workflow

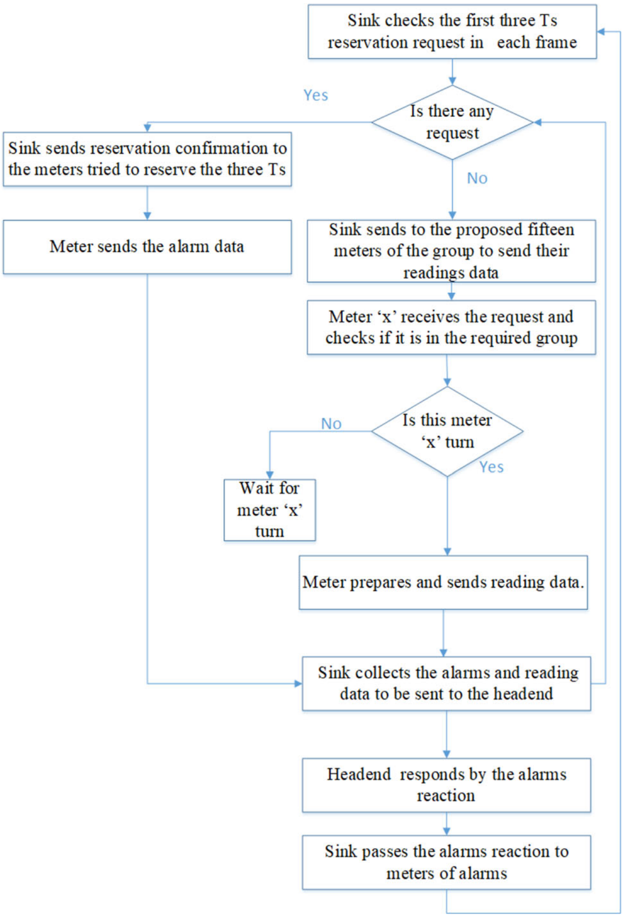


Fig. 12 Hybrid model flowchart

The simulation setup is considered as the following:
- Maximum sink capacity Sc = 100,000 ms.
- Number of groups N = 100 groups.
- Number of meters per group M = 1000 ms.

To carry out our simulation, the actual values of the message processing time are considered based on the real PLC characteristics of [46, 48]. The simulation scenarios are run for 60 min. Figure 13 shows a sample OPNET simulation network.

The signaling flow is created by the ACE Whiteboard, which is a tool used to design and edit a new application's behavior in a graphic environment. After modeling an application, its performance can be predicted using discrete event simulations. It has a tree view, a data exchange chart, a tier pair, connections, subtasks, and logic scripts. Every ACE Whiteboard file contains several tiers, each of which

CR	CR	CR	AD	AD	AD	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D

Fig. 11 SUTSA hybrid model frame details

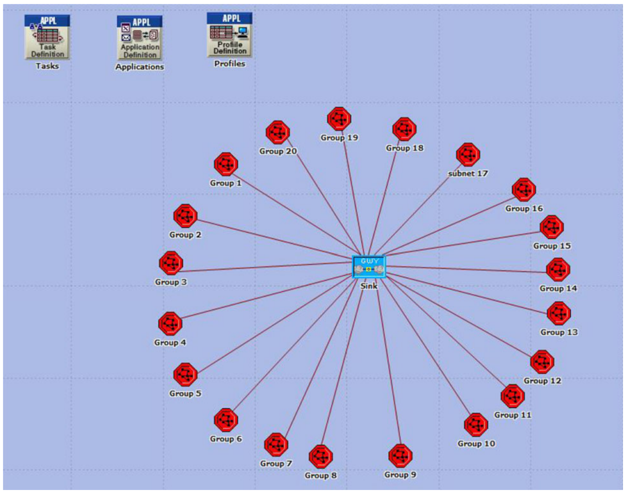


Fig. 13 Sample OPNET simulation network

represents a device that sends and/or receives traffic. This simulation uses three tires for the meter, sink, and headend.

The results obtained from the simulation are as follows:

Scenario 1: “SUTSA Sequential Access Reading” The first group receives a data-reading request from the sink, and each meter is configured to submit its reading at a specific time. The reading is gathered by the sink and sent to the headend.

Scenario 2: “SUTSA Random Access” which simulates a meter that requires sending reading data or an alarm at any time, and first sends a request for a channel reservation through one of the predefined ten time slots. The meter waits until acknowledgement is received from the sink. After the sink receives the request, it assigns a Ts for the meter to use during the entire communication period.

Scenario 3: “SUTSA Hybrid model” which simulates the sink sending a data-reading request to the first group. The meters responded to the sink in sequence. Also, at the same time, three meters from any group can send “channel reservation” requests to send alarms. The sink aggregates the readings and sends them to the headend and handles the alarm within the same frames.

Figure 14 shows the average hourly loads of the three models on the sink node. In the SUTSA Sequential Access, the data rate used is approximately 4200 bit/s, which is almost full bandwidth utilization. In the SUTSA Random Access, the data rate used is only approximately 2800 bit/s. In the case of the SUTSA Hybrid model, the data rate used is approximately 3600 bits/s. Furthermore, the results revealed that no traffic dropped during the simulation time and that all meter readings are successfully gathered.

Based on the simulation results, it can be concluded that the first model, the “sequential Model,” is an organized method that is highly scalable, but if there is a high alarm density within a group, it will delay the reading of the next group because it does not move on to the next group until the current group’s alarms have been completed, and it also limits the alarm sending. The second model, “random access,” allows alarms to be sent at any time, but this increases the reading time and is difficult to manage because there are no

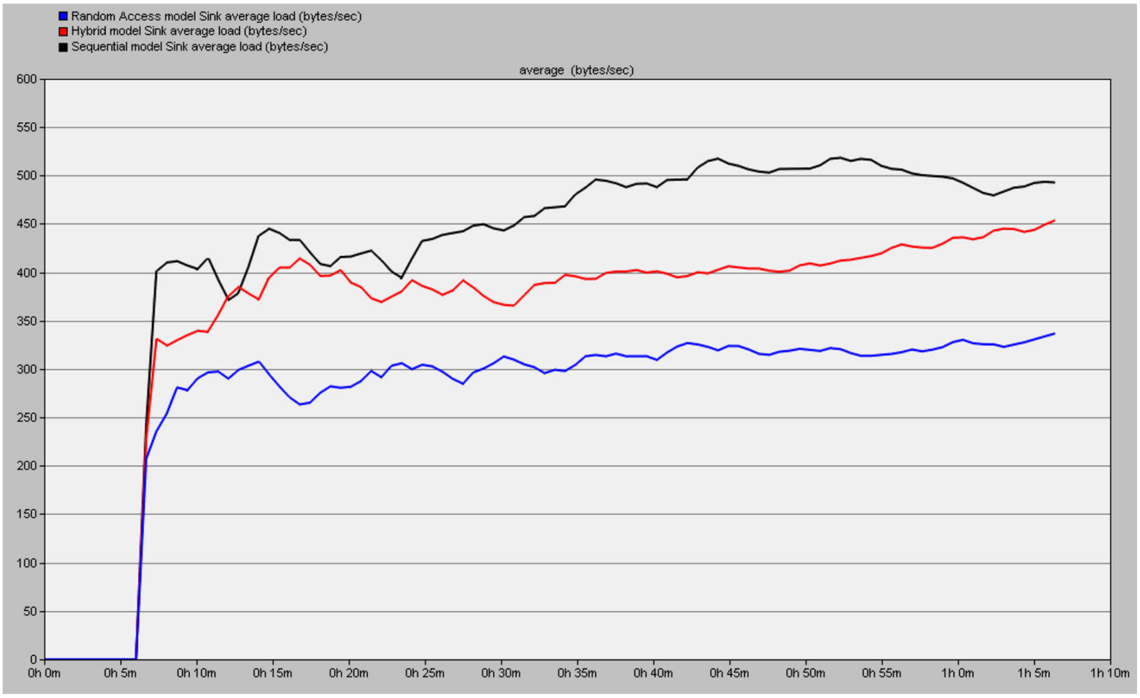


Fig. 14 Sequential model sink average load within one hour

Table 3 Results

	Reading Handling Delay (minutes)	Alarm Handling Delay (minutes)	Frame data load
Sequential Model	Best 79.3	worst 87.2	Best 100%
Random Access	worst 166.67	Best 16.67	worst 50%
Hybrid model	Average 111	Average 55.5	Average 85.7%

groups, whereas the third model, the “hybrid model,” combines the advantages of the previous two models. It is scalable owing to the use of grouping. The probability of collision is reduced because it occurs only during alarm transmission. To address this, priority can be assigned to the alarms within each group. Comparing the average sink load, the results illustrate that the sequential model achieves full bandwidth utilization.

To evaluate the applicability of the three models introduced in different areas, the frame data load and time needed to collect the smart meters alarms are taken into consideration. The frame data load is the ratio of the number of TSs carrying data (reading/alarms) to the total number of TSs in a frame. According to the calculations, the BW is divided into twenty-one time slots. In the sequential model, frame data load is the best as the TSs are dedicated to carrying either readings or alarm data. No BW wasted in the channel setup or control messages ((100% BW utilization). However, in the random access model, frame data load is the worst as 50% of TSs are dedicated to CR process. In the hybrid access model, it is average in frame data load as channel reservation is limited to only three TSs; hence, the frame data load is (18/21)= 85.7%.

Moreover, the time required to collect meter readings from all groups in our simulation:

a- SUTSA Sequential model: 100,000/21 = 79.3 min.

b- SUTSA Random Access model: 100,000/10 = 166.67 min.

c- SUTSA Hybrid model: 100,000/15 = 111.1 min

The sequential access model performance is the best in data readings collection.

The time needed to handle the smart meters alarms is studied assuming 10% of alarms ratio, 10,000 ms need to send alarms data at the same time:

a- SUTSA Sequential model: assume that alarms are distributed in all groups, so it will wait for all other groups to complete sending their reading data groups time (79.3 min) + alarms time (10,000/21 = 7.9 min) = 87.2 min

b- SUTSA Random Access model: sink will give priority to alarms at this time and assign all available ten time slots to alarms 10,000 alarms/10 TSs = 16.67 min.

c- SUTSA Hybrid Model: It can handle only three alarms per frame 10,000 alarms/3 TSs = 55.56 min.

As shown in Table 3, the random access model achieved the lowest time needed to collect the meters alarms. It approximately takes 16.67 min to handle all meters’ alarms. Therefore, this model is the most fitted for encountering a high volume of alarms.

These results indicate that the three models can be utilized in different situations based on application requirements. Table 3 presents a comparison summary of the three models proposed.

Table 4 presents a comparison between related works and our proposed work. Our work minimizes the system complexity by using an existing infrastructure network, archiving on-demand reading requests, and handling alarms. Employing a wired network overcomes the interference that causes a wireless network to malfunction.

To evaluate the performance of our proposed algorithm against other algorithms proposed in related work, we compare our proposal with the optimal proposal in [21] and TDMA-NNFS in [27]. The comparison is made in terms of data collection time, packet delivery ratio (PDR), and end-to-end delay for 100 smart meters. The results in Figs. 15, 16, 17 show that our proposal has the lowest end-to-end delay and data collection time of 680 ms and 4.80 sec, respectively. In addition, the highest PDR of approximately 99.86% is achieved.

5 Conclusion

In this paper, a smart utility traffic scheduling algorithm based on the IoT is proposed. It helps in developing smart metering networks, which enables utility companies to offer their services more effectively by collecting meter readings, data, and alarms in real-time automatically.

The importance of the proposed model stems from several factors: First, it is built on a wired network infrastructure to address and overcome all wireless issues based on similar techniques. Second, it reduces system complexity by using power lines as a data transmission medium. Three different scheduling models are proposed for collecting the smart meters readings data and alarms that are suitable for different practical implementations.

Different simulation scenarios are used to test the validity of the proposed models. The results indicated that the sequential model achieved the best frame data load with a high average time in response to the alarm. The random access model achieved the least frame data load with the best alarm response time. The hybrid access model achieved the average frame data load and alarm responding time. These three

Table 4 A comparison between the related work and the proposed work

Paper	Objective	Scalability	Load Scheduling	Load Management	Cost reduction	Transmission Latency	Interference	System Complexity
[19]	MAC layer user scheduling algorithm for broadband power line carrier communication in a concurrent mixed service scenario	No	Yes	Yes	Yes	Low	No	Yes
[22]	Intensive data collection method for smart energy and smart building systems	NA	Yes	No	Yes	Low	No	Yes
[23]	Scheduling of data collection utilizing metadata from sensors that are describing dynamics of information	No	Yes	No	No	Low	NA	Yes
[51]	A multi-gate mesh network to handle the metering traffic, under time varying outage conditions	Yes	Yes	No	NA	Low	Yes	No
[24]	Formation game based joint resource scheduling algorithm (FGRSA)	Yes	Yes	Yes	No	High	Yes	Yes
[25]	A traffic scheduling mechanism based on interference avoidance for meter data collection in Meter Data Collection Building Area Network (MDCBAN)	Yes	Yes	Yes	No	High	No	No
[26]	Data collection and da transmission algorithms for Neighborhood Area Network	No	Yes	Yes	NA	Low	Yes	Yes
[52]	A performance analysis of the RPL routing protocol in a typical AMI network	Yes	Yes	Yes	Yes	Low	Yes	Yes
[28]	Improve the scalability of 802.11 s, making it better for Smart Grid AMI applications	Yes	Yes	NA	NA	High	Yes	No
[30]	A fair-delay constraint energy consumption scheduling method in smart grid distribution	Yes	Yes	No	No	High	NA	No
[31]	Shaping users' electricity load profiles using demand response management (DRM)	Yes	Yes	No	NA	Low	NA	No
Our work	Smart Utilities Traffic Scheduling Algorithm (SUTSA) collects meter readings data and alarms, peak load traffic management	Yes	Yes	Yes	Yes	Low	No	No

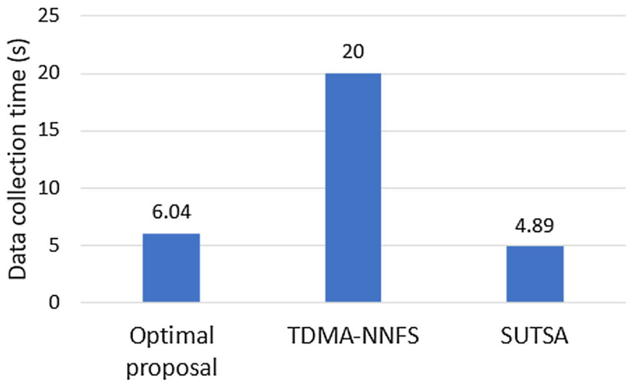


Fig. 15 Data collection time for 100 SMs

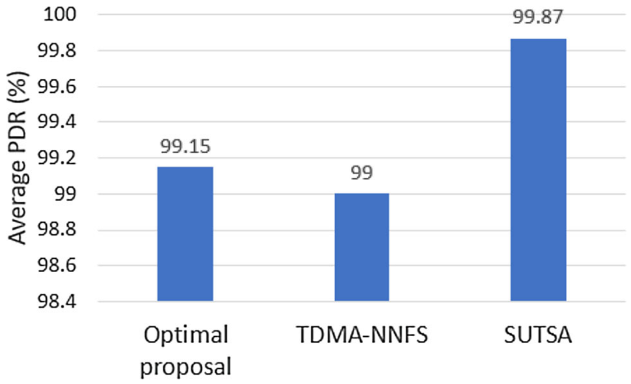


Fig. 16 Packet delivery ration PDR for 100 SMs

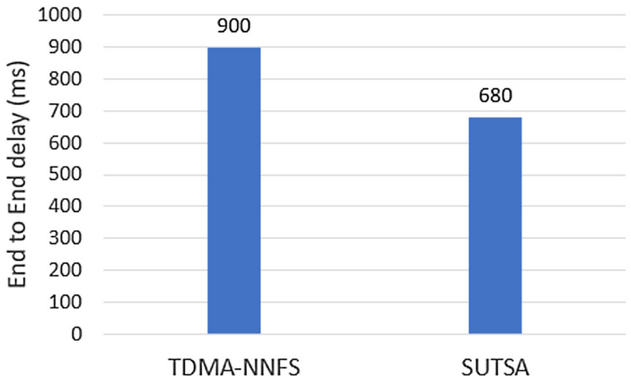


Fig. 17 End-to-End delay for 100 SMs

models can be utilized in different situations based on different application requirements. These findings validated the efficacy and performance of the proposed algorithm.

In the future, we are looking to evaluate the model with a redundant sink node for network redundancy. In addition, security solutions are studied to ensure the comprehensive security of the PLC system, including all different nodes (meter, sink, and headend).

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Declarations

Conflict of interest Authors declare that they have no conflict of interest.

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

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