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A self-sustainable opportunistic solution for emergency detection in ageing people living in rural areas

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Abstract

There are contexts where communication with TCP/IP protocol is not possible due to the lack of infrastructure or a reliable and continuous data transmission. In this cases, alternatives such as Opportunistic Networks (OPPNets) are valid. Such challenging conditions are common in rural areas and are a significant obstacle for the deployment of eHealth technologies for older adults. Considering this context, the present work introduces Interest-based System for Communication in Isolated Areas (ISCA), an OPPNet architecture for remote monitoring and emergency detection in ageing people who live alone. For this, the energetic requirements are considered, providing efficient and sustainable operation. The proposal makes use of a routing algorithm based on interests which enables asynchronous communication among entities. ISCA is evaluated over a realistic scenario and compared with similar state-of-the-art solutions. Experimental results show that ISCA notably improves the delivery probability with an enhancement of 52.25% in comparison to the second best alternative and provides a suitable average latency. Moreover, it also achieves better performance in terms of overhead and hops number compared to the other studied protocols

Keywords Dtn · Performance assessment · Isolated elderly people monitoring · Opportunistic networks · Sustainable · Routing algorithm · Rural areas

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1 Introduction

There are contexts where communication with TCP/IP protocol is not possible. The high requirements of a consistent path between the sender and the destination nodes makes this technology impracticable for certain situations. Some places lack the required infrastructure to perform Internet-based transmissions, shaping a network where nodes face interference, connection interruptions and latency. This is the case of the rural areas, where these challenges may prevent healthcare and industrialisation [1]. The lack of communication infrastructures or Internet coverage becomes adverse for deploying eHealth proposals. This fact exacerbates the health risks, specially for older adults who live alone. Then, services such as home medical assistance or emergency detection are sometimes hard to deploy [2].

Technological solutions have become disruptive tools for healthcare. There are many projects which provide clinical assistance [3], as well as emergency detection [4]. Therefore, the recognition of risks in ageing people is

enabled even when they live alone [5]. Projects benefit from the Internet, smartphones and wearable devices to create programs that allow virtual care. Therefore, new dimensions of health assistance and attention are unprecedentedly achieved. However, these techniques and applications reveal the significant technological gap between places with an Internet connection and unconnected regions, especially in rural and low-income areas [6]. Thus, these differences highlight the unbalanced industrialisation and the contrast between urban places and rural areas.

As a consequence of this situation, the present work aims to provide a self-sustainable solution for isolation monitoring and emergency detection in rural areas, where a continuous connection and the routing to the Internet is not always possible. Based on the concept of opportunistic networks [7, 8], Interest-based System for Communication in isolated Areas (ISCA), a communication architecture is proposed to alert about potential risks. Equipping homes with presence sensors allows the architecture to detect anomalies in the presence of ageing people at home. Therefore, dangerous situations are identified, such as eventual falls or walks with no return. This way, the anomaly information is transmitted to the medical centers by opportunistic communication provided by intermediate nodes, which can be vehicles, pedestrians or throwboxes [9, 10].

The proposed architecture aims to provide communication with a self-sustainable operability. Therefore, the energy requirements to exploit and maintain the data delivery have to be aligned with a low power consumption. This factor is specially motivated by the necessity of involving heterogeneous devices in the network, requiring their viability to perform as nodes while carry out other independent tasks. Considering this specification, the architecture proposes the deployment of throwboxes powered by solar panels.

This paper is organised as follows: firstly, Sect. 2 exposes related works about eHealth and opportunistic based solutions. Secondly, Sect. 3 describes ISCA and the core of the proposal, introducing the system and its different components. Then, Sect. 4 analyses the performance of the solution, comparing the results with other alternatives. Finally, Sect. 5 draws some conclusions of the approach and presents future work directions.

2 State of the art

The present work involves a set of different disciplines, technologies and techniques such as health assistance, emergency detection and offline communication.

Therefore, the next subsections introduce the techniques and state-of-art works of these disciplines.

2.1 Telemedicine for ageing people

The global pandemic situation and the widespread ageing have positioned telemedicine solutions as one of the most relevant for healthcare. Multiple works provide effective remote health assistant to patients, providing monitoring, communications and diagnosis [11]. In this section, some of these solutions applied to ageing people are summarised.

The work presented with CardioNet [12] studies the impact of IoT on the design of eHealth solutions. This proposal exposes the real relevance of IoT solutions and the role they will play in medicine. In this line, the work described in [13] makes use of image processing techniques to identify eye diseases from patient pictures with low-cost instrumentation for low-income areas.

The monitoring of vitals defines also a solid research line with Bluetooth Low Energy (BLE) technology [14]. Other works apply BLE to trace accompaniment patterns in people [15] or image processing to study psychiatry well-being of the patients [16].

All these proposals show the progress in telemedicine, remote assistance or emergency detection. Furthermore, technologies such as 5G [17], artificial intelligence [18] or robotics [19] disrupt in these contexts. However, many of these contributions are not applicable for rural areas which lack of Internet infrastructure. Next, some works which explore solutions in these scenarios are detailed.

2.2 Offline eHealth solutions

There are still many regions where the Internet connection is not enabled [20]. Thus, some approaches bring alternative communication models to provide services.

Advances described in [21] propose the deployment of a local wireless network which allows communication between social workers and doctors. In the case of [22], tele-ultrasound based on volumetric sweep imaging is used for health data transmission. Works such as [23] propose an Intranet for rural areas in Bangladesh with a local cloud to share information and discuss local issues between inhabitants. In this line, Suciu et al. [24] exposes the "basic Internet", a local offline Internet built with text and images. Following a different purpose but centred on health assistance, the works proposed in [25, 26] address therapeutic adherence with an offline voice assistant that reminds ageing people to take medication.

In conclusion, these works serve as a model for new proposals which explore the possibilities of technology for these contexts. This way, opportunistic solutions become

suitable to provide systems with communication, agnostic to Internet availability.

2.3 Opportunistic-based solutions

Opportunistic networks (OPPNets) are a network paradigm based on proximity that enable applications characterized by delay tolerant, asynchronous traffic of low priority information [7, 8]. Making use of intermediate nodes and their cooperation, data is transferred from source to destination, operating without a conventional Internet connection. This way, physical proximity becomes the engine to provide data transmission, using short-range wireless technologies. The own nature of these solutions motivates the deployment of opportunistic networks in scenarios where there are not communication infrastructures due to natural disaster contexts, spatial or sub-aquatic transmission and battlefields [27]. Next, some of these ideas are introduced and compared.

Works such as [28] review more classical applications of OPPNets such as natural disaster scenarios. However, many works explore beyond and provide ultimate services such as [29], which purposes Unmanned Aerial Vehicles (UAVs) to provide efficient cellular coverage for areas without Internet. On an eHealth context, the work [30] analyses how a set of offline solutions respond to challenging contexts. From a technical view, the contribution [31] reviews the use of passing vehicles to shape a network for local information. Concretely for rural areas, Yaacoub and Alouini [21] surveys some proposals which try to provide isolated rural areas with Internet access in a sustainable way, such as [32], a proposal to provide Internet service in regions with intermittent connectivity. Similarly, the project [33] proposes the "Near Cloud", a distributed network based on IoT for rural areas.

ISCA, the solution described in the present work, makes use of a routing solution to transmit information. The routing algorithm has been presented for alternative applications such as an office or a shopping mall [34, 35]. The present work brings these advances together and extends the line with a deeper evaluation of the routing algorithms in a complex realistic scenario. This extension is specially focused on the sustainability of the solution, analysing the technical viability and the power requirements.

In conclusion, opportunistic networks become a suitable option to provide communication to isolated areas in which there is a lack of Internet connectivity. This way, this approach serves as the basis for the current proposal. The next section focuses on the description of the proposed solution and how the work aims to detect and warn about possible emergency situations for ageing people who live alone in isolated areas.

3 ISCA: interest-based system for communication in isolated areas

ISCA proposes a communication architecture for isolated rural areas, based on opportunistic networks, and centred on detecting possible emergencies in ageing people's homes. The introduced mechanisms monitor ageing people's presence without an Internet connection, detecting anomalous behaviours using presence information. This way, sensors installed along homes gather the presence data and transmit it to intermediate nodes, which collaborate to forward messages to the destination. These routing possibilities respond to the necessity of transmitting information in disconnected areas. Therefore, ISCA can be exploited to generate and communicate multiple kinds of data.

The present approach is centred on detecting possible emergencies on ageing people but, considering the deployment in a rural context, ISCA can be easily conducive for other relevant functions such as local businesses. Hence, businesses such as hives or livestock can potentially benefit from the proposed architecture, generating and sending information about crop performance, animal's position or food supplies. As a result, owners and workers can be notified about events and production statistics.

To perform the communication of the collected data, the work makes use of intermediate nodes which can serve as information mules between senders and destination. These entities can be smartphones, vehicles or throwboxes [10, 36]; collaborating to asynchronously forward data following routing policies based on the interests of nodes so that intermediate nodes only cooperate with the topic of their interest. As a result, the solution distinguishes three possible interests for nodes: presence of ageing people, performance of local rural companies and both.

Energy requirements and power consumption are also variables considered in the architecture. Aiming to improve the autonomy and independence of the proposal, the work makes use of throwboxes, independent devices powered by solar panels. Taking into account this feature, throwboxes are deployable in isolated points without requiring a connection to the electrical network. Additionally, considering that autonomous devices such as smartphones and cars are also involved in the data forwarding, the architecture aims to enhance the viability of these elements to perform as nodes while execute another tasks.

In this section, the concept of the proposal is explained more thoroughly, highlighting the multiple functions and the most relevant design decisions of the work. Thus, the considered architecture is explained through the division into three main stages: (1) data gathering, (2) data forwarding and (3) data delivery. Figure 1 depicts these three
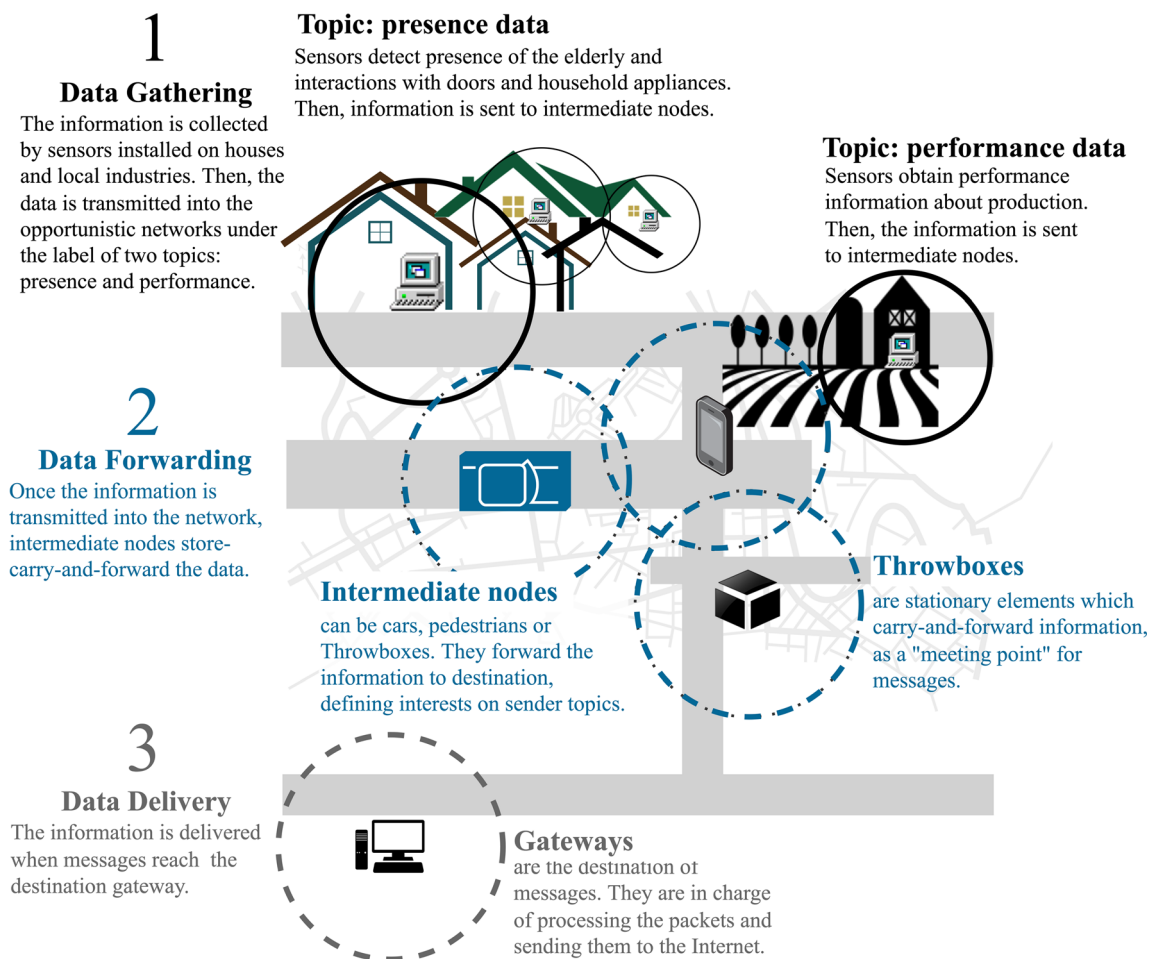
1

Data Gathering

The information is collected by sensors installed on houses and local industries. Then, the data is transmitted into the opportunistic networks under the label of two topics: presence and performance.

Topic: presence data
Sensors detect presence of the elderly and interactions with doors and household appliances. Then, information is sent to intermediate nodes.

Topic: performance data
Sensors obtain performance information about production. Then, the information is sent to intermediate nodes.

2

Data Forwarding
Once the information is transmitted into the network, intermediate nodes store-carry-and-forward the data.

Intermediate nodes
can be cars, pedestrians or Throwboxes. They forward the information to destination, defining interests on sender topics.

Throwboxes
are stationary elements which carry-and-forward information, as a "meeting point" for messages.

3

Data Delivery
The information is delivered when messages reach the destination gateway.

Gateways
are the destination of messages. They are in charge of processing the packets and sending them to the Internet.

Fig. 1 Elements in ISCA

stages, along with the different elements of the architecture.

3.1 Data gathering

The network architecture proposed in this work supports different delay-tolerant applications enabling distinct services. In this particular case: (i) the presence of ageing people at their homes and (ii) the performance information of rural businesses. Therefore, there are two sources of data: the ageing people's homes and the local rural companies.

3.1.1 Presence information from ageing people's home

Information about the people's presence is obtained at their homes. This way, data about daily habits and patterns are monitored. A large amount of registered information allows the detection of anomalous or dangerous situations, notifying the status to the health service using the proposed opportunistic solution.

The set of multiple sensors installed along the house provide the information collected about the presence (Fig. 2). Thus, devices are located in strategic points like doors, appliances, windows or corridors, detecting the movements and storing the data in the main computer. This element is called *home brain* and is in charge of processing and gathering all the information, carrying out the transmission to the opportunistic network. This device can be a computer but it is not required much performance so it can be implemented on a Raspberry Pi [37]. As a result, multiple data can be obtained like the time spent indoors and outdoors, sleeping time, visitors records, paths inside the home, the usage of appliances or even the use of a medicine box. Considering a large number of records in the dataset, emergency detection and proactive predictions are performed remotely. Therefore, new reports about presence are remotely processed, detecting anomalous values like long absences and feeding the previous knowledge to achieve better performance at predictions. This mechanism enables refining the system to distinguish between usual
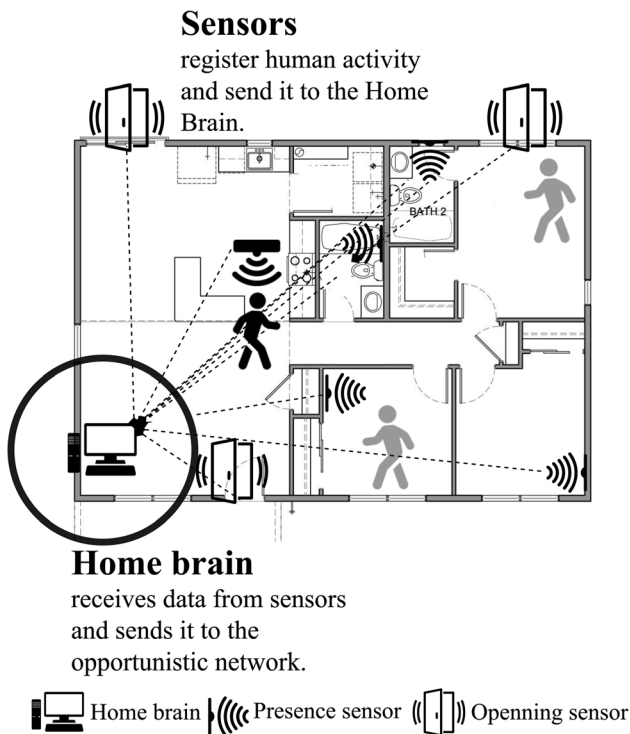
Sensors
register human activity and send it to the Home Brain.

Home brain
receives data from sensors and sends it to the opportunistic network.

🖥 Home brain)(((Presence sensor ((|)) Openning sensor

Fig. 2 Sensors located inside an elder's home

absences and hazards. As a result, the local brain just gathers and transmits the data toward the network.

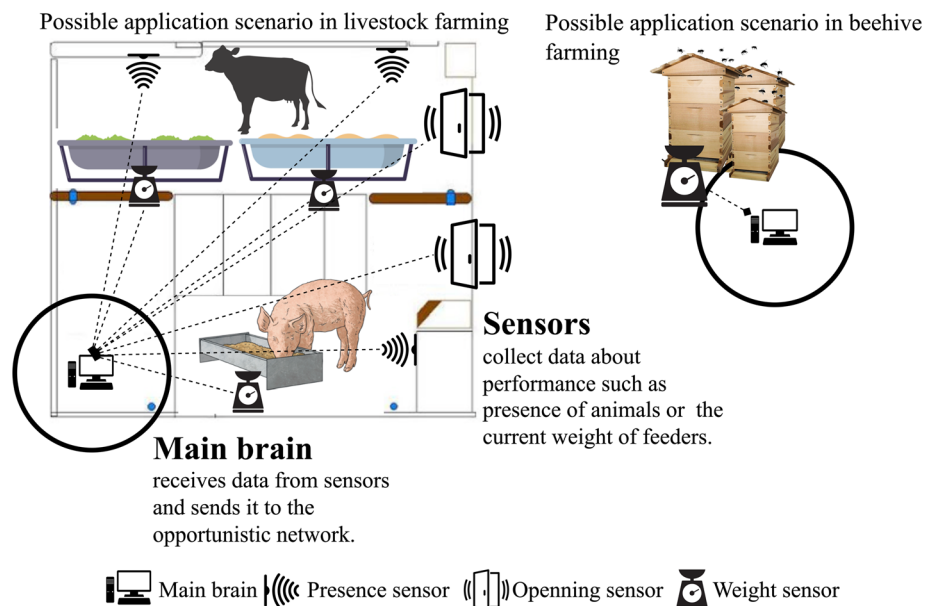### 3.1.2 Performance data from local rural companies

The proposed network architecture provides local companies, livestocks, crops or farms with the transmission of performance data to remote servers (Fig. 3). The obtained

records allow owners to know details about the production processes and how crops or beekeeping are evolving. Therefore, this function is eminently oriented to the owners of distant farms. Considering the variety of local companies in rural areas, the way the performance monitoring is done depends actively on the sector. However, sectors like cattle raising, hives or livestock find monitoring especially attractive to track animals, check food supplies or collect products. Thus, sensors can provide interesting values. This way, in the case of hives, the weight of boxes denotes the honey production or, in the case of farms, the weight of feeders shows the available food supplies for animals. In the same way as in the ageing people's homes, the sensors communicate with the main brain which gathers and broadcasts the information using the opportunistic network.

Considering the two sources of information, the generated messages are prepared to be transmitted through the network. Taking into account that the gathered information is lately processed when it is received to detect emergencies, all measurements are transmitted with the same priority. The main idea of this is to define a clear definition of the behaviour patterns of the older adults in the destination entity. Then, a large set of values enhances the potential detection of anomalous behaviour. Furthermore, processing large amounts of information enables the application of data mining processing or machine learning predictions, techniques which evidence the relevance of exploring activity to infer and detect patterns [38, 39]. Thus, once the main brain receives the data from the sensors, it transmits the measures to the opportunistic network.

The information about presence activity and performance data is sent into the network using JavaScript Object Notation (JSON) format [40]. Then, each measured value

Fig. 3 Sensors located in farm companies

Possible application scenario in livestock farming

Possible application scenario in beehive farming

Sensors
collect data about performance such as presence of animals or the current weight of feeders.

Main brain
receives data from sensors and sends it to the opportunistic network.

🖥 Main brain)(((Presence sensor ((|)) Openning sensor ⚖ Weight sensor

is mapped to a 3-tuple of type {time, sensor, measurement}. (1) The first parameter indicates the time in which the data was registered by the sensor. Thus, the time and the date are specified in this field. The field (2) sensor identifies the device which generates the information, including its reference and its placement details. Then, the (3) value of the measurement is provided. As a result, the format enables the comprehensive identification of the data source and its value. Illustrating this explanation, Fig. 4 draws the format of the JSON file for a transmitting data from a home brain.

In the next subsection, the process of data exchange between information sources and destination gateways is described, distinguishing the different roles of these network nodes and the mechanisms used to forward the messages.

3.2 Data forwarding

Once the source of information (senders) generates new data that must be sent through the network, the involved entities are in charge of communicating the messages to the destination nodes (gateway). Following the philosophy of store-carry-forward of opportunistic networks, intermediate nodes make use of proximity to replicate the data to nearby nodes to reach destination, which can be health centres, cultural centres...etc, that are connected to the Internet. As a result, the involved devices move and interact between them, serving as data mules exploited for their mobility, thus, linking senders and receivers.

The routing process is explained in Fig. 5, which represents two different timelines with different colours: timeline 1 in blue and timeline 2 in orange. The first line represents the sender sending a message for the surrounding devices, vehicle A and phone A. Both entities move across the scenario. On the one hand, vehicle A shares the information with the throwbox, which stores the data. On

Fig. 4 JSON format of the transmitted measurements

the other hand, phone A finds another smartphone (phone B) and copies the message to it. This way, timeline 2 shows how vehicle B appears and obtains the information from the throwbox, following its path and reaching the destination. In addition, phone B also reaches the gateway and delivers the message to it.

The routing processes depend on the interests that the device defines. Thus, nodes accept or decline messages depending on the interests they agree with: (i) the people's presence, (ii) the performance of local businesses or both. This way, a virtual profile based on [41] keeps all the topics in which the node is interested. Therefore, nodes only operate with the data in which they are interested, ignoring the non-matching topics. As previously explained, depending on the device involved in the network, three different types of intermediate nodes are considered: pedestrians, vehicles and throwboxes. Their main differences are the mobility features and the communication range in the scenario. Table 1 shows the features of the three device groups sorted by distance range. In the following section, the role of each element is described.

3.2.1 Pedestrians

People in the street who carry a smartphone are considered pedestrians in the architecture. Smartphones are equipped with multiple communication technologies, which become a key element in the system. ISCA exploits this to communicate information asynchronously. To make this possible, it is necessary to provide smartphones with an application that is able to receive, store and replicate the information. This program enables the cooperation as a network node, providing connection with surrounding pedestrians, vehicles, throwboxes and any data source.

The app enables the device to subscribe to one or more topics. Therefore, the smartphone only accepts, stores and forwards messages related to those topics of interest. Considering that smartphones count on a battery which allows the device to perform multiple simultaneous tasks, energy optimization in phones is not taken into account in this work.

3.2.2 Vehicles

Vehicular nodes allow travelling long distances and communication on surrounding villages with gateways or areas with Internet connection. The way message transmission is implemented on vehicles can be performed in two different manners: (i) to use the smartphone of the driver or any traveller in the car, or (ii) to equip the car with the technology to receive, store and forward information [42]. Any of these options can be easily used in the proposed architecture. However, the possibility of deploying in the car a
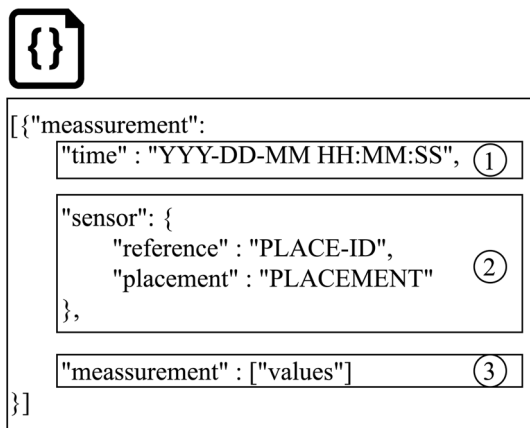
Fig. 5 Example of routing with intermediate nodes

Sender transmits the information to surrounding devices.

Intermediate nodes may encounter synchronously.

Intermediate nodes may never encounter but Throwboxes enable communication.

phone A t1

car A t1

phone B

car B t2

Sender Throwbox Destination Message

Timeline 1 Timeline 2

Timeline 1 < Timeline 2
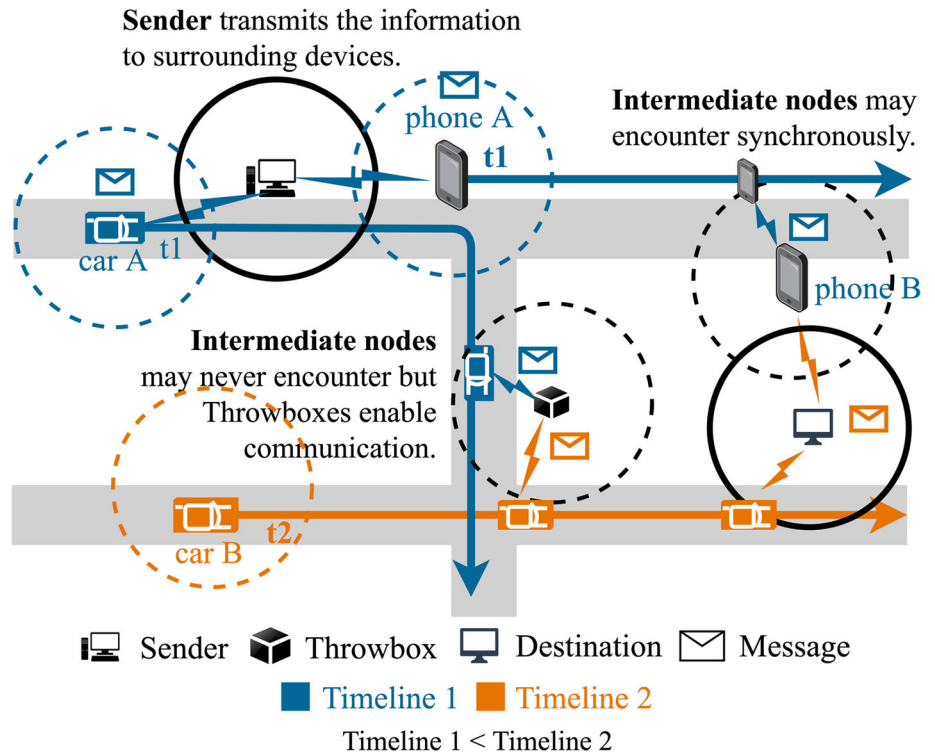
Table 1 Features of the intermediate nodes

Device	Mobility model	Message reachability
Smartphone	Mobility limited to specific areas with low speed	Local areas
Vehicles	Wide mobility possibilities with high speed	Regional areas
Throwboxes	Stationary. It acts like a message interchange point	Fixed remote areas

wide-range Bluetooth antenna becomes especially interesting. Considering the multiple devices integrated in the architecture, using Bluetooth simplifies the communication process, enabling a common technology for all nodes. Equipping this technology on vehicles is based on onboard computing units which provide limited computation and storage [42]. Therefore, vehicles are considered as independent elements of the architecture. Besides, the energy consumed by car nodes is not considered in the proposed solution because of the small impact of the communication tasks in the global energy consumption of the vehicle.

3.2.3 Throwboxes

Throwboxes [36] are autonomous static devices installed in roads and crossroads which receive, store and forward messages opportunistically to encountered nodes. This way, throwboxes enable communications between source and final destination nodes without requiring a direct contact between them, making possible transmissions that would not be possible in other circumstances. Hence, these

elements require a self-sustainable operability which enables its autonomy and independence.

The possibilities of throwboxes to store and transmit information to passing devices make the physical location a key characteristic. Assuming that the devices are potentially deployed in isolated rural areas, it is necessary to supply them with power, independently of the global electricity grid. For this, throwboxes are fed with a solar panel which provides energy to the battery. Nevertheless, the battery consumption depends actively on the operations that the device performs. Therefore, every performed task has a cost in terms of energy consumption. Hence, it is relevant to explore the viability of the throwboxes and the eventual power constraints in the proposal. For this, the results section analyses the energy consumption model, energy gathering and battery evolution of this element of the architecture.

As it can be seen, ISCA is based on the cooperation of different elements. Thus, once the data is distributed through the network, the destination node receives the messages and is able to send it to the Internet. To explore

this, the next section describes the process of data reception.

3.3 Data delivery

The last step in the proposed network architecture is the process of delivering the information at the gateways. Therefore, these devices must reunite a set of required features.

Gateways are autonomous devices that are able to receive, store information and transmit data to the Internet. Therefore, gateways must count with a stable Internet connection. Moreover, this condition forces the gateway to be installed outside the isolated area. As a result, when the new data is received by the device, the gateway transmits it to the cloud, serving the collected records to the corresponding web service.

Communications in ISCA are performed thanks to an opportunistic routing protocol. This way, it is possible to integrate well-known routing solutions to perform data transfer in the architecture. Nevertheless, ISCA fits perfectly with the algorithm SACAR OCVN, a protocol which enables the data delivery based on topics and subscriptions. In the next subsection, the functioning of this algorithm is detailed.

3.4 SACAR OCVN

SACAR OCVN is the routing algorithm integrated with ISCA to provide data transmission between nodes. Although this component was originally defined in the works [34, 35], it has been adapted to the current proposal. SACAR OCVN defines the policies and rules required to forward the information based on the interests of the nodes. In order to do it, the algorithm makes use of virtual profiles for each node in the network [41]. Originally, these entities distinguished between the nodes aimed at performing tasks and the nodes able to satisfy them. However, this philosophy has been adapted to use the virtual profiles as a resource to define the topics that the nodes are interested in. Hence, it is possible to automatise the communication between nodes, restricting the traffic to those interested in the topics matching the transmitted information.

As Fig. 6 shows, SACAR OCVN follows three steps to perform transmission based on interests: (1) devices with virtual profiles are encountered; (2) virtual profiles are exchanged; and, if there is a match between interests, (3) information is sent.

These phases of interactions with SACAR OCVN are based on an architecture of four main tiers: (1) virtual profile, (2) messages buffer, (3) Application Programming Interface (API) for interactions, (4) Communication

Application and (5) Bluetooth. Figure 7 reflects the distribution.

1. Virtual profile. This element is in charge of storing the set of interests of the node. This way, topics are kept to identify those messages which become relevant for the node. The implementation of this component fits with a database and it is compatible with other proposals for data storage such as SOLID [43].
2. Message buffer. This component stores the messages that the node has created or received. Thus, it is possible to transmit them when the node encounters an interested device. For this, messages are structured with the fields: *id of the message*, *source node*, *destination node*, *topic* and *message content*.
3. Application Programming Interface (API) for interactions. This component enables the interaction and manipulation of the information stored in the virtual profile and in the message buffer.
4. Communication Application. This component makes use of the upper layer 5) Bluetooth to discover surrounding devices and to transmit and receive messages. However, the communication technology can be generalised to any type of connection protocol such as 802.11n/ac/ax or 802.11p [44]. In order to interact with the messages in buffer, the application makes use of the API interface to check, add and remove the stored information.

SACAR OCVN provides a routing algorithm which prioritises the individual interests of the nodes. Thus, the protocol enables sharing data when the encounters are interested in the information. As a result, it provides a suitable way to forward messages toward destination, aligning its philosophy with the communication features of ISCA. The light computation, which do not require the deployment of heavy computation engines, and storage requirements make SACAR OCVN viable for heterogeneous networks, where multiple types of devices collaborate. Considering the insights of the proposal, the next section analyses the performance of the solution, comparing the results with other routing protocols as well as studying the energy consumption requirements.

4 Experimental results

In this section, the proposed architecture is evaluated through simulations in a realistic rural scenario. Results are evaluated and the global performance is compared with other state-of-the-art opportunistic routing solutions.

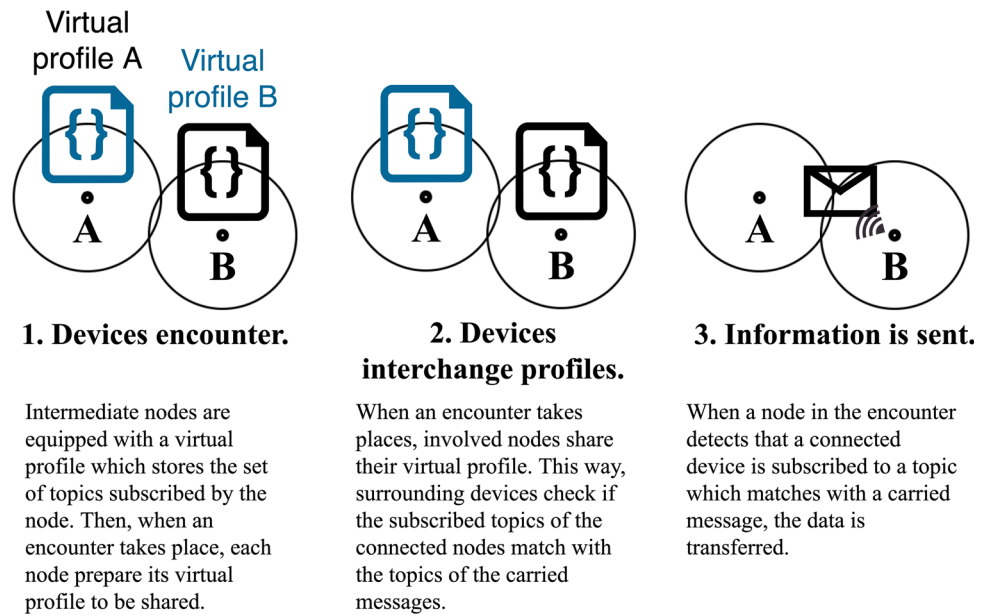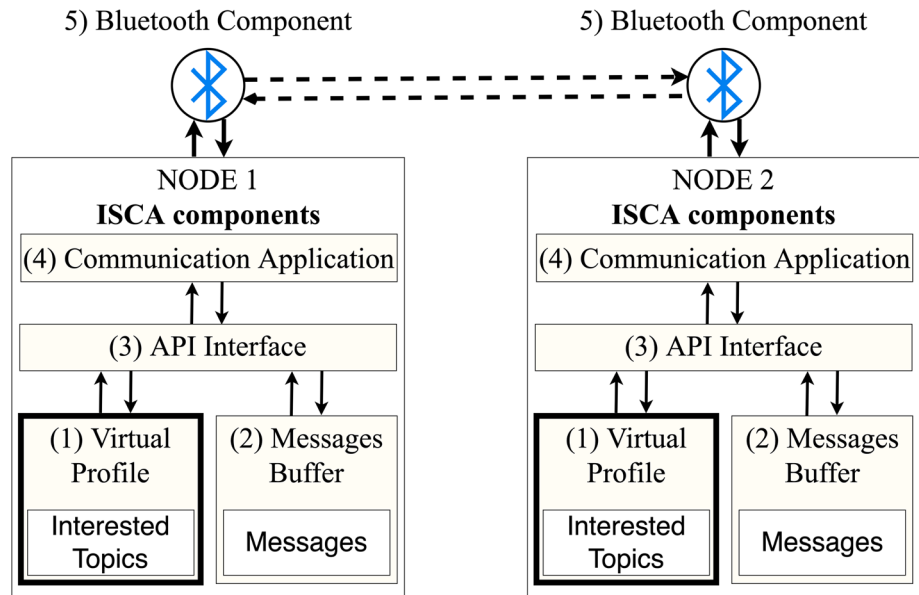**Fig. 6** SACAR OCVN communication procedure

1. Devices encounter.

Intermediate nodes are equipped with a virtual profile which stores the set of topics subscribed by the node. Then, when an encounter takes place, each node prepare its virtual profile to be shared.

2. Devices interchange profiles.

When an encounter takes places, involved nodes share their virtual profile. This way, surrounding devices check if the subscribed topics of the connected nodes match with the topics of the carried messages.

3. Information is sent.

When a node in the encounter detects that a connected device is subscribed to a topic which matches with a carried message, the data is transferred.

Fig. 7 SACAR OCVN architecture components

4.1 Simulation setup

We have defined the simulation setup using The ONE Simulator [45] version v1.6.0.[1] The scenario recreates a rural area from Las Hurdes, Extremadura, characterized by its agriculture and disperse population. Thus, nodes in the scenario are distributed in the map (see Fig. 8a) following the next groups: (1) ageing people's homes and (2) livestock farming produce information to be sent to the network, which is composed of intermediate nodes such as (3) pedestrians, (4) vehicles and (5) throwboxes, each one with its interests. Thus, all these devices serve as data mules to

reach one of the three (6) gateways located in the scenario. Figure 8(a) shows the aerial aspect of the real localities and Fig. 8(b) represents the simulated scenario.

The most relevant simulation parameters are as follows: scenario dimensions, $A = 33.07 \, [\text{km}^2]$, which achieves the most similar aspect to the real scenario; simulation length, $T = 28,800 \, [\text{s}]$, which represents the hours of more activity in the place, from 08:00 h to 15:00 h; message generation interval, $\omega = 60, 900, 1800, 3600, 14,400 \, [\text{s}]$, which specifies the frequency at which messages are generated; communication interfaces, $I = Bluetooth$, finding on Bluetooth an adequate wireless technology for the heterogeneous devices of the architecture. Stats from [46] are

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[1] https://github.com/akeranen/the-one.
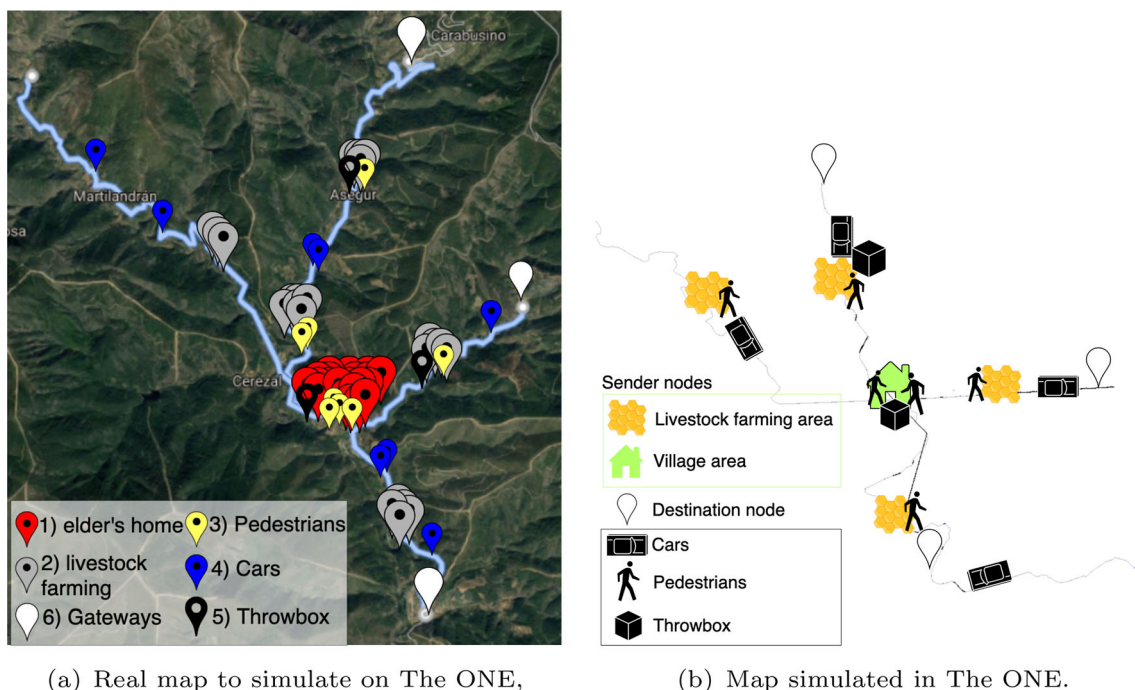
(a) Real map to simulate on The ONE,

(b) Map simulated in The ONE.

Fig. 8 Map implemented for simulations

adopted to define the range, I_r, of 100 ms and a transmission rate, I_s, of 1 MB/s. Finally, considering the present work bases the energy consumption measurements in the advances of [47, 48], the metric of message size, M_{size}, is 300 [KB], according to these proposals.

4.1.1 Nodes

The node distribution aims to recreate the average population of rural areas [49]. For this, There are six main node types in the scenario: two kinds of senders, three possible intermediate nodes and one gateway type. Intermediate nodes define irregular interests about the transmitting data: some carry information about the presence of ageing people; others define interest in livestock data; others define both; and others lack any interest. Following an average profile for rural areas [49], the global number of nodes in the scenario, N, up to $N = 152$. Within this number, the three different groups of the architecture are distributed: senders, intermediate nodes and destinations. The first ones are almost half of the population, defining 52.6% of sender nodes. Behind this, 60 senders are ageing people's homes and 20 are rural businesses. Thus, the remaining 47.4% is composed of intermediate nodes of different types, 19 pedestrians, 47 vehicles and 3 throwboxes; and by 3 gateways located in the scenario. Considering this distribution, the visual aspect of the simulation is shown in Fig. 8(b).

4.2 Performance analysis

This section analyses the results obtained after executing the proposed solution over the considered scenario. Firstly, the parameter settings are described.

4.2.1 Performance metrics

The performance of the solution can be determined by four main metrics, provided as outcomes from The ONE Simulator [50]: delivery probability, d_{prob}, which reflects the percentage of unique messages which reach the destination node; average latency, τ, which reflects the average time needed to receive a message once it is sent; overhead ratio, θ, which relates the duplicated received messages; and average hop number, γ, which represents the average number of intermediate nodes needed to reach destination.

In addition, the message generator interval, ω, manages the overall number of messages sent, M_{gen}. Therefore, this variable defines the load of the network. Then, it is relevant to identify the most favourable configuration and its impact on the performance metrics. Thus, after a sensitive analysis, five different values are considered: $\omega = 60$ [s], $\omega = 900$ [s], $\omega = 1800$ [s], $\omega = 3600$ [s] and $\omega = 14,400$ [s]. As the emergency detection requires recent data to provide better response, the intervals are the lowest realistic values (60, 900, 1800 and 3600). Also, considering that the simulation time is $T = 28,800$ [s], the interval 14, 400 [s] is included as the maximum possible value for the scenario.

4.2.2 ISCA performance evaluation

The set of results obtained after applying ISCA over the considered scenario are shown in Fig. 9(a), (b), (c) and (d).

Figure 9(a) shows the delivery probability as a function of the message generation interval. As can be seen, as more messages are being sent, less probability to receive them is registered. As a result, the number of messages decreases but d_{prob} improves. Following the positive trend, $\omega = 3600[s]$ achieves a delivery probability of $d_{prob} = 97.50\%$ whereas the maximum is reached at $\omega = 14,400[s]$ with an absolute $d_{prob} = 100\%$. However, since $\omega = 14,400[s]$ and $T = 28,800[s]$ would only provide one round of new messages, values may result into bias. For this reason, the interval $\omega = 3600[s]$ brings the best performance of the solution, with a good relationship between M_{gen} and d_{prob}.

Latency results are shown in Fig. 9(b) as a function of the message generation interval. When the number of messages received at destinations is low the experienced latency is also low. This can be understood as the few messages received were transmitted quickly. In the rest of the simulation, average latency keeps at $\tau = 2872.5[s]$,

which is an acceptable value compared with other situations [51].

Figure 9(c) shows the overhead (θ) results as a function of the message generation interval. This value reflects the relation between duplicated messages (M_{copies}) and received ones ($M_{received}$). Therefore, it reflects the utilisation of the network resources (i.e., bandwidth, storage). In this case, θ reaches the maximum peak in $\omega = 14,400[s]$. Considering the high delivery of this interval, it is easy to deduce that many additional copies were obtained.

The value of hops average (σ) is shown in Fig. 9(d) as a function of the message generation interval. This parameter is a value that depends on the number of new messages in the network. Thus, in low values of ω the recurrent routing of new messages without previous hops, notably decreases the average. However, when ω increases and there are few messages in the network, nodes interact with a small amount of information, increasing the average number of hops.
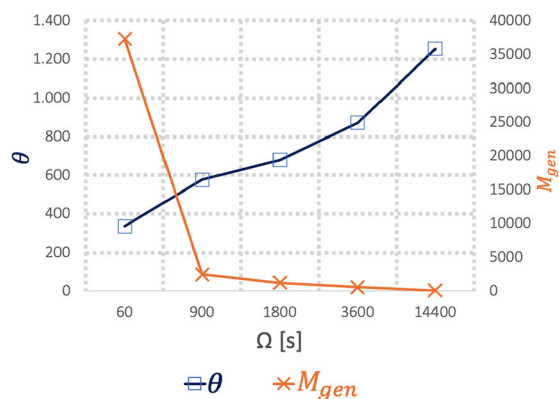
As a result, the delivery probability manifests the practical success of the network and the effectiveness of the communication. Also, the time required by a message
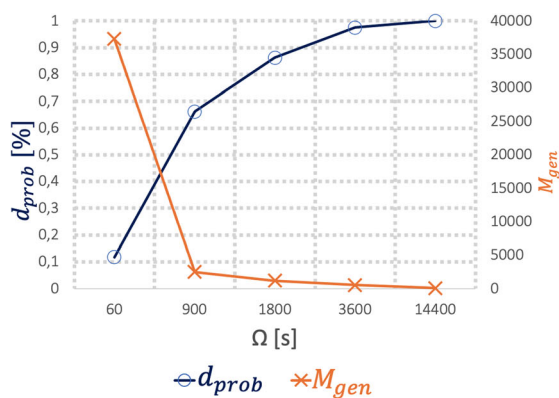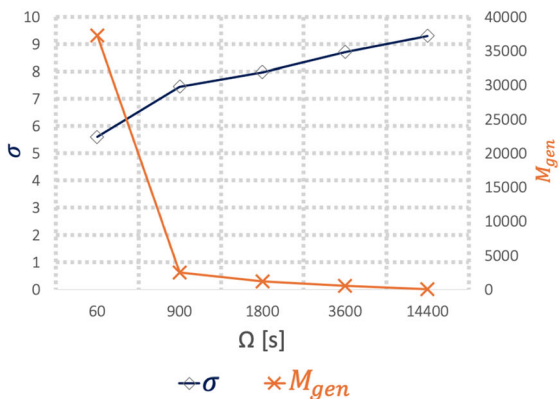

(a) Delivery probability (d_{prob}).
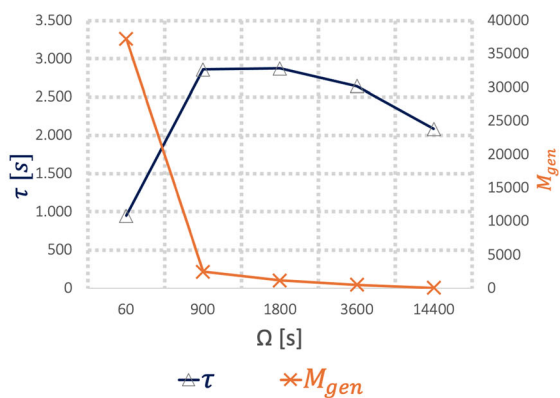
(b) Average latency (τ).

(c) Overhead ratio (θ).

(d) Average hop number (σ).

Fig. 9 Performance comparison

to be received is satisfactory while overhead value and the hops average denote a good performance. This way, based on the best configuration ($\omega = 3600[s]$), the next section compares these results with alternative protocols found in the literature.

4.2.3 Comparison with other solutions

The next section compares the obtained results with consolidated alternative routing protocols which are references in the field [52, 53]. Thus, the considered algorithms are: Life Router [52], which applies the influence of the encountered nodes to perform routing, fitting with the community shapes defined in the scenario; GeoSpray Router [54, 55], which makes use of geographical data to achieve a great performance at vehicular networks; Wave Router [52], which bases the communication on intervals, fitting with the proposed idea of transmitting ongoing data; Simbet Router [56], a solution which makes use of similarity and centrality in node communities, fitting with the case of use described in the scenario; and Distributed BubbleRap Router [57], an algorithm that improves the original BubbleRap by avoiding congestion using encounters, also aligned with the proposal. Thus, the metrics are the same as the previous performance analysis, executing the simulations with $\omega = 3600[s]$, value which provides the best results of ISCA and the most realistic behaviour of the network. By analysing Fig. 10, it can be seen that overall results are favourable to ISCA.

Figure 10(a) compares the delivery probability, d_{prob}, values, showing a great difference between ISCA, $d_{prob} = 97.5\%$, and the other protocols. The improvement in d_{prob} is 52.25% over Wave Router, $d_{prob} = 46.56\%$, the second-best result. In the case of the latency, τ, Fig. 10(b) shows how ISCA reaches the highest average value, $\tau = 2568$ [s]. However, this value can be assumed since the delivery probability is almost absolute. For the overhead, θ, Fig. 10(c) manifests how ISCA keeps a very low value while LifeRouter, SimbetRouter and BubbleRapRouter, due to its flooding mechanims, reach the top values. At last, the hops average, σ, are showed in Fig. 10(d). For this value, ISCA keeps the second lowest value. Among these metrics, delivery probability, d_{prob}, is the most relevant one since it reflects the success at transmitting information towards destination. Then, considering this metric as the main outcome, we can confirm ISCA as the best option among the evaluated solutions.

Considering this, ISCA becomes the best choice for the proposed scenario, providing a communication mechanism with a high delivery probability and acceptable latency. Therefore, we can consider ISCA fits perfectly with the working scheme and becomes a good choice. However, the

solution counts with more dimensions than routing tests. Sustainability performance and energy consumption are also mainstays of the work. Thus, the next subsections study and analyse the energy consumption.

4.3 Energy consumption analysis

One of the premises of the work is performing sustainable communications between nodes. This way, low energy consumption and renewable energies are considered. Therefore, this section analyses the results based on the advances of [48, 58].

4.3.1 Operational energy cost

Considering the simulation scenario executed for the performance comparisons in previous section ($\omega = 3600[s]$, $d_{prob} = 97.5\%$, $\tau = 2641.5[s]$, $\theta = 872.1$ and $\sigma = 8.72$), we analyze the results obtained in the same context.

The parameters considered from the report to be analysed are: node device type (D), number of sent messages (D_{sent}), number of received messages (D_{rec}), number of contacts (D_c) and energy consumed by the node (E).

Figure 11 shows the obtained results. It is composed of three common axes: message interval generation ($i[s]$) in the x-axis, the three devices (smartphone, vehicles and throwbox) in the z-axis and y-axis, which varies between the sub-figures, referring to consumed energy, number of contacts and number of messages, respectively.

The global energy consumption of each device during the simulation is shown in Fig. 11(a). On the one hand, contacts are the most expensive operation, since there is a clear pattern between the energy consumption (E) and contacts, D_c (Fig. 11b). Contacts in nodes are not regular, experiencing a peak at the beginning that decreases as nodes disperse.

On the other hand, sending and reception of messages, shown in Fig. 11(c) and (d), evidence how reception is linked to the message creation. Thus, we can deduce that almost every message created quickly finds a data mule for transmission. Furthermore, two peaks are found in two points of the simulation, i.e., at $i = 14,400[s]$) and $i = 25,200[s]$. However, they have not an evident impact on energy consumption.

In conclusion, the average energy consumed by each device during the simulation shows that vehicles are the devices that require more energy in the scenario. In the case of smartphones, results reveal that they are the devices that consume less energy.

Additionally, throwboxes obtain low values for energy consumption. There are two peaks at message sending and receiving in which throwboxes have served as main
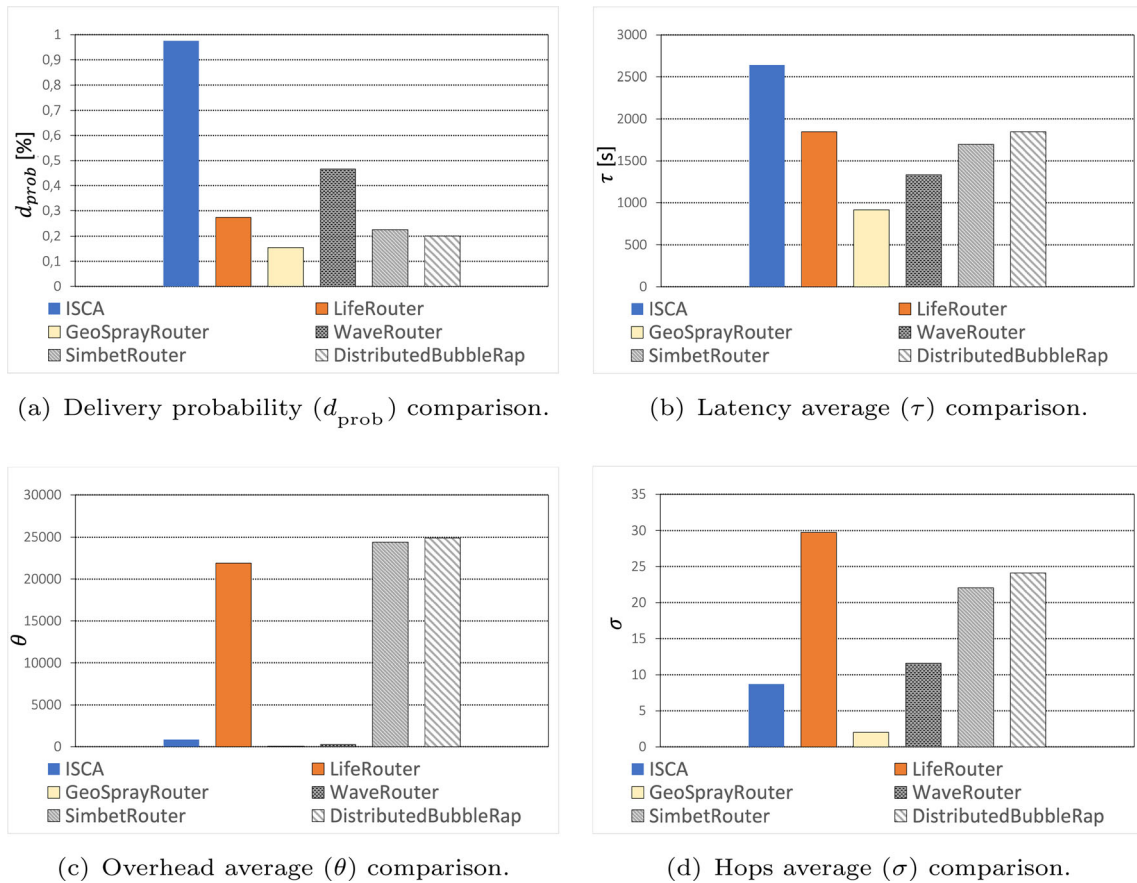
(a) Delivery probability (d_{prob}) comparison.

(b) Latency average (τ) comparison.

(c) Overhead average (θ) comparison.

(d) Hops average (σ) comparison.

Fig. 10 Performance comparison with other solutions

information providers to the network. As a result, the power they consume is low, serving as sustainable options for routing. To explore this, the next subsection studies in detail the energy requirements of throwboxes.

4.3.2 Throwboxes's battery evolution

In contrast with smartphones and vehicles, throwboxes are devices specifically deployed in the network with the aim of collaborating with message forwarding. They are located in strategic points so the easiest way to feed throwboxes with electricity is using solar panels [59]. Considering this, it is possible to determine the viability and sustainability of the proposal, comparing the consumption results with the energy obtained from the solar panel. Hence, real values about the energy production in Extremadura are obtained from PWatts.[2]

As a result, Fig. 12 compares the evolution of three variables: energy consumed (C), energy obtained (E_c) and the battery level (B %), as function of the time (i) in the simulation. Furthermore, the battery counts with a capacity of $B_{\max} = 2300$ mAh and its initial value is $B_0 = 1024$

mAh (44.5% of battery, estimated from the radiation during previous days).

The evolution of E_c and C during simulation evidence a clear ascending trend for the energy captured. As we have seen in previous section, a peak of consumption is detected in the interval at 9:00am. However, once the simulation goes ahead, C stabilises and follows a plain tendency. At the same time, the capture of energy begins with low values which correspond to the first hours of sun at 8:00am. Thus, as the day goes on, E_c value increases until reaching a peak at 13:00pm and at 14:00pm. This tendency draws how the energy provided by the solar panel is higher than the consumed one, manifesting the sustainability and viability of the solution.

4.4 Discussion

The results analysis provides a detailed report about the performance of the solution and the comparison with other routing alternatives.

On the one hand, the presented results show good results at delivery probability rate, latency, overhead and hop average. This results are compared with alternative routing
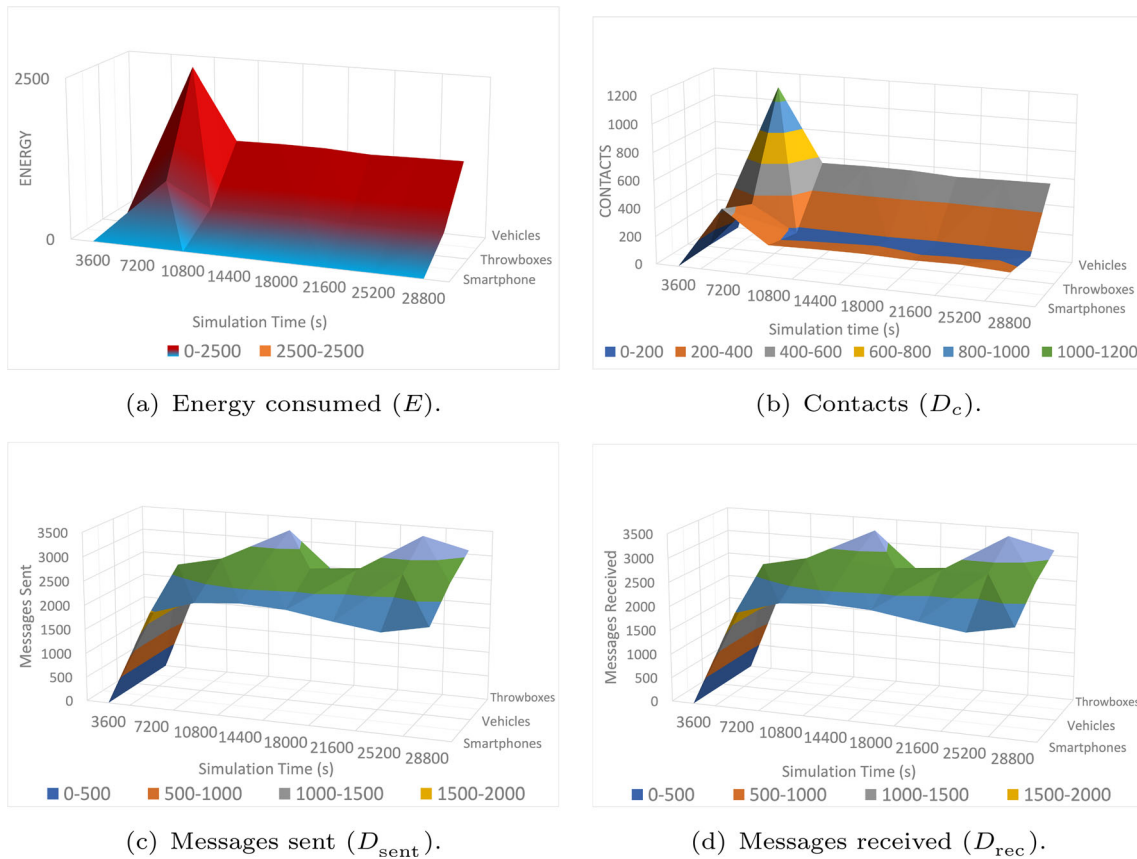

(a) Energy consumed (E).

(b) Contacts (D_c).

(c) Messages sent (D_{sent}).

(d) Messages received (D_{rec}).
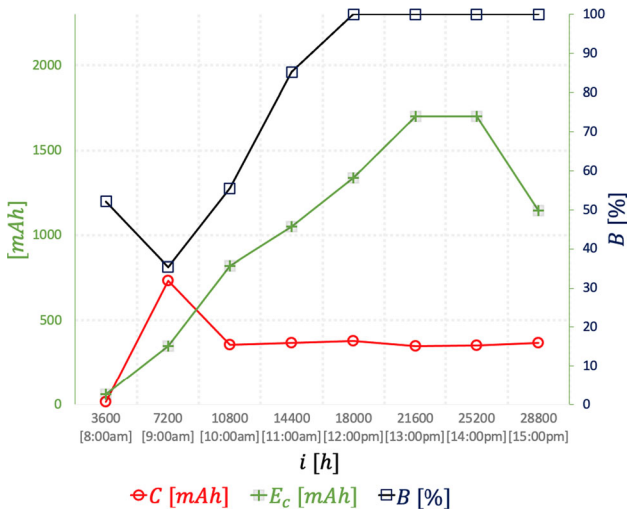
Fig. 11 Energy consumption comparison

Fig. 12 Energy consumed (C), energy captured (E_c) and battery level (B) in throboxes

algorithms such as Life Router, GeoSpray Router, Wave Router, Simbet Router and Distributed BubbleRap Router. The performance stats show ISCA provides better results compared with the other solutions. Additionally, it is interesting to consider that the analysed values are

expressed as averages of the results. It means that behind the outcomes, peak values can be unnoticed. This is the case of latency, dimension which is extremely relevant for the emergency detection. Then, in spite of the suitable average, there can be concrete situations where long-delay events or latency peaks happen. This is very hard to tackle in the opportunistic routing, since it is mainly based on random encounters of autonomous devices. Then, it is hard to guarantee, under all circumstances, quick responses for emergency situations. However, the negative impact of these contexts can be addressed applying prediction techniques to proactively detect dangerous situations. For this, resources such as data mining or machine learning become important mechanisms to enhance the performance of the architecture for these cases.

On the other hand, the sustainability of the solution is evaluated. Thus, we find a direct relationship between contact tasks and energy consumption. It was demonstrated that vehicles are the devices that consumed the most energy whereas smartphones provide a very good energy consumption performance. Furthermore, throwboxes play a significant role in information broadcast and counts with a reasonable consumption of energy. Moreover, the power they obtain from the solar panel feeds them successfully

during simulation, charging the battery at its maximum capacity. As a result, the energy consumption is technically viable and the solution is sustainable.

5 Conclusion and future work

Many rural areas are not compatible with TCP/IP protocol and Internet architecture. Factors such as the geographic conditions, the demographic characteristics and the high investment requirements become significant obstacles to the deployment of communication infrastructures. In these scenarios, services such as eHealth solutions for older adults become hard to deploy, due to the recurrent dependence of the Internet connection. Thus, many isolated rural areas face the challenge of detecting emergency situations of those older adults who live alone. As a response for this scenario, the present work proposes ISCA, an architecture which makes use of OPPNet to detect and transmit potential emergency events. For this, houses of older adults are equipped with sensors which measure the physical presence, transmitting this data towards a destination gateway, which is connected to the Internet, making use of intermediate nodes as a path. Additionally, exploiting the application of the opportunistic network, the architecture enables local business to communicate performance reports.

The performance of the architecture is studied with a realistic simulated scenario, where the opportunistic network is assessed and compared with state-of-art alternatives. As a result, the performance of the network is high, with a 97.5% of delivery probability, improving 52.25% the second-best result. Furthermore, energy consumption displays good results. Thus, the simulation is technically viable, manifesting self-sustainable feasible power requirements.

The next steps in the work will be to improve ISCA transmission with an enhanced next hop selection and incentives for intermediate nodes. In the same way, it is relevant to study the application of data mining and machine learning techniques over the data delivered at destination, specially to predict emergencies which are hard to identify due to high latency or long-delay events. However, the biggest most promising step in the line will be implementing and deploying the solution in a real testbed. Thus, this advanced proposal will coordinate disciplines like the Internet of Things, physical devices, artificial intelligence and telecommunication infrastructures. Definitively, this work is another promising brick in very significant research to improve science, communications and, of course, breaking barriers for people.

Data availability Data is available under demand.

Declarations

**Conflict of interest** The authors declare that they have no competing interests.

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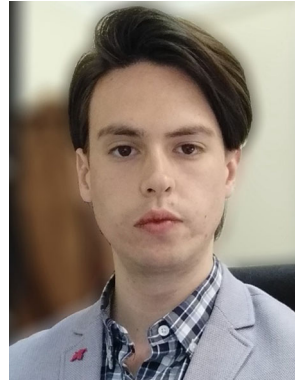
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