Energy Efficiency in Cooperative Wireless Sensor Networks

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Abstract. The transport of sensitive products is very important because their deterioration may cause the value lost and even the product rejection by the buyer. In addition, it is important to choose the optimal way to achieve this end. In a data network, the task of calculating the best routes is performed by routers. We can consider the optimal path as the one that provides a shortest route. However, if a real transport network is considered the shortest path can sometimes be affected by incidents and traffic jams that would make it inadvisable. On the other hand, when we need to come back, due to features that symmetry provides, it would be interesting to follow the same path in reverse sense. For this reason, in this paper we present a symmetric routing mechanism for cooperative monitoring system for the delivery of fresh products. The systems is based on a combination of fixed nodes and a mobile node that stores the path followed to be able of coming back following the same route in reverse sense. If this path is no longer available, the system will try to maintain the symmetry principle searching the route that provide the shortest time to the used in the initial trip. The paper shows the algorithm used by the systems to calculate the symmetric routes. Finally, the system is tested in a real scenario which combines different kind of roads. As the results shows, the energy consumption of this kind of nodes is highly influenced by the activity of sensors.

Keywords: Energy efficiency, Symmetric routing, Cooperative monitoring, Wireless Sensor Networks (WSN), Delivery, Fresh Products.

1 Introduction

Our current consumer society works in a global environment. Companies and individuals acquire more and more products anywhere in the world. There are multiple patents and proposals about systems for tracking and delivering packets. For example, Michigan Versus Technology, Inc. [1] proposed a real-time method for locating a mobile object or person in a tracking environment and R. Witmond et al.

presented a method for tracking a mail piece [2] which introduced a system and process for verifying the status of a mail piece in an email stream. For this reason, currently, there are lots of systems and technologies used to locate a packet. Among them, we can find active and passive RFID systems, WiFi, Global Position Systems (GPS), Infrared, and Bluetooth, although, the most commonly used technology for locating objects is RFID. This kind of technology is being widely investigated, mainly in security [3] and protocol performance [4]. Scanning an object equipped with an RFID target can provide a variety of data including the manufacturer, item information, its path to get to the store, and almost any other relevant data.

In order to decide the best route to reach a destination we can interpolate the techniques used in data networks. We can also understand the operation of this network as a kind of Vehicular Ad hoc Network (VANET) [5] where Packet Delivery Ratio (PDR), the end-to-end delay and number of hops are some of the most important parameters to take into account to calculate the best route. In this case, we can use symmetric routes to provide more stability of Internet routing [6]. With that networks will need lower computational activity and lower amount of packets retransmissions and consequently, the network will consume less energy.

Normally, when a packed of fresh products like fruits or fish is transported, the product must be refrigerated or covered with ice. Wireless sensor networks (WSN) can help to solve this problem. It is widely known the wide range of applications where a WSN can be applied [7-9]. Moreover, if we were capable of relating the environmental conditions with the transportation features, we would be able to use the resources more efficiently. But this kind of decisions can only be made if we have lot of information from systems with similar characteristics. It is known as collaborative decisions [10] [11].

In this paper, we analyze the energy efficiency in cooperative wireless sensor networks for the delivery of fresh products. We propose a WSN composed by both mobile and fixed nodes that tracks the position and monitors the packet status through several sensors. The information gathered by these sensors is sent through the fixed nodes to a data base. The system has been developed to fuse the information provided by professionals and business owners who work with fresh products. The system is based on a Zigbee network of fixed nodes installed along a city and a mobile node, which is put inside the packet to be transported allowing end users and vendors controlling the progress of the packet as well as the conditions of internal and external temperature and if it has had any hit. To decide the optimal route to reach a destination and to come back to the warehouse the system will use the symmetric routing mechanism that enhance lower power consumption in the whole network because the reutilization of available information will reduce the processing activity is also smaller than performing a new calculation of optimal route to reach a destination. The paper also presents the architecture design, the smart algorithm used to correctly operate and the test bench performed in a real scenario with different kinds of roads and the values of gathered data from sensors. The results show that the sensors activity is highly related with the consumed energy.

The rest of this paper is structured as follows. Section 2 shows some interesting works where symmetric techniques are used and systems developed to track packets. The principles of symmetry used by our system are shown in section 3. The description of the system and the used hardware are shown in section 4. The collaborative algorithm for combining the data of nodes is shown in Section 5. Section 6 shows the measures gathered by a mobile node Waspmote placed in the packet which is driven through different kind of roads. Finally, conclusion and future work are shown in section 7.

2 Related Work

The concepts of cooperative networks and the application of symmetry in routing processes are quite novel. It is relatively easy to find work where the concept of symmetry is applied but in many cases, it is not directly applied to networks. This section summarizes some of the main works we have found related to the application of symmetry in networks. In addition, we would like to apply the concept of symmetry to the task of transporting sensitive goods. We did not find any paper that relates these two concepts.

Regarding the concept of symmetry in networks, U. Weinsberg et al. [6] presented a large-scale analysis to see the implications of using symmetry techniques in routing process in complex networks. Authors focused their study in the modern Internet using adaptable algorithms to enhance the network stability as a function of distance. Authors get these improvements taking into account the changes in the order of hops followed to reach a destination as well as changes in the hops themselves. Authors analyzed the en-to-end route stability of more than 100,000 routes where the path stability and symmetry was studied in 6 levels of granularity as a function of the device affected, i.e., router, point of presence, address prefix, autonomous systems, city and country. Results show that the measurement of parameters in symmetric routes as a function of distance provides interesting information in regard to the network stability. Authors concluded that stability properties are kept for opposing pairs, meaning that the routes in both directions are either stable or not-stable.

F.N. Silva et al. [12] presented a framework to quantify the symmetries around nodes in concentric networks. Authors used two topological transformations that permit the characterization of the different types of symmetry appearing on networks. These transformations were applied to some network models such as Erdős–Rényi, Barabási–Albert, random geometric graph, Waxman, Voronoi and rewired Voronoi, among others. Results showed that Erdős–Rényi model presented a high degree of symmetry. Authors also found that the degree of symmetry presents low relation with metrics such as node degree and centrality. Finally, authors presented real-world application to the financial market network where the concept of symmetry could be used.

Finally, we want to mix the concept of symmetry, cooperative networks and tracking systems. Related to transport and monitoring devices, R. Jedermann et al. [13] presented a reduced scale prototype of an autonomous transport monitoring system. Authors tested the application of KQ-Models for quality supervision of tomatoes. The reduced scale prototype demonstrated that it is feasible to integrate a real-time supervision system into standard reefer trucks or containers. The information to select the appropriate model was stored in a standard RFID tag that was attached to the freight item. A software agent provided the freight operator with an estimation of the keeping quality and updated the estimation only to prevent data transmission costs.

In [14], authors explored the potential of wireless sensor technology for monitoring fruit storage and transport conditions. They studied the feasibility of using two types of wireless nodes (Xbee and Xbow). They stated that the performance of this kind of systems could be improved by the implementation of advanced network topologies, such as point-to-multipoint, peer-to-peer and mesh, improving the reliability and robustness of the system.

A. Shamsuzzoha et al. [15] presented an overall approach to track in real-time the delivery shipment from the starting point to the end customer. The paper discussed and analyzed the outcomes from the case project to be useful for tracking needs. They considered the operational ways of the tracking devices in respect to frequency of data transfer, interpretation of the data in a usable format, specification of the tracking devices (battery life, power consumption, data roaming, etc.), essential programming for the devices, etc., with the view to implement the tracking technology on delivery networks.

All these systems are focused on the tagging or tracking of packets, which can be useful even in emergency and rescue scenarios [16], but none of them try to know the packet status. In addition, they do not take into account the data gathered from the network to improve conditions for subsequent shipments and to make a more efficient use of the available resources. Our system is going to use some of the considerations addressed in [17] to define the concept of optimal symmetric route.

3 Principles of Symmetry Used by Our System

The concept of symmetry can be applied to many areas, mainly in graph coloring problems [18] and studies on design of complex molecules [19], among others. It can also be used in the design of routing protocols in complex networks. This section will explain the principles of symmetry that uses our system.

According to the statement made by V. Paxson [17], we can consider that a route is symmetric if the path between two hosts A and B equals to the path between B and A, ie, if N1, N2, ... Nn represent nodes visited on the way from A to B and N'1, N'2, ... N’m represent nodes visited on the way from B to A. We consider that the path is symmetric if and only if (See Expression 1):

$$m = n. \qquad (\mathbf{1})$$

Fig. 1 shows a situation where the nodes visited in the ways of return are the same, however the routes taken to complete the route between A and B is different from the path between B and A. In this case, we would be in a situation of semi-symmetry.

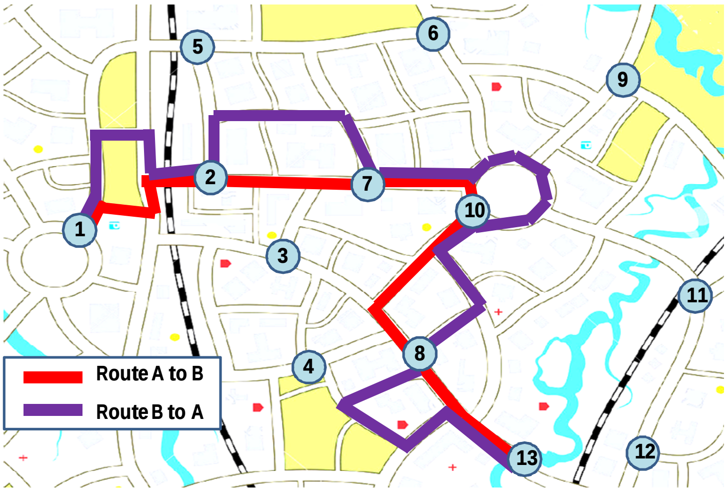

Fig. 1. Scenario with semi-symmetric routes.

To demonstrate the performance of our algorithm, we assume a scenario consisting of 13 nodes, which represent a geographical point in our scenario where a wireless node records the passage of the mobile packet. Reaching a node entail a cost. In our case this cost indicates the difficulty of reaching a geographical point because the amount of traffic (number of cars, traffic lights and difficulty node to transmit information) that exists in this way.

We initially considered that all nodes start with the same characteristics and likely to be achieved. The first step will be the calculation and allocation of the cost. To do this, we use an image recognition system by cameras, as proposed in [20]. After this task, we get a graph like the following one (See Fig. 2).

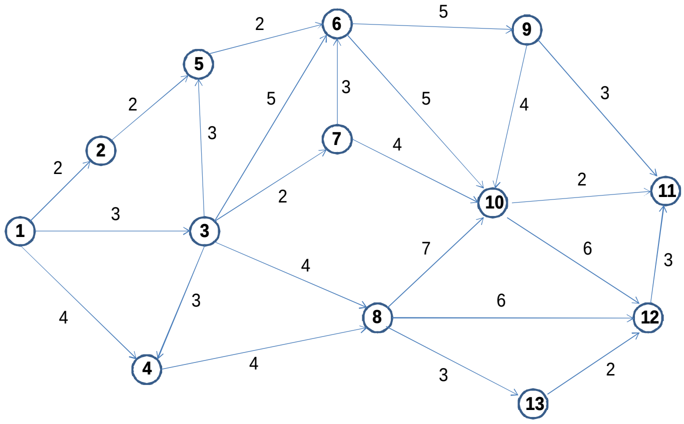

Fig. 2. Graph.

We calculate the best route between nodes 1 and 11. In our case, we assume the best route as the shortest route with the lowest cost. For the graph of Figure 2, the optimal route is:

cost = 11
Num_Hops = 5
Route = 1-3-7-10-11

Ideally, assuming that the costs of the routes to reach the nodes in the opposite direction are the same, the shortest path between nodes 11 and 1 matches with the initial route:

cost = 11
Num_Hops = 5
Route = 11-10-7-3-1

However, this behavior would obtain only in ideal situations, considering that the nodes have an ideal behavior and the difficulty of reaching a geographical point, because the amount of traffic (number of cars, traffic lights and difficulty node to transmit information) does not vary within the time. However, if we consider a real network, the traffic costs will vary. When we try to go the path back, first we calculate the best route and, whit all probability, the result will be different from the original path

Our system will take the information from the system of image recognition and data stored in the database in previous trips and the likelihood that food be damaged. Depending on the processed information a route will be penalized. If possible, the system will try to reach the destination initially following the same route, to ensure that the expected time to reach the original point is similar to that used in the first trip. If this is not possible, the system will calculate the alternative semi-symmetric route that will visit the original nodes but taking alternative routes to ensure that the specified delivery times match those of the original route. In this way, we will achieve stability and ensure service reliability. In addition, the system will try to maintain this symmetry while the energy consumption is lower than calculating a new route. Finally, if we consider that our system will search for the shortest route with smaller number of hops, our wireless network will require less retransmissions and network updated. As a conclusion, our network will consume less energy.

4 System Description and proposed algorithms

This section presents our system and the hardware used to implement it. The system is based on a wireless network using IEEE 802.15.4 standard, which is able to transmit the information about the packet status and how the distributors and vendors can cooperatively contribute to update the information of the ambient temperature for preparing their orders of fresh products.

4.1 System Description

The main aim of this system is the cooperative monitoring of fresh products such as fish, shellfish or fresh fruit to be transported carefully in order to avoid damaging the product by hits or temperature changes and keep well conserved for its consumption. We propose a communication architecture based on a wireless ad hoc network to extend the communication along the city. Devices of the network are deployed using a Waspmote node and a wireless XBee Pro module [21]. The packet of fresh products is equipped with the Waspmote node and a temperature sensor. This node communicates with fixed nodes that are scattered around the city. While the packet is transported, the node sends the packet status information (packet movement and inner temperature) and the environmental temperature to the fixed nodes. At the same time, vendors, distributors and even end buyers can check the package status and include any external parameter such as the delivery time, or any type of threshold in the temperature or the movement. This information can be accessed at any time by distributors and vendors of fresh products when they are sending them to the restaurants and stores. Using this information, they can prepare the packets in the right way to make an efficient use of the resources, such as the amount of ice used to keep fish cold and properly program the temperature of the refrigerated vehicles. In this way, users update the information available in the network and they can use this useful information to prepare their own orders (See Fig. 3). End buyers can track and monitor the packet only accessing through Internet and check at any time if the packet has suffered a hit or the content has experienced excessive temperature change.

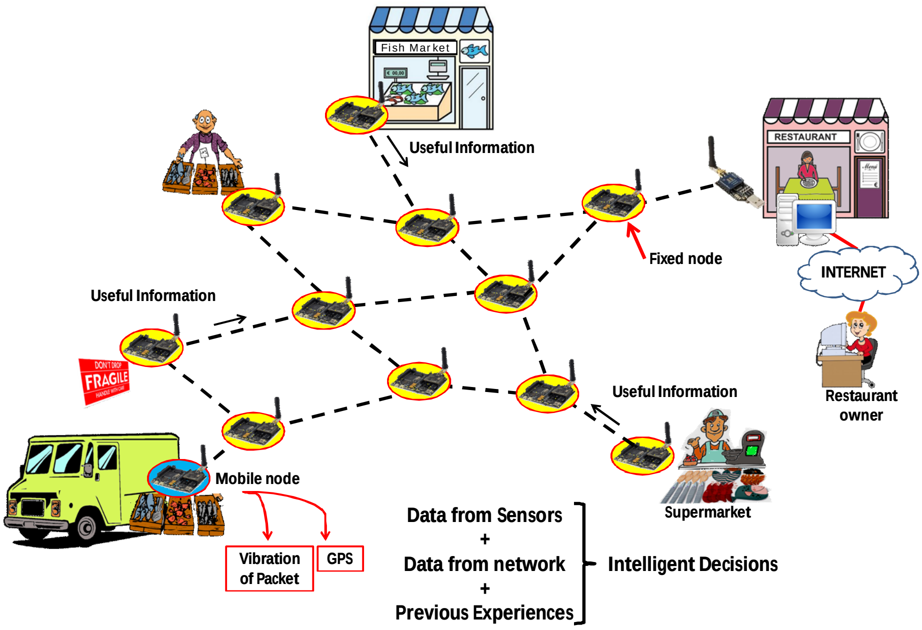

Fig. 3. Network architecture in a real application.

4.2 Sensors and wireless module

Libelium Waspmote with the Xbee-pro Module [21] (Fig. 4a) is a device designed to create wireless sensor networks with some quite specific requirements and intended to be deployed in a real scenario. Libelium Waspmote can be seen as an evolution of other devices such as Arduino, which is usually used in school settings. It has a consumption of 0.7 uA in sleep mode and seven different models of radios that can be chosen according to the frequency and the transmission power. According to its specifications, Waspmote should reach up to one mile working at 2.4 GHz and 63 mW of transmission power. In addition, Waspmote module has an integrated 3-axis accelerometer which allows real-time monitoring of the Waspmote movements or vibration. Finally, the module is powered with a lithium battery that can be recharged via a connector prepared for solar panel. This option is especially interesting for deployments in natural and rural environments such as forests and crop fields.

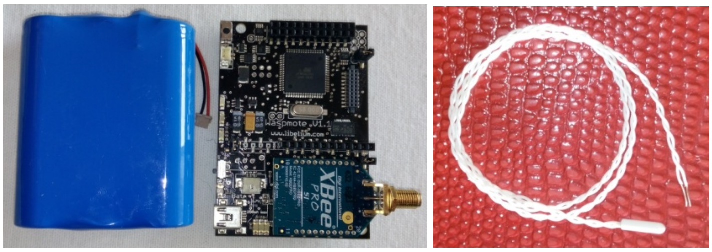

Fig. 4. a) Zigbee module, b) sensor of internal temperature.

To acquire the temperature value (See Fig. 4b), we only need to read the value from an analog input with the command "int VAL1 = analogRead(ANALOG1);". With this command, the Waspmote reads the input identified as ANALOG1 and stores its value in the variable VAL1.

To locate the mobile node, we have integrated a GPS receiver into the Waspmote module. Data of latitude and longitude are sent through UART port (See Fig. 5). We have selected a A2235-H module as GPS receiver. It is a SMT-based integrated GPS antenna module with a power consumption of 35mA when satellites are being searched. To connect this module to our wireless node, it is only needed to take transmission (TX) and Reception (Rx) signals from the GPS module and connect them to an UART port.

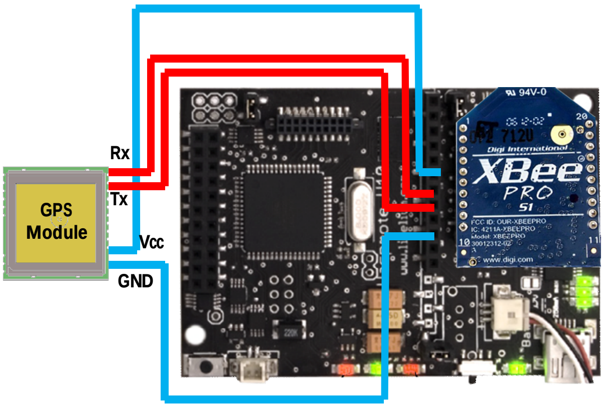

Fig. 5. GPS module connected to Waspmote node

After that, it is needed to make a small program to read the information gathered by GPS module (See Algorithm 1).

```
#include <HardwareSerial.h>
float Position;          //Define variable
char Pos_string[16], P;
int i;
void setup(){
        Utils.setMuxAux1(); // Select UART port used
        beginSerial(9600,1); //Conf. Baud Rate UART port
}
void loop(){          //System is waiting to receive data from UART
        i=0;
        while(serialAvailable(1)){
                Pos_string[i] = serialRead(1);
                i++;
        }
        Pos_string[i-2] = 0;
        P = atof(Pos_string);  // Convert string to double
        USB.print(Pos_string); //Show Data
        USB.print(P);  //Show Data
        delay(500);
}
```

Algorithm 1. GPS module connected to Waspmote node

Finally, to receive and store the mobile node position, this information is sent through the Zigbee network to a server which will store these data with the information from sensors (See Fig. 6).

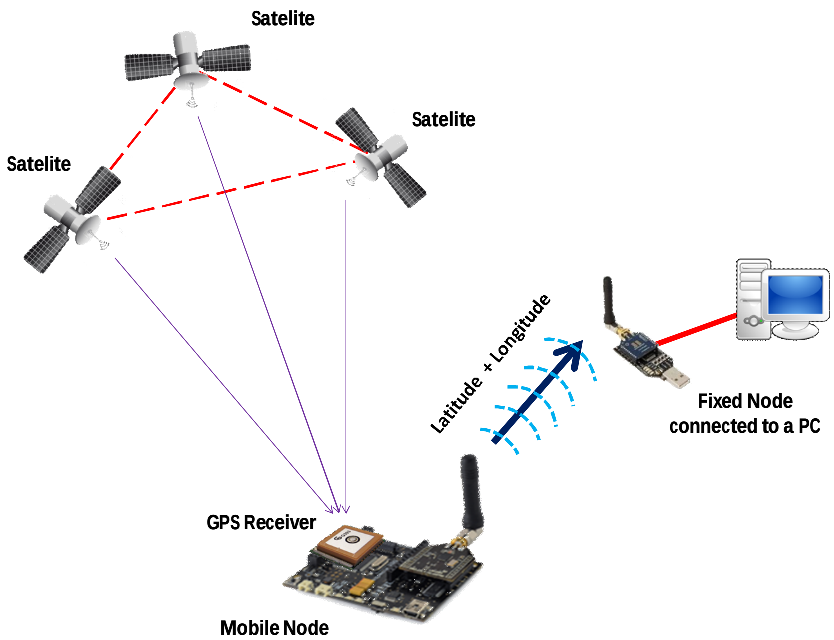

Fig. 6. GPS System to send the position through fixed nodes.

5 Algorithm for collaborative monitoring and Symmetric routes calculation

The system needs to run an algorithm to exchange data between nodes. This information is related to the routes status (thank to a recognition pattern system [22]) and data from the network. The correct combination of them allows the users to estimate the transport parameters and the optimal route.

The system will attempt to find symmetry from 2 points of view, that is, the system will try to keep the route back by the same path. However it is possible that one of the nodes is not able to ensure the information transmission and therefore loses overall stability system that provides symmetry. Therefore, attempt to find symmetry, trying to ensure shorter delivery times, resembling the maximum delivery times round package (See Fig.7).

To do this, we have a database (DB) with information about nodes, estimated time required to reach a destination, sensor values registered and road conditions. This information is updated in the database in each new iteration.

When we want to send a packet, the system checks whether this package is original or is a packet that is performing the way back. If this is the first time that the package runs along the road, the system must calculate the optimal route taking into account information about nodes, estimated time required to reach a destination, sensor values registered and road conditions. After establishing the transport parameters, the packet will be sent. The system will periodically monitor the status of the packet and its geographical position. If its state is labeled OK, we will check if the destination has been reached. Conversely, if the packet recorded some value out of a set of thresholds, the system will send an alarm message to the seller and to the end user. When the packet reaches its destination, all the information collected will be stored and updated in the database.

On the other hand, if the packet is going to perform the way back, the system will process the information slightly differently. The first step will be to analyze the available information on the nodes, sensor values registered and road conditions to verify that the nodes used to reaching the initial destination can ensure the routing of information using the symmetric path back. If this is possible, the system will load route information and send out the packet. With this, according to [17] it will provide greater stability in the network and lower computational cost and power consumption. If it is not possible to guarantee the use of symmetric route, the system will search for symmetry through searching the RTT value closest to that obtained in the first path. In the last case, we would speak of a semi-symmetric system which seeks to reach the destination in the same time used in the initial route in regards to the elapsed time where the end user will not suffer any delay. This process would be completely transparent to network users, although information about the route followed could be seen in the database.

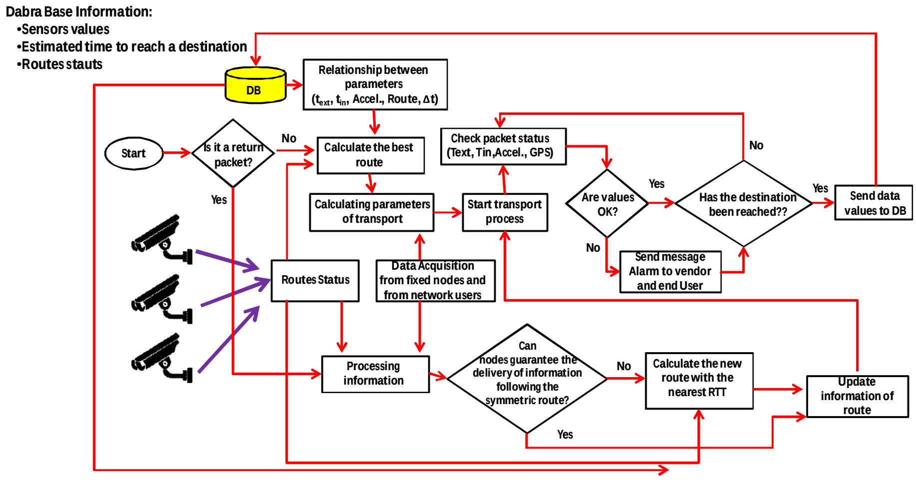

Fig. 7. Smart algorithm for collaborative monitoring and estimation of symmetric routes.

Finally, our system will take into account the power transmission needed to connect with the closest fixed node, i.e., the system will adapt the level of power transmission of mobile node as a function of the distance to the fixed nodes. In order to determine the exact value of minimum transmission power, the mobile node uses the received signal strength from the fixed nodes to calculate the minimum quantity of energy used for data communication. Since we know the minimum energy level to ensure the correct communication between 2 devices, we can calculate the minimum energy needed to transmit the packets from a node to another (See Fig. 8) In our case, we have estimated that the minimum energy transmission will be those which warranty a RSSI (Received Signal Strength Indicator) equal to -70dBm.

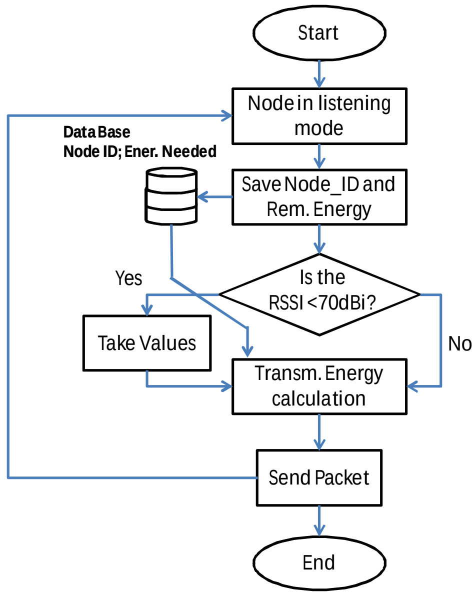

Fig. 8. Energy calculation phase flow chart.

6. Packet Monitoring During a Real Trip

To test the correct operation of the node and its location along the route, a route with different road types, i.e., highway, urban road and rural road is established. Fig. 9 shows the different types of route. In Addition, this section shows the measures gathered by a mobile node Waspmote placed in the packet. The measured parameters are the temperature, XYZ accelerometer, battery level and geographical position (latitude and longitude). The packet has been monitored during one hour and 20 minutes while the packet is driven through different kind of roads.

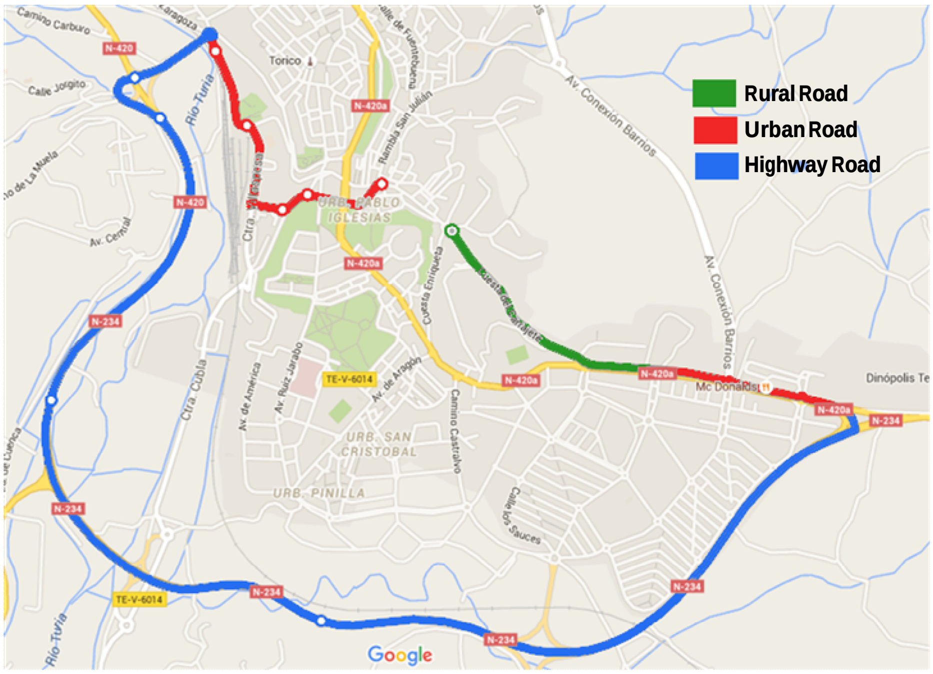

Fig. 9. Route followed by the mobile node.

Fig. 10 shows the XYZ axis values of the accelerometer during a trip along the different kind of roads. As we can see it is easy to observe the transitions between each kind of road although the most notorious change is observed when the packet is driven in the rural road.

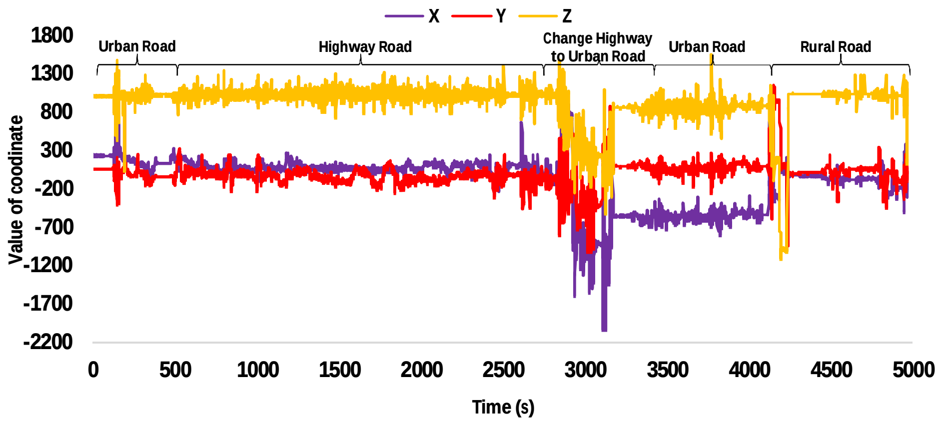

Fig. 20. XYZ- Axis values of the accelerometer during a trip.

We have also compared the battery consumption as a function of the kind of road and the elapsed time (See Fig. 11). In this case, the initial level of the node is about

1.68 V of its maximum capacity. It is easy to see that the battery level presents some fluctuations when the node changes from highway to the urban road. These fluctuations are also observed when it changes between urban and rural roads.

These variations can be due to a bigger activity of sensors and because the node needs to process all these changes.

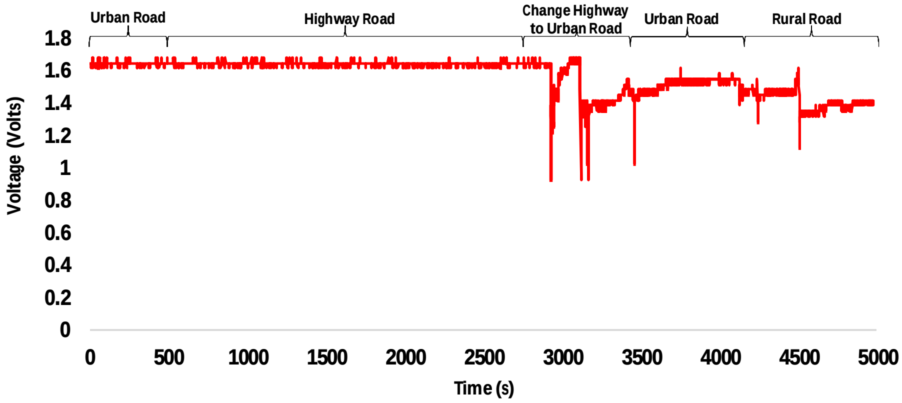

Fig. 31. Remaining battery voltage of the mobile zigbee node.

Another important parameter for our system is the packet temperature. Fig. 12 shows the evolution of temperature as a function of the elapsed time. According to the desired effect, the node temperature is increased to the temperature of the environment (31ºC) at the testing time.

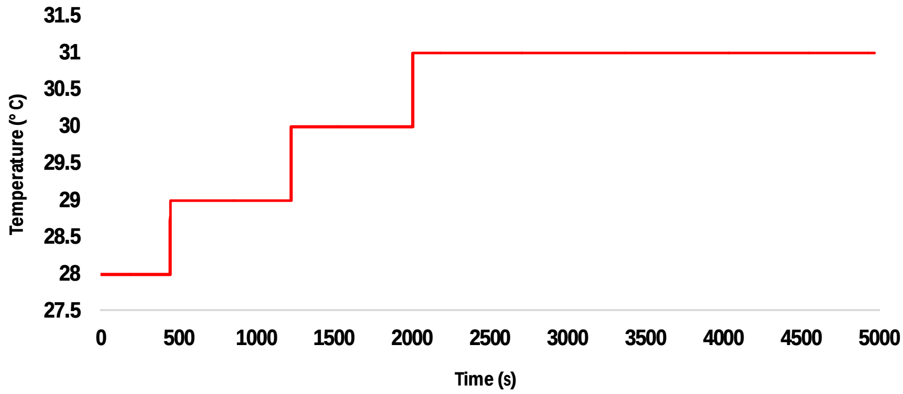

Fig. 42. Evolution of packet temperature gathered by the mobile node.

Finally, the node sends us its geographical position thanks to the installation of a GPS receiver. In this case, the node reads its position in latitude (see Fig. 13) and longitude (see Fig. 14) and transmits the fixed network nodes distributed along the path followed.

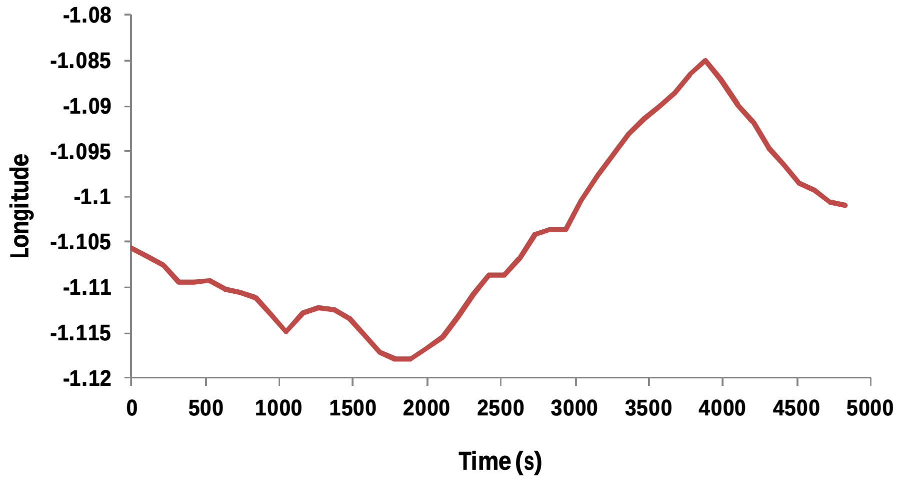

Fig. 53. Longitude of position for the mobile node.

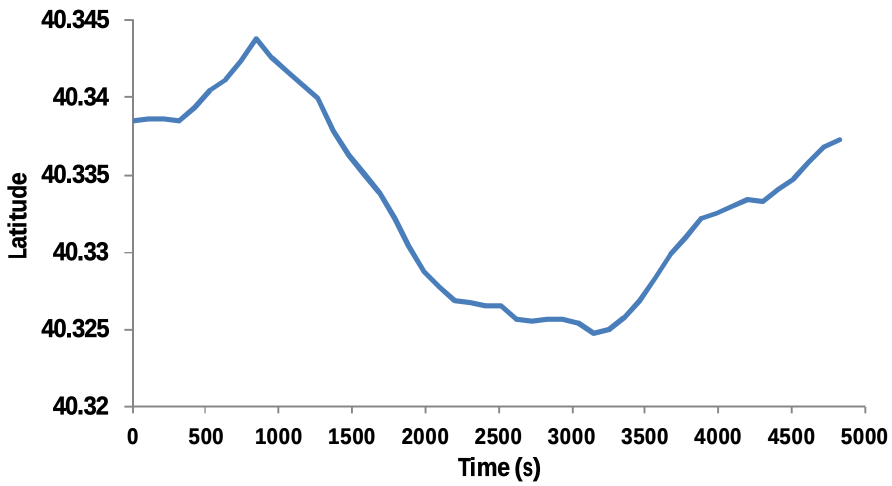

Fig. 64. Latitude of position for the mobile node.

7. Conclusion

In this paper, we have presented a new symmetric routing mechanism in cooperative networks for the delivery of fresh products. The system is based on a set of fixed nodes installed along a city and a mobile node which is put inside the packet to be transported.

The mobile node consists of several nodes that allow to end users and seller to see the packet status and check if some problem has happened during the trip. The information gathered by these sensors is sent through the fixed nodes to a data base. The information stored in this data base is subsequently used to recalculate the optimal route to reach a destination. In regards to the calculation of the optimal route, the system uses different information such as the amount of traffic, i.e., number of cars, traffic lights and node status. To recalculate the path to come back to the warehouse (for example), the mechanism tries to send the packet back following the same nodes but in reverse sense. If this is not possible because the route is too busy, the system will find out to an alternative route that ensures the same delivery time. With this symmetric routing mechanism, we achieve lower power consumption in the whole network because the processing activity is also smaller than performing a new calculation of optimal route to reach a destination. The paper has also presented the architecture design, as well as the test bench performed in a real scenario with different kinds of roads. In addition, we have explained the smart algorithm where thanks to the data stored in the network and data provided by users, we can make more efficient decisions. Finally, we can see that the sensors activity is greatly related with the power consumption in nodes. If it is detected fast and continuous changes in a monitored parameter, the node will need to process these changes because they can imply that some problem is happening. As future work, we would like to integrate secure mechanisms to make our infrastructure more reliable and secure [23], as well as add an energy harvesting system [24]. Moreover, we are going to extend it using group-based topologies [25] which are also indicated to achieve lower power consumption.

Acknowledgement

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