Energy Optimization for Video Monitoring System in Agricultural Areas using Single Board Computer Nodes and Wireless Ad hoc Networks

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Abstract

This paper presents the design and implementation of a set of prototype nodes that have the ability to establish communication links in ad hoc mode. The prototypes were implemented using low cost, single board computers with embedded Linux (Raspberry Pi devices). The implemented stations aim to set a wireless sensor network for the capture of variables applied to agricultural environments. In particular, a camera module has been included on a node for remote video monitoring of farming zones, and also a GPS module for the capture of geolocation information. Nodes can be accessed remotely by means of the developed web interface. The routing process between nodes is carried out using the S-OLSR mechanism (OLSR modification) in order to set up routes taking into account the energy limitations as well as the location of each device in the topology. Results describe the contribution of this work to the design of monitoring applications on agricultural zones by means of the deployment of autonomous ad hoc nodes and energy routing optimization.

1. Introduction

An ad hoc wireless network has the capacity to self-configuring without the need of a central station or a pre-existing infrastructure. Moreover, due to its decentralized nature, the network operation involves cooperation among intermediate devices, especially when the target node is located out of the operation range of the transmitter node.

Wireless Mesh Networks (WMN), Vehicular Ad Hoc Networks (VANETs) and Wireless Sensor Networks (WSN) are some examples of ad hoc communication technologies.

In particular, WSN are the ad hoc communication scheme that more acceptance has experienced, both in academic and industrial segment. That success is due to the different specific application scenarios that could be implemented in real operating conditions. Traffic monitoring systems, emergency response systems, or health monitoring and medical applications are examples of WNS in urban environments [1]. Nevertheless, there is a growing demand of WSN applications in rural environments [2], especially in precision agriculture. In that kind of environments, sensors are deployed to measure temperature, humidity, soil salinity, and so on.

Moreover, image and video recording of wide crop areas are gaining a lot of attention. For instance, video and images allow visual remote monitoring of crops by means of plant appearance analysis to detect plagues or diseases, and enable video surveillance.

The sensor nodes of such video and image applications demand a lot of computing capacity and communications, but nowadays, that could be supported using Single Board Computers (SBC).

In this paper, we present the design and implementation of a video monitoring system for agricultural areas.

Specifically, a set of ad hoc nodes were implemented, using development platforms with embedded Linux (Raspberry Pi) [3], in order to setup a network for data transport.

Specifically, one of the nodes is provided with a web cam for video capture, and also a set of sensors in order to get information about geolocation as well as environmental conditions, such as temperature, humidity and pressure. In order to access the stored information, a web application was developed using Node.js [4]. This web interface allows getting information about the platform status (e.g. CPU load, temperature and energy consumption).

Moreover, in order to optimize the energy expenditure during the network operation, an energy-aware routing protocol named S-OLSR (Strategic OLSR) [5] has been implemented on the platforms. In particular, it consists in a modification of the standard OLSR protocol (Optimized Link State Routing) [6], widely used in ad hoc networks.

Results show a proper operation of the implemented architecture as well as a decrease of the energy consumption, especially on nodes with higher connectivity on the network.

The rest of the paper is organized as follows. Section 2 presents related works. The design and implementation of the video monitoring architecture, as well as an evaluation of the developed prototype, are detailed in Section 3.

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Section 4 describes the mechanism used for energy optimization, as well as the results of the experiments performed. Finally, conclusions are presented in Section 5.

2. Related Work

The use of cameras as though they were any other sensor presents a great interest for precision agriculture. In particular, [7] and [8] describe proposals which implement a mobile node on an UAV device (Unmanned Aerial Vehicle), for the capture of data transmitted from fixed nodes, and also for the capture of images on large areas.

This is performed in order to classify and detect the health of crops as a low cost alternative to satellite image services.

Additionally, [9] describes the set up of cameras in sensor networks, in this case, in order to implement a surveillance system for detection of intruder agents (e.g. animals, unauthorized personnel), which could affect crops.

A video system for monitoring bees as pollinator agents has been proposed in [10]. The study implements nodes on Raspberry Pi (RPi) devices, and also stands out the platform operation for video capture in real time.

Moreover, one of the main aspects that should be taken into account in the design of sensor networks is the analysis of the energy constraints, due to the fact that nodes are powered using batteries.

An optimization scheme widely used consists in the definition of intervals for nodes to keep a power-saving state (sleep mode) [11]. Nevertheless, the main drawback of such mechanism is the higher probability to increase packets losses, increase delay, as well as route breakages, due to the loss of connectivity.

In that sense, [12] descibes a proposal that uses statistical techniques in order to manage the intervals of operation in low consumption mode and to decrease its effect on network connectivity.

An alternative to these proposals is the design of routing mechanisms that allow optimizing the energy expenditure.

Specifically, [13] and [14] describe studies that include the energy analysis as an additional metric for the routing computation on sensor networks.

In paritcular, in this paper, we used an optimization mechanism at routing level, which operation is detailed in Section 4. Below, we present the implementation of the video monitoring system proposed.

3. Architecture: Video Monitoring System

3.1. Ad hoc Node Implementation

Figure 1 presents the functional diagram of the node, the ad hoc setup is performed through the configuration files, *intefaces* and *wpa_supplicant,* of the Linux Operating System (Raspbian distribution).

Additionally, an NTP (Network Time Protocol) client was installed to carry out the synchronization during the startup. In regard to the hardware, the prototype has five peripheral devices.

The wireless card used for communications is Awuso36nh [15], which supports ad hoc mode (IEEE 802.11 standard), and also is compatible with the RPi platform (driver rt2800/chipset RT3070).

For the video capture, we used a webcam (5.7MP/HD720p) and the encoding process was carried out by means of the free software tool FFmpeg [16].

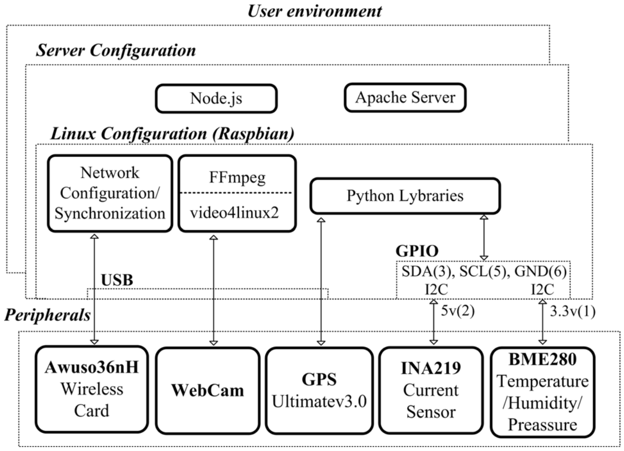


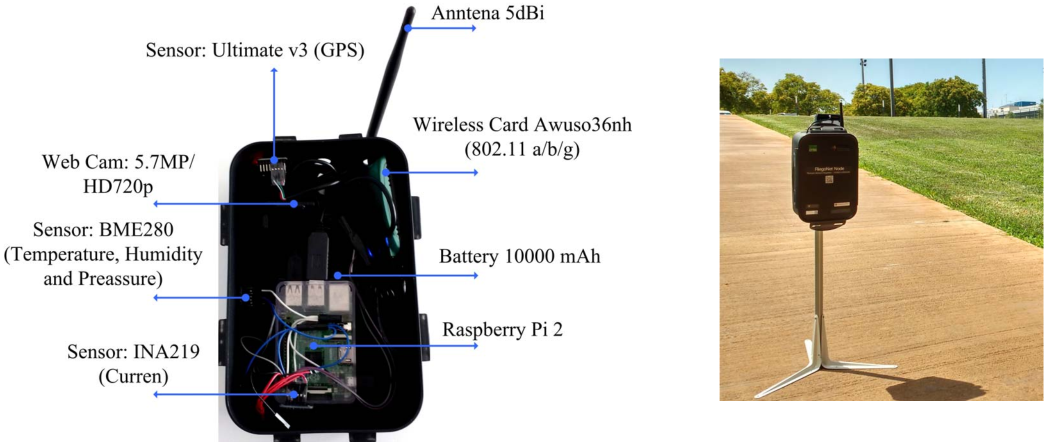
Figure 1. Functional diagram of the ad hoc node prototype.

Regarding the sensors, a USB GPS device (Ulimate v3.0) [17] has been attached to the RPi (TTL-USB cable), as well as other sensors that communicate with the platform through an I2C (Inter-Integrated Circuit) bus.

Specifically, the current sensor INA219 [18], which operates at 5V, and the BME280 sensor [19], which allows the acquisition of information about environmental conditions (temperature, humidity and pressure), and works at 3.3V.

The sensors are handled using a set of Python libraries developed by Adafruit [20]. Moreover, the prototype is powered by a high current density lithium battery (10000mAh).

Figure 2 shows pictures of the implementation. Figure 2(a) describes the node components, and Figure 2(b) presents the actual setup during an experiment.



(a) (b)

Figure 2. Ad hoc node implementation: (a) Node components. (b) Setup in a real environment.

3.2. Architecture Implementation

Figure 3 shows the functional diagram for the video monitoring system implemented on the prototype node previously described. In particular, we configured an HTTP server based on Node.js (v0.10.2) that enables the remote access to the platform using a browser. To perform the data exchange as well as the event handling in real time, we have used websockets through the socket.io library [21]. The web interface provides users with tools to manage the node, such as webcam activation or retrieval the information about the node status and the data captured by the sensors.

Regarding the camera control, the server starts a script for the video capture. Then, the encoded is performed by means of the FFmpeg tool, using the H264 [22] codec and encoding based on average bitrate.

The transport protocol HLS (HTTP Live Streaming) [23] was configured in order to segment and embed the video on the web. The generated segments are stored and served using Apache web server. Finally, the video playback compatibility in the browser was guaranteed through a Flash fallback included on the web player code.

In regard to the system status, the server sends messages with information about the temperature and CPU load (RPi), and the energy consumption of the platform obtained from the sampling process performed by the current sensor (INA219). In this case, information

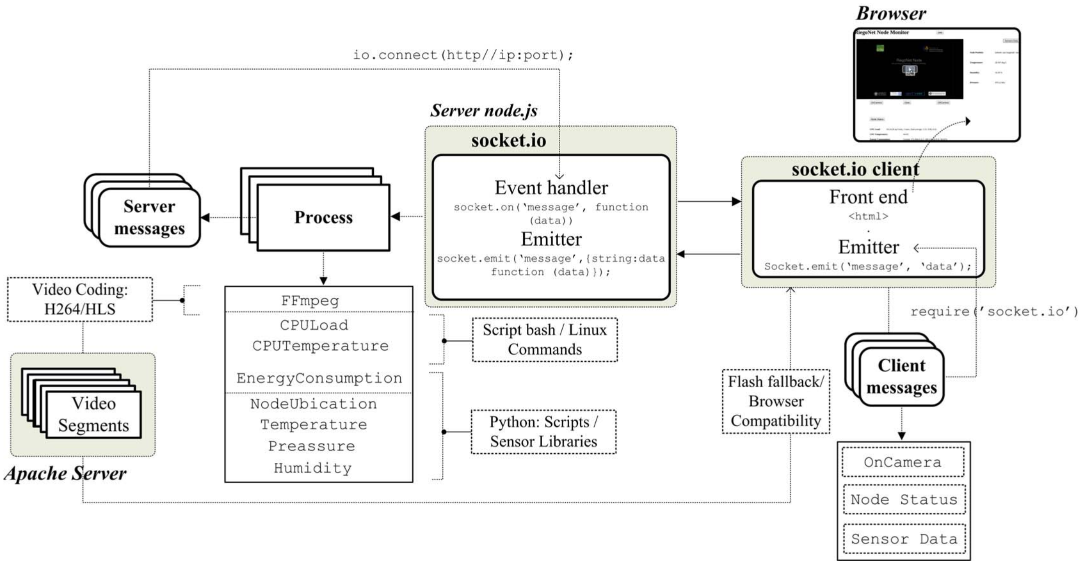


Figure 3. Functional diagram: Architecture of the Video Monitoring System.

about the current demand, the energy expenditure (mAh) as well as the remaining energy (%) is shown on the web interface.

Similarly, data obtained from the GPS and the environmental sensors (BME280) are processed. Then, the server sends a set of messages about geolocation, temperature, pressure and humidity.

Furthermore, all this information is also stored in the memory card of the node in order to keep a history of measures.

3.3. Prototype Evaluation

This section presents a set of measurements that describe the system status under operation conditions, i.e. during acquisition, processing and transmission of the data captured by the sensors.

Regarding video parameters, an encoding rate of 300 Kbps and a HLS segment time of 2s have been defined.

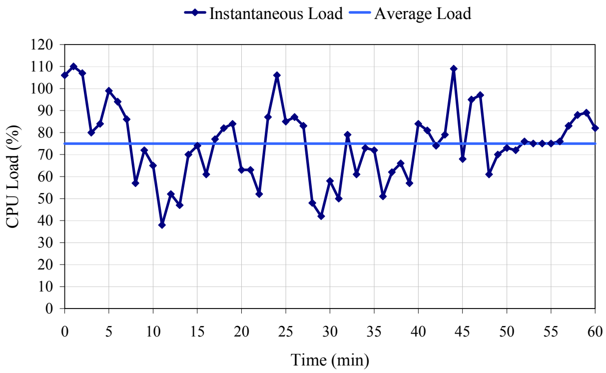


Figure 4. Experiment: CPU load monitoring.

Figure 4 shows the behavior of the CPU load throughout one hour of operation. The samples were captured at intervals of 1 minute.

Results indicate a safe value of CPU load on the platform, specifically an average of 74% for the analyzed interval.

Therefore, this is an indicator that states that the processes demanded by the sensors along with the video coding do not involve a constant overload on the prototype.

Moreover, Figure 5 shows the temperature monitored on the CPU. As can be seen, results describe minimal changes with variations between 38 and 44°C which are distant from the maximum value recommended in the technical specifications (70°C).

Also, it is worth indicating that the average ambient temperature along the experiment was 25°C.

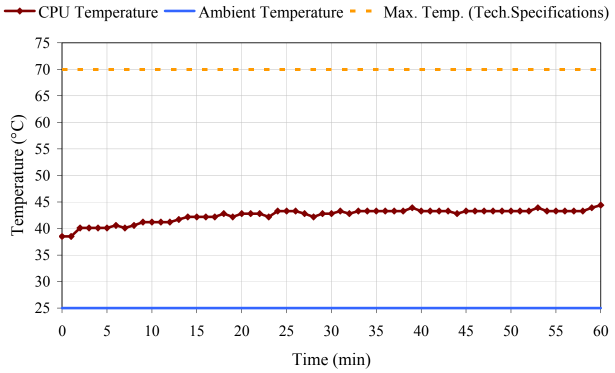


Figure 5. Experiment: CPU temperature monitoring.

Regarding energy consumption results describe an approximate demand of 670mAh on the node for 1 hour of operation. Therefore, considering the battery capacity (10000mAh), the operation time expected for this prototype is approximately 15h. Additionally, Figure 6 shows a characterization of the demanded current depending on the connected peripherals.

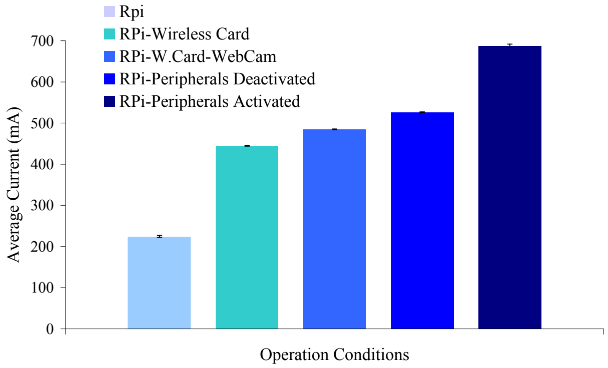


Figure 6. Average current demanded by the prototype with different connected peripherals.

As can be seen, the platform (RPi), presents a base consumption of approximately 220mA. The wireless card doubles the current demand (aprox. 450mA) while working. The addition of the webcam but while it is not working (i.e. deactivated) entails an approximate demand of 484mA. Similarly, the sensors (GPS and BME280), also in deactivated mode, result in a current consumption of 526mA.

Finally, the overall platform operation, along with all peripherals, generates the current demand previously indicated (670mA). Consequently, the operation time expected depends on the functions required for a node. In particular, for nodes that are only in charge of forwarding data and ensuring the network connectivity (i.e. platform and wireless card, no sensors required), the estimated autonomy is around 22h.

4. Energy Optimization

4.1. Strategic OLSR (S-OLSR)

In order to optimize the consumption during the network operation, an energy aware routing protocol was implemented on the platforms. This mechanism consists in a modification of the OLSR standard protocol named Strategic OLSR (S-OLSR) [5], the functional diagram is presented in Figure 7. Additionally, a previous evaluation of S-OLSR over Ad hoc Networks was described in [24].

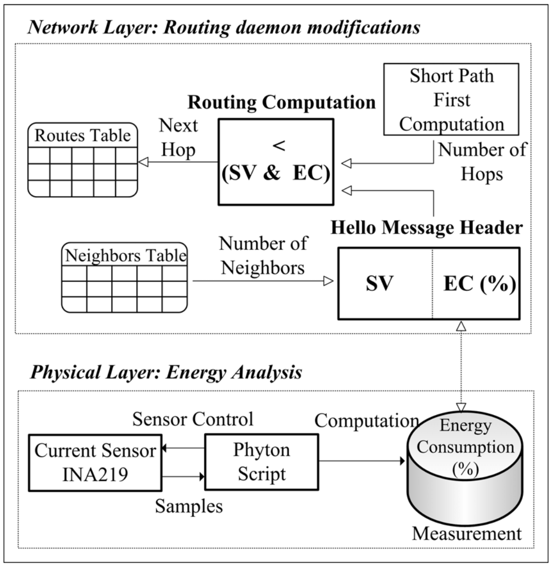


Figure 7. Functional diagram of Strategic OLSR (S-OLSR).

In particular, such modifications allow nodes to share information about its energy consumption and, additionally, its connectivity level (i.e. the number of neighboring devices located at one hop). This metric is named Strategic Value (SV) because it reports the importance of a specific node in the network. The energy expenditure is determined from the sampling process performed by the current sensor, whereas the SV is deducted from the neighbors table collected by the protocol. Such metrics are included into the header of the Hello messages that are exchanged periodically between one hop neighbors during the standard protocol operation. Finally, the routing computation mechanism was modified in order to add new parameters to the computation. In this case, the number of hops, energy consumption and SV metrics are evaluated in order to select nodes with less strategic value and less energy consumption as next hop nodes. This priority that has been given to the neighbors with less SV is intended to reduce the traffic, and therefore the energy expenditure on those nodes with higher importance in terms of connectivity (i.e. nodes with higher strategic value).

4.2. Experimental Evaluation

Regarding the mechanism evaluation, we implemented the multi-hop scenario presented in Figure 8, using ten prototype nodes in a laboratory environment, emulating a sensor network deployment. Moreover, a set of layer-2 filters in each node have been configured in order to replicate the connectivity as it is shown in the diagram.

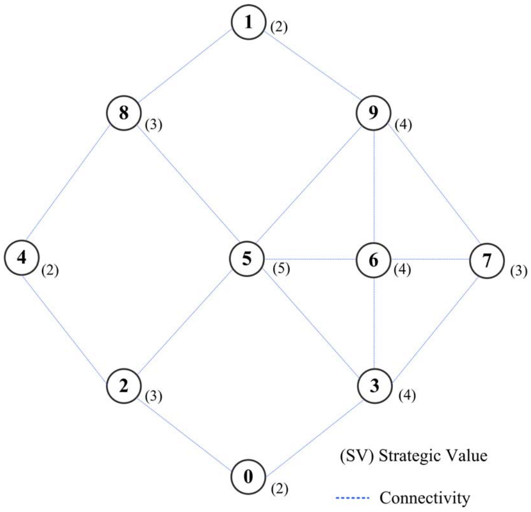


Figure 8. Scenario designed for the experimental evaluation.

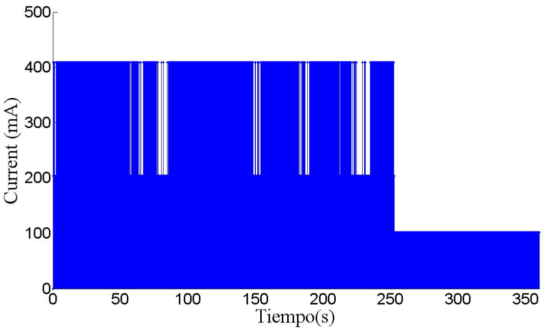
In regard to the network traffic, we select video sequences in order to evaluate the operation in real conditions. Specifically, the video flows (6 min duration) are configured and sent simultaneously from N0 to N1 (average bitrate of 200Kbps), from N2 to N8 (average bitrate of 400Kbps), and from N3 to N9 (average bitrate of. 400Kbps). Then, we focus the analysis on node 5, which is the node with the highest strategic value on the network. Specifically, the evaluation consists in the assessment of the impact that the traffic load generated by the standard protocol causes in the node energy consumption, compared with the consumed energy using the optimized mechanism. For this purpose, the current sensor is connected to the wireless card interface (USB wire) of node 5. Thus, the sampling process of current is used as an indicator of the traffic load and also the energy demand. Moreover, an initial low energy level was intentionally configured on node 5 in order to emulate a power depletion (e.g. due to the power demanded by sensors). Therefore, when a critical energy consumption level is reached (90%), the node wireless interface enters in a power-saving state. Figure 9 shows the experiment set up in the laboratory environment.

Figure 9.Testbed evaluation in the laboratory environment.

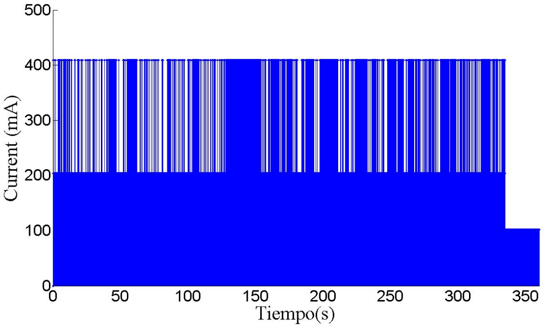
4.3. Results

Figure 10 shows the results obtained from the sampling process carried out on the wireless card. The intensity levels describe the operation states of the radio interface.

As can be seen, the graphics indicate three main consumption levels, a lower value of approximately 200mA; a level of 400mA, that can be inferred to be the current demanded during the transmission state; and finally an approximate level of 100mA, corresponding with the power-saving state.



(a)



(b)

Figure 10. Experiment results: Current samples captured on wireless card of node 5. (a) OLSR standard. (b) S-OLSR mechanism.

In particular, Figure 10 (a) depicts the standard protocol operation. Results describe the constant operation in the highest consumption state (transmission mode). This is an indicator that node 5 is being selected as the intermediate node for data forwarding. As result, the critic energy consumption is reached approximately at 250s, and then, the power-saving mode is activated. Additionally, Figure 10 (b) describes the consumption pattern generated by the S-OLSR mechanism. In this case, it can be seen a decreasing of the transmission states, which describe the routes establishment through alternative nodes (e.g. nodes 4 and 7). This is the expected operation for the mechanism, which is achieved by means of the inclusion of energy and SV metrics, previously described. Thus, route breakages and packet losses due to node energy depletion are prevented.

In particular, the operation time is extended from 250s to 330s on the node with the highest connectivity level, which represents an increase in around 22% taking into account the experiment interval (360s).

5. Conclusions

In this paper, we presented the design of a monitoring architecture for agricultural environments. Specifically, low cost hardware platforms have been used in the implementation of prototype nodes with the capacity to set wireless links in ad hoc mode for the deployment of a sensor network. In particular, additionally to the environmental conditions, geolocation data, as well as the video of a monitored zone, are captured by means of a GPS sensor and a web cam that has been included on one of the prototypes.

Regarding the prototype evaluation, experiments carried out show an appropriate operation. Specifically, an average of CPU load of 74% was detected along the simultaneous operation of peripherals, as well as a temperature (av. 42°C) far from the maximum level defined by the technical specifications (70°C). Moreover, a current sensor has been included in order to characterize the energy expenditure as well as to estimate the autonomy of operation. Results indicate a lifetime between 15h to 22h, depending on the number of peripherals connected. In particular, we implemented a mechanism for optimizing the consumption by means of an energy-aware routing protocol, which aims to keep the network operation while extending the time of life on nodes with higher connectivity level and energy demand. Results describe an approximate increase of the overall network lifetime of 22% for the setups designed in the experiments.

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