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Architectural Issues of a Location-Aware System Applied in Fruit Fly E-Monitoring and Spraying Control

T. Tsiligiridis[1], C. Pontikakos[1], D. Perdikis[2]

[1] Department of Agricultural Economy and Development, Informatics Laboratory, Faculty of Food, Biotechnology and Development, Agricultural University of Athens, Athens, Hellenic Republic.

[2] Department of Crop Science, Laboratory of Agricultural Zoology and Entomology, Faculty of Agriculture, Engineering and Environmental Science, Agricultural University of Athens, Athens, Hellenic Republic.

Abstract

In the present paper we describe an e-monitoring location-aware system, based on a real-time Wireless Multimedia Sensor Network (WMSN), integrated with a semi-automatic trapping and insect counting, based on existing traps, able to acquire and transmit data to a remote server, and a Decision Support System (DSS) that will perform the final optimization of the control treatments. In spite the tremendous technological advances in recent years, WSNs cannot meet all the requirements of ubiquitous intelligent environment mainly because scalar data such as temperature, air humidity, air pressure, etc., are not able to detect all environmental events, like insect detection. For this reasons the efforts are concentrated on the design issues of a WMSN platform, able to collect and integrate multimedia data from the field. Further, a flexible architecture needs to be adopted for integration of a WMSN to the cloud for multimedia sensor data collection and sharing using Web services.

Key words

Fruit flies, invasive species, traps, monitoring, sensors, spraying control, decision support.

Introduction

Fruit flies of the family Tephritidae consist one of the most economically important groups of insect pests threatening a multibillion (€) fruit producing industry of the Mediterranean countries. In addition, there are major invasive species such as the peach (African) fruit fly, Bactrocera zonata and others that have dispersed over the last few years either in some countries of the area or in neighbouring countries, which expand the list of pestiferous Tephritids beyond the "native" Med fruit fly, European cherry fruit fly, and the olive fly. A key issue in the productivity of the Mediterranean olive groves or fruit orchards is the accurate and timely monitoring pests' population, as well as, their control which may require repeated chemical treatments. Nowadays, the problem is faced with the development and implementation of environmentally effective, e-monitoring, and ground spraying control solutions, which will be based on prototypes, technological innovations, and knowledge transfer for specific key-pests, in order to increase the quality and quantity of available fruit to local consumers at lower prices. A judicious monitoring program usually provides an essential tool for environmentally friendly control strategy based on the reduction of chemicals, against the well established as well as invasive fruit fly species in different countries of the Mediterranean basin.

Despite the efforts to develop appropriate monitoring and control methods against these pests, their economic impact remains high. This is mostly due, in addition to other attributes, to their high mobility and also to their ability to directly damage the fruit. These two characteristics clearly indicate that monitoring in large areas coupled with rapid data transfer and decision making should be the essential components in any effort targeting the development of an effective and reliable control system. The need for wide area control of these pests has repeatedly been reported and already applied in several areas. However, the efficacy of such systems is toughly related to the knowledge of the associated spatial data and the timely delivery of the temporal data. In fact, the application of these systems in many cases suffers from inadequate geospatial and temporal information, i.e. the exact areas to be sprayed within the larger area, monitoring of fly numbers in too long intervals, inadequate integration and interpretation of meteorological data, inappropriate spraying process and no traceability etc.

Note that early detection, and its spatial and temporal components, consists one of the most important elements of programs dealing with the control of invasive fruit flies. There are extensive and intensive surveillance projects dealing with invasive fruit flies in different parts of the globe such as the United States of America, Australia, China and Japan. This is because early detection and warning of invasive species into the region is essential for the initiation of immediate actions aiming at eradication of the insects to prevent establishment. However, there is no an integrated approach in the Med area regarding fruit flies and other invasive species. As a result, new innvasive species may spread in large areas without being noticed. It is therefore necessary to provide an easy-to-use "Rapid Alert Warning'' system, which can be adopted as a part of a federal phytosanitary policy, contributing towards developing and implementing a powerful, case-sensitive, quarantine detection network that will be part of the EU and Federal phytosanitary strategy. So far, misidentification of invasive fruit flies, such as B. zonata, may have resulted into rapid and wide distribution.

Monitoring pest insect populations remains the first key issue in agriculture and forestry protection. Conventionally, at the farm level, human operators typically perform periodical surveys of the traps randomly spreaded over the specified control area to estimate the pest population. Each trap is properly installed with pheromones and/or other chemicals that attract and captures the specific insects we may interesting in. Here, one should note that methods to cover spray broad spectrum insecticide, such as proteinaceous liquid attractants or mass trapping with food-based or synthetic attractant or bio insecticides, are still underdeveloped because of high monitoring and application costs. The traps are of certain type (e. g. Delta, McPhail, sticky type traps) and they are designed in such a way that insects are unable to leave it. Pest monitoring systems on attendants who periodically collect and count the captured pests of each trap by hand to perform pest control monitoring. This task is not only labor and time consuming, but often yielding poor results, significantly affected by observer's ability, or by surveying conditions. Additional key resources for insect detection are temperature, air humidity, air pressure, sunlight (light intensity) along with other factors that can be of less significance. Again, a traditional approach to measuring these factors in an agricultural environment meant individuals manually taking measurements and checking them at various times. Overall this approach is a labor-, time- and cost-consuming, particularly for large plantations, so it would be of great advantage to have an affordable system capable of doing this task automatically in an accurate and a more efficient way.

One option to overcome these difficulties is to use an automatic counting trap to collect pest information. Several attempts have been made so far (Guarnieri et al., 2011, Lopez, et al., 2012, Oberti et al., 2008, Tirelli et al., 2011). A brief summary about various methods and technique which were provided by various authors for detection of agricultural pests with the help of image processing is provided in Kandalkar et al., 2013. Each automatic counting trap provides directly an insect count and transmits the processed scalar data (counted pest number and environmental data) to the gateway which is connected directly to the cloud based on the available/appropriate low-power, long-range wireless network. From a network point of view, the usual approach is to set up a remote monitoring system made up of sensor node, coordinator, and server. Sensor nodes send data wirelessly to a server, which collects the data, stores it and will allow it to be analyzed then displayed as needed.

Nowadays, on-going advances in low cost CMOS/CCD image sensors, as well as in wireless communication technology provide a significant contribution in facing pest insects e-monitoring by establishing a Wireless Multimedia Sensor Networks (WMSN) able to remotely access images of the captured insects in the traps. Based on these advances this research proposes an innovative, integrated, Location-Aware System (LAS) suitable for e-monitoring and ground spraying control of some particular fruit flies. The e-monitoring system will be integrated with a Real-time Trapping and Insect Counting (ReTIC) system to support countering measures selection, a time-stamped record of insect counts, and estimate insect populations and alarm spraying levels, which enables the pest operators to determine optimal and accurate treatment timings for some specific key-pests. The LAS enables rapid prototyping of web services in an intelligent Precision Farming (PF) environment combining location sensing technologies with wireless Internet, Geographical Information Systems (GIS), WebGIS, Expert Systems (ES), and Decision Support (DS). Embedded multimedia sensor technologies will make feasible the accurate location-, time-, and demand- specific interventions to the agricultural process by the farmer. Thus, energy saving will be achieved, but most importantly, pesticide and other chemicals usage will be reduced to a minimum. Moreover, if the infestation risk maps for a specific region indicate differences in the various part of fruit growing area, the spraying applications can be directed only in those part interested by the specific key-pest. Based on continuously updated maps of pest insect population dynamics, LAS would potentially facilitate the decision making process of the specific insect control strategies need to be followed. This approach is of great research importance in insect control; however, developers should take into consideration the hardware/software requirements as well as the power capacity required by an operative WMSN with a typical density of the order of one up to i.e. ten nodes (traps) per hectare.

In the above framework, the FruitFlyNet project aims to develop, implement, test and demonstrate an innovative, integrated, Location Aware System (LAS) for fruit fly ground spraying control, by means of four pilots in five Med-countries (Hellenic Republic, Italy, Israel, Jordan, and Spain). LAS will be optimized towards performance maximization, pollution mini- mization and energy conservation, cross-complying with minimum EU standards regarding the environment. It will be unique for many important agricultural pests applying management solutions for established fruit fly populations at different spatial scales providing a fundamental element of planned and implemented area wide integrated pest management programs. Similar developments exist, for example, in the case of olive fruit fly; Pontikakos et al. 2010, 2012 developed and implemented a LAS using meteorological data in the area of Laconia, Hellenic Republic, whereas in the case of med-fly, Cohen et al., 2008, developed a spatial decision system on citrus. The proposed LAS will be developed implemented and tested as follows: Bactrocera oleae (in Spain, Jordan and Hellenic Republic (test site), Ceratitis capitata (in Italy), Rhagoletis cerasi (in Hellenic Republic), Dacus ciliatus and Bactrocera zonata (in Israel).

In this paper we concentrate on some architectural issues the implementation of LAS is facing and related with the automation of the system. The paper is organized as follows. Following the Introduction presented in this first section, the Materials and Methods section provides some background information by means of the state of the art on the available WSN and WMSN platforms. It also includes the sensor nodes with multimedia capabilities and the WMSN architectures, as well as the communication protocols used so far. The third section provides the results and discussion. It includes some of the basic features of the underlying FruitFlyNet architecture we are developing along with the technology adopted and the tools used. Details about data acquisition, the proposed architecture and access to the cloud services is also provided in this section. Finally, in the last section the main conclusions along with the future work are presented.

Materials and methods

1. WSN: Platforms

WSN is an emerging technology gained significant importance in the last few years. Its primary function is to collect and disseminate critical data that characterize physical phenomena around the sensors targeting a number of important application scenarios, including the agricultural sector. Today WSNs are used on large scale capable of gathering information from the physical environment, processing it and transmitting the processed information to remote server or location. A sensor node is generally defined as a cheap and small piece of hardware, which consists of four main units:

- One or more sensors that detect physical phenomena and/or monitor scalar values of temperature (air, soil), humidity, pressure, light intensity, etc.
- A data processing unit which controls sensing, application logic and network transfer. It receives data from the sensors as well as it can filter, compress or correlate data from a series of measurement. The network structure, the communication process and the power management of the node are also organized by the processing unit.
- A wireless data transmission unit which is usually based on the IEEE 802.15.4 compliant or ZigBee standard because of the low-power consumption and the availability of low-cost radios.
- Although significant progress has been achieved in the area of energy consumption, today's standard power supply for sensor nodes is still the battery.

Generally sensor nodes are designed to be widely spread without pre-configuration. A sink, is normally an embedded or a personal computer which is configured to collect, save or react according to the data. The network between the nodes and the sink is built dynamically and is considered to be self-organizing. Software development for WSNs nodes is a complex issue. Many researchers program the modes from scratch, using operating system components, specific middleware, or by higher programming abstractions. Table 1 summarizes the details of some important WSN platforms.

2. WMSN: Sensor nodes with multimedia capabilities

A WMSN is an extension of a scalar WSN. The availability of low power CMOS/CCD image sensors, as well as advancements made in digital signal processing chipsets realized the development of WMS nodes which provide separate processors to handle multimedia data. They are capable of retrieving, processing, and wirelessly transmitting/receiving multimedia content such as audio, video, and still images. Currently used processors in WMS nodes begin from simple 8 bit processors and end at embedded computer systems. Nowadays different WMS nodes are available: MeshEye, WiCa, MicrelEye, Cyclops, CITRIC, Stargate, CMUcam3, IMote2, eCAM, FireFly Mosaic. Farooq M.O. et al. 2014 provide a comprehensive review on WSNs test-beds and stat-of-the-art on WMSNs. Although these WMS nodes can be classified according to their performance, it should be noted that executing compression and coding algorithms locally (on WMS nodes), usually causes computational overhead, which in turn reduces the effectiveness of the corresponding deployed WMSN. In addition, the widespread use of image sensors can be expected only if WMSNs will preserve the low-power consumption characteristic and therefore, low-resolution image sensors are actually preferred in many WMSN applications.

Although many reviews exist in the literature regarding the high demands on the hardware of the WMS nodes and boards in Table 2 we summarize the details of the most important WMSN platforms.

3. WMSN Architectures

Network architecture in WMSN can be broadly classified into the following three categories depending on the nature of targeting application

Device Name	Micro controller	Transceiver	Memory RAM + Flash	Data Rate (Kbps)
GWnode	PIC18LF8722	BiM k	64KB	
BTnode	ATmega128L	CC1000	64KB +180	
Mica2	ATmega128L (8 bit) 7.37MHz	CC1000	4KB+512KB	38.4
Mica2Dot	ATmega128L (8 bit) 4 MHz	CC1000	4KB+512KB	38.4
MicaZ	ATmega128L (8 bit) 7.37MHz	CC2420	4KB+512KB	250
FireFly	ATmega128L (8 bit) 8 MHz	CC2420	8KB+128KB	250
TelosB	MSP430F1611 (16 bit) 8MHz	CC2420	10KB+48MB	250
Tmote Sky	MSP430F (16 bit) 8MHz	CC2420	10KB+1MB	250
EyesIFX v2	MSP430F1611	TDA5250	10KB+48MB	
EPIC mote	MSP430	CC2420	10KB	
TinyNode	MSP430	XE1205	8KB	
Imote 2	PXA271ARM XSale (32 bit) 13-416 MHz	CC2420	256KB +32MB SDRAM	
Stargate	Intel PXA-255 XScale (32 bit), 400 MHz	CC2420 BT IEEE802.11	64MB + 32MB	250 Kbps 1–3 Mbps 1–11 Mbps
XYZ	ML67	CC2420	32KB	

Source: own processing

Table 1: WSN Platforms.

Platform	Processor	Memory RAM	Memory Flash	Camera & Resolution	Radio	Power Consum
Cyclops	ATMEL ATmega 128L MCU + CPLD 8-bit	64 KB	512 KB	Agilent Compact CIF CMOS ADCM-1700 128x128 30fps	Interfaced with Mica2 or Micaz IEEE 802.15.4	110mW – 0.76 mW
Imote2 +Cam	PXA271 XScale proc 32-bit (Imote2)	256 KB (Imote2)	32 MB (Imote2)	IBM400 camera OmniVision OV7649 640x480 30fps	Integrated with CC2420 IEEE 802.15.4	322mW -1.8 mW
FireFly Mosaic	LPC2106 ARM7TDMI MCU 32 bit 60 MHz	64 KB	128 KB	CMCUCam3 352x288 50 fps	Interfaced with FireFly mote IEEE 802.15.4	572.3 mW – 0.29 mW
eCam	OV 528 serial bridge controller J PEG compression only	4 KB (Eco)	---	CoMedia C328-7640 (includes OV7640) 640x480 30fps	Interfaced with Eco Wireless mote nRF24E1 radio RF 2.4 GHz 1 Mbps	70 mA at 3.3V
MeshEye	ARM7TDMI based on ATMEL AT91SAM7S 32 bit 55MHz	64 KB	256 KB	Agient ADNS-3060 30x30 Agient ADCM -2700 640x480 10fps	Integrated with CC2420 IEEE 802.15.4	175.9 mV - 1.78mW
Panotopes	PXA255 XScale CPU 32 bit 400MHz (Stargate)	64 KB (Stargate)	32 KB (Stargate)	Logitech 3000 USB 160x120 30fps 640x480 13fps	PCMCIA IEEE 802.11 wireless card	5.3 – 58mW
WiCa	Xetal II SIMD + 8051 ATMEL MCU 84 MHz	1.79 MB + 128 KB DRAM	64 KB	VGA color camera 640x480 30 fps	Aquis Grain ZigBee IEEE 802.15.4	600 mW max
MicreEye	ATMEL FPSLIC 8-bit	36 KB +1 MB external SRAM	--	OmniVision OV7649 320x240 15 fps	LMX9820A BT 230.4 Kbps	500 mW max
WiSN	ARM7TDMI based on ATMEL AT91SAM7S 32 bit 48MHz	64 MB	256 MB	Agilent ADCM-1670 352x288 15 fps Agilent ADNS-3060 30x30 fps	Integrated with CC2420 IEEE 802.15.4	110 mA – 3 mA at 3.3 V
CITRIC	PXA270 XScale CPU 32 bit Intel 624 MHz	64 MB	16 NB	OmniVision OV9655 1280x1024 15fps 640x480 30fps	Interfaced with Tmote Sky mote IEEE 802.15.4	1 W max
Fox+Cam	LX416 Fox Board 100MHz	16 MB	4 MB	Labtec Webcam bro QuickCam Zoom 640x480	USB BT IEEE 802.15.4 100 m	1.5W at 5V
XYZ+Cam	ARM7TDMI based on OKI ML67Q5002 (XYZ)	32 KB (XYZ)	256 KB + 2 MB on board (XYZ)	OmniVision OV7649 640x480 320x240 4.1fps	CC2420 IEEE 802.15.4 (XYZ)	238.6 mW – 2.2 mW

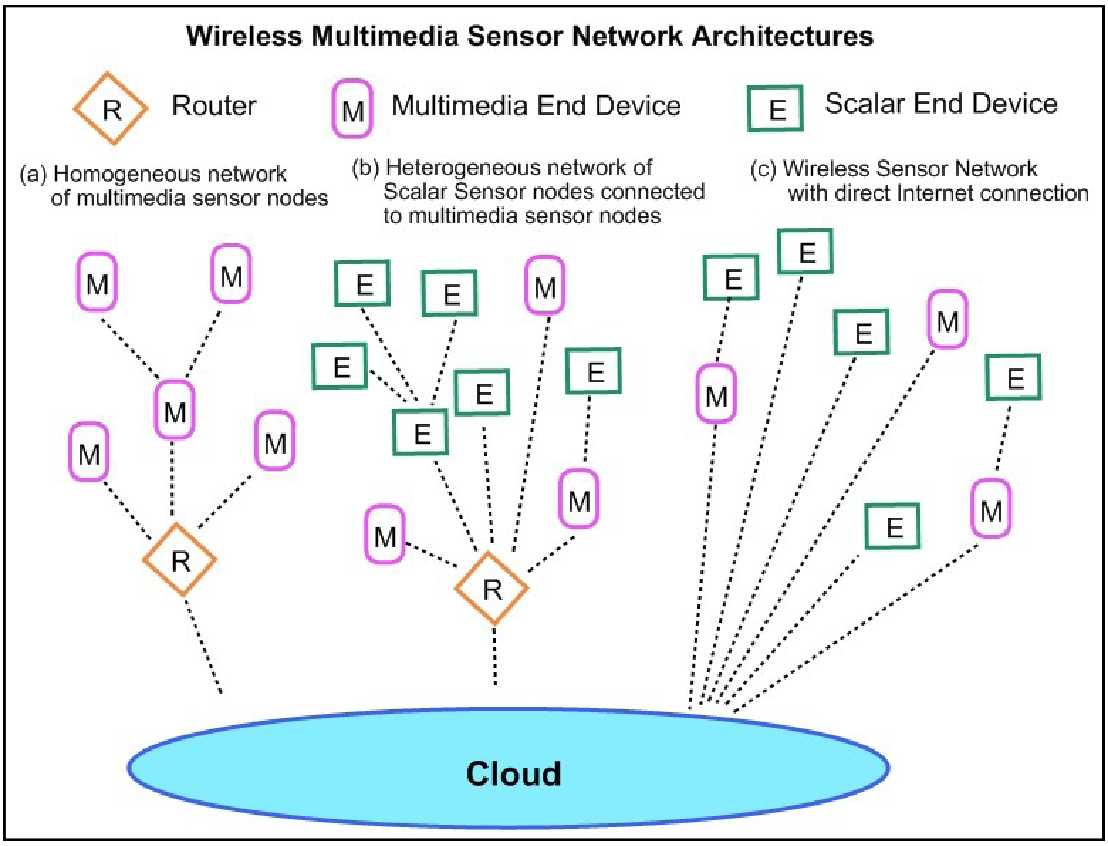
Source: own processing

Table 2: WMSN Platforms.

(Akyildiz et al., 2008, Zacharias et al., 2010).

- Single-tier flat architecture having homogeneous sensors (Figure 1 (a)).
- Single-tier clustered architecture having heterogeneous sensors (Figure 1 (b)).
- Multi-tier architecture with heterogeneous sensors support (Figure 2).

In single-tier flat architecture (Figure 1(a)), the WMSN is deployed with homogeneous sensor nodes. Note that by definition homogeneous sensor nodes are assumed to have the same sensing, computational, communication and hardware capabilities. Therefore, a homogeneous sensor network is composed of tiny, resource-constrained devices, using the same platform. The network functionality serves mainly the purpose of gathering the sensed data and sending it to a central location. All the nodes can perform any function from image capturing through multimedia processing to data relaying toward the sensor node in multi-hop topology. In particular the nodes serve two purposes either used for basic multimedia information extraction from surrounding environment or used as multimedia processing hub, which is computationally more powerful than WMS node. The multimedia information is wirelessly transferred in hop-by-hop fashion from the source nodes to sink/storage device via the gateway. This architecture offers benefits like distributed processing, easy management



Source: own processing

Figure 1 (a, b, c): Single-tier WMSN Architecture.

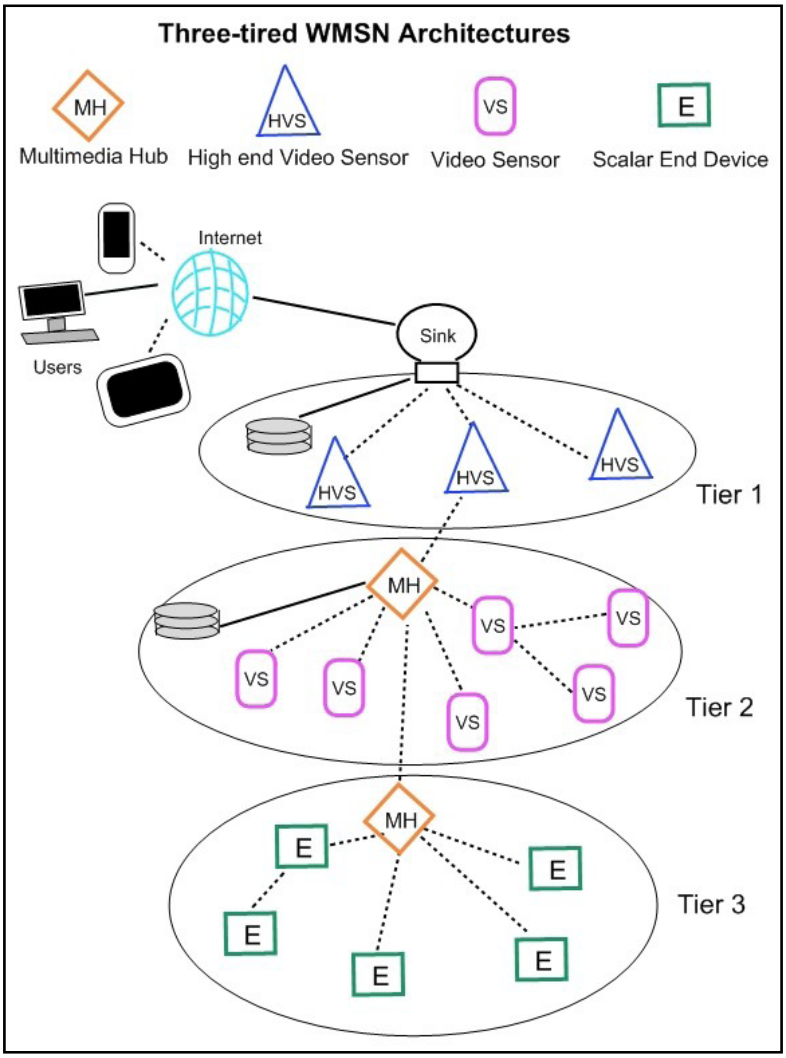
because of homogeneous nature of nodes, as well as long network life time mainly because of low-powered WMS node energy consumption.

As it was noticed earlier the IEEE 802.15.4 compliant standard or ZigBee is designed for very low-power, delay tolerant and slow networks with a very small duty cycle and the theoretical data rate which does not exceed the rate of 250 kb/s. Therefore multi-hopping, interference, and network traffic make this nearly impossible for a real-time application. A solution would be to transfer less data. In order to achieve this, the requirements on the data collection have to be checked. In many applications the data analysis result is important and not the data itself. So reducing the amount of data can sometimes already be achieved while monitoring.

Figure 1(b) represents the second type single-tier clustered WMSN architecture, composed of heterogeneous sensory nodes. The sensor nodes in the cluster gather scalar as well as multimedia information and send it to the cluster head which act as central processing unit for that cluster (having more resources and computational power as compared to other cluster nodes). The processed information is then wirelessly transmitted to sink/storage device via the gateway. The advantage of using this architecture is that it can address a range of application scenarios ranging from simple scalar application to multimedia information processing.

Based on the bandwidth problems that occur, not many existing WMSNs rely on sensor nodes with multimedia capabilities. A common design is the combination of a scalar WSN with a second network, which is triggered, to measure multimedia data. This architecture tries to overcome the restrictions of classical WSNs by the usage of computer networks. The multimedia network is mostly an Internet protocol-based computer network using the IEEE 802.11 standard. This single-tier architecture is quite easy to realize and is widely used so far (Figure 1(c)). The disadvantages of using a personal computer or even an embedded computer instead of a microcontroller are big size, high power consumption and high costs.

Finally, the multi-tier architecture is comprised of three tiers (Figure 2). The first tier is composed



Source: own processing

Figure 2: Multi-tier WMSN Architecture.

of scalar WSN nodes for performing simple tasks of gathering the scalar information from the surrounding environment. The middle tier comprised of medium resolution video sensor nodes capable of gathering multimedia information. The final tier composed of high-end vision sensor nodes for complex task like object recognition, tracking objects features etc. Every tier has a central processing hub which is basically a video node having more computational and communication resources. So the storage and the data processing can be performed in the distributed fashion at each different tier. The high-end WMS nodes gather information from the lower tier processing hubs in addition to its own gathered information from the targeted location, relayed the processed data wirelessly to the gateway for storage or to the sink. Such a network offers advantages like better scalability, high functionality, reliability and better coverage as compared to single-tier network architecture. However only limited applications have been implemented so far using this architecture.

4. Communication protocols

Generally, the communication between the sensor nodes can be achieved through one of the four protocol standards for short-range wireless communications with low power consumption. Note that from an application point of view Bluetooth (over IEEE 802.15.1) is intended for cordless mouse, keyboard, and hands-free headset, Ultra-WideBand (UWB, over IEEE 802.15.3) is oriented to high-bandwidth multimedia links, ZigBee (over IEEE 802.15.4) is designed for reliable wirelessly networked monitoring and control networks, while Wireless Fidelity (Wi-Fi over IEEE 802.11) is directed at computer-to-computer connections as an extension or substitution of cable networks. Specifically:

- Bluetooth is intended for low data rate, short range distances (around 10 meters) with a low power supply. It is most appropriate for Wireless Personal Area Network (WPAN) communication.
- ZigBee is intended for low data rate, short range distances with a low power supply. It is most appropriate for WPAN communication. Since ZigBee may also reach 100m in some applications it is also appropriate for Wireless Local Area Network (WLAN).
- UWB is intended for high data rate, short range distances with a substantial power supply. It is most appropriate for WPAN communication.
- Wi-Fi is intended for high data rate, long range distances with a substantial power supply. It is most appropriate for WLAN communication.

The above classification justifies to a certain extend the reason of considering ZigBee, as well as any IEEE 802.15.4 compliant to be the most reliable solution for connecting sensor nodes with the coordinators in the WSN. Due to low power consumption, simple network deployment, low installation costs and reliable data transmissions, these two standards are mainly preferred, over Wi-Fi and Bluetooth. In any case, Zigbee is usually selected as the best, low-power, short-range, transmission technology for the sensor node–coordinator link, due to its openness, performance, cost, and time of implementation in many different applications. On the other hand, WiFi is usually selected in case of short–range transmission. However, this protocol requires more power consumption. For the coordinator–server link, long–range wireless network (2G (GPRS), 2.75G (EDGE), 3G (UMTS), 3.5G (HSDPA), 4G (LTE), and satellite) has been the only reasonable choice.

Results and discussion

1. *FruitFlyNet* WMSN Architecture

As it has been pointed out the network architecture in WMSN can be broadly classified into three categories depending on the nature of targeting application. In our case the WMSN architecture can take any configuration shown in Figure 1. For example, one obvious choice is to set up a multi-hop architecture with a back-end server. In this first approach, the traps are taking the role of sensor nodes (*FruitFlyNet* sensor nodes) so as to form a homogeneous WMSN. Every *FruitFlyNet* sensor node is responsible for gathering, processing and transmitting the measurement data periodically. In terms of communication the specifications require a mid-range wireless transmission protocol for the link between the *FruitFlyNet* sensor nodes and the coordinators (gateways/routers) and a long-range wireless transmission protocol between the server and coordinators. The coordinator node equips two wireless radios. One is responsible for collecting data from *FruitFlyNet* sensor node and therefore they share the same IEEE 802.15.4 compliant (ZigBee) or IEEE 802.11 (Wi-Fi) protocol. The other is a 3G radio, which is responsible for transmitting the collected data to the selected server.

An alternative to the multi-hop architecture described above and explored also in this study, is to consider every *FruitFlyNet* sensor node as a stand-alone device equipped with a 3G wireless radio that has the capability of acquiring and transmitting multimedia data (scalar environmental data and still images) to the selected server.

In all cases the server stores the incoming data stream to a database and also processes the captured images to identify the insects in the trap. Using a web browser, a user can request and view historical data as well as the last gathered “almost real-time” data from the server. The server will also provide an interface to the operator to show in real-time the population map and its trend, as well as an alarm when insect density exceeds a threshold.

2. *FruitFlyNet* Sensor Node

Any *FruitFlyNet* sensor node has to satisfy some particular requirements. First, the sensor node should be capable to carry out some on-line data processing, such as format conversion, data calculation and value calibration. Second, it should be capable of compressing the captured images on-site. Uncompressed raw images are too large to be transmitted to the gateway node using the low power IEEE 802.15.4 compliant (ZigBee) protocol and in almost all cases they are compressed before transmitting. The algorithm automatically inspects the newly taken insect images and determine their number. Under this mechanism, the WMSN can take insect photos at a higher frequency, but the amount of data to be transferred is reduced.

The sensor node consists of:

- A novel trap based on some well-known trap designs such as delta, or sticky. McPhail traps present difficulties to adapt an image sensor in an efficient way.
- An open source embedded controller, which is based on a modular architecture responsible for the sensors data storage unit, antenna, temperature and humidity sensors and other peripheral components.
- Images acquisition is achieved with a high resolution micro camera. Alternatively, a USB web camera module that allows real-time capturing of the insects in the trap may be used.
- Scalar temperature and humidity values are acquired with a digital sensor directly connected to the controller.
- An xBee adapter and an appropriate antenna for transmitting the images and other information data to the coordinator. Thus, all the traps in the field communicate with each other using WiFi (IEEE 802.11), protocol, or the ZigBee (IEEE 802.15.4 compliant) protocol, depending on the field to be covered.
- A long-range, 3G (UMTS) communication module for transmitting multimedia data (still images and environmental data).
- A rechargeable battery connected to a solar panel and charger, responsible for the powering of the system, thus making the whole system completely autonomous.

A possible hardware solution for the development of the WMSN is based on a single-board PC, as for example the Raspberry Pi Model B/B+. The platform of Raspberry Pi has a Broadcom BCM2835 system on a chip (SoC), which includes three core: A low power ARM1176JZF-S, 700 MHz applications processor, a dual core VideoCore IV multimedia Co-processor, Graphics Processing Unit (GPU), and finally an Image Sensor Pipeline (ISP). It has 256 MB of RAM (Model A), upgraded to 512 MB (Models B and B+). The device is running Linux based OS and has several I/O ports: 2/4 USB 2.0 (Model B/B+), 1 GPIO socket, 1 Ethernet 10/100 and 1 composite video out, 1 HDMI, 1 audio female jack. The board is powered at 5V with a micro-USB plug and has a power rating of 700mA. It does not include a built-in hard disk or solid-state drive, but it uses an SD card for booting and persistent storage, with the Model B+ using a MicroSD. The main advantage on using this Rasp board is related with its capability to operate with a large variety of digital sensors via the GPIO socket or the USB ports (i.e. temperature, humidity, etc.) and plug to the same GPIO socket a RF serial communication modules like xBee that accomplish to ZigBee/WiFi protocol. It has also a dedicated slot for a cheap 5 Mpxl camera with or without IR that can accomplish the necessity to capture images from the trap.

To send captured images to, say, an FTP folder on the server and to write environmental sensing data to the DB server, it is possible to use also a WiFi 802.11 connection or a 3G/GPRS, instead of a RF connection that has low bandwidth. In case of WiFi it's possible to create a star architecture to a central omnidirectional access point connected server network (locally or in a remote site). The Raspberry WiFi connection can be achieved with an 802.11N USB dongle. In alternative, the Raspberry 3G connection can be achieved with a USB modem with an active data SIM inside. All the devices need to be powered by a solar panel with batteries and charger limiter of an adequate size.

3. Typical Network Parameters

In this section we present some typical network parameters need to be considered. Taking into account that every vendor has different specifications that can vary a lot, below we present some, the most common ones.

- Antenna range: Theoretically it can vary from 10 m to 12 km (outdoor). Note that the typical range that the vendor may provide can be significant less in case of obstacles. For the purposes of our test sites we propose that antenna range is > 70m.
- Communication Protocol: Two are the basic communication protocols that can be used; IEEE 802.15.4 compliant (ZigBee) or IEEE 802.11 (Wi-Fi). Zigbee and Wi-Fi both use the 2.4GHz ISM band and have some overlapping channels.
- Data Buffer: Each node, depending on the vendor, will have different capacity for storing data before sending them. These will range from a few KBs up to some GBs if the node can take an SD Card. We propose that nodes with SD card should be preferred especially in the case that cameras are WMSN

integrated.

- Data Transfer Rate: Each WSN can have data transfer rate from a few Kbps to some hundreds Kbps. In the case of WMSN is integrated with cameras faster rates are required.

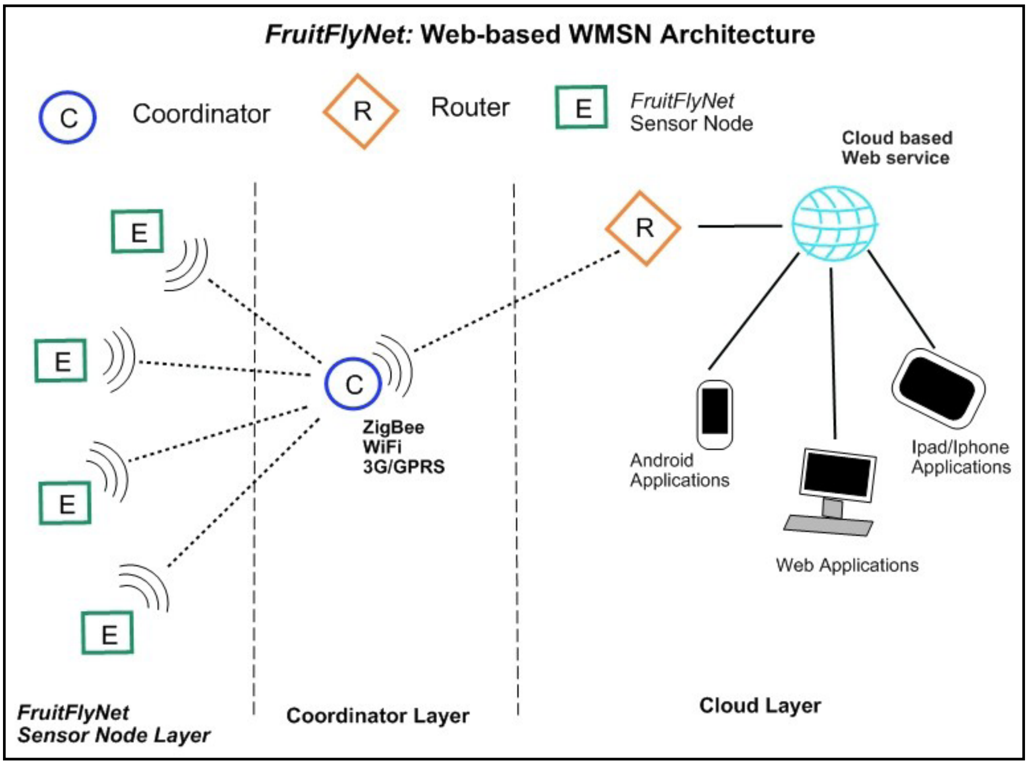
4. Access to Cloud Services

As it is well known the cloud consists of hardware, networks, services, storage, and interfaces that enable the delivery of computing as a service (Perumal. B et al. 2012). The most open and interoperable way to provide access to remote services or to enable applications to communicate with each other is to utilize cloud services. These services need to provide to users real-time data at any time and in the most flexible, powerful and cost-effective way. The access to them is generaly easy, direct, open and interoperable and in this sense, the provided communication means and Application Programming Interfaces (APIs) are easy to implement on every platform and developing environment.

There are two classes of cloud services: Simple Object Access Protocol (SOAP) and REpresentational State Transfer (REST). REST is a much more lightweight mechanism than SOAP offering functionality similar to SOAP based cloud services. In addition, it is also possible to upload the data obtained from the wireless sensor nodes based on SOAP and REST, using messaging mechanisms or social networks (Alcaraz et al. 2010).

As it has been pointed out the collected data from the *FruitFlyNet* sensor nodes are processed, stored and analyzed on a server, via an API. The integration of WMSN with the Internet and the cloud services can be achieved into three stages or layers (Figure 3): The *FruitFlyNet* sensor nodes layer, the coordinator layer and the cloud layer. The *FruitFlyNet* sensor nodes layer consists of sensors that interact with the traps. Every *FruitFlyNet* sensor node uses an IEEE 802.15.4 compliant or ZigBee platform. An alternative option is to use WiFi particularly in case uncompressed (or lossless compressed) insect images have to be transferred to the server. The *FruitFlyNet* sensor nodes form a mesh network (several mess protocols can be examined) and send the information gathered to the Coordinator.

The coordination layer is responsible for the management of the data received from the sensor network. It temporarily stores the gathered data into buffer and sends it to the cloud layer at predefined intervals. The coordinator serves



Source: own processing

Figure 3: Web-based WSN/WMSN Architecture.

as a mini server between the *FruitFlyNet* sensor nodes and the WMSN. It is based on Raspberry B/B+ board but it has more advanced computational resources compared to the FruitFlyNet sensor nodes. It is also connected to the Internet using 3G radios.

Finally, the cloud layer accommodates the web-server to connect and publish the sensor data on the Internet. This layer stores the sensor data in a database and also offers a web-interface for the end users to manage the sensor data and generate statistics. The cloud layer uses HTTP service, which provides a SOAP/REST based API to publish and access the sensor data, allowing, existing networks to be connected into other applications with minimal changes.

Conclusions

The surveillance and the monitoring of the pest population in order to timely apply bait-sprays is the most important activity for pest management. Prompt and accurate detection of pest populations may limit and reduce direct and indirect economic costs to the agricultural sector, environment and society. However, efficient surveillance and monitoring is labor intensive, economically demanding and requires a high level of expertise and accuracy. Based on LAS a new approach is proposed. Multimedia data is obtained based on a real-time WMSN that is capable to access and receive it simultaneously from various sensors in order to perceive the environmental status, make the method more accurate, provide valuable insights for the effectiveness of pest control strategies based on a pheromone sticky e-traps network, and finally assist decision actions for protecting citizens, animals, and environment. Advances in pest management using low-power imaging sensors techniques will also be tested.

This paper firstly described the physical problem of pest management control of some important fruit flies and highlighted a new approach, which was based on the development and implementation of LAS. The research was concentrated in one of the main objectives of LAS, namely, to make a significant contribution to the implementation of a resource constraint WMSN. For this reason we proceeded to a comprehensive overview and development status for existing WMSNs including hardware, software and network architecture. Based on the lessons acquired so far, the paper provided some of the basic features of the underlying FruitFlyNet WMSN architecture we were developing along with the technology adopted and the tools used. Details about the data acquisition, and integration of WMSN to the cloud for sensor data collection and sharing using web services was also provided.

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Corresponding author:
Theodore Tsiligiridis
Informatics Laboratory, Department of Agricultural Economy and Development, Athens, Faculty of Food, Biotechnology and Development, Agricultural University of Athens,
75 Iera Odos, 11855 Athens, Hellenic Republic.
E-mail: tsili@aua.gr

Costas Pontikakos
Informatics Laboratory, Department of Agricultural Economy and Development, Athens,
Faculty of Food, Biotechnology and Development, Agricultural University of Athens,
75 Iera Odos, 11855 Athens, Hellenic Republic.
E-mail: costas_pontikakos@yahoo.co.uk

Dionysios Perdikis
Laboratory of Zoology and Entomology Athens, Department of Crop Science, Faculty of Agriculture, Engineering and Environmental Science, Agricultural University of Athens,
75 Iera Odos, 11855 Athens, Hellenic Republic.
E-mail: dperdikis@aua.gr

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