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A New Remote and Automated Control System for the Vineyard Hail Protection Based on ZigBee Sensors, Raspberry-Pi Electronic Card and WiMAX

Marco Cagnetti, Fabio Leccese and Daniele Trinca
Science Department, University of "Roma Tre", Roma 00146, Italy

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Abstract: A new inexpensive vineyard protection against hailstorm has been realized and tested. The system has been designed and organized in such a way to perform autonomously local activities to physically control the protection of the vineyard but also to transmit information toward a remote control. Each row has an "umbrella" designed by the authors which, unlike other commercial solutions, protects the product without hindering all the mechanical activities typical of a modern vineyard. Locally the single umbrella uses an electronic card for the management and a ZigBee mesh telecommunication network to transmit data to a central control unit which manages the protection. Because of its efficiency, a Raspberry-Pi control card has been chosen as central unit. Finally, a WiMAX connection was chosen to remotely control the system, thus allowing the authors to overcome distance limitations of commercial Wi-Fi networks. The system has been realized and tested for some months in field also during a hailstorm. The results of these tests proved how the system is easy to use and effectively protects against hail; moreover the authors proved the high reliability of the mechanical components which allow the authors to lower the maintenance costs.

Key words: Anti hail, vineyard, WiMAX, ZigBee, Raspberry-Pi, remote control.

1. Introduction

Hailstorm is one of the biggest problems in agriculture [1, 2]; in particular, it creates big problems for the correct grapes growth and ripening [3-5]. Its action can be extremely dangerous for the grapes breaking the berries and therefore precluding the vintage and the quality of the wine [6-9]. The problem is particularly felt for the most precious type of grapes. For example, one of the most appreciated North West Italian grapes quality in the world "Nebbiolo", base of famous long ageing wines as Barolo, Barbaresco or Nebbiolo d'Alba, has the characteristic to sprout early and ripen later [10, 11]. Hail is a form of solid precipitation and it consists of balls or irregular lumps of ice, each of which is called a hailstone and has a measure between 5 mm and 15 cm in diameter [12]. The damages caused by hail are obviously joined with hailstone dimensions evaluated by Torro Hailstorm Intensity Scale [13]. Unluckily the hail phenomena are sudden and random, even harsher during the summer when the grapes are ripening and are still too tender [8]. So a correct protection in real time of the vineyards is practically impossible. There are methods available to detect hail-producing thunderstorms using weather satellites and weather radar imagery. They are efficient systems, but unluckily they are extremely expensive and difficult to manage by small or medium farmers which normally do not possess the technical ability to control an advanced electronic system. The protection findable in commerce are static [14-16] or preventive [14, 17-19]. The firsts are the classical hail net which are efficient against the hail, but prevent the mechanical machining actions on the vineyard which are absolutely necessary for a modern vineyard

Corresponding author: Fabio Leccese, assistant professor, research fields: power quality, sensor networks. E-mail: leccese@uniroma3.it.

management, and in some cases, reduce the air circulation that can favor the development of grey mold and sour rot which can compromise the quality of the wine [20]. On the contrary, the preventive system as anti-hail cannon or cloud seeding obtained introducing silver iodide in the cloud by means of earth-air missile or airplane, has no significant effect [14, 17-19] and is also expensive.

The protection system is based on an "umbrella" realized with a plastic net opened by an electric piston. This piston is locally supplied using a system realized with photovoltaic panels (PV) and batteries and are able to open the umbrella in just 1 min. The stability of the net is assured by the strength of the piston and the use of a plastic grid instead of a "continues" canvas which reduces the sail effect warranting a good opposite action against hail. The system, even if partially static because mounted on the rows of the grapevines, is normally off and fully integrated in the rows allowing the full operative of the machining actions typical of a vineyard, also the mechanical ones. It is activated only in case of dangerous through a wireless command coming from the central unit which manages the area. The central unit is realized by a Raspberry-Pi electronic card which, thanks to its good calculus performances and low cost, represents an optimal solution for this kind of application [21-24]. The control unit constantly communicates with an environmental control station which constantly checks humidity, temperature, sunlight, direction and velocity of the wind. If one of these parameters becomes critical then the control unit sends a wireless command to open the "umbrella" to protect the vineyard from hail. On the rows of the grapevines, local electronic cards, which receive the signal and drive the opening, are mounted. The communication happens by a ZigBee mesh telecommunication (TLC) network which allows an efficient transfer of the information fully covering the area under control [25-27].

To make the system fully available to a remote control, a WiMAX technology, which has been already imagined in food engineering [28], has been happily used. The WiMAX modem/router has been connected to the local central unit to constantly check from remote device (computer, tablet and mobile phone) both the environmental condition of the area and the functioning parameters of the actuators.

The aim of this work is therefore to present a new automatic system based on new technologies, to protect the vineyard from the hailstorm. The system has been realized and tested in a vineyard in the centre of Italy. The results will be also shown.

2. Materials and Methods

To address the issue, the authors realized a vineyard protection system able to open a special umbrella when the risk of hailstorm is present in the area. The system can be divided into three sections. The first, called local, is composed by the set of mechanical and electronic apparatus placed on the rows which allows the opening of the umbrella. The second is the local management system which is autonomously able to evaluate when to drive the opening. Even if other wireless technologies have been already applied in food engineering [29-31] and agriculture [32], the first and the second section are connected between them by a wireless telecommunication network realized by ZigBee devices which supports a mesh connection. The third is the connection to the internet realized with a WiMAX sub-system, because the vineyard is in a rural area not reached by both GPRS/3G and ADSL connectivity.

In the next subsections the authors are going to analyze the single devices and methods used in this work.

2.1 The "Umbrella"

As shown in Fig. 1, the umbrella is composed by two opening segmented arms able to cover the row for overall 1.2 m (60 cm on the left and 60 cm on the right). Each arm has a central articulation which halves

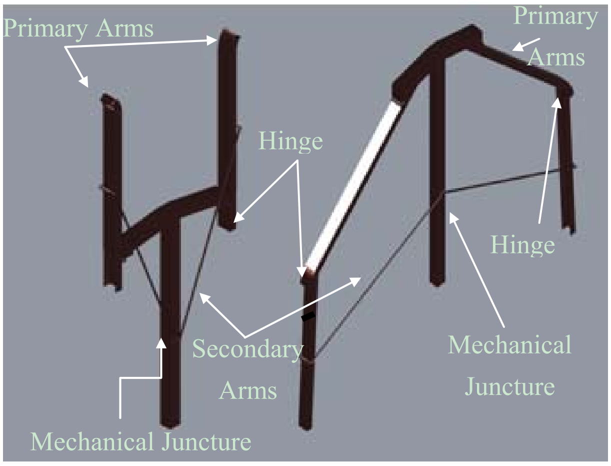

Fig. 1 The umbrella closed (left side) and opened (right side).

the total height to 30 cm in rest conditions allowing the mechanic operations on the vineyard. The opening mechanism is similar to an umbrella, one in which a steel rope, connected to a hydraulic piston, pulls the mechanical juncture pulling also the secondary arms which allows the opening of the primary arms. The complete opening of the latter is obtained by the hinges placed exactly in the middle of each arms. There is a plastic anti-hail net resting on the arms which, when the umbrella is opened cover the vineyard plants. The mechanical parts of the umbrella are made with stainless steel.

The opening is managed by an electric piston able to open the umbrella in 1 min. The piston chosen is the GLA4000 of the Gimson Robotics [33]. The GLA4000 is a 12 V_{DC} (direct current) linear actuator designed for heavy-load applications. It can provide up to 4,000 N (407 kg) of pushing force and 3,000 N (305 kg) of pulling force at the rated voltage. This model is currently available in four different stroke lengths (distance of piston travel) of 50, 150, 200 and 300 mm; the authors chose this last to have the maximum range available for the correct calibration of the system and it has an approximate cost of 50€.

The plastic grid realized in polyethylene which assures stability against ultraviolet and oxidant degradation [34] is placed on the arms of the umbrella. This material is resistant to the hail, but at the same time, being holed, is less sensible to the gusts of wind than a continuing canvas reducing the sail effect and making stable the system. It has a low cost (0.1€ × m^2). In the application the authors used a net with a width of 1.50 m, but generally the width depends on sizes and types of the vineyard. Fig. 2 shows the mechanical parts of the umbrella prototype with the anti-hail net, mounted on the pole.

2.2 The Local Electronic Card

The motor of the piston is driven by an electronic card mounted near the motor. The core of the card is a microcontroller (μC) which is able to manage the electronic card and to drive the motor. The whole system checks that when the environmental condition for a hailstorm is verified, then the central control unit, placed in a building far from the vineyard, sends a wireless command toward the electronic card. This signal is received by the ZigBee Tx/Rx module mounted on the card and directly connected with the μC which acts on the piston until the final position of the arms is reached. This position is signaled to the card using a limit switch already present in the piston.

The most important elements of the card are: the voltage controllers which power all devices; the μC (Microchip PIC 16f688) which manages the system where the firmware is uploaded; the XBee module, connectors for programming the Programmable Integrated Circuit (PIC) (ProgPort), for optional serial transistor-transistor logic (TTL), for an external reference voltage, necessary for the correct activity of the PIC Analog to Digital Converter, and for the I/O ports necessary to pick up sensors information and to drive the piston. Fig. 3 shows the realized prototype inserted in one type of its box ready for tests. This is one of the prototypes tested in real-life conditions. It is possible to see the XBee module.

Fig. 4 shows the box mounted on the top of the concrete pole leader of the row. Each electronic card manages a single row.

The receiver has a very high sensitivity and a low probability of receiving corrupted packets (less than

Fig. 2 The image shows the umbrella closed with anti-hail net.

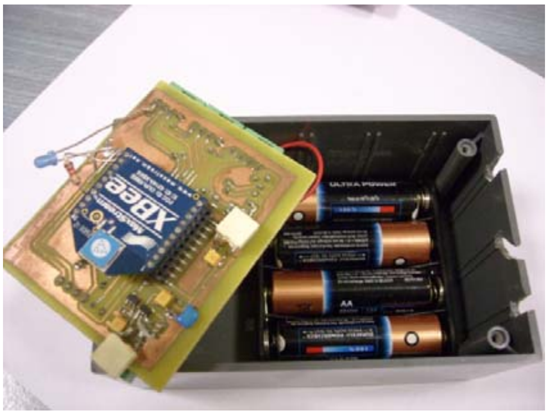

Fig. 3 The electronic control card mounted in its box: it is possible to see the particular of the XBee device.

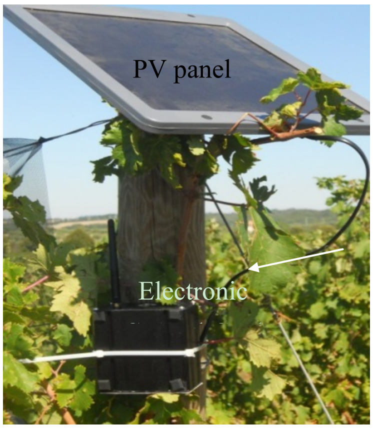

Fig. 4 The electronic control card mounted on the pole.

1%). The modules should be supplied by 3 V from a DC source; the current consumption is in the order of 50 mA (for XBee) and 150-200 mA (for XBee PRO) in uplink and in the order of 50 mA in downlink (identical for both versions), moreover they support a sleep mode where consumption is less than 10 µA. The XBee modules are distributed in three versions of antennas: with on-chip antenna, wire antenna and with integrated connector for an external antenna. The authors used this last configuration for the XBee module closest to the central control unit and the XBee with chip antenna for the others. This choice is joined with the idea that the first electronic control card could be placed far from the building while the others are close together (2.5 m). So the first receives the wireless signal and transmits it toward the others acting as a repeater.

To better manage the system the authors foresaw a check of the battery which provides energy to the system and a check of the limit switch. If the test are negative, i.e., because the battery does not provide energy or the motor does not run, the single electronic card registers this information and sends it to the central control unit once a day. Here, locally or by the website, the farmer can decide how to restore the system.

To verify if anything is correctly functioning, the system, if the environmental condition allows it, checks itself every day. A procedure of opening and closing of the pistons with the check of the battery is executed and if there is something wrong or faulty, it is immediately signaled to the central system.

2.3 The Motor Supply Plant

Following the idea to completely separate the vineyard from the other buildings, also to avoid placing long cables, to supply the electrical engines and the electronic cards, the authors decided to use a system based on PV panels, placed on the head of the row. Each row is supplied by a PV panel system. It is composed by a battery recharged by a solar panel during the daytime. Fig. 5 shows the schematic diagram used, where a battery is charged by a solar panel through a charge controller. In order to determine the right inclination and orientation of the

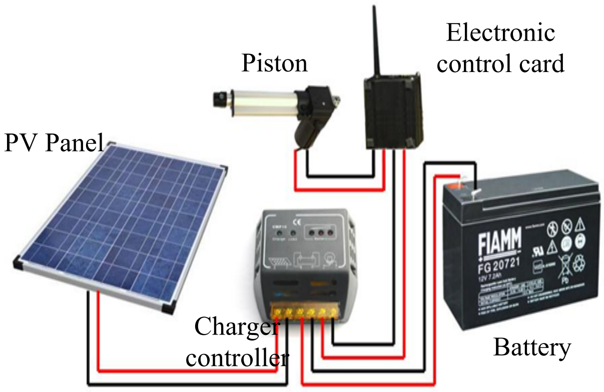

Fig. 5 Schematic block of the PV system.

solar panels to allow the best outcome of the operation, a careful study of the site irradiation curves have been set during the project (UNI 10349 data obtained by PVGIS [35]), and an adjustable structure has been used to correctly tune the azimuth angle inclination (southern direction).

For the sizing of the supply system, it is necessary to determine the annual energy required by the motors. The particular application reaches high power but low energy, so a battery of 12 V 8 Ah has the capacity to satisfy the requests of the motors. To design the PV panel, the project data necessary to determine the energy produced annually by a photovoltaic panel are: location of the installed panel, inclination and orientation of the absorbing surface, soil reflectance, nominal power of the panel, losses of the solar panel and efficiency of the charger controller. Helped by specialized software a 5 W solar panel has been chosen.

The charge controller manages the processes of the battery charge and power supply. Current generated by photovoltaic panels is handled by the controller to provide an output current for battery charge. The chosen model (CMP12 JUTA of HARBIN Hopeful STAR [36]) provides voltage regulation of battery charging as a function of temperature and has a built-in electronic protection to contrast overload, short circuit and overvoltage.

Thanks to the little dimension of the PV panel, it has been mounted on top of the poles of the row, while the battery and the recharger are placed in an

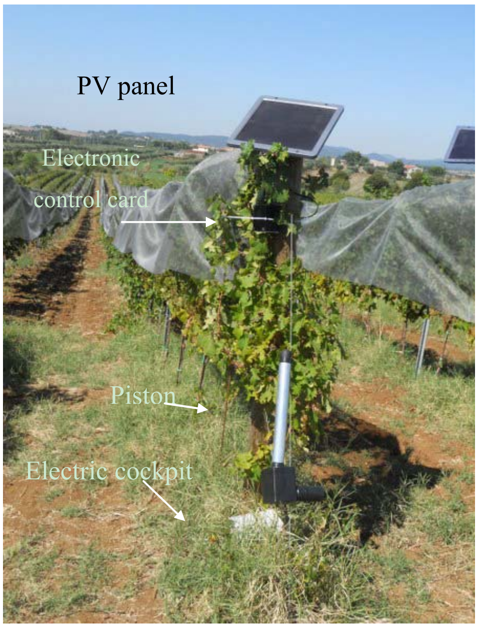

Fig. 6 It is possible to see the PV panel, the cockpit before to be inserted in the ground, the piston, the electronic card and the opened umbrella along the row.

electric cockpit placed in the base of the pole as shown in Fig. 6.

2.4 ZigBee Network

The signal to drive the motors comes from the central unit and it is sent via wireless. The choice of wireless is linked to the idea to make the control unit independent, normally placed in buildings having electrical energy coming from the mains, from the vineyard, normally not reached by the mains and often far from the buildings. In this way, no wire has to be placed between the buildings, where the central unit is located, and the vineyard, where activity can be extremely annoying in place where cultivars act or where there are rodents; in fact, if the wire is sheared by the cultivars or the rodents, it is extremely difficult to find the exact broken point and restore the wire.

To manage a wide area as a vineyard efficiently, the ZigBee wireless communication technology based on the IEEE 802.15.4 standard for communication among multiple devices in a wireless personal area network (WPAN) is particularly suitable. In fact rather than other famous and diffused WPANs as Wi-Fi and Bluetooth, it allows to control up to 65,000 devices in the network and can have a battery life up to 200 times more (up to 1,000 days) than the others [23]. It also allows to create a mesh network at a low cost and it has low power consumption. Its intrinsic difficulty to cover big distances or to support high transmission baud rate are not important in this kind of use. In fact the first problem has partially gone beyond by means of the mesh network while the application does not foresee the use of high baud rate because the information for and from the central unit are few [37-41].

ZigBee wireless communication network has been implemented using the XBee module of the Digi-MaxStream [42, 43]. These devices have compact dimensions, are simple to use, require very low power and are a reliable solution for data transmission. They operate in the ISM band at the frequency of 2.4 GHz.

In the proposed system, the ZigBee network is built to transfer information from the control unit towards the vineyard and vice versa. The first direction allows to send the signal to open the umbrella, while the other direction allows to transfer the sensors information related to each pole towards the central control unit.

The already cited problems with rodents and cultivars suggest installing an electronic card for each row.

The transfer of information from the nth electronic card toward the central control unit can be managed in two ways: directly or exploiting the ability of the mesh network. The first is advisable in case of proximity between the electronic card and the central control unit. This solution is extremely simple because the ZigBee protocol already provides a procedure to manage a so conceived net. In fact thanks to the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) which is a network multiple access method with carrier sensing integrated in the XBee module, the nodes avoid collisions by transmitting only when the channel is sensed to be "idle". Instead, when the central control card is far from the local ones, it is possible to transfer the information from the farthest pole toward the nearest passing through the intermediate poles developing a suitable algorithm [25]. The data sent by the nth pole and received by the nth-1 pole are grouped and sent to the nth-2 and so on up to the first. Here the data will be memorized and then sent to the central control card. It has been tested how, even if two consecutive electronic cards are broken, the information coming from the previous poles however reaches the last pole [25]. In the test chapter the authors repeated some of these test to warranty the reliability of the system.

2.5 The Open Signal Generation: Weather Central Unit and Weather Website

Without the specific local radar it is impossible to foresee the hail formation in the cloud. This kind of instrumentation could be extremely expensive for a single farmer, so other solutions have to be studied. With this in mind the authors evaluated two possibilities: the first is the use of a local weather central unit (WCU), the second is to take information from specialized meteorological website. The WCUs are able to give general information on meteorological parameters as temperature, atmospheric pressure, precipitation, insulation etc., but unluckily these are not information immediately usable to determine the hail formation. The second possibility is the analysis of specialized websites as the Italian Military Aviation meteorological website [44] which is reporting information on the area where the vineyard is placed. These sites use the word "hail" or "hailstorm" to indicate a probability of hailstorm in the area (obviously the site is in Italian so the reference word is "grandine"). so, simply analyzing the text which meteorologically describes the area, it is possible to know if there will be a probability of a hailstorm. Unluckily also this information is not precise because generically talks of a hailstorm risk in the area which could be also very wide. Generally all information coming from the website or the WCU are considered as indexes of a possible hailstorm. Respecting the "precaution principle" the authors developed a software which acts as an OR port: if at least one of the indexes signals the possibility of hailstorm, the software decides to send the opening signal.

The PCE-FWS 20 [45] Meteorological Station (Fig. 7) is a multi-functional device which allows the accurate detection of wind direction, wind speed, temperature relative humidity and precipitation. The meteorological data can be sent by radio to the base unit from a distance up to 100 m. This device is equipped with the latest technology used in meteorological analysis. The touch screen allows recalling data onto the screen easily. The USB port and the cable which is included, allows transmitting data from the device to a computer. Data can be date and time stamped to ensure that it can be analyzed effectively long after being collected. Software for analyzing data is included, which enables to analyze and check meteorological fluctuations, presenting data in graphs and diagrams for measurements over prolonged periods of time. Everything is included with the device so it is ready to be used straight out of the box. For the WCU data, the authors chose some limits which are managed by the Central Control Station following a specific algorithm. For example,

Fig. 7 The winery building with on top both the PCE-FWS 20 Meteorological Station and the picocell with the WiMAX modem backhauling described in a next paragraph.

some conditions to open the umbrella are a wind speed more than 8 m/s (Beaufort scale [46]), relative humidity over 75% [47], or temperature not included in 5-30 °C range (beyond of this range the rain in Italy is almost impossible). Obviously it is not always sufficient to overcome one of this limits to open the umbrella, it is necessary to respect more contemporary conditions, i.e., if the wind is over the limit but the temperature is too high (more than 20 °C) the rain and so the hail is not possible, as well as if the temperature is suitable for the rain, but the humidity is too low, the rain can't come. Fig. 7 shows the meteorological station mounted on an angle of the winery building. Anyway, in addition to the automatic control of the system, there is also a manual control override. In this case the farmer, evaluating the weather conditions can open the umbrella simply acting to the panel control of the software mounted on the Central Control Station.

2.6 The Control Station: Raspberry-Pi

Raspberry-Pi [21-24] is a low-cost (≈ 25€), basic computer contained on a credit-card size single circuit board and features ports for HDMI, USB 2.0, composite video, analog audio, power, internet, SD card. It assures high computing power.

The Raspberry-Pi has a Broadcom BCM2835 system on a chip (SoC), which includes an ARM1176JZF-S 700 MHz processor. Its firmware includes a number of "Turbo" modes so that the user can attempt overclocking up-to 1 GHz. It also has a VideoCore IV GPU and it is shipped with 512 MB of RAM. It does not include a built-in hard disk or solid-state drive, but uses an SD card for booting and long-term storage.

Although its performances are not comparable with normal PCs, this device is revolutionary for its low cost and price-performance ratio. In fact it's a capable little PC which can be used for many things normally made by a PC desktop, like spreadsheets, word-processing and games, and also allowing high-definition video playback.

The computer runs entirely on open-source software and gives the ability to mix and match software as the user whishes.

The Raspberry is the hub of the system. It is connected toward the vineyard by a control card used only to transmit data through its XBee module. In this direction it sends all the information to open the umbrella and receives information by the electronic control cards on possible faults on the rows. Locally it is connected to the weather central unit which sends information about meteorological local conditions and if the fixed limits are exceeded, the Raspberry-Pi sends the opening signal. It allows also the local visualization of the entire system allowing users to verify if there is something which needs recovery action.

Also wanting to realize the remote control and being the vineyard area far from cities and so often not reached by an internet wireless signal or an ADSL line, the authors used a satellite internet connection by a modem ViaSat Surfbeam 2 [48] connected with the Raspberry-Pi. In this way, it is possible to monitor what happens in the vineyard checking the associated website uploaded on the Raspberry which shows the electronic control cards and the connected sensors activity.

2.7 WiMAX and Satellite Connection

Fiber and wire-line technologies are usually located in highly populated areas, while in rural areas the only effective economic solution is a wireless extension. WiMAX is a wireless solution chosen that can extend the reach of an existing broadband network to low density rural areas.

The system can be remotely monitored and controlled by a WiMAX connection; each location is connected to a WiMAX outdoor 3.5 GHz modem model HES-319M [49] which provides an internet connection to the plant via an Ethernet cable. The modem is powered at 48 V_{DC} by a DC-DC boost based on LTC3862ENG [50] and can be used in battery backup conditions, too.

The WiMAX connection is a good choice for rural areas where ADSL and 3G connections are not yet present, for example, for all those areas in digital divide condition; in the test, WiMAX connection is used as a machine-to-machine (M2M) data link.

Anyway many digital divide areas in rural country are not yet covered by a WiMAX service. Two main situations for the vineyard out of WiMAX coverage can be distinguished:

(1) The area is not WiMAX covered at all and no data link is available near the vineyard;

(2) The area is in proximity of a WiMAX but it's out of cell coverage.

It could be hypothesized that a WiMAX 802.16e picocell could be installed near the vineyard fields and redistribute the WiMAX service over the land around. The WiMAX picocell, in fact, is an easy-to-deploy outdoor solution and can provide a sustainable business model of an overall broadband service offering.

The picocell solution is compact fully integrated form factor Base Station (BS) that can reduce the capital expenditure (CapEx) and the operating expenditure (OpEx) needed to enable a Broadband Carrier to deliver broadband service where it's needed [51, 52].

The picocell used for the test is an Airspan Sinergy2 4G Pico Base Station [53] working at 3.5 GHz TDD, an ultra-compact sectored device with a front mount antenna for a single piece deployment can support a maximum of 256 attached users per 10 MHz channel size sector (64 active users) and a maximum output power of 54 dBm; declared performances are 40 Mbps PtMP (point to multipoint) downlink, 17 Mbps PtMP uplink.

The BS antenna is Cobham SA12-3.5-DS/1916 [54], a 60 degrees sectored panel with 11 dBi gain and it is linked with the front of the pico-element.

The total system weight is about 7.1 kg and can be mounted on an existing pole in example like a street light pole. The total power consumption is about 60 W at 48 V_{DC} and it suggests that pico-element could be powered by solar plant.

Test on the field shows that the pico-element in the configuration above can provide WiMAX coverage in a range of about 2 km using HES-319M outdoor CPE as client device.

The internet connection to the pico-cell can be served in different ways, depending from the WiMAX coverage scenario:

(1) The area is not WiMAX covered (Fig. 8) at all and no data link is available near the vineyard. In this scenario the authors tested the satellite backhauling using a ViaSat Surfbeam 2; it represents the alternative solution to a microwave radio-link.

(2) The area is in proximity of a WiMAX but it's out of cell coverage. The authors used an additional HES-319M CPE as a WiMAX backhaul aiming to the next BS available in the range of 10 km. This is the cheapest solution when vineyards are bordercell adjacent. The WiMAX signal can be extended by the pico-cell to other customers in out of coverage of 2 km (Fig. 9).

In the application the authors found themselves in the latter scenario because the WiMAX antenna was close enough to satisfy their necessity, nevertheless they also tested the first scenario to verify the functionality obtaining good results. The Airspan Syneregy software defined radio (SDR) supports the iBridge mode, a vendor specific configuration that delivers backhaul functionalities utilizing advanced point to multi-point access techniques; each picocell becomes a relay node to extend WiMAX coverage.

2.8 Remote Management Software

The remote management software is a web based application running on a dedicated web server on internet, it collects weather data from the meteorological stations and monitors a meteo-service in order to send alert commands to the hail interested vineyard protection plants.

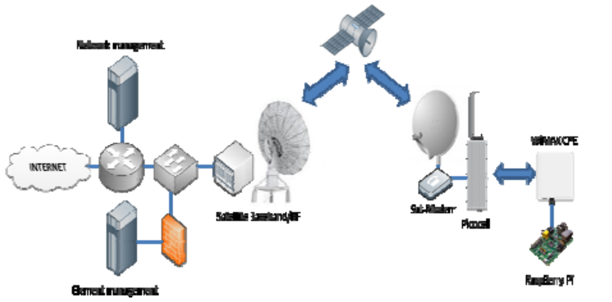

Fig. 8 Scenario 1: area is not covered by the WiMAX, it is necessary for a satellite to create a TLC link.

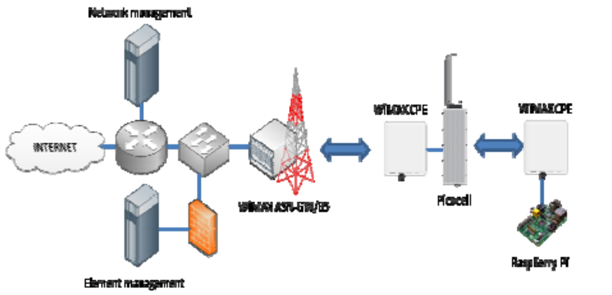

Fig. 9 Scenario 2: area covered by the WiMAX.

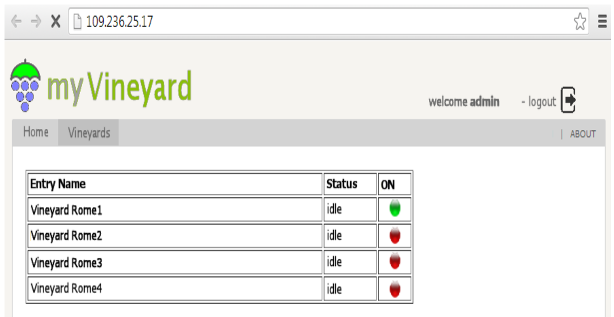

Fig. 10 Vineyards site.

When a registered plant is under hail risk, the server sends to the specific Raspberry-Pi the command to activate the vineyard protection system.

Each Raspberry-Pi must be configured with its own account credentials and have to be registered into a web server database with the GPS position of the vineyard (in case there are more vineyards). User can also manually activate the vineyard protection logging in his own page on the web server; the server collects user's plants and simply shows the activated protections with a green lamp (Fig. 10). User can turn on or off the process by simply changing the lamp status on its page.

On the website, it is also possible to verify the situation of the single local electronic control card. In fact a log file reports the sensors checked by the cards in order to quickly act for the restoration of the single row system.

3. Test and Measurements

As already said the system has been realized and tested in field. The authors conducted some experiments to verify the ZigBee network activity and some reliability tests [23] to check the umbrella opening/closing. Moreover, the authors also conducted a lucky test on July 21 [55] during the installation of the system when a hailstorm hit the area of the vineyard.

3.1 ZigBee Test

The communication reliability of a ZigBee mesh network, also in different environmental conditions, is satisfactory [25]. However, to be sure of the final result, the authors repeated some tests to confirm the communication reliability. The tests were performed in open field directly on the realized system. Considering the plant of the system, the authors obviously have open field and line of sight between the local control cards (maximum distance 2.5 m) and between the first of these and the central control unit (about 30 m).

The tests were carried out using the standard XBee modules with patch antenna. They are technically suitable [25, 39, 44] and inexpensive. The tests allow to check the network both for clear weather conditions and in rain ones. Using the X-CTU software provided by Digi-MaxStream to check the transmissions, 10,000 transmissions were done for each test [25]. The procedure involves that a known test packet is sent by the central control unit through the network up to the farther module. When the test packet is received, it will send the packet again through the network. The test packet will then be received from the central control unit which will verify its sameness with the one sent previously. Using the lower possible power for the transmission, the average reliability was absolutely satisfactory and equal to 100%.

Another functionality field test was to verify what would happen in case of a local control card fault which was not able to answer a data request from the master. To perform this test the authors simulated the absence of one of them verifying that the hub software reported the malfunction on its graphical interface.

3.2 Opening/Closing Test

This has been a simple reliability test to check the mechanical reliability of the umbrella. Also in this case the authors realized the test both during clear weather and windy and rainy ones. The authors verified on three rows if the umbrellas showed signs of fatigue or breaking. They performed 2,000 tests of opening/closing in clear weather conditions and 989 in different conditions of rain and wind and the umbrellas always answered correctly. The test has conducted forcing the opening/closing procedure realizing specific test software on the Raspberry-Pi.

3.3 The Test during the Hailstorm

As extremely lucky case, the authors conducted a test during a hailstorm happened in the vineyard area on July 21 [55]. In this date a typical Italian hailstorm with hailstones of 1-2 cm diameter hit the vineyard where the authors were to test the system. Following the precaution principle when the wind overcame 8 m/s, with humidity over 75% and a temperature unusually low (15 °C) for that period in that area, the umbrella opened. Despite the wind speed reached 12 m/s, the umbrella did not suffer damage. Unluckily the rows which are not covered by the umbrella and hit by the hail suffered damages reducing the overall production of grapes.

4. Conclusions

A specific system designed and realized by the authors themselves has been used to protect a vineyard against hail. The system is based on a mechanic part called "umbrella" which, if opened, protects the vineyard; on the contrary if closed it does not prevent the mechanic activities typical of a modern vineyard. The opening is fully managed by a complex remote system which checks the possibilities of a hailstorm and in that case sends the opening command.

Locally, each row of the vineyard is managed by a local electronic card which manages the opening and communication with the local central unit by a ZigBee wireless mesh network. The central control unit is realized by a Raspberry-Pi which performances fully satisfy the calculus exigencies at a very low cost, and at the same time, allows to create a web page for a remote management of the system. To complete the remote control, the authors integrate the system with WiMAX technology which allows to overcome both the distance limitations typical of Wi-Fi and the absence of an ADSL, situation of typical rural area and in particular where the system has been tested. The test in field verified as the system correctly acts.

Considering the success of the experiment the farmers decided to develop the system on the finest quality of grapes of the vineyard (Moscato and Cabernet Sauvignon).

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