A Modified MPRR Protocol for WSN in Agricultural Scenario

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Abstract: This paper analyses the use of a WSN for agricultural scenario, referencing to the modality of communication between the network nodes, and proposes a modified version of Multipath Ring Routing (MPRR) to improve performances and robustness of the network on the long period. Through simulations with Castalia, some limits of the standard MPRR have been highlighted, and through the possibility to modify the algorithm itself, improvements have been made that make the modified MPRR suitable for our scenario.

1 INTRODUCTION

Precision Agriculture is a Management System integrated with the aim of optimizing the efficiency of the agricultural production, product quality and profitability, increase climate and environmental sustainability, using tools and innovative technologies.

Italy has provided for Rural Development Programs in various Italian regions, through intervention strategies related to the spread of agronomic management methods and approaches.

The Ministry of Agricultural Policies and Europe itself invested many funds on precision agriculture and agricultural engineering (Ministero delle Politiche Agricole Alimentari e Forestali, 2017).

The development of applications more and more suitable for national productions is important for many reasons: from production and quality optimization to the reduction of business costs, from minimizing environmental impacts with seeds, fertilizers, agro pharmaceuticals up to cutting water use and fuel consumption. In fact, the monitoring of the environmental parameters permits to manage many interesting areas as:

- the use of pesticides and harmful substances,
- the quality of air and water
- monitoring of fires and atmospheric events or natural and non-natural disasters etc.

The research field of precision agriculture is having an increasing interest from the scientific community due to its importance and the possibility of using technology and IoT to improve processes.

For example, the use of an optoelectronic sensors to evaluate the radial growth of a fruit, monitoring fruit production, has been evaluated (Thalheimer 2016), while in (Pahuja et al., 2013) has been monitored the climatic trend in commercial greenhouses, in order to evaluate the production trend and the health of the plants, through Wireless Sensor Networks (WSN). In (Leccese et al., 2019) has been studied the development of a WSN for smart monitoring of pesticides on agricultural land, designing an electronic nose starting from an array of commercial gas sensors developed for other environmental applications. In (Kim et al., 2008) a distributed Wireless Sensor Network has been used to remotely control an irrigation system. In (Nisio et al., 2020) fast detection of olive trees affected by xylella fastidiosa from uavs using multispectral imaging has been implemented. In (Giaquinto et al., 2019) a sensor for leak detection in underground water pipelines has been developed. In (Cagnetti et al., 2020) a comparison between the most suitable routing protocols for WSNs applied in wide agriculture scenarios is shown and it evidences the most suitable protocol for a particular scenario.

In our paper, we are going to analyze the use of a WSN for the agriculture, referencing to the modality

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of communication between the network nodes, and proposing a modified version of Multipath Ring Routing (MPRR) to better performances and robustness of the network on the long period.

Through Castalia, a free simulation tool, the limits of a standard MPRR have been evidenced, giving us the possibility of modify the implementation of the algorithm, improving it significantly.

2 WIRELESS SENSOR NETWORK

WSNs are widely studied and applied to many various contexts (Gallucci et al., 2017; Spagnolo, et al., 2020). They are composed by many sensors (called nodes) and all is necessary to their functioning and communications; each node communicates with each other and with a sink that collects, analyzes, tracks and eventually sends data to other platforms, and typically is connected to Internet and mains (Leccese et al., 2014; Leccese et al., 2017).

The node is a device formed by sensors, a microcontroller to manage the communication between nodes, transmitter to connect with the other nodes and sink through an antenna and an adaptive circuit, a power supply circuit, and some I/O interfaces to manage signal from sensors.

The topology of a WSN (Figure 1) describes the physical position of each node: it strictly depends on scenario and on sensors. Nodes are spatially disposed according to the area to monitor, and they communicate, auto organize themselves and coordinate with each other through a routing protocol.

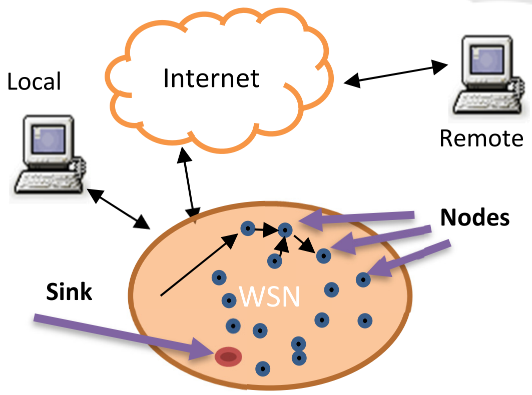

Figure 1: A generic WSN architecture.

The environmental monitoring is a typical application of WSNs, for example to monitor archeological sites or museums (Leccese et al., 2017; D'alvia et al., 2017; Leccese et al., 2018), for surveillance (Morello et al., 2010; Islam et al.2012; Caciotta et al., 2014), in aerospace scenarios (Pasquali et al., 2016; Cagnetti et al., 2020) or street light control (Leccese, 2013). They are very flexible and robust structures that can be configured in the correct way according to the scenario; in fact, an ideal network cannot exist since each scenario has some characteristics that should be evaluated (Pasquali et al., 2016; Pasquali et al., 2016).

3 AGRICULTURAL SCENARIO

The definition of the operative scenario is fundamental to design a WSN correctly; in fact, each scenario has some characteristics we need to know and analyze, and a wide number of parameters should be considerate and studied.

It is important to guarantee the transmission, that must be reliable and safe (a node sensor can stop working compromising the stability of the network or requiring a new configuration), and the number of nodes must be compatible with the area to be monitored (too few sensors could decrease accuracy and too many sensors could increase energy consumption). The scenario is an agricultural field where the sink is positioned at the center of the structure, and is connected to the national electrical grid and to internet.

Sensors are arranged in a radial pattern around the sink, their number is between 9 and 15 each hectare, spaced about 25/50 m; the sink provides to send them to specific system for data analysis through internet connection.

Various specific constraints should be evaluated:

- Open field position of devices: sensors are often on open field, so they are exposed to meteorological events. They needs to be made in a very simple and a light way, using robust and reliable components as Commercial-off-the-Shelf (COTS).
- Energy saving: the evaluation of the supply type of network is an important part of agricultural scenario; in fact, the connection to the National electric grid could be not provided. A cabled power supply is not recommended due to the possible damages of cables caused by water, or animals, but batteries have limits to their life and dimensions. To improve energy saving, the choice of electronic components and of communication modality, as routing protocol and strategies for a limited use of resources, is fundamental. E.g., a sensor can be activated for a limited time, to avoid a continuous use of

batteries, or network can be configured using low-energy routing protocols.

- Sensor maintenance: a structure that does not require great maintenance should be used; sensors arranged in open spaces are subjected to problems that would require heavy and/or expensive maintenance.
- Economy: the structure must have affordable costs for maintenance and commercial development.
- The network is static or dynamic: the sensors are placed in the field and remain in place until they are naturally switch off.

4 ROUTING ALGORITHMS

The hardware of sensors and sink can be technically composed by specific low energy components, and the adaptive structures can be designed to minimize energy consumption, but the network management can be optimized searching for the best communication modality between nodes and sink.

The consumption of a sensor is due to the transmission phase, so an energy saving can be obtained using specific protocols that guarantee reliability of transmission, accuracy of information, low consumption and maximize the life of the nodes.

A high consumption can be due to the overlapping of information that are lost and should be transmitted again, to the listening time of a node or the reception of wrong packet.

Routing algorithms are a central point to work on to save energy. Routing works managing the hops between nodes and sink, creating the shorter path as possible. Some protocols are designed to use clustering, aggregating data before the dispatch. The data aggregation is very useful to decrease energy consumption, limiting the transmission time of a sensor.

Analyzing literature and according to our experience, the most suitable protocols to limit consumptions are the LEACH or Low-Energy Adaptive Clustering Hierarchy (Leccese et al., 2019), the PEGASIS Power Efficient Gathering in Sensor Information Systems (Shekar, 2012), the AODV or Ad hoc On Demand Distance Vector (Maurya et al., 2012) and the Multipath Ring Routing or MPRR (Pandya & Mehta, 2012).

LEACH is a cluster based protocol, in which sensors are divided into clusters and each one contains a cluster head that collects data and sent them to sink, limiting the time of transmission and consequently the consumption. The node disposition is a limitation because some nodes could be very far from sink.

The AODV protocol is specifically used for mobile networks and creates a table of shorter path between nodes when requested by them. If the network topology changes, paths are rebuilt. It’s limitation is due to a bad managing of network congestion.

Multipath ring routing uses multiple propagation path between each sensors, to maximize network reliability and avoid the loss of packets. The sink provides a configuration signal to the nearest nodes, assigning them a hierarchy. They are set with a level of ring 1, so they send the signal configuration to the nearest nodes that configure them as level 2 and so on, until a level number, called ring number, characterizes each sensor. At the end, network provides almost the best paths between nodes. During the transmission phase, a signal from node N is sent towards all the N-1 nodes that send it toward the N-2 nodes and so on until it arrives to the sink. A sensor could break or switch off; in this case the multiple paths ensure that the signal reaches the sink through another node of the same level, but its limitation is due to initial configuration that could spent some energy and time.

5 MPRR AND CASTALIA

We focused our attention on MPRR, providing more simulations through Castalia, a very useful tool for studying WSNs.

It is a free application that includes the implementation of some routing protocols that are applied to the specific topology of the scenario defined by user. For this reason, we could compare the routing protocols, according to the specific scenario: each scenario has some characteristics that can be evaluated through a simulation.

We also worked for a visual tool to show the network physical topology and package trend during a transmission time.

We focused our attention on MPRR for its characteristics of being very robust and efficient, reducing possibility of losing information. In fact, although it provides multiple propagation paths, if the nodes of a certain level shut down, the nodes of the previous level could not receive messages to send toward the sink. A multi-hop structure can be used; in this case, the dead node is bypassed, permitting to the message to arrive; obviously, it is very expensive for consumption because of the more distances between nodes and can create problem of overlapping.

For our scenario, MPRR is not the first choice because of the consumption during the initial configuration phase, and the transmission can bring to an early shut down of the network (Leccese et al., 2014). However, the arrangement of the nodes is compatible with MPRR, so we ask if it was possible to improve this algorithm to make it more efficient. Our simulations highlighted these problems and allowed us to evaluate the configuration of the nodes in MPRR.

In fact, the network configuration occurs only one time and it sets the best routes for each sensor. In this case, a little percentage of node could be wrong or no configured: these nodes could not ever communicate between the other nodes and the sink. This problem is caused by the contemporary node's transmission, so during the configuration phase, an overlapping of signal, and a reduction of signal/noise ratio, could occur, causing a bad configuration of some sensors.

Castalia tool showed clearly and visually this configuration problem, in which some nodes appeared to be inactive.

The wrong configuration can be characterized by:

- one or more nodes that are not configured, making them invisible to the network;
- one or more nodes that can acquire a wrong ring number, incrementing the route to the sink.

Our scenario provides a central sink and many nodes disposed around it, equally spaced and with the same initial energy.

Figure 2 shows the configuration: a central sink sends the configuration message to the nearest nodes.

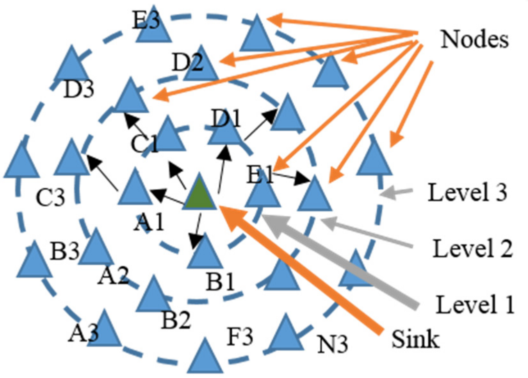

Figure 2: The topology of our scenario.

During the configuration, the sink sends a message to the nodes that configure themselves as level 1, then the nodes of level 1 (A1,B1 …) send messages to the nearest nodes that configure themselves as level 2 (A2, B2…) and so on until each node is configured.

Only one configuration message could be necessary to configure all nodes correctly, but in the reality, the distance between nodes is not the same, so these situations can happen:

- more packets collide between each other (Figure 3). In this situation, the configured node A1 and B1 transmit the message at the same time towards the node N2 that does not configure itself as level 2 because it cannot decode the message. When node A3 will send the configuration packet, N2, which has not been configured yet, will configure itself as level 4 instead of level 2, incrementing the hop number from the sink.

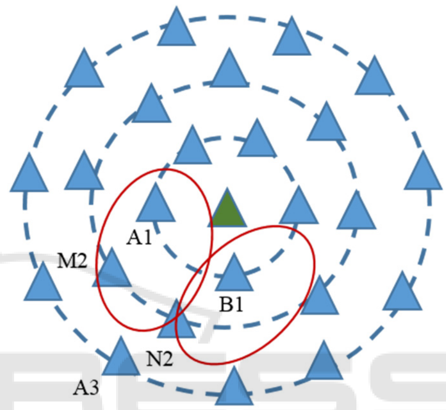

Figure 3: The collision between two packets makes N2 not configured.

- Nodes transmit in every direction (Figure 4). The configuration packet from A1 is intercepted by A2 but it can be intercepted also by A3 that configure itself as level 2 instead of level 3. Therefore, nodes already configured are not newly modified, but nodes of higher level could configure themselves wrongly.

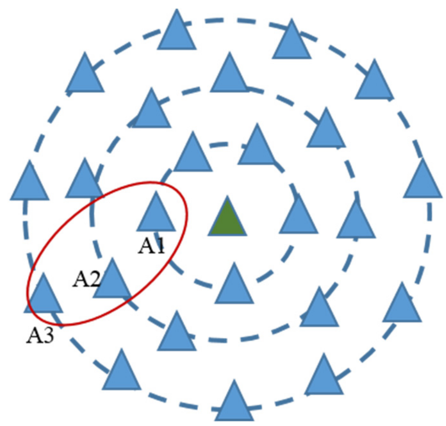

Figure 4: The signal from A1 is intercepted by A3, which is incorrectly configured.

Our simulations have confirmed the inefficiency, due to the bad configuration; through a visual tool, we monitored the configuration of all nodes, evidencing the overlapping of signal and the loss of configuration packet.

To avoid a bad configuration, we have modified Castalia's core to manage:

- a little delay to avoid the contemporary transmission of packet by nodes, reducing the probability of interferences;
- a double configuration signal. The first configuration packet starts from the sink toward the nearest sensors to configure the whole network according to the standard MPRR, while a second signal checks the network and re-configure it when the first signal failed, warranting a correct configuration of all nodes.

According with these modifications, in case of Figure 3, the node N2 that was not configured by the first configuration signal will be configured as level 2 by the second signal. In case of Figure 4, node A3 is configured wrongly as level 2 by the first signal from A1, but the second configuration signal rechecks the ring number and re configures node A3 as level 3. The reconfigured nodes will reconfigure also all nodes of higher levels. Therefore, compared to an initial increase of energy consumption due to the reconfiguration, at the end, the network is correctly configured and it does not need configuration anymore.

Figure 5 shows the initial topology for a simulation of 108 sensors. No sensor is configured, because it is waiting inactive for a configuration packet from sink.

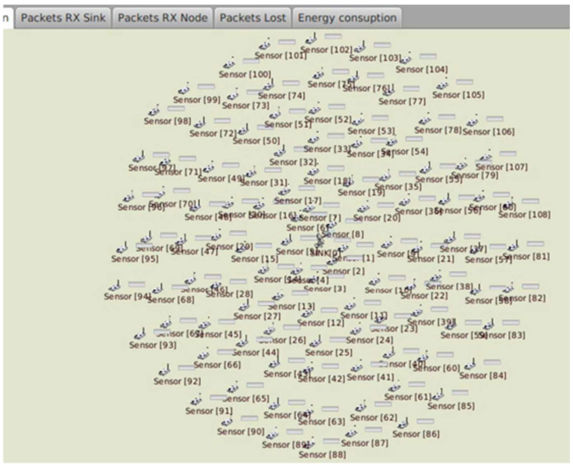

Figure 5: Initial topology for a network of 108 nodes. The sink is at the centre of the network.

When the sink starts to transmit, the nearest node configure themselves as level 1. Figure 6 shows in green the nodes of level 1 just configured and, in red, the nodes of level 2. The black circles represent the configuration packet expanding for the entire network, while Figure 7 shows a completely configured network.

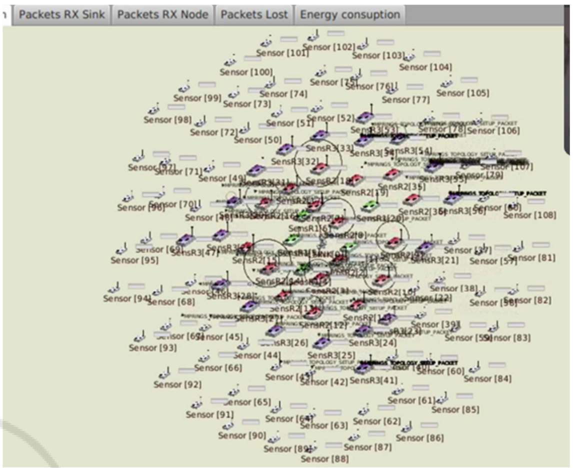

Figure 6: The configuration signal starts from the sink to the sensors, which self-configure to create the best paths.

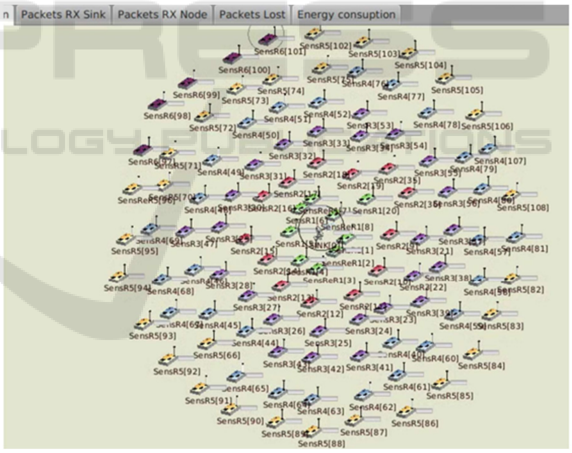

Figure 7: The whole network is configured.

Figure 8 shows a detail of the first configuration phase: green nodes are configured as level 1, while red nodes are configured as level 2.

Figure 9 shows the reconfiguration of nodes 2, 3, 7 and 8: in Figure 8 they were configured as level two (red), while after the second configuration signal are reconfigured as level one (green).

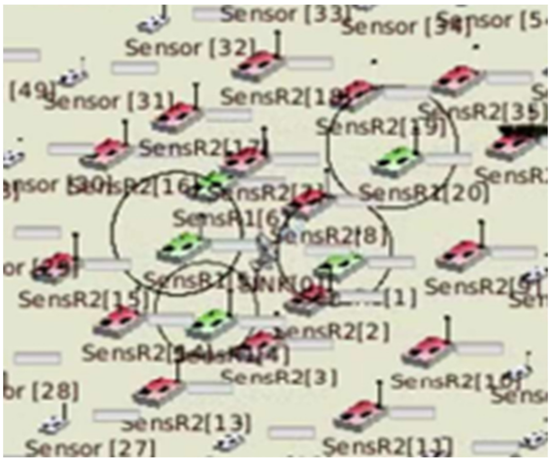

Figure 8: The configuration of levels 1 and 2 by the first configuration signal.

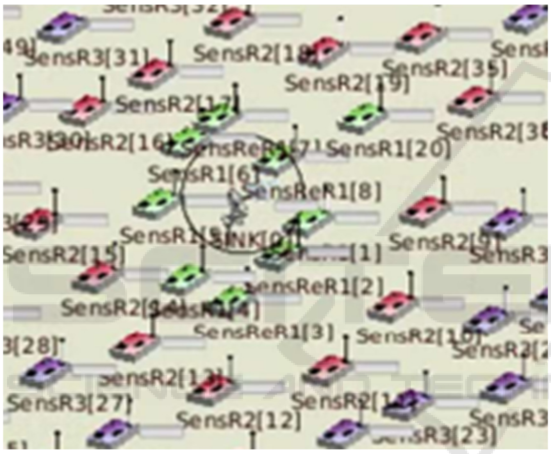

Figure 9: The re-configuration of nodes after the second configuration signal.

6 SIMULATION AND RESULTS

Through Castalia we evaluated:

- the number of transmitted and sent packets between nodes and sink;
- the life span of nodes, caused by excessive consumption of batteries or physical damage;
- the energy consumption of the network.

Performances information can be extracted from simulations, studying the trend of the number of packets received by the sink, and dividing it by the number of nodes remaining active during the network's life.

The performance index η_L is defined as:

$$\eta_L = N_R / S - D$$

where N_R is the number of packets received by the sink, S is the number of initial node and D is the number of dead nodes after a fixed time.

Higher values show energy inefficiency (due to more transmission toward sink) and more reliability, while lower value show a greater number of death nodes but less energy consumption.

The abscissa represents the temporal evolution; it is expressed in epochs and each epoch corresponds at 2 months of network working.

The ordinate axis represents the performance η_L value. Figure 10 shows the average of about 50 simulation cycles, considering about 108 nodes.

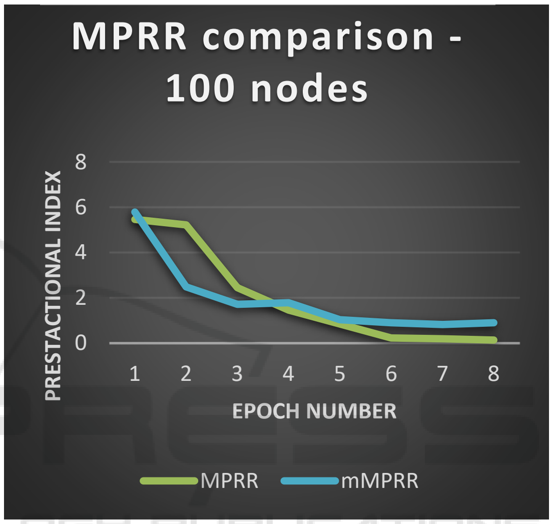

Figure 10: Comparison between standard and modified MPRR for a network of 100 nodes.

The comparison between the standard MPRR and the modified MPRR is well highlighted; in the first epoch, standard and Modified MPRR are both inefficient, with a very large packet redundancy and a very high consumption. In fact, each node transmits its package toward sink through more than one path (one level has more nodes), so the sink receives duplicated information that will be managed by the sink itself.

From the second Epoch, nodes start to switch off for damages or low batteries, and in the MPRR, the nodes nearest to the sink switch off before than the nodes that are more distant because of the great number of packets.

They do not switch off at the same time, thanks to the network configuration, so at least one node remains alive to send message to sink: on the long time, the number of packets received by the sink decreases. The standard MPRR, for this scenario, provides a not completely correct configuration, so the nodes nearest the sink shutdown faster than the modified MPRR. After 8 epochs, the network based on standard MPRR is dead, while the network based on the Modified MPRR is still alive. On the long period, the modified MPRR seems to be the first choice to guarantee the best compromise between energy saving and robustness of network. This situation is confirmed incrementing the number of node. Figure 11 shows the average of about 50 simulation cycles for about 200 nodes; it confirms the modified MPRR robustness on the long time for a wide network, while a WSN using standard MPRR shut down earlier.

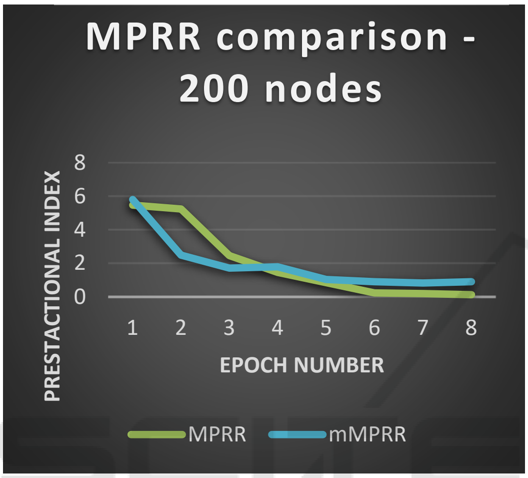

Figure 11: Comparison between standard and modified MPRR for a network of 200 nodes.

7 CONCLUSIONS

In order to correctly design a WSN, it is important to study various parameters, including how the nodes communicate with each other and with the sink. During the evaluation of the best routing algorithm for our agricultural scenario, we identified some critical issues in the use of the MPRR standard.

Therefore, we tried to understand if it was possible to modify the MPRR so that it could be used effectively in an agricultural scenario. Some changes have been made to the routing algorithm, bringing a clear improvement in its performance.

Through Castalia, a free tool for studying WSN routing protocols, we evaluated the comparison between the standard MPRR and its modified version to exceed the MPRR limits due to the characteristics of agricultural scenario.

Compared with the standard MPRR, the modified MPRR provides two signal for configuring the network, a first signal makes the network configured in the standard way, while the second signal reconfigures the wrong nodes to improve the routing paths between nodes and sink.

In order to reduce the possibility of interferences and loss of information, even a little delay during transmission has been adopted.

Performances of the modified MPPR have been evaluated, evidencing the better life span, despite a bad initial performance.

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