Reliability Comparison of Routing Protocols for WSNs in Wide Agriculture Scenarios by Means of η_L Index

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Abstract: A comparison between the most suitable routing protocols for WSNs applied in wide agriculture scenarios is shown. The protocols, already present in literature, have been conceived to better manage the power budget of the nodes and are particularly suitable to cover the energy issues that wide agriculture scenario can request. This study aims to indicate which of the protocols eligible for this scenario is the most suitable. Comparative simulation test will be shown.

1 INTRODUCTION

Although an ultimate definition has not provided yet by the scientific community, the term Wireless Sensor Network (WSN) is typically referred to a network of spatially dispersed devices, even called nodes, for the sensing of the around environment and able to transfer the acquired data by means of wireless communications (Shi & Perrig, 2004; Akyildiz et al., 2002). Typically, the nodes should be characterized by a low level of complexity, low dimensions and their power consumption should be low (Leccese et al., 2014; Leccese et al., 2017). Obviously, these characteristics, so as the overall price of the nodes, depend from the final use. Therefore, aims in which high reliability and/or high power consumptions is needed are generally more complex and expensive than to nodes used in less challenging contexts (Iqbal et al., 2017; Abruzzese et al., 2009; Ming et al. 2009; D'Amato et al., 2012; Abruzzese et al., 2009; Pasquali et al. 2016; Pasquali et al. 2017). From a communication point of view, the nodes often respect a hierarchical structure in which the lowest level is composed by nodes that have not a direct access to the outside. They can transmit data to neighbouring nodes that route own data and received ones coming from other nodes to an upper level node enabled to transfer outside the data. This last node is called "sink or gateway". The ways to route the data and the way to decide who will cover and how long depend by the routing protocol implemented by the network. Therefore, data locally acquired and gathered are usually related to the sink by a routing based on multiple hops that involve many nodes placed between the farthest with respect to the sink. The sink, making available the data to the outside, allows to other clients to receive the information collected by the local WSN. Fig. 1 shows an idea of a WSN topology.

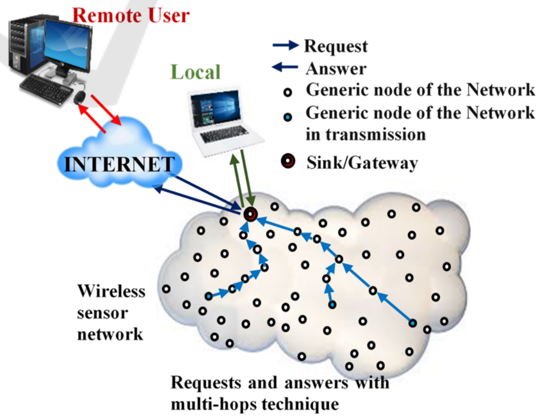

Figure 1: Typical architecture of a WSN.

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The parameters on which working to design a WSN are many and are linked to the scenario in which it will be apply. In fact, as example, a WSN for a smart city could not have electrical energy problems because placed closed to the mains while, for an application in open field far from the mains, the procurement of power might be critical pushing the designers to adopt all the possible solutions and strategies to limit the power consumption.

Whithin of the design parameters, there are some more evident, as the capacity of the batteries, and other more complicated for which a deeper analysis is necessary, as the routing protocols. In fact, the energetic autonomy offered by a battery to a node is directly proportional to its energy capacity. Instead, for routing protocols that have different strategies to route the data, it is more complicated to foresee their impact on the power consumption of the nodes of the WSNs. This is even more correct as some of them can automatically change their setting during the time (Al-Karaki & Kamal, 2004; Leccese et al., 2017).

In this paper, we are going to focus our attention on the routing protocols trying to compare the performance of existent protocols to find the more suitable ones for an agricultural scenario in terms of efficiency of the WSN. After a description of the scenario in which we imagine to work, a description of the routing protocols eligibile for this scenario will be provided. At the end, a comparison between them will be obtained by means of a suitable simulator.

2 OPERATIVE SCENARIO

The parameters involved in the definition of a WSN are many, therefore, its designing is strongly dependent by the scenario in which it is going to work (Lamonaca et al., 2017; Gallucci et al., 2017; Morello et al., 2010; D'Alvia et al., 2017; Islam et al., 2012; Shen et al., 2001; Vicentini et al., 2014; Pecora et al., 2019; Polese et al., 2019). For this reason, before any consideration on the WSN, it is necessary to descript the operative scenario. In our case, we considered a wide agricultural site (WAS). We define a WAS as a land of at least one hectare, in which there some kind of crop. In order to simplify the geometry, but taking nothing away from the generality of possible cases, we imagine the soil flat and squared. Within of the land, we decide to place a cert number of sensors that depends by the needs. Fig. 2 gives an idea of the placing of the sensors. The nodes (red circles) are placed in the centres of an ideal grid made of internal squares with a side of 15 m, therefore we could have 36 nodes for hectare, but this number is absolutely aleatory and is fixed only to define a possible operative scenario necessary for the further analysis. Imaging that the land is far from farm, the nodes have not the possibility to receive electrical energy from the mains and have to be supplied by local sources as batteries.

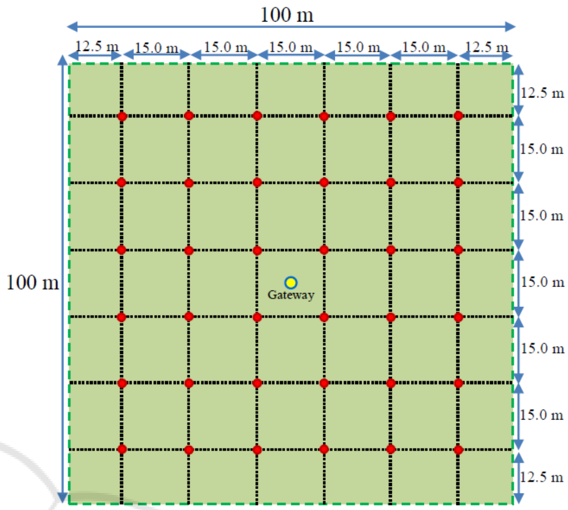

Figure 2: Possible operative scenario in which 36 nodes are placed in a hectare of an agricultural land.

The use of other local electrical energy sources as renewable ones, e.g. photovoltaic panels, is not considered since the idea is to make as efficient as possible the WSN. This leads a deep analysis of the routing protocols because in order to increase as much as possible the efficiency, the power consumption of the WSN must be as low as possible. Between the nodes placed in the land, we decided to put the gateway in the centre of the WSN.

3 ROUTING PROTOCOLS

After the definition of a possible operative scenario, which revealed the problem of power consumption and so the need to make the network as efficient as possible, a description of the routing protocols that in literature are pointed out as the most suitable for this kind of scenario is necessary. Between the routing protocols present in literature four of them seem suitable for our scenario: Ad hoc On Demand Distance Vector routing protocol or AODV (Maurya et al., 2012), Low-Energy Adaptive Clustering Hierarchy or LEACH (Shekar, 2012), Power-Efficient GAthering in Sensor Information Systems or PEGASIS (Lindsey, 2013) and Multipath Ring Routing or MPRR (Pandya & Mehta, 2012).

3.1 AODV

The Ad-hoc On-Demand Distance Vector (AODV) is a reactive protocol principally conceived for ad hoc mobile networks and is able to set both unicast and multicast routing. It builds routes between nodes only as desired by source nodes (in this sense, it is an on demand algorithm) maintaining they active until is requested by the source nodes. All the routing information are uploaded in a routing table driven, and so updated, by the demand reducing the typical problem of the proactive routing protocols which try to up to date all the time the routing tables engaging many computational resources.

For destination, AODV uses sequence numbers that avoid routing loops so preventing problems such as the "counting to infinity" more typical for more classical distance vector protocols.

Other advantages are the quick adaptation to dynamic link evolutions, a low overhead of processing and memory, it has the ability to find unicast routes to destinations within the ad hoc network, self-starting and scales to large numbers of mobile nodes.

Unfortunately, this protocol presents problems in case of managing of network congestion where an overloading of nodes is typical. This makes slower the transmission speed of the network but, even more important from our point of view, the nodes should be energetically weaker.

3.2 LEACH

Low Energy Adaptive Clustering Hierarchy (LEACH) is conceived for hierarchical clustering WSNs. A cluster is a set of nodes that, in order to make similar the power consumption, randomly, after a fixed time, elects a cluster-head (CH) rotating this role between the nodes within of the cluster. The CHs collects data coming from the nodes aggregate them and compress the total amount of information that will be send to the base station (BS). In MAC layer, a TDMA/CDMA technique is implemented to reduce the possible collisions inside the cluster or between different clusters. The collection of data is centralized and can be set both periodically or asynchronously making it suitable to constant monitoring activities.

The set-up of the WSN is performed in two successive steps called setup phase and steady state. During the setup, there is the organization of the clusters which elect the own CHs while, in the second phase, the data transfer inside the cluster and to the BS is done. The procedure foresees that during the setup phase, a small number of nodes elect themselves as CHs notifying their own role to the other nodes using a broadcast message. The other nodes, alerted by this message, on the base of the signal strength, decide on which cluster they want to belong informing the appropriate CHs that they are a member of that cluster. Once established the cluster, a TDMA schedule is established by the CH node, which assigns a time slot to each node for the transmission. This schedule is sent to the other nodes of the cluster through a broadcast message. During the steady state phase, the data are transmitted. After an aforethought time, a new setup phase is launched.

The principal advantage of the LEACH protocol is the high lifetime of the network. On the contrary, it assumes that all nodes have enough power to transmit to reach the BS and that each node has been designed to work with different MAC protocols. Therefore, if the network is not properly designed, its application for networks deployed in large regions could be critical. Another disadvantage is the fact that it is not ensured that the CHs are uniformly distributed in the network having the possibility that the CHs can be concentrated only in a part of the network. This implies that some nodes may not be close to CHs. Another disadvantage is that the dynamic clustering leads further overhead caused by head changes, advertisements etc., which drains the available energy. Moreover, the protocol supposes that, at the beginning, all nodes have the same quantity of energy in each round, wrongly assuming that each CH consumes a similar quantity of energy.

3.3 PEGASIS

Power-Efficient GAthering in Sensor Information Systems can be considered as an optimization of the LEACH algorithm. It does not group nodes in clusters but forms chains of sensor nodes. With this architecture, each node talks only with the closest neighbors receiving and transmitting data only from the previous ring and with successive ring of the chain. In this way, the nodes can adjust the power of their transmissions. Even in this case, the single node performs the aggregation of data coming from the previous with own and forwarding the new set to the next node of the chain up to the BS. Each round, foresees that one node of the chain is elected to communicate with the BS and the chain is built according to a greedy algorithm. The final packet that will be sent out of the WSN is made with the data collected from all nodes so realizing a “data fusion.” This texture has the great advantage to reduce the overall amount of the data transmitted to the BS because reduces the number of ancillary data that forms, together with the measured information, the data packet coming from a single sensor.

With respect to the LEACH, the main advantageous of the Pegasis is the lower transmission distance between the nodes, moreover, since the nodes are selected for only the time of the transmission round, the power dissipation during the time is balanced between the nodes. On the contrary, PEGASIS presents many disadvantages:

- requests that the CHs have to be located near the BS;
- since the energy of the CH at the beginning is unknown, there is the risk that the nodes could discharge during a transmission losing all the data coming from the whole WSN;
- the presence of an only CH could be a bottleneck for the network causing delays;
- the lack of redundancy increase the risk of lost;
- if the packets have a low number of bits, the energy efficiency is low.

3.4 MPRR

In order to make data collection robust against communication failures, multipath routing architectures allow setting up multiple propagation paths between each sensor node and the base station. In this way, data collected by a node are successfully sent to the base station as long as any one of its propagation paths is failure-free (Huang et al., 2013).

In MPRR, nodes do not have a specific parent and the construction phase organizes the network into levels, even called rings, according to hop distance from the sink node to a sensor node. This means that, at the end of the build phase, each node will have a number that indicates how many hops is far from the sink node and this number corresponds to the level or ring of belonging.

At the beginning of the construction phase, the BS sends a broadcast setup packet indicating the ring number 0. The nodes that receive this topology setup packet will increment it 1 (nodes belonging to ring 1) and rebroadcast it. This process continues until all nodes will have a ring number. After topology setup phase is completed, when a node needs to send data to the gateway, the node sends a broadcasts message endowed of its ring number. Any node having a smaller ring number will receive that packet and rebroadcasts it. The process continues until the packet reaches to sink. In this sense, MPRR is a proactive routing protocol in which the network initialization is performed prior to the data dissemination, all nodes are distributed randomly in the field under analysis, the base station is responsible for gathering data from the whole network, moreover, route discovery is also not required before data transmission.

Because of its own architecture, MPRR is natively reliable in the transmission data; in fact, the possibility to set more paths to reach the sink ensures that the data sent by the generic sensor node has more possibility to reach the gateway respect to a less complex topology. On the contrary, the major disadvantage is the overall overhead of the WSN that drains inefficiently energy from the nodes.

4 CASTALIA SIMULATOR

In order to study the most suitable routing protocol for the described agricultural scenario, we used a WSN simulator able to implement low-power embedded devices: its name is Castalia. We chose this simulator since it is “open source.” This allows studying the algorithm following step by step what happens during the simulations verifying the compliance of the software with the theory and allows introducing check points to avoid problems as infinite loops, etc. At the same time, it allows modifying already defined algorithms, and, even more important, allows implementing, developing and validating new algorithms (Boulis, 2019). Anyway, in order to find the best protocols, we decided to not change the already algorithms testing the original version of the protocols implemented in the simulator.

5 TEST AND RESULTS

A comparison between different routing protocols can be scientifically insignificant because each protocol has been conceived to exalt some characteristics with respect to the others. For instance, AODV has been conceived for mobile networks and surely will better fit to the exigencies of those nets instead of static architectures. This leads that the test are typically focused on a single aspect (resilience, energy consumption, transmission speed, etc.) analysing how and how much a specific protocol is better than the other for that specific aspect. Although this approach is overall reasonable because there is not a perfect WSN for all possible scenario, in order to try a more suitable and objective index for our test, we used a performance index that takes into account both the energy aspects and the reliability of data transmission.

5.1 Performance Index

The index, called η_L, is defined as the number of packets received by the sink after a fixed time divided for the difference between the initial nodes and those that during the activity are switched off.

$$\eta_L = \frac{N_p}{S - D} \quad (1)$$

where:
η_L: performance index
N_p: number of packet received by the sink after a fixed time.
S: number of initial nodes (they are initially active.)
D: number of dead nodes after a fixed time.

For dead nodes, we mean even those unable to communicate with the gateway. The index gives an indication of how much efficient the network is in the delivery of the information considering both the number of packets that are running in the network and that arrive to the sink and the number of nodes that fail over the time. This fail could be linked to the energy lack caused by the stress that some nodes could suffer due to the strategy adopted by the routing protocols. The index is built to have values lower, higher or equal the unit value that represents the ideal performance of the network in which the number of the received packets is equal to the number of alive nodes. This condition is certainly achieved by protocols that do not provide redundancy in the transmission of data and at a time (necessarily initial) in which all the nodes are "alive". Numbers different by the unit mean inefficiency: higher values indicate that there is plenty of packets; lower values indicate fewer packets than the number of live nodes.

5.2 Test, Results and Discussion

To perform the test, it has been assumed that each sensor node is powered by on board battery (Caciotta et al., 2013; Leccese, 2007). Additionally the battery cannot be replaced or recharged, therefore the battery discharge leads the failure of the node and determines the lifetime of the WSNs. Considering the supposed scenario of Fig. 2, it is assumed that one of the node will perform the role of gateway. Moreover, the quantity of data transmitted toward the gateway from each node is equal for each routing protocol. It is clear that in each epoch, depending on the specific protocol, a certain percentage of nodes fail. Fig. 3 shows the average of 100 simulations obtained by Castalia for a network composed of 100 nodes. Consequently, the dimension of the hypothetical area analyzed with the simulation is bigger than one hectare. The numbers on the abscissas of the graphs (from 1 to 8) indicate the evolution of the time expressed in epochs (in real cases an epoch could be equal to 2 months).

As it is possible to see, in the first epoch, the first three protocols are similar showing optimal results, while the MPRR shows high inefficiency cause the redundancy of the packets that are running in the network. High inefficiency does not mean that the packets do not arrive to the sink, but simply that the number of packets is redundant and so a high-energy consumption without a real necessity happens.

After the first epoch, the first three protocols lose efficiency, while the MPRR recovers efficiency even if the improvement is strongly limited for the second and for the third epoch.

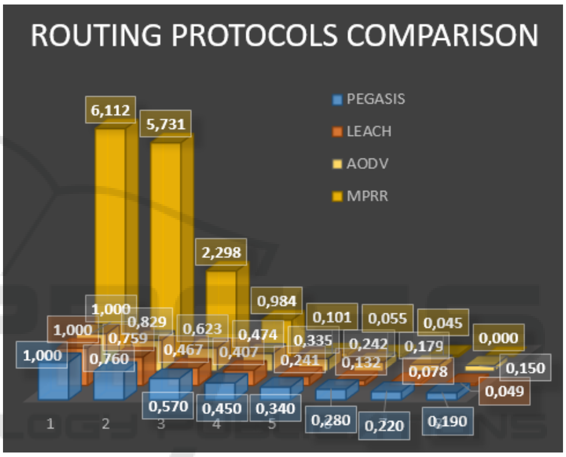

Figure 3: Service performance index with respect to the protocol: number of packets arrived at the SINK divided by the difference between the number of initial nodes and those switched off. Simulation obtained with CASTALIA for a network of 100 nodes. The values are the average of 100 simulations; each simulation needs about 40 minutes to be performed for a total simulation time of about 100 hours.

Between the first three protocols, the networks managed by LEACH is surely weaker if compared with PEGASIS and AODV. This can be explained with the distribution of the dead nodes that is linked to the protocol: in fact, in the LEACH, the CHs are more stressed with respect to the other nodes even if they are normally a limited number. Moreover, the probability to select the CHs is higher for the nodes nearer to the sink. The better performance of the PEGASIS with respect the LEACH is due to the fact that it is an improved version of this last, while the good behavior of the AODV could be due to the particular scenario. The behavior of the MPRR needs some explanations. Considering how its routing protocol works, it is highly inefficient at the beginning even if, in the first epochs, it ensures the highest reliability of the network because all the packets find a route to arrive to the sink. Always considering its way to work, the nodes in the lower levels are energetically more stressed than those belonging to the upper levels and far from the gateway. This leads an early death of the nodes belonging to lower levels with respect to the other routing protocols and this prevents to the nodes of the higher levels to communicate with the gateway. Therefore, even if many nodes of the higher rings are still alive, they cannot communicate with the gateway and so are considered died. This justifies its behavior highly reliable at the beginning but that early becomes unsuitable. In fact, after the fourth epochs, the number of dead nodes belonging to the lower rings is such as to prevent an acceptable transfer of information. The simulations were performed on an ASUS Notebook, with an Intel Core Pentium i7-3630QM CPU @ 2.40 GHz and memory RAM of 8 GB. Each simulation took 40 minutes.

In order to validate our test we repeated the it with a bigger number of nodes. The second test used 200 nodes and each simulation needs about 100 minutes to be performed and a total simulation time of about 6 days. 300 nodes composed the third network and the simulation needs about 360 minutes. In this case, we performed only 50 simulations for a time of about 12,5 days. The results are shown in figures 4 and 5.

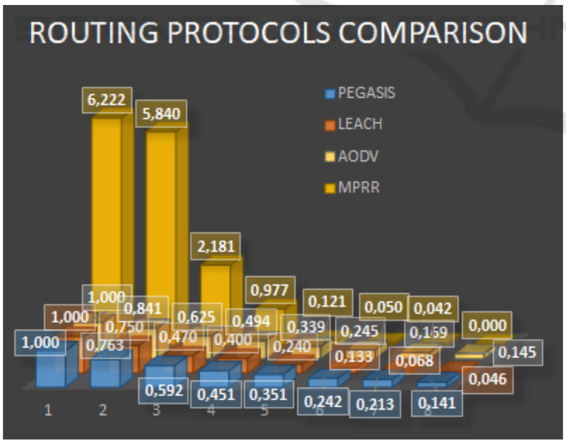

Figure 4: Service performance index with respect to the protocol. Simulation obtained with CASTALIA for a network of 200 nodes. The values are the average of 100 simulations; each simulation needs about 100 minutes to be performed for a total simulation time of about 6 days.

As it is possible to see, even in these cases, the graphs show that we have similar answers for similar protocols (LEACH and PEGASIS) with PEGASIS better than LEACH, while different architectures (MPRR) suggest high reliability of the transmission only for a short time. Anyway, even if the differences between PEGASIS and AODV are not high, the simulations identify in the AODV routing protocol a good competitor for PEGASIS resulting both the more suitable routing protocols for this scenario. This leads that, if you have the possibility to change the batteries of the nodes of if you have the possibility to provide a safe and continuous energy source for the nodes as the photovoltaic one, the better routing protocols is surely the MPRR. If these possibilities are not sure, a PEGASIS or an AODV could be the better strategies for the WSN in this kind of scenario.

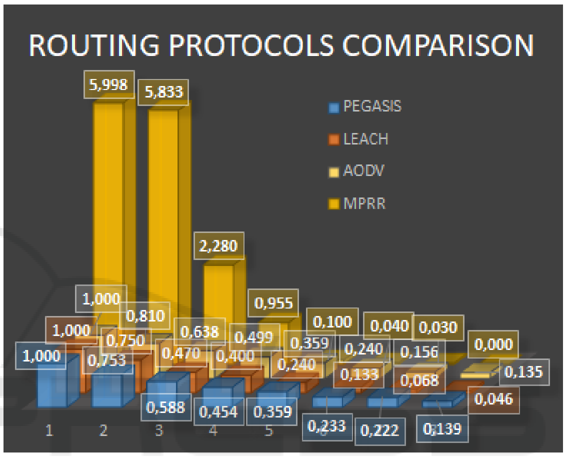

Figure 5: Service performance index with respect to the protocol. Simulation obtained with CASTALIA for a network of 300 nodes. The values are the average of 50 simulations; each simulation needs about 360 minutes to be performed for a total simulation time of about 12.5 days.

6 CONCLUSIONS

In order to find a routing algorithm that can better fit the exigencies of a wide agricultural scenario, a comparison between the most suitable protocols present in literature has been done by the use of a particular performance index that points out how many the network is reliable during the time. The simulations have been realized with a scenario that foresees an equally space spaced nodes in a flat land with the gateway placed in the centre of the WSN, with the nodes that start with the same amount of energy and that send the same quantity of information. This last choice is linked to the idea of realizing the objective of the document without possible facilitations. The simulations find that the MPRR, although highly inefficient under the energetic profile, ensures the deliverable of the information during the first epochs showing itself as the most reliable but only for a limited time. PEGASIS, being an improvement version of the LEACH, shows a performance better of this last, while, paradoxically, the simulations identify in the AODV protocol, conceived for mobile networks, a valid competitor of the PEGASIS. This result can be due both to the particular scenario and to the energy requests of the other routing protocols.

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