IMPACT OF THE NODES DENSITY ON G3-PLC NETWORKS PERFORMANCE

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ABSTRACT

G3-PLC is emerging as an attractive communication standard for smart metering applications. This standard includes different mechanisms and protocols allowing to deal with the poor transmission performance of the power line channel. In particular, all nodes of the network can act as relays. In 2014, G3-PLC standard proposed the LOADng protocol to perform the routing. In this work, we analysed the performance of this protocol in PLC topologies. For that purpose, we developed our own simulator in the Contiki/Cooja platform in which we have implemented the LOADng protocol as well as the different features of G3-PLC networks. Based on our tool, we studied the impact of the average number of neighbours that a node can reach (i.e., the effect of the node density). In particular, we report the results we obtained for different node densities and for different link qualities. These results highlight that it exists an optimal average number of neighbours for which the performance are improved.

INTRODUCTION

The deployment of Smart Grid applications requires efficient means of communication. Among those, G3-PLC standard [1] has been specially developed for Smart Metering applications. This standard includes different mechanisms and protocols allowing to deal with the poor transmission performance of the power line channel characterized by important and time-dependent losses. In particular, in G3-PLC networks, each node can act as repeater. This specific feature allows to improve the transmission performance and to extend the network coverage. The communication between the smart meters and the concentrator is so done hop-by-hop in G3-PLC network.

This particular communication scheme requires to use an efficient routing protocol. In its last version of 2014, G3-PLC standard recommends to use the Lightweight On-demand Ad hoc Distance-vector Routing Protocol - Next Generation (LOADng) [2]. LOADng is a reactive routing protocol allowing to find the communication path prior to the effective data transmission. As it is a central part of G3-PLC communications, it is of high importance to analyse its performance in the context of PLC networks.

Some studies about the routing performance of G3-PLC networks have been already presented in the literature [3-5]. However, they are mainly related to the 6LowPAN Ad Hoc On-Demand Distance Vector Routing (LOAD) [6] protocol, a protocol previously recommended by the G3-PLC standard [7].

In this work, we study the performance of the LOADng routing protocol used for G3-PLC networks. For that purpose, we developed our own network simulator that includes the LOADng protocol as well as the different features of G3-PLC networks. This tool has then been used to analyse the influence of the node density on the routing performance.

This paper is organised as follows: we firstly present the LOADng routing protocol. Then, we describe our G3-PLC simulator as well as the simulation scenario. The results showing the impact of the node density are finally reported and discussed.

LOADng

LOADng was firstly developed for Wireless Sensor Networks and was then integrated in the G3-PLC standard with some amendments [1]. It is a reactive protocol for which routes between nodes are established only when data has to be sent and when there does not exist an entry of the destination in the routing table. To establish a route, nodes start a route discovery process. Three different kinds of packet are involving in this process: Route Request (RREQ), Route Response (RREP) and Route Response Acknowledgement (RREP_ACK) packets.

The discovery process is illustrated in Figure 1. Let us consider that node A wants to obtains the data from node F and this destination is not present in the routing table. The first step of this process (cf. Figure 1-a) is to broadcast a RREQ packet to all the neighbours. Then, the neighbours broadcast themselves the RREQ to their neighbours and so one upon it is received by the destination (F). The destination replies to the originator by using a RREP packet through the best route taken by RREQ packets as reported in Figure 1-b. Unlike RREQs, RREPs are unicasted and not broadcasted. For each transmission between two nodes, RREP packets have to be acquitted by a RREP_ACK. If it is not done because of a harsh transmission, the node is blacklisted by the previous one. In this case, later RREQ packets broadcasted from this node will be ignored because of blacklisting. The objective

of this mechanism is to avoid the use of bad quality links for discovered routes. Let us mention that it exists a fourth packet called Route Error packet (RERR) used when an active link is broken.

Whatever the packet is, when a node receives a packet, it records in its routing table the addresses of the originator as well as the previous hop, or updates them if entries already exist. The hop count of packets is also incremented. Hop count is the metric used by default to determine the best route but other parameters can be used such as the Link Quality Indicator (LQI) [1]. Let us finally mention that each entry has a limited Time to Live (TTL). This is managed by a timer; when it expires, the entry is removed. For routing tables, the timers are also reset when the route is used.

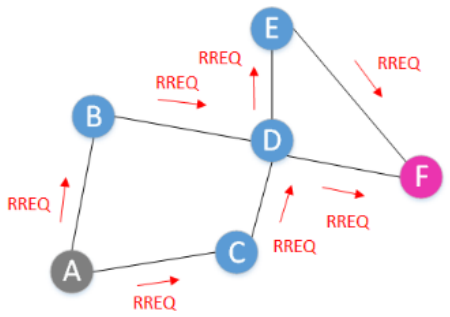

Figure 1-a - Route discovery process: RREQ packets

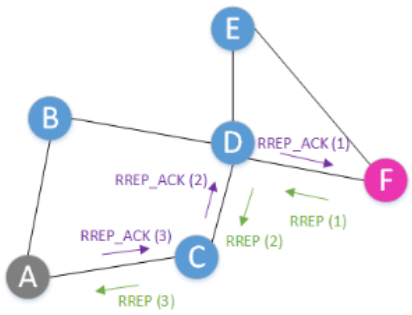

Figure 1-b - Route discovery process: RREP and RREP_ACK packets

SIMULATION MODEL

We studied the impact of node density thanks to our G3-PLC simulator. In this section, we present the simulation platform we have developed as well as the topology and the scenario we have considered in our study.

Simulation platform

Given the fact that it does not exist off-the-shelf simulator G3-PLC, we choose to start from Contiki/Cooja[8], a WSN simulator that contains a protocol stack compatible with the G3-PLC standard. In particular, it includes CSMA/CA mechanism as well as an implementation of the LOAD protocol, an older routing protocol with some characteristics shared by LOADng. We thus extended the Contiki platform by developing LOADng. In addition, we used the Direct Graph Radio Medium (DGRM) module of Contiki to build a PLC topology.

PLC topology

The chosen PLC topology has a big impact on the results. Therefore, we considered a generic electricity topology suggested in [9] that we have adapted. In this network illustrated in Figure 2, we defined that the concentrator is placed at node 1 and the other 34 nodes act as smart meters. Let us mention that the representation in Figure 2 is not in scale. The different lengths of the electric cables between nodes are those defined in [9].

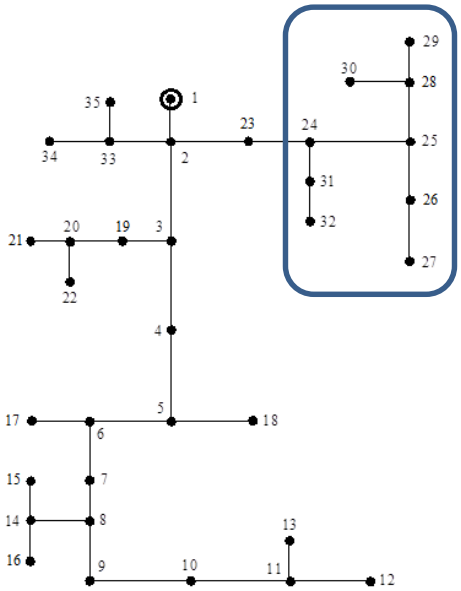

Figure 2 – Generic PLC topology

In order to consider non-ideal transmission in our simulation, a Frame Error Rate (FER) of 10^{-2} is associated to each link. In addition, we considered that the network possesses some weak links, i.e. links with very poor transmission performance. For these links, we fixed the FER value to 0.5.

With the aim of testing the influence of the node density, i.e., the average number of neighbours (n) that a node can contact when it is emitting, we have considered different transmission ranges over the PLC links. Table 1 reports the transmission range values that lead to the different average numbers of neighbours we have considered (from 5 to 12). To illustrate the relation that it exists between the transmission range and the number of neighbours, we show in Figure 3 the logical configurations of a subpart of the grid (from node 24 to node 32) for an average number of neighbours of 5 and 9, respectively. As we can observe, more nodes are linked together when the transmission range is increasing. Figure 4 reports the distribution of the neighbours of all nodes in the network for these two node densities. As we can see, when the average number of

neighbours is too low, some nodes have only one neighbour. In practice, this situation can have a strong impact on the network performance. Indeed, if this node is blacklisted, nodes of a subpart of the network connected to this node can be inaccessible until the expiration of the blacklist entry.

Table 1 - Relation between average numbers of neighbours and the transmission range

Average number of neighbours	5	6	7	8	9	10	11	12
Transmission range (meters)	402	452	512	550	586	647	683	720

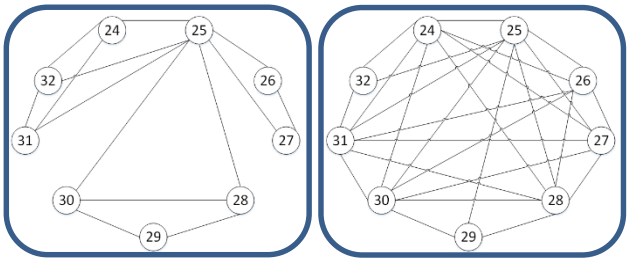

Figure 3 - Logical configurations for average numbers of neighbours of 5 (a) and 9 (b) in the subset network of Figure2

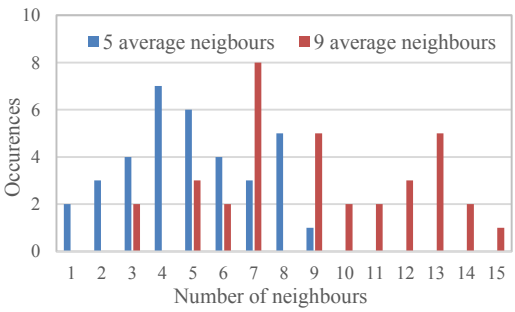

Figure 4 - Neighbours distribution

Simulation scenario

In our test, we consider that the concentrator has to obtain consumption data from each smart meter. At the beginning of the simulation, all the routing tables are empty so that the concentrator must start a route discovery process to find a route for each smart meter. The data collector attempts to contact a smart meter until it effectively receives consumption data and then passes to the next node.

Timer entries have to be configured following G3-PLC standard's recommendations. As defined in [1], these values depend on the maximum time to reach the farthest node in the network, i.e. node with the maximum hop count. Considering that this time equals 3s in the case of our topology, the route discovery process lasts 6 seconds and the TTLs for the blacklist entries and a route entries are 90 seconds and 540 seconds, respectively.

Several simulations have been performed for different values of the average number of neighbours (from n = 5 to 12). For these 8 densities, we considered 6 different weak link rates: 1, 5, 10, 20, 30 and 40 %. We then generated five different logical topologies with randomly placed weak links for all those combinations. In addition, each topology was simulated five times. As a consequence, each simulation point presented in the following corresponds to the results obtained over 25 simulations.

RESULTS

Figure 5 shows the number of attempts requires to reach all smart meters regarding the weak link rates and for different average numbers of neighbours. We can see that for lower densities (n = 5 and 6), important variations appear on the curves, while the results from n = 7 lead to monotonically increasing curve. In addition, from n = 8, the average number of neighbours has less impact on the results.

Indeed, when the average number of neighbours, and so the density, is too low, the number of potential routes to reach a destination is lower. If one of them includes a weak link, this one could be blacklisted, so that, if this link involves in the only route to access to a subpart of the grid, this subpart cannot be reached until the timer's expiration of the blacklisted entry.

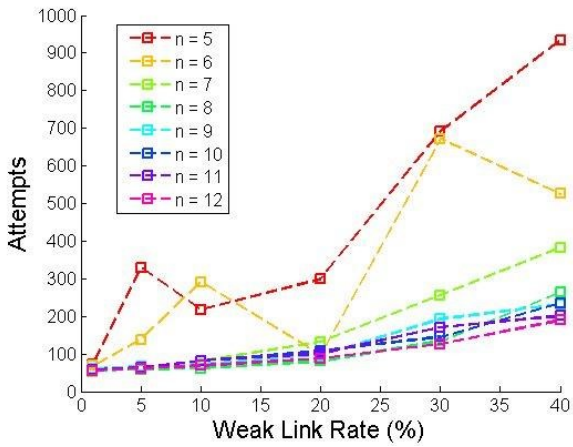

Figure 5 – Total number of attempts to obtain all consumption data depending on the weak link rate

In addition, location of weak links has a big impact on the result. By analysing the log files related to the 5% and 30% of weak links for n = 5, we observe that some randomly placed weak links were situated close to the data concentrator. Since these links are more used that links situated at the border of the network, this scenario has led to very poor performance. In such conditions, it is therefore possible to obtain better results for higher weak link rates because of the random. This phenomenon is attenuated with the increasing of average number of neighbours. Indeed, this ensures to have more alternative routes to reach a destination and so, if a link is blacklisted,

there are alternative links that can be used to reach it.

Figure 6 shows another view of the number of necessary attempts to reach all smart meters depending on the average number of neighbours for the different weak link rates we have considered. We observe that, anyway the weak link rate, there is a stabilization of the number of attempts from an average number of neighbours of 8. This result shows that it exists a threshold from which an increase does not necessarily lead to better performance.

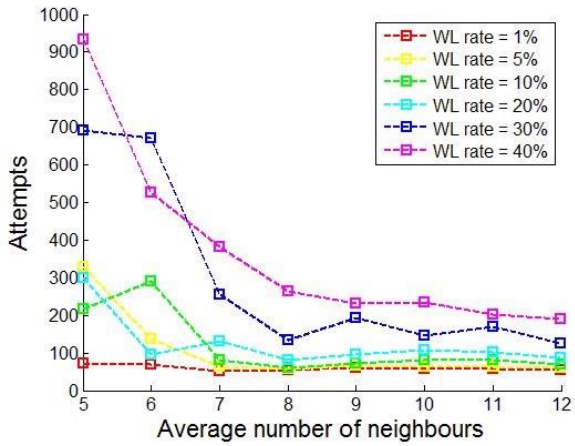

Figure 6 - Total number of attempts to obtain all consumption data depending on the average number of neighbours

In Figures 7 and 8, we give another representation of the results by showing the success rate regarding the number of attempts for 10% and 30% of weak link rates, respectively. In Figure 7, we see that curves for 5 and 6 average numbers of neighbours do not reach 100% of success rate even after more than 30 attempts. However, from 7 neighbours, 90% of the smart meters can be reached in maximum 5 attempts and 100% are reached in maximum 10 attempts. The best performance is so obtained for a number of neighbours equals to 8. In Figure 8, we obviously notice that the performance are globally reduced for the weak link rate of 30%. Nevertheless, the average number of 8 neighbours remains the best result

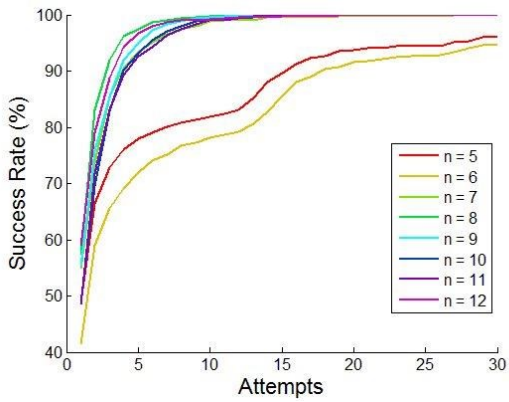

Figure 7 - Success rate vs attempts for a single node with 10% weak link rate

We can draw very interesting conclusions from these results. Firstly, when the average number of neighbours is too low, the performance is bad because subparts of the grid cannot be reached until the expiration of blacklist entries. Secondly, we derive that it exists an optimal number of neighbours, which is equals to 8 for the topology we considered. Beyond this threshold, the performance do not necessarily increase. Indeed, since RREQ packets are broadcasted by each G3-PLC node, the packets load in the network during the discovery process is increasing with the nodes density. In this condition, the risk of collision increases and reduces the performance.

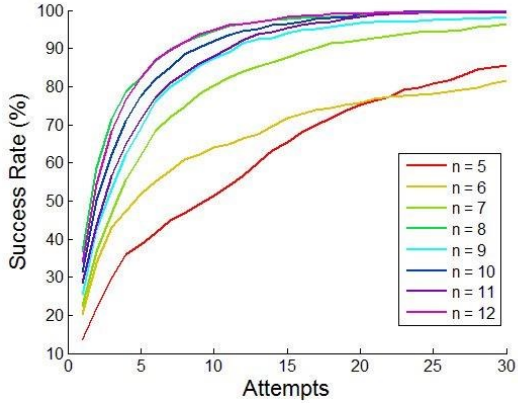

Figure 8 - Success rate vs attempts for a single node with 30% weak link rate

CONCLUSION

Thanks to the implementation of the LOADng routing protocol into Contiki, we are able to study the communication's performance in various case of PLC topologies. We highlighted that it exists an optimal average number of neighbours for which the performance are improved. In particular, for the topology we have considered, an average number of 8 neighbours have led to the best performance. In future work, it could be important to analyse the relation that it exists between this specific value and the features of the considered topology.

However, some topologies requires a particular deployment because of the constraints. Performing a similar analysis can be very useful for the DSO managers in order to evaluate the performance of the deployed G3-PLC network as well as to optimize its configuration. Indeed, it is possible for the DSO to add additional fictitious smart meters in some area to ensure a sufficient nodes density. Our simulator can then be used to design the number of required meters needed to optimize communication in specific subparts.

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