A Comparative Study of Routing Metrics in G3-PLC LOADng routing protocol

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Abstract

PLC or power line communications is an interesting technology for smart grid applications, which is gaining a lot of momentum. A detailed state of the art of PLC is presented in [1]. PLC is rapidly emerging as a promising technology in the field of utility and industrial communication. One of the main advantages of this technology is the use of the existing electrical network as a support for data transfer. This enables devices to be networked without the introduction of additional wires or cables. Contemporary PLC uses OFDM (Orthogonal Frequency Division Multiplexing), which is a well suited technique for powerline media. Two main OFDM based specifications have evolved in recent years, PRIME and G3-plc. They are both designed to provide a robust, long range and low data rate communication on the electrical grid [2]. A comparison between the two standards is exhibited in [3]. In this paper, our aim is to provide a comparative study between three different routing metrics using the G3-PLC standard: the default *Composite* metric with the default parameter set, the Composite metric with an alternative configuration, and a new metric: the *Capacity metric,* already specified in the french smart meter program *"Linky"*. Our simulation results show that significant improvement on the round trip time and the success rate can be achieved using these two last routing setups.

Index Terms

G3-PLC, LOADng, Routing, Metric, PLC channel

I. INTRODUCTION

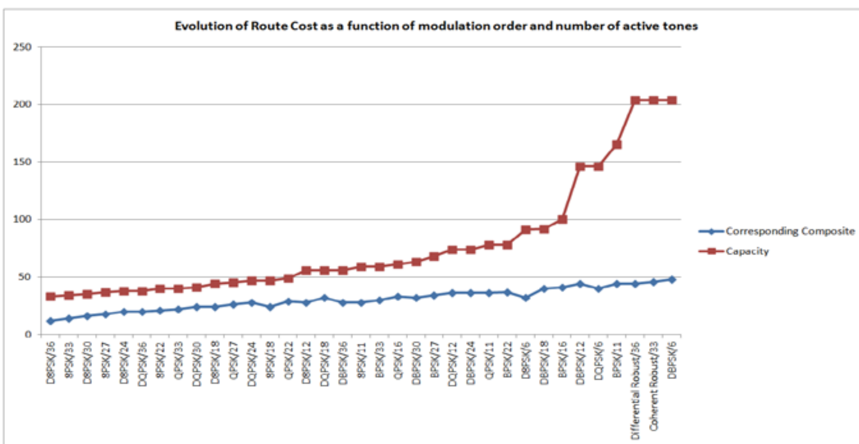
THIS paper's aim is to present a comparative study of three different approaches to routing data in G3-plc networks, and to show significant gains achieved by using the Capacity metric. Routing, an essential part for smart meters network, ensures good coverage and reliable communications. Even though all meters are wired through a unique electrical network, some links can experience communication failures. This is due to the nature of powerline channel where impulse response is known to be variable in time, frequency selective and can be impacted by various electrical equipment on the network that may modify the overall impedance and create an unpredictable aspect of the propagation media and the associated route creation process. To this purpose, the routing metric plays a crucial role by dealing with all these variations to provide meaningful route costs. By comparing these route costs, the routing protocol will be able to choose the best available path, resulting in a robust and self-healing mesh topology. Thus, it is important to define a routing metric that is able to overcome the challenges of a lossy network media such as the electrical grid. To this purpose, simulation results are presented to compare the performances of the different metrics. We also introduced an alternative parameter set of the default *Composite* metric to evaluate the improvements with respect to the default parameters. These simulations run in the nSim G3 simulator developed by Neuron [4]. The rest of the paper will be organized as follows: section II presents a state of the art about the routing protocol and its main operations, section III takes in charge the definition of the metrics concerned. Section IV focus on the simulator and the topology used while the results are presented in section V followed by a conclusion in section VI.

II. STATE OF THE ART

LOADng is the default routing protocol for G3-PLC [5] [6]. LOADng is a reactive routing protocol that will create the route when needed. In comparison to its predecessor, LOAD protocol, additional mechanisms have been introduced in the G3-PLC standard like the weak link count, smart RREQ and the route repair mechanism. Several studies were associated to this protocol in PLC networks [6]; a study on the impact of links with low SNR (weak link count) is shown in [7]. In [8], other routing cost functions are studied. The basic operations of this protocol include (a) the generation of Route Requests (RREQ) that are broadcasted to discover a route and (b) generation of Route Reply (RREP) in a unicast hop by hop process towards the generator of the initial request. If the route breaks or and the resulting route repair mechanism fails too, Route Error (RERR) messages are generated toward the originator to trigger a new route discovery. Some tables are used to handle the routing process: the routing table, the neighbor table and the blacklist table. The neighbor table records the quality of the links toward neighboring nodes of the device. It logs the modulation, short address, link quality indicator (LQI), as well as other information concerning the link between this device and its direct neighbors. The routing table records information about the different routes like the associated route cost, weak link count, next hop to reach the destination, etc. The blacklist table contains a list of nodes that were not able to send an acknowledgement to the RREP message, meaning that the link may be unidirectional. Any RREQ message from a blacklisted node will be ignored for a given period of validity. The flooding nature of the route discovery process requires a trustful metric to parse all available path toward the destination and identify the best one. Moreover, a bad route selection can results in path breakage, inducing a *Route Repair* that will generate a flooding that could have been avoided if the proper route was selected in the first place. Finally, the network flooding during route establishment and repair uses valuable channel capacity and can lead to increased packet loss due to collisions.

III. METRIC DEFINITION

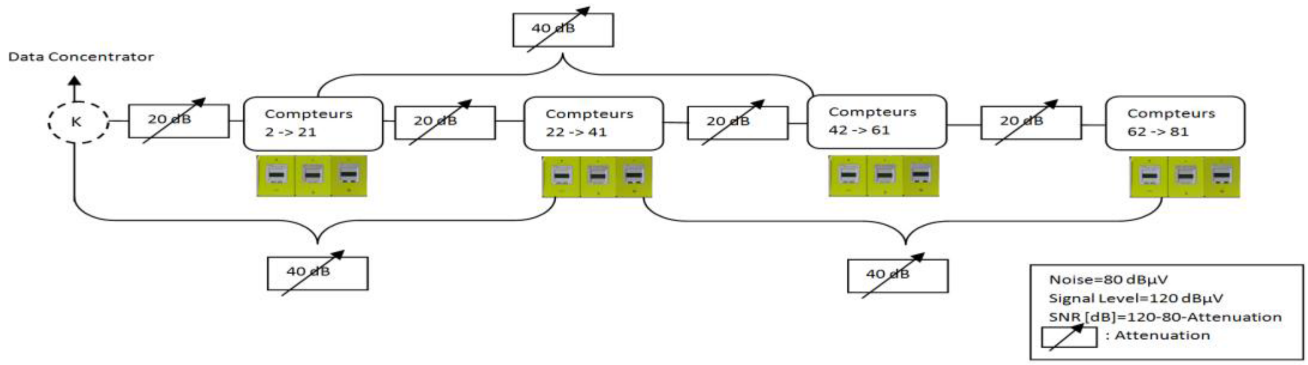
The default metric in G3 is the ***Composite***. This metric combines several factors (number of hops, weight factors for LQI, ROBO mode, number of acrive sub-carriers, etc.) to tackle with various phenomena that could occur in the routing creation process. A metric is a quantitative assessment that provides a cost to compare available paths between each others. The best route is the one with the lower cost, according to the metric used.This paper proposes, quantifies and analyzes the performance of a new metric: the ***Capacity*** metric by evaluating and comparing its performances with respect to the default metric. Route costs in the *Capacity* metric reuse the *Tonemap* link evaluation mechanism by associating a route cost to each modulation/active tones couple. According to the modulation type, scheme, order (differential, coherent, BPSK, QPSK, etc.) and the number of carriers negotiated by the corresponding peers (both nodes of the given link), a link cost will be attributed. The particularity of this metric is the dynamic range offered with respect to the default metric. This dynamic is crucial to distinguish between various route quality. For example, the *Capacity* metric penalizes ROBO (repetition of the same bit 4 times) mode by associating a high route cost (Fig. III-1) to avoid these links that do not present the same robustness as higher modulation order. Based on the bit error rate curve defined in [2], links established in ROBO mode will handle a shorter gap of SNR drop than 8PSK links and will be more sensitive than to impulsive noises and attenuations. According to [2], if ROBO modulation is selected after a tonemap exchange, that means that this link is actually in the very last zone of the sensitivity of the transceiver, and a light degradation of the channel quality may overpass these capacities.



III-1: Evolution of Route Cost for the *Composite* and *Capacity* metric

IV. SIMULATOR

The G3 nSim simulator developed by the Neuron Company is used to evaluate the three metrics setup. This simulation software allows us to configure each PLC link by setting different parameters such as noise, droprate, selection of active carriers, or attenuation. This simulator thus supports unidirectional and bidirectional links, different attenuation per link direction and can build arbitrary tree and mesh topologies. Noise and attenuation can be specified on a per sub band basis. As LOADng uses broadcast messages during route establishment it is important to have a realistic channel access (CSMA) and collision simulation. The nSim core coordinates the simulation time so that it is precisely aligned between the different simulated devices and coordinator. The synchronized time allows for an accurate channel simulation, especially of occupancy and collisions. CSMA parameters as outlined by the G3-PLC specification are supported. The full featured G3 network stack running in the simulator shares the same code base as the stack used in Neuron's commercial products, which has shown interoperability with other G3-PLC equipment. In order to validate behavior of the simulator and to align it with the different characteristics of the G3-PLC equipment, a series of tests were made and a comparison between field and simulation results was established. The topology used to evaluate the metrics performances is shown in Fig. IV-1.

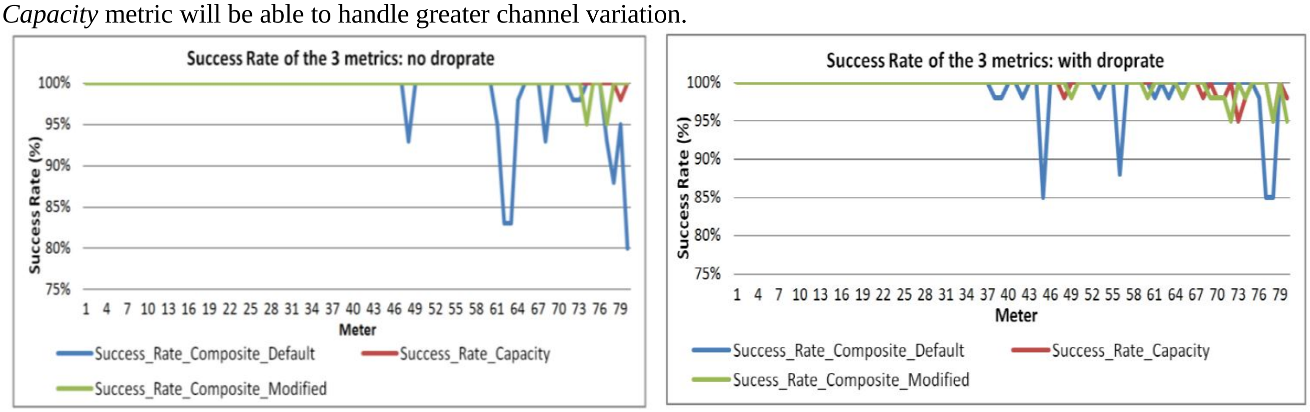


IV-1: Topology of the network used for the comparison of the metrics

The topology is designed in order to show that the Composite metric will select routes with fewer hops and low SNRs while Capacity metric will select routes with more hops and better SNRs. We expect performances improvements starting from the second group(SNR ≈0) as the meters of the first group will establish direct links with the concentrator (SNR=20 dB). Thus we will not be able to see the effect of routing, and the different metrics will look the same. The second group will choose between a direct communication with the DC or a 2 hop path through the first group. Given the dynamic range offered by higher order modulation, we expect the *Capacity* metric to provide better performances.

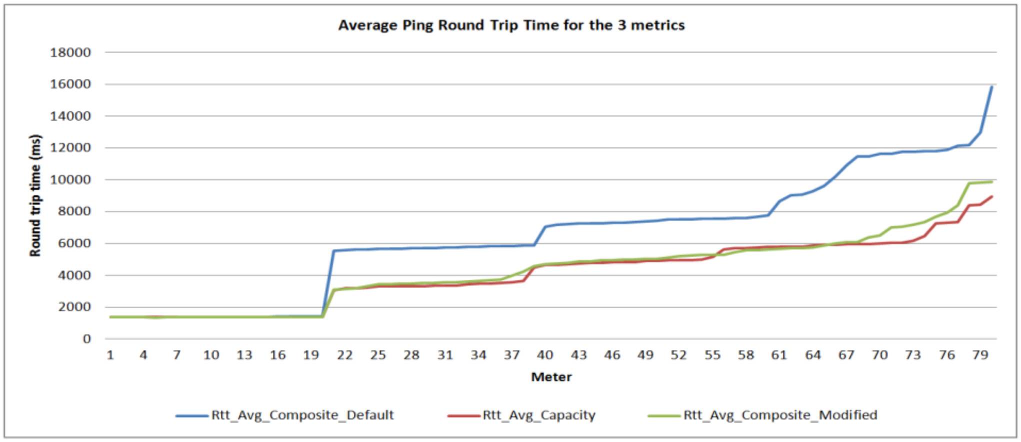
V. RESULTS

Two main indicators are used to evaluate the performances of the different metrics: round trip time of pings (1200 bytes) and success rate of the messages. Two main scenarios are applied, the first corresponds to stable links with no time variation of the PLC channel. The second consists of injecting a random droprate (percentage of packets dropped) in the topology. The goal of this manipulation is to address the random aspect of the network and the instabilities of the links. We expect the *Capacity* metric to handle these variations better than the default *Composite;* as high modulation order links selected by the *Capacity* metric will be able to handle greater channel variation.



V-1: Success rate without and with droprate

The goal of this simulation is to show that the behavior of the *Capacity* metric is more adequate in the case of a varying PLC channel. Furthermore, we aim to demonstrate that if we modify the adpKr parameter (responsible for the attribution of route costs for ROBO links) from its default value 0 to a value of 20 (in order to penalize the ROBO mode with a higher route cost than with the default parameter set), we would get similar results. In Fig. V-1, the success rate of both *Capacity* and alternative *Composite* is close to 100% without droprate while the *Composite* metric with default parameters shows failures mainly due to the expiry of the ping's time to live. This is mainly due to the use of ROBO mode for the transmission of segmented and fragmented packets. For the scenario with droprate, we can see failures for the 3 metrics but the behavior of the alternative *Composite* and the *Capacity* metric is far more reliable. So, in variable and stable channel conditions, we can notice that with large packets being routed, penalizing the ROBO mode is improving the quality of the exchanges between the nodes; the routing process is therefore optimized. In Fig. V-2, we show that the use of the alternative metric or the *Capacity* metric enhances furthermore the throughput of the transmission. The average time of pings is the same for the first group of meters given that no routing is required. On the other hand, the performances are much better starting from the second group where we can clearly see that the use of the two proposed metrics gives us an average ping time much lower than the original one. So, not only are we assuring a reliable communication (success rate), also we are getting faster data transfer which is also a critical goal.



V-2: Round trip time for the 3 metrics

VI. CONCLUSION

In this paper we propose the use of a new metric: the *Capacity* metric. We showed the improvements of this metric regarding the round trip time and the packet success rate compared to the default *Composite* metric with default parameters. As the *Capacity* metric is not described yet in the G3 specification, we also showed that similar improvement could be achieved with an alternative parameter set of the *Composite* metric. On the other hand, the *Capacity* metric can be tested in the Linky project in order to evaluate its performances in real field conditions.

PERSPECTIVES

This paper shows improvements that can be achieved by the use of the new *Capacity* metric, or the modification of the default metric. However, when simulating dense topologies, the MAC layer may be of primary importance in the overall performances. In complex topologies, the channel access algorithm (CSMA/CA) is unable to avoid all collisions when flooding occurs. Thus, many messages such as RREQ may be lost during the route discovery of repair process. In this case, the route selection may be affected by these losses, as a restricted set of all possible routes may be received by the destination, possibly limiting the choice of some of the best routes. In this case, the exploitation of routing performances has to rely on the optimization of the MAC layer that is subject to other modifications like the extension of the contention window to minimize the probability of collision during flooding.

ACKNOWLEDGMENT

The authors would like to thank all the members of the PLC team in ENEDIS for their help in setting the various experiments as well as the efforts made by Neuron group for all the enhancements and modifications for the adaptation to the G3 simulator.

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