Simulation of Powerline Communication with OMNeT++ and INET-Framework

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***Abstract*—This paper presents the work that is done embedded in the EEnergy project [1] "E-DeMa" [2] to simulate powerline communication systems (PLC) for access and inhouse applications in a smart grid scenario. The simulation is implemented in a C++ builder using OMNeT++ [3] and its sub module INET [4]. OMNeT is an event based network simulation tool, and INET is a collection of common network units and technologies, so far excluding powerline. First, the rudiments of the implementations are presented – second, a real network to verify the simulation is described and third, the results are compared and analyzed.**

Keywords: Powerline Communication, OMNeT++, Simulation

I. INTRODUCTION

The simulation of multiple powerline technologies is difficult, because PLC is not yet fully standardized (though some standards exist, e.g. [8]). This changes the normal approach for OMNeT++ implementations, because it is not possible to code just along a certain protocol. The objective is to supply a "toolkit", which is a collection of common powerline features, that can be configured to work as close to reality as possible to emulate a desired powerline variant. Some configuration data comes from experienced data, other needs to be measured. It is important that this simulation attempt focuses on smart grid applications due its embedding into an EEnergy project. Smart grid scenarios are normally static, because the communication takes place (inhouse) between domestic appliances and a control unit or (access) between a local control unit and a remote control unit in a substation. Protocols for dynamically attached and detached components are not, and will not be, implemented within this project.

II. IMPLEMENTATION APPROACH

The implementation starts from the already available Ethernet modules of INET, because CSMA/CD (carrier sense multiple access / collision detection) medium access, back off algorithm, and collision detection are featured and only need to be modified accordingly. This also guarantees the compatibility to existing upper layer modules like network and transport.

A. Physical layer

The physical layer of the simulation controlling the volatile channel quality relies totally on statistical functions that are fed by experienced data and measurements. For example, the current data rate of an (relatively) up to date HomePlug AV 1.1 [5] system is randomly picked of a gamma distributed function with minimum of 6 MBit/s (the ROBO data rate – ROBO = robust OFDM (orthogonal frequency division multiplex), minimal BPSK (bipolar phase shift keying) on all carriers), a maximum of 200 MBit/s and an average of 45 MBit/s. Further algorithms reduce the available data rate due to (e.g.) presence of other (incompatible) systems or activated smart notching [6]. The PER (packet error rate) is correlated to the data rate, because a low data rate indicates a bad channel, and this bad channel should have an increased PER.

B. MAC layer

The MAC (medium access control) layer features both CSMA/CA (collision avoidance) and mastered TDMA (time division multiple access) as medium access variants, that can be used exclusively (TDMA only, like in [7]) or combined in a dynamic scheme (like in [5]). CSMA/CA supports prioritized access in up to 4 levels. In TDMA, modems who wish more bandwidth can request the central coordinator (CCo) for additional time slots. The priority itself is randomly attached to each frame by a statistical process, because the existing upper layer modules in the INET Framework cannot supply sufficient information without major changes. The Inter System Protocol (ISP) [8] is also implemented. The CCo keeps track of active alien systems and decreases the bandwidth of the associated modems due to the current medium load situation.

C. Internal PLC Modems

The compound module "Internal_PLC_Modem" (see figure 1) emulates a built-in PLC modem, e.g. for MUC (multi utility control) systems [9]. It consists of a queue module for incoming messages from the network layer, an encapsulation/decapsulation module for creating frames out of messages with attached control information, and a MAC module, that fulfills all tasks of channel access, back off procedures and the like. The lower layer gate of the MAC module is directly connected to the channel module outside the compound.

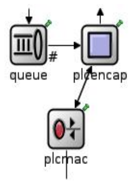

Figure 1. Internal PLC modem as a compound module

D. PLC Socket Adapters

The more common usage of PLC adaption is to adapt from a device's Ethernet socket to the mains – such adapters are produced by numerous manufacturers. The compound module consists of an Ethernet side and a PLC side, both with roughly the same parts as the internal variant.

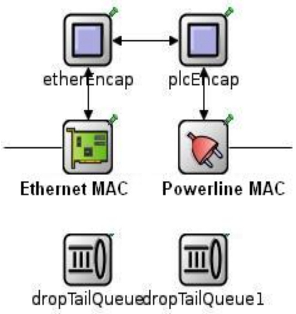

Figure 2. PLC socket adapter as a compound module

E. The Central Coordinator

The CCo is a variant of either the internal PLC modem, or of the socket adapter modem, with an additional channel manager module, that contains all functions of physical channel management and TDMA controlling as well as ISP supervision. The channel module "PlcNet" is both a physical channel simulation and a central coordinator. Though the system is static ("Static" means the participants normally do not dynamically connect and disconnect), the CCo will not change. This module is mandatory for all PLC networks, even if they rely only on an unmastered CSMA medium access scheme. The inapplicable functions are simply deactivated for that use case (or others).

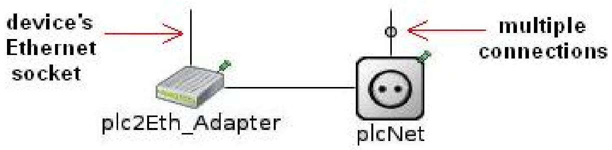

Figure 3. PLC socket adapter with an additional channel manager that forms the central coordinator

III. Checking the Plausibility

First of all the general performance plausibility is checked with an artificial network that is not a realistic use case. The test network (see figure 4) is designed to stress all implemented features as far as possible, and to verify the underlying statistical processes for data rate, PER and priority distribution.

A. A test network

The opposing hosts communicate through the two PLC networks in between. The two hosts (powerlineHost and standardHost) on the left side (wish to, but) cannot establish a communication, because their ID is configured incompatible to the CCo's ID. They act just as sources for disturbance. All run time data (as well as data rate and packet error rate statistics) is collected by the dataCollector module by sendDirect() (size less, zero time communication) functions in all PLC components.

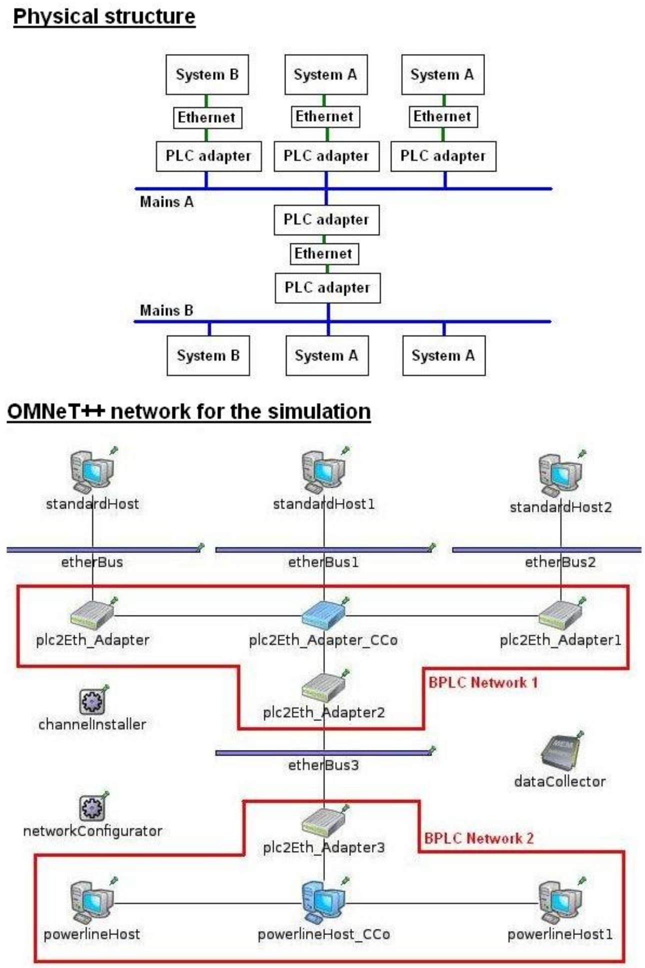

Figure 4. Test network

B. Sample results

Table 1 shows data from a sample run over 200 seconds. The average PER is set to a relatively high value of 1% (to observe the impact / the behavior of the system of a lost packet in short time and to verify the correlation between data rate and PER). Every 100 messages an automatic collision is provoked to observe the correct behavior. The PLC network's modems used both TDMA and CSMA in a dynamic scheme with a maximum data rate of 200 MBit/s. The average run time delay from (right above) MAC layer of a PLC device to the MAC layer (right above) of the target PLC device in a PLC connection is 485µs (this value is chosen, because the objective of the whole is to compare different PLC systems). To show the plausibility of this value, the shortest and the longest frame time is calculated for the average data rate of 45 MBit/s.

MAX
1616 Byte / Packet * 8 Bit/Byte * 1 / (45 MBit/s) = 285µs

MIN
162 Byte / Packet * 8 Bit/Byte * 1 / (45 MBit/s) = 29µs

In the worst case, the modem has to wait a whole max. frame time plus inter frame gap (IFG) to send it's frame, so the maximum time is (under otherwise ideal conditions) at approximately 570µs (still neglecting run time, delayed channel access, collisions and error packets). So, the value of 485µs seems to be quite plausible.

TABLE I. SAMPLE RESULTS FOR THE TEST NETWORK

Parameter	Maximum	Average	Minimum
Run time	2000.03 µs	458.57 µs	98.37 µs
Data rate	200 MBit/s	31.77 MBit/s	6 MBit/s
Priority	4	2.15	1
PER	2 %	1.62 %	0.11 %

Figure 5 and figure 6 show the shape of the underlying gamma distribution function for the data rate and the correlated function for the PER.

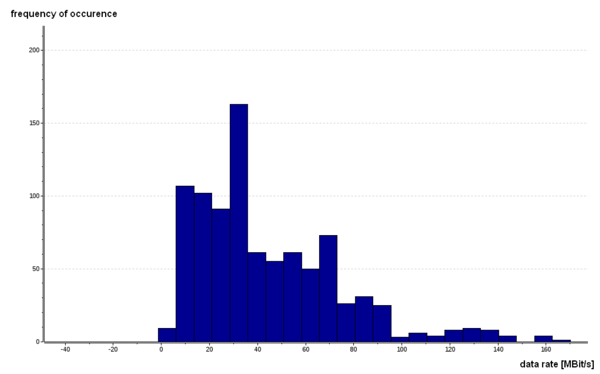

Figure 5. Data rate – gamma distribution function (900 random values)

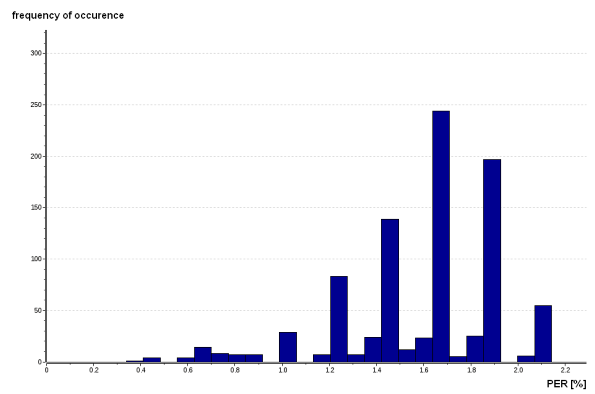

Figure 6. PER – correlated gamma distribution function (900 random values)

IV. A REAL NETWORK

To verify the simulation model, a real test setup (see figure 5) was build with two incompatible PLC systems. One is a relatively new PLC system which has a maximum data rate of 200 MBit/s and the second is an older version with a maximum rate of 14 MBit/s. Four laptops are connected and produce the maximum possible TCP/IP (transmission control protocol / internet protocol) traffic with kPerf [10]. The slow system "plays" an advanced metering connection (AMI), while the faster one "plays" a common private users internet connection.

A. The Test-SetUp

Every PLC socket modem is placed inside a shielded enclosure and communicates to the mains through a coupling/decoupling network (CDN) that separates the mains power and the high frequency signal (HF). The connection to the laptop is established via optically discoupled Ethernet. The HF net is build with BNC cables that connect the CDN's HF ports. The connection is an (approximately) ideal flat one.

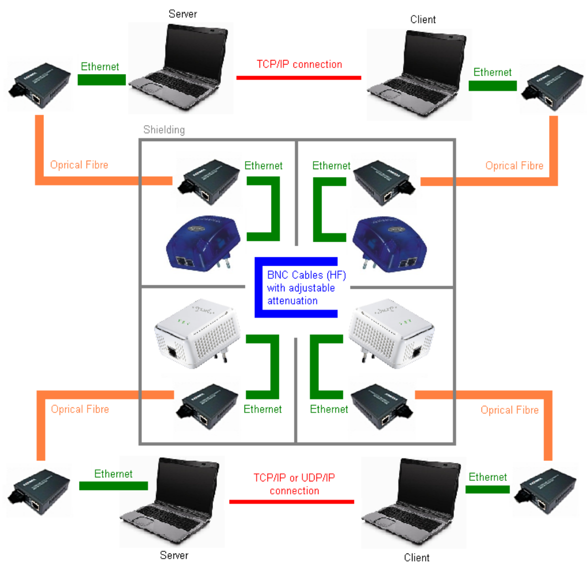

Figure 7. The "real" test setup

The attenuation is varied from 0dB to 36dB on all connecting BNC cables. Please take notice that the CDN already attenuate each with about 12 dB, so the minumum is 24dB.

As a preparation, the uninfluenced average data rate of each system is measured for every attenuation (this value will find use in the configuration of the simulation – see figures 9 & 10).

B. The Simulation of the Test-SetUp

This network is recreated in OMNeT++ (see figure 8). The two modem types are emulated trough two different configurations. A configuration holds about two dozen parameters. Each system has a CCo modem and a "normal" modem. The PlcNet sub modules of the two CCo are connected so that interference can occur.

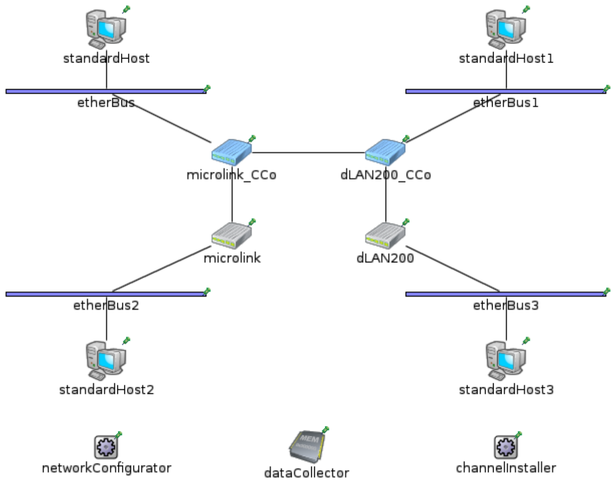

Figure 8. The simulated “real” network

Because this should not burst the bonds of this paper, the simulations performance is only verified for a single data point at 6dB additional attenuation. The model is not yet capable of dynamically adjusting its interior parameters along with an outer attenuation, and certain properties are simply not illustratable in simple gamma distribution function – so for each other data point, certain scaling factors need to be adjusted to imitate the real network correctly. The scaling factors model, how severe a system is disturbed for the time beeing by other incompatible systems in its vicinity.

Because the target network (e.g. a template for an inhouse network) is static, this is not a major problem to fulfill the project's task. The scaling factors will be adjusted until they fit, and then the template is copied until a city scale scenario is created.

In table 2 one can see that the average data rates are the undisturbed measured values from the preparation (at an additional attenuation of 6dB – in total 30dB). The maximum data rate comes from the device's description itself and the minimum data rate is the ROBO data rate of the device (for fast PLC), and the lowest measured data rate (for slow PLC, because this value was simply yet unknown).

TABLE II. CONFIGURATION FOR THE SIMULATION

Parameter	Max.	Average	Min.
Fast PLC data rate	200 MBit/s	64.5 MBit/s	6 MBit/s
Slow PLC data rate	14 MBit/s	4.79 MBit/s	1.2 MBit/s

Different from the measurement, the simulation will rely on UDP/IP (user datagram protocol) traffic, because the UDP traffic generators can easily be adjusted to a certain frame output rate and be forced to constantly send for a very long time (this is difficult for the INET TCP traffic generators). The simulation will calculate an average bit time for each UDP frame with a given data rate. That is why it is not problematic, that the net may be idle in the time between frames. The resulting data rate is, so to say, more an overall capacity than an actual throughput.

Example: The current available data rate on the net is 20 MBit/s. A frame is about to be send by a modem which will check for the available data rate and report to the data collector “20 MBit/s” (is possible at the moment). Then it calculates the transmission duration upon that rate and transmits the frame with a bit time of (20 MBit/s)$^{-1}$ seconds/bit. At the end of the simulation the data collector will average over all received values (data rate and run time).

That is the difference between simulation and reality – in the simulation, one can simply ask for the maximum channel capacity by reading out the parameter.

C. Sample Results for the Measurement

In figures 9,10 and 11 one can see the outcome of the measurement performed on the real test network.

Figure 9 shows the performance decrease of the fast PLC system, when a second incompatible system is present. The loss is constantly about 50 % (little above) of the undisturbed data rate.

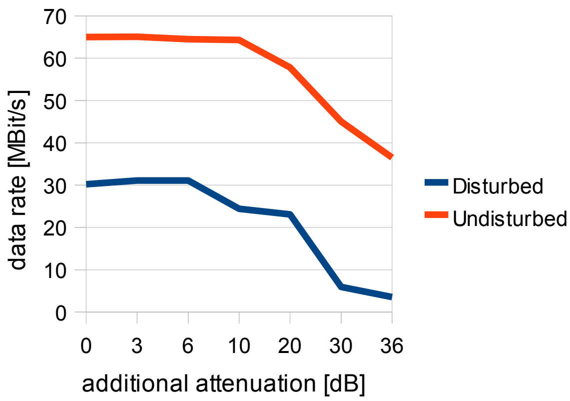

Figure 9. Decrease of data rate versus additional attenuation for the fast PLC system– with and without an incompatible system in the vicinity

Figure 10 shows the performance decrease of the slow PLC system, when a second incompatible system is present. The loss starts with about 50 % for low attenuation values (just like the fast PLC system), but then the additional attenuation begins to decrease the amount of noise the slow system receives from the fast one. The remaining performance decrease is only 13 % at 36 dB additional attenuation.

Figure 11 shows both “disturbed” graphs in one diagram. The faster system does not benefit from lesser alien system disturbance trough higher attenuation.

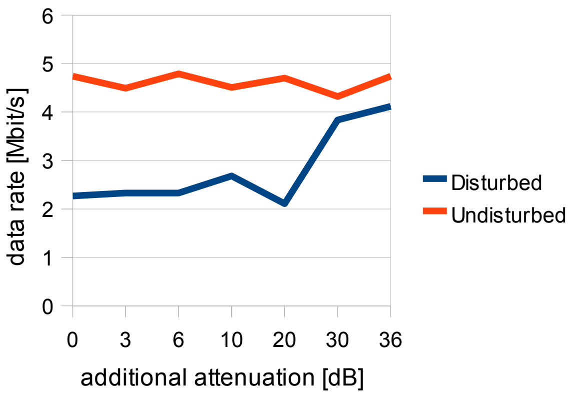

Figure 10. Data rate versus additional attenuation for the slow PLC system– with and without an incompatible system in the vicinity

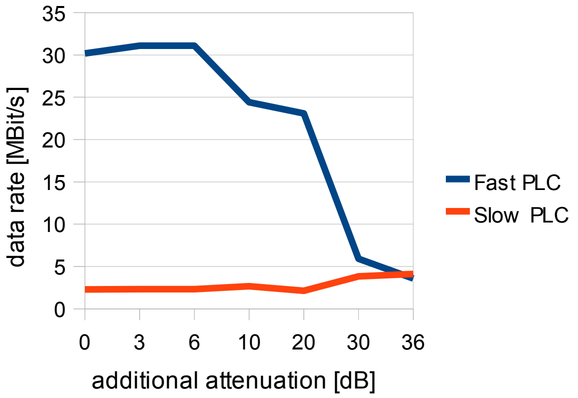

Figure 11. Data rate versus additional attenuation for the slow and the fast PLC system– with an incompatible system in the vicinity

D. Sample Results for the Simulation

TABLE III. Sample results for the simulation

Parameter	Measured	Simulated	Accuracy
Fast PLC data rate	31.1 MBit/s	31.18 MBit/s	99.7 %
Slow PLC data rate	2.33 MBit/s	2.48 MBit/s	93.9 %

Now it is attempted to reproduce the behavior of the real system in the simulation at the data point of 6dB additional attenuation. The simulation is run for 500 seconds with steady traffic on both systems to get about 50.000 values (meaning also 50.000 frames transmitted for each pair of modules) for the averaging of the data rate. The results are stable, multiple runs delivered the same results.

V. Conclusion and Outlook

The results of the simulation make confident, that the chosen way of creating a simulation toolkit was a good one.

As soon as the consortium member in E-DeMa responsible for the detailed scenario generation provides a “typical household”, several modules for all kinds of PLC variants will be configured and verified for this scenario. A first comparison on suitability of the different systems will be performed.

The next step will be the implementation and verification of PLC access technologies. That, together with the inhouse technologies, will allow the simulation of city scale scenarios of smart grids, and the performance of PLC system combinations (one access system and one in house system) can be compared to each other.

It should be stated clearly, that the impelmentation is done only by a single person within a limited project run time, so that some mechanisms can only be implemented in a simplified way.

Acknowledgment

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