Simulation of Powerline Communication with OMNeT++ in (static) Smart Grids

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ABSTRACT
This paper describes the implementation of power line communication (PLC) [1] systems in OMNeT++ with help of the INET framework. Because PLC is in not yet fully standardized (though ambitions exist, e.g. IEEE), the attempt is a little bit different from just copying an existing protocol for OMNeT++.The objective is to supply a “toolkit” which can be configured to work as close to reality as possible like a desired powerline variant in a short time effort. Through the help module *DataCollector*, the run time statistics of very large networks can be simulated.

An important notice is that this work is embedded into the EEnergy (http://www.e-energy.de/) project “E-DeMa” (http://www.e-dema.com/de/index.html), which focuses on smart grid applications. The in home smart grid scenario is, by practical means, a rather static one – so protocols for dynamic network changes are not yet implemented – and apart from that, some more work must be done in the near future to simulate all properties of powerline communication.

General Terms
Performance, Design, Verification

Keywords
Broadband Powerline Communication, InHouse, Smart Grid

1. INTRODUCTION
Broadband powerline communication (in house) is a technology where existing power cables of a house installation are used for signal transmission in the frequency range of 2 MHz up to 30 MHz (in the near future, an extension to 70 MHz is aspired). Because every relevant domestic appliance has a power plug, and every home has a mains installation, PLC seems to be a clever network solution. The modems use OFDM [2] with up to 1024 carriers with a modulation scheme on each carrier, that is selected by the individual SNR at the carrier, which can range from BPSK up to a 1024 QAM. The challenge of PLC is, that the channel changes it's properties constantly – leading to the necessity, that the modulation scheme is adiusted in the same manner.

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Additionally, known radio services have to be excluded from the transmission scheme by static notches, while unknown radio services have to be handled dynamically (this is called “smart notching”).

On MAC layer, PLC uses mastered TDMA, CSMA/CA or a dynamic combination of both – according to the specific variant in use. Some systems also feature prioritized traffic (privileged medium access for high priority data). To cope with foreign PLC systems, the inter system protocol (ISP) is introduced by IEEE P1901 [3].

2. APPROACH
The implementation of the simple modules starts from the original Ethernet modules (already part of the INET Framework), because CSMA/CD is already realized there, and it is a common medium access scheme for powerline modems – naming for example the HomePlug AV 1.1 standard [4]. The basic modules are in principal the same. A *EtherMAC* becomes a *PlcMAC*, an *EtherBus* becomes a *PlcNet* and so on.

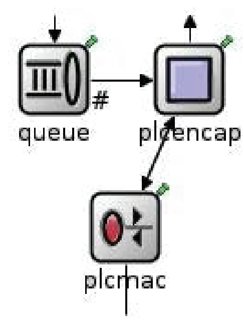

Figure 1. Internal broadband powerline modem as a compound module

This was made to ensure the compatibility with existing compound modules in the INET Framework. The changes necessary to come from Ethernet to PLC are huge. The resulting source code exceeds the original by far, and not all features have been implemented yet.

3. FEATURES OF PLC
The next section will give a (incomplete) list of the features that are already implemented in the project and operate on MAC layer. All of the features can be switched on and off (or configured in detail) in the configuration file to adopt the properties of a certain market technology.

3.1 CSMA/CA

CSMA/CA is a brother of the well known CSMA/CD. Both use carrier sense and multiple access. The collision avoidance method adds a random time interval to the wait time after a collision has occured, so it becomes more unlikely to have a follow up collision, when multiple modems have a sending wish. The overall MAC protocol is a combination of a carrier sensing mechanism, a priority resolution and a backoff algorithm [5].

In the simulation this can be easily implemented with adding a rand()-function in the “scheduleAt” line– but in this protocol, this additional wait time can be correlated with the messages priority, so it becomes a little bit more complex (see “3.5 Prioritized Channel Access”).

3.2 TDMA (mastered)

For high priority traffic, or traffic that needs quality of service (QoS), some newer powerline variants can switch dynamically to a TDMA medium access - some systems rely only on mastered TDMA (e.g. [6]). Another common scheme is to have certain areas reserved for CSMA and certain areas reserved for TDMA in a repeating scheme.

For the simulation, a managed token system was implemented. The central coordinator (CCo) sends tokens, telling who is allowed to send in a certain time slot - the clients tell the CCo their wish to send by a request message. The CCo also keeps track of which clients are active senders, and throws silent modems from the list.

3.3 Inter System Protocol

The IEEE P1901 defines an inter system protocol to allow up to 4 different PLC systems to co-exist on the same network. Every participant must support the ISP to function properly. The sharing works on frequency splitting – so every system uses only a certain band as a subset of the whole range – this is, of course, slowing every system down. For the simulation there is only one CCo in the net (normally there would be as many as there are different systems). But, as noticed later, the CCo role is somehow abstracted to get the simulation not too complicated. So, the systems already share one medium (making their overall performance decrease). But there are two mechanisms implemented to emulate the ISP. The first is, that the CCo keeps track of which systems are active (pretty much analogue to the TDMA access), and, depending on their number, he will add some additional data rate decrease, because the sharing of the frequency band needs some guard intervals between the bands used by the different systems.The second is, that every PLC frame is marked with a vendor ID, and only modems that belong to the same vendor ID (can) process the messages.

3.4 Smart Notching

Smart notching, which is introduced by [7], is a physical layer technique, that is able to detect foreign radio services that couple into the network and other participants, using the same network as a communications medium. This (logically) is also the fundamental technology for the inter system protocol.

Smart notching suppresses the disturbance degree of powerline systems, which they introduce into their environment trough radiation from wires [8], because active services are excepted from the modulation scheme and will not experience unbearable interference.

Because the physical layer is only modeled by statistical functions, this technology does not need to be implemented in detail here. [7] (p. 188) says, that active smart notching reduces the data rate about 23% in worst case – so, if this feature is switched on for a single modem, its data rate will be reduced accordingly. It can, of course, be configured for each modem individually.

3.5 Prioritized Channel Access

The standard HomePlug AV 1.1 features (for example) 4 levels of priority, which determine the fastness of medium access. High priority messages get privileged access to the shared medium. Because it is not easily possible to implement the higher layers to provide sufficient information about the messages' type, this is simulated by a random picked priority, that is attached to each frame leaving a modem. The distribution function of this process comes from correspondence with manufacturers.

In CSMA/CA the height of the priority determines the amount of additional random wait time after the medium is free again. The maximum wait time is divided into 4 slots (to simulate a HomePlug modem), where high priority traffic will only randomly pick a wait time out of the first interval, and so on.

In the TDMA mode, modems can request the CCo for additional time slots in the same overall period to get a higher throughput. This is implemented in a way that every time, when a modem has a high priority message in its queue (and TDMA is active) it will ask for another time slot in addition to the one it already has got. Theoretically, a single modem can occupy many slots this way, but really high important traffic is seldom in the smart grid context.

4. Simulation of the Channel Properties

As mentioned before, the channel is only emulated by statistical functions. The managing of the channel characteristics are done by a single module, the PlcNet.

4.1 Varying Data Rate

The current data rate, which will vary permanently, is randomly picked from a gamma distribution, which (in the case of HomePlug) has a maximum of 200 Mbit/s, a minimum of 6 Mbit/s and a average of 45 Mbit/s. It will change (drastically) every 5 to 10 seconds and the modems will receive a size less message (because in reality they perform a measurement themselves) about the change.In addition, some small fluctuations are implemented through a preamble (sometimes called “trainer”), that is overwritten by the PlcNet, when the message passes through.

4.2 Varying Packet Error Rate

The packet error rate (PER) is also picked from a gamma distribution experiment, but is also correlated to the data rate – low data rates, which indicate a bad channel do also have bigger packet error rates. Unfortunately, there is no experienced data about this, so this cannot be used as an realistic parameter, yet. It is, at the moment, only interesting how the PER is linked with the run time delays, and the overall throughput.

For real technology simulations, a PER of zero would be the best choice, because the PLC modems usually adjust their forward error correction intensity to the channel quality.

4.3 Length Depending Attenuation

Experienced data shows that (under ideal circumstances apart from that) the maximum data rate decreases, when the connecting wire length exceeds approximately 120m, then dropping by 0.8% per meter. The maximum length is about 200m.This is already implemented, but not interesting yet, since the focus lies on in home applications, where the lengths are in the range under 120m. It will become interesting, when the work in home is done, and the simulation of access technologies follows (of course the attenuation behavior will change for this scenario).

4.4 Interference of Incompatible Systems

Experiments performed at the institute show, that if two different systems are active in a single network, it strongly relies on the positions on the "bus", how severe these incompatible systems will disturb each other by decreasing the SNR of the alien system. If a foreign modem is on the line in between two befriend modems (1-2-1-2), it will decrease the available data rate for the system – but even if the systems are arranged in a 1-1-2-2 shape, stray signals transmitted by the common used line will interfere (but not in the extend as in example 1).This is impelemnted through a decreasing factor, that is calculated on the actual topology of the network.

5. The Different Compound Modules

Several different compound modules have been designed to emulate the different PLC medium access types.

The Internal PLC Modem

The compound module shown in figure 1 is an internal PLC modem for the simulation of devices that already have a modem build in. This is more common for narrow band PLC technologies, but this may change through the introduction of more and more intelligent household appliance.

The Socket Adapter Modem

The more common usage of PLC adaption is to adapt from an Ethernet socket to the mains. Such devices are produced by numerous manufacturers. To simulate this, a network bridge was designed as a compound module (see figure 2).

The Central Control Unit (CCo)

Both the internal modem and the adapter have a "big brother" with an additional simple module for network management (the PlcNet module as described before). This was integrated into the compound due to guidelines from the E-DeMa project partners (see figure 3).

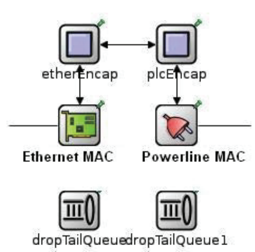

Figure 2. Compound module simulating an adapter modem

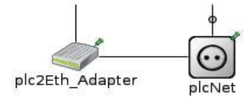

Figure 3. Compound module consisting of a socket adapter modem (see figure 2) and a network management module

6. A Sample Network

In figure 4 one can see a sample network making use of all compound modules. This is not a realistic use case – it is designed to stress all implemented features as far as possible.

Description of the 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 vendor ID is configured incompatible to the CCo's vendor ID. All run time data (as well as data rate and packet error rate statistics) is collected by the dataCollector module by sendDirect() functions in all PLC components.

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 MAC layer of a PLC device to the MAC layer 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 packet 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. packet time plus inter frame gap to send it's packet, so the maximum time is (under otherwise ideal conditions) at 570µs (still neglecting run time, collisions and error packets). So, the value of 485µs seems to be quite plausible.

Table 1. Sample results collected by the dataCollector module

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 %

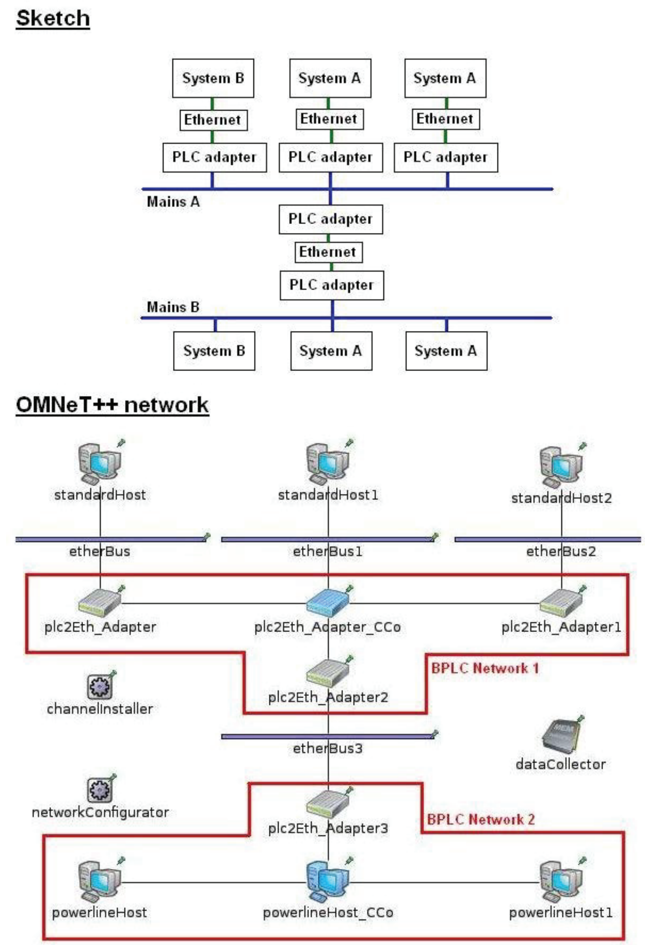

Figure 4. Sample network with adapter modems, internal modems and two CCo, each managing one PLC network

The run time is, for so small lengths, in the range of nano seconds, and does not have a significant impact on the overall delay – but for future technologies with higher data rates and range, the bit time and the run time will converge.

The data rate and the priority level duistribution meet the requirements of the experienced data (smart notching is switched on on some of the modules and different systems are active, so the average data rate is below 45 MBit/s).

7. The Modules in Large Scale Scenarios

The dataCollector is a nice to have for such small scenarios (because it is possible to check the data of every module by hand in a manageable amount of time), but becomes mandatory if the focus switches to city scale scenarios (which is the goal for the simulation in E-DeMa). Otherwise it would be problematic to find a single parameter to compare different PLC technologies to each other.

8. Conclusion and Outlook

So far, the simulation has proven at least to be plausible, even though not all features work in a final version. Future work will consist of different steps. First, finishing the toolkit. Second, emulating currently available and near future technologies to compare them in a smart grid context. Third, investigating the influence of certain system parameters on the overall performance.

9. ACKNOWLEDGMENTS

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