Simulations in GAD Project: BPL Networks

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ABSTRACT
This paper presents the simulation tasks carried out by CITIC in the framework of the Spanish R&D project *Gestión Activa de Demanda (*Active Demand Management), with the acronym GAD. Before the actual development of the hardware and software in the GAD project, the entire system architecture was defined. During this initial phase two simulation tasks were performed in order to demonstrate the feasibility and efficiency of GAD communications both inside a potential customer's home as well as in the upper levels of the electric distribution network. CITIC, working for Ericsson as a research organization, has carried out a specific task to simulate an in-home Broadband over Power Lines (BPL) network, applying the recently developed network simulator ns-3. New features have been added to this simulator in order to complete this task.

Categories and Subject Descriptors
I.6.6: Broadband over Power Lines Network Simulation – *network simulator 3, powerline communications.*

General Terms
Measurement, Performance, Design, Experimentation, Verification.

Keywords
ns-3, network simulator, BPL, powerlines, PLC.

1. INTRODUCTION
1.1 GAD Project
The GAD Project is a Spanish R&D project with the objective to define mechanisms for the optimization of household electrical consumption [5]. The solution proposed by the GAD Project is based on the communication between different actors over the electrical grids. The communication workgroup defined the ICT (Information and Communications Technology) architecture and established communications requirements, splitting the communication system in two different segments, named WAN and LAN segments. This division was necessary due to different characteristics of the Distribution Network and the Home Grids.

Before the implementation of the system the communication workgroup defined a simulation phase, in order to simulate both Distribution Network and Home Grid communications. CITIC was in charge of the Home Grid side, simulating communications between smart appliances and a Domestic Power Manager (DPM), in a previously defined home scenario.

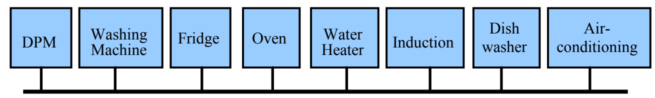

Figure 1. Proposed scenario

This DPM will manage the in-home consumption by communicating with smart appliances, using KNX [8] and in particular KNXnet/IP [1] as upper levels protocols.

1.2 System Architecture
The proposed scenario is composed by a DPM and seven electric household appliances: dishwasher, washing machine, fridge, oven, water heater, induction stove and air-conditioning. All these actors communicate through power lines using BPL technology, with the great advantage that no new wiring is needed.

1.3 Ns-3
The ns-3 is a discrete-event network simulator aimed primarily at research and educational use. It's an open-source project where researchers can contribute and share their software.

When the GAD simulation task started, ns-3 was in Release Candidate version, but it showed several advantages over other simulators, resulting in its final choice by CITIC researchers.

Ns-3 source code needed to be modified by adding a new channel implementation that could emulate a power line and new applications to emulate the new actors´ behavior.

2. DEVELOPMENT
2.1 Inputs
If real at home power line propagation characteristics are desired, it is necessary to get input data, such as real world measurements and channel models from previous studies, before developing a new channel in ns-3.

At the end of this simulation task, the applicable BPL standard (IEEE P1901 working group [7]) was not yet approved, therefore simplified medium was simulated.. The BPL standard will use CSMA CA as Medium Access Control (MAC) layer. Also after collecting and analyzing several studies about the propagation characteristics of power lines, it was concluded that the most significant ones are attenuation, delay and noise. Therefore the simulation took place on a Physical (PHY) medium, also

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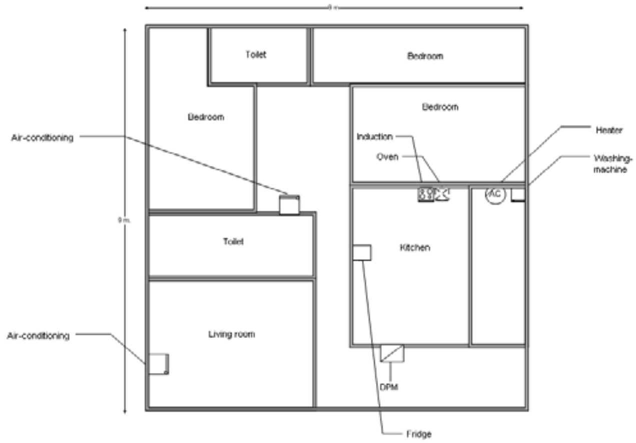

Figure 2. Simulated home plan

characterized by its attenuation, delay and noise, and a MAC layer using CSMA CA.

Furthermore it was necessary to develop a KNXnet/IP over UDP stack. Any GAD action will generate one or several KNX messages, that will be delivered to the network as KNXnet/IP messages, forming the payload of several UDP datagram.

2.1.1 Real World Measurements

According to the website of the Spanish National Statistics Institute [14], 42,2% of Spanish homes had 5-6 rooms in 2008, with a total size between 61 and 105 $m^{2.}$

Table 1 reflects the hypothetical distance between a DPM and different appliances in five of these Spanish homes. These measurements will be used as the channel length in the simulations.

Table 1. Average distance between appliance and DPM

Appliance	Average Distance to DPM (m)	Appliance	Average Distance to DPM (m)
Fridge	5.7	Washing Machine	10.8
Induction	8	Air-conditioning	6
Dish-washer	8.6	Oven	7.8
Water heater	11.1		

2.1.2 Channel Modeling

For a correct channel modeling, previous studies were analyzed. There are not a lot of studies about power line communications using BPL frequencies, and most of them show the results of measurements from real experiments placed in different parts of the world [2][4][6][16], where power lines can have different propagation characteristics. Therefore the studies on Spanish power lines [2][6] were considered as one of the most important information sources.

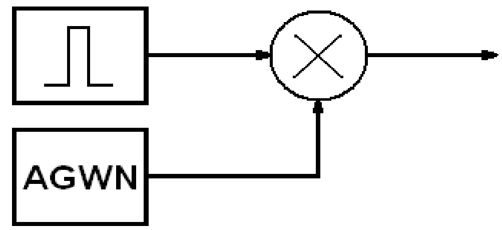

Figure 3. Impulsive noise model

2.2 Channel + Modems Implementation

After studying supplied *doxygen [3]* documentation, and taking the base of CSMA channels, a new *bpl-channel* has been developed for the PHY layer, and a *bpl-net-device* [9] for the implementation of MAC layer characteristics. New channel and device characteristics have been included as variables that can be modified according to requirements, making it possible to use these channels and devices in any BPL simulation.

The new characteristics of the channel, in addition to CSMA channel properties are its attenuation, expressed in dB/m, and its maximum length in meters, that cannot be exceeded.

The new net-devices characteristics are: distance to the DPM, transmission power, and reception threshold. Every net-device has a function in charge of deciding whether the incoming frame is correctly received or not. This function will estimate the received signal power, and compare it with the own net-device threshold.

New *helpers* have also been developed, to ease the tasks of creating and managing devices and channels.

Finally, to include impulsive noise effect in the channel (impulsive noise will be the most significant component of noise), it is modeled according to documentation [2] for asynchronous impulsive noise. It is modeled as a multiplication of white noise with a random sequence of square pulses, characterized by its amplitude, duration and time between pulses.

The amplitude is modeled by a Rayleigh random variable, while the duration assumes a worst case situation. The time between pulses is modeled by an exponential random variable. All this will be translated into several noise pulses. The amplitude of these noise pulses will attenuate the signal if it coincides with a pulse.

$$f(x;\sigma) = \frac{x}{\sigma^2}\exp\left(\frac{-x^2}{2\sigma^2}\right) \quad \text{for } x \in [0,\infty)$$

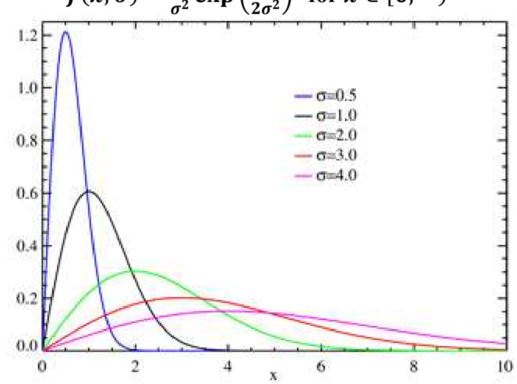

Figure 4. Rayleigh distribution

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Table 2. Maximum KNXnet/IP messages size

Message Name	Maximum size (bytes)
SEARCH_REQUEST	14
SEARCH_RESPONSE	78
DESCRIPTION_REQUEST	14
DESCRIPTION_RESPONSE	86
CONNECT_REQUEST	24
CONNECT_RESPONSE	20
DISCONNECT_REQUEST	16
DISCONNECT_RESPONSE	8
TUNNELING_REQUEST	26
TUNNELING_ACK	10

2.3 Applications

Any GAD action will generate one or several KNX messages, that will be delivered to the network as KNXnet/IP messages, forming the payload of several UDP datagrams. The maximum size of the KNXnet/IP messages is shown in Table 2.

In a GAD simulation, every appliance can be considered as a generic *Load*, so there are two kinds of devices in the system: the DPM and loads. In ns-3, a new *application* [10][11] was developed for both types of devices:

- DPM: will manage the login and logout from loads. Once a load is registered, the DPM will send randomly (with a configurable maximum time between messages) a message with a command to one of the registered loads, including broadcast destination.
- Load: its first objective is to login the DPM. Once it is registered, it will change its state randomly, sending a corresponding message. It will also answer incoming messages from the DPM.

New helpers have been developed to facilitate the creation and management of these applications.

2.4 Using Real Hardware

Ns-3 has the capability to connect to real networks on real machines, so both upper levels protocols and the physical medium can be simulated separately.

This capability has been used to simulate upper levels protocols, and using a real network, with commercial BPL modems and real power lines.

The only source regarding this subject [12] applied only one real Ethernet card, creating two virtual machines by using VMware (an application for creating virtual machines), which communicates in an echo client-server structure. However to appreciate the effect of attenuation and delay of a real power line it was necessary to use more Ethernet cards, in order to separate clients and servers. . Consequently the code was adapted to the new situation, capacitating it to simulate several schemes, with one server and several clients either on the same machine or on different machines.

These simulations were held in real-time, making it possible to capture traffic with Wireshark (former Ethereal) [15] as network analyzer.

3. SIMULATIONS

Based on the scenario proposed in Figure 1, input data and the OPERA alliance draft proposal for the IEEE P1901 standard [13], values were assigned to the simulation parameters. The distances between the DPM and appliances were measured on a straight line these distances were tripled to take the wiring into consideration.

Several simulations were executed with different channel lengths, and under different conditions. These simulation results were analyzed by three methods: debugging by command line, using Wireshark both with real time simulated traffic and the PCAP files generated by ns-3, and analyzing ns-2 format traces generated.

3.1 Simulation: 24 Hours

This simulation tried to cover a whole day of normal household activities, with a total simulation time of 86.400 seconds. The different appliances simulated a normal behavior, according to the use cases defined by the GAD Project.

Table 3. 24 Hours Simulation Brief

Total simulation time	86400 seconds
Total number of packets in the network	2629 packets
Average number of packets per second	0,03 packets
Average packet size	55,471 bytes
Total number of bytes	145834 bytes
Average bytes/second	1,688 bytes/second = 13,504 bits/second

As Table 3 shows, the traffic generated in the network is scarce, just a packet every 33.3 seconds with an average length of 55.47 bytes.

From packets destination addresses, shown in Table 4, it can be concluded that nearly 50% of the total amount of packets in the network has as destination address the DPM. This result was expected, taking into account that any appliance asks the DPM for permission to turn on, as well as for any change on its status.

Table 4. Packets Destinations

IP	Packets	% Packets	Packets Tx	Bytes Tx	Packets Rx	Bytes Rx	Bytes
10.1.1.1	1128	49,52	534	33362	594	43272	76634
10.1.1.2	64	2,81	33	2300	31	1896	4196
Broadcast	46	2,02	0	0	46	3084	3084
10.1.1.3	25	1,10	13	880	12	764	1644
10.1.1.4	11	0,48	7	508	4	300	808
10.1.1.5	286	12,55	161	11164	125	8106	19270
10.1.1.6	25	1,10	14	980	11	712	1692
10.1.1.7	290	12,73	163	12508	127	7786	20294
10.1.1.8	380	16,68	201	14708	179	10630	25338
10.1.1.9	23	1,01	13	884	10	744	1628

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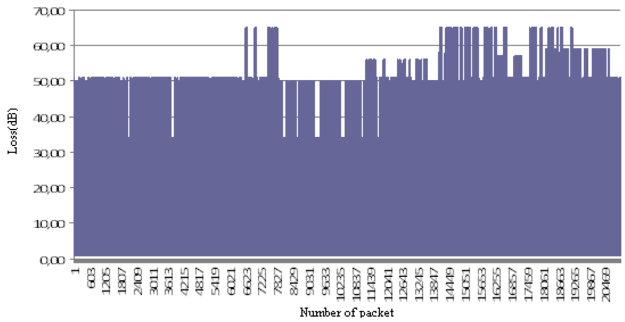

Figure 5. Packets Loss

It is interesting to highlight that there aren´t any packet losses during the 24 hours of simulations. This is due to the fact that the difference between the transmission power and receivers threshold is nearly 100 dB, while it shows that the maximum attenuation suffered by a packet is less than 70 dB, because there is no collision between impulse noise and a packet transmission. This is caused by the scarce network traffic.

3.2 Simulation: 10 Seconds

This second simulation tried to bring the scenario to a limit situation by making packet loss visible. With this objective, the washing-machine distance to the DPM was increased to 60 meters, and impulsive noise pulses duration was set to 2 seconds (10000 times bigger than before). Traffic amount was also increased, reducing packet arrival intervals.

Table 5. 10 Seconds Simulation Brief

Total simulation time	10 seconds
Total number of packets in the network	64 packets
Average number of packets per second	6,4 packets
Average packet size	69,906 bytes
Total number of bytes	4474 bytes
Number of loss frames	24 frames
Average bytes/second	447,4 bytes/second = 3579,2 bits/second

In this simulation packet losses were appreciated, caused by the extreme conditions under which these simulations took place.

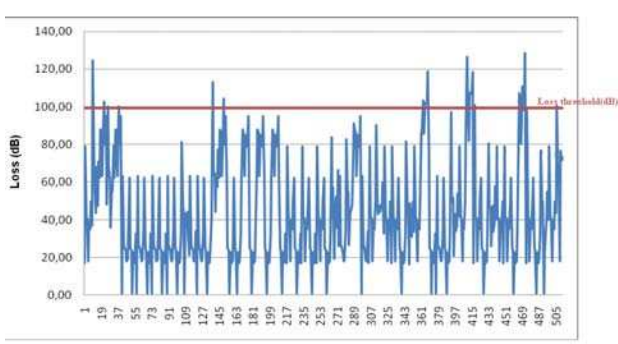

Figure 6. Loss in 10 seconds Simulation

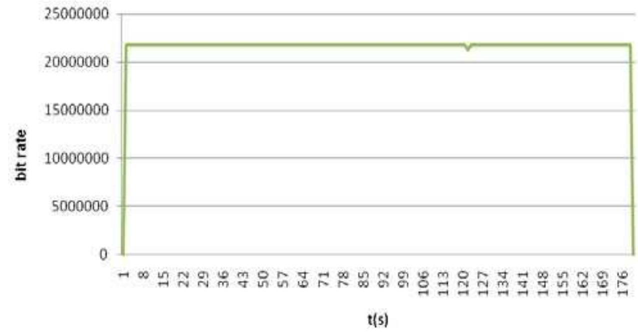

Figure 7. Network bit rate

3.3 Simulation: HDTV Traffic

This scenario tried to test the coexistence with other traffic sources, adding a simulated HDTV traffic source to this simulation, in addition to GAD traffic. Channel quality was also reduced, until a throughput of 20 Mbps. Finally, the time intervals between packets were reduced to increase GAD traffic.

Under these conditions, several 3 minutes simulations were executed. The average rate was considerably increased to nearly 21 Mbps, reaching channel limits. As Table 6 shows, most of the traffic in the network belonged to non-GAD sources.

Table 6. HDTV Simulation Brief

Total simulation time	179,017 seconds
Total number of packets in the network	870248 packets
Average number of packets per second	4861,269 packets
Average packet size	557,312 bytes
Total number of bytes	484999712 bytes
Average bytes/second	2709243,926 bytes/second = 21,674 Mbit/second
GAD traffic (%)	0,13
Non-GAD traffic (%)	99,87

This result seems logical, because HDTV traffic was simulated by a Constant Bit Rate (CBR) source.

The bit rate of the network, shown in Figure 7 is very similar to a CBR source, with the GAD traffic hardly noticeable.

It's remarkable that this time four packets were lost. This was caused by new channel occupation that increased the probability of concurrence between a transmission and a noise peak, and these simulation conditions were extreme enough to cause packet loss. Despite this extreme condition the packet loss number represents less than 0.002 % of total packets.

3.4 Simulations on Real Hardware

Ns-3 capability was used to execute several simulations on real networks, to compare results between simulated and real net-devices and channels.

With this objective, the same ten minutes simulation was executed, both on a simulated network and on a real network. An OvisLink PLC adapter connected to an electric plug was used for

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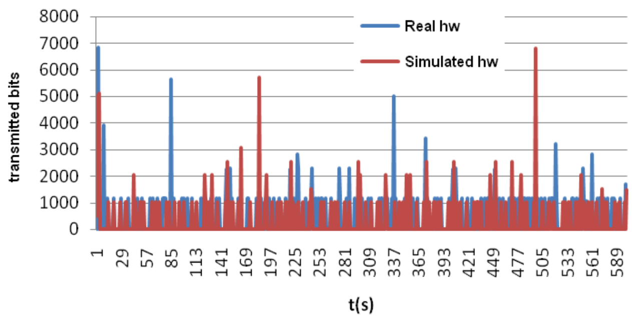

Figure 8. Bit rates

real network simulations, with the DPM and appliances instances on the same computer in such a way each message had to exit the electric network before reaching the final destination.

Table 7. Real HW vs. simulated HW comparison

	Real HW	**Simulated HW**
Total simulation time	597,998 seconds	600 seconds
Total number of packets in the network	338 packets	341 packets
Average number of packets per second	0,565 packets	0,568 packets
Average packet size	75,036 bytes	68,147 bytes
Total number of bytes	25362 bytes	23238 bytes
Average bytes/second	42,412 bytes/second = 339,296 bits/second	38,73 bytes/second = 309,84 bits/second

Table 7 shows a comparison between representative cases of each situation. Results of simulations on real hardware are very similar to results on a PLC channel implemented on ns-3. Slight differences were due to the randomness of the designed applications. For example, DPM application chooses randomly the destination and size of its requests.

This randomness can be appreciated in Figure 8 through the location of different peaks, where the higher peaks belong to broadcast messages. The main difference between both simulations is that real hardware simulations have more realistic timings.

4. CONCLUSIONS

Several simulations of GAD in-home communications have been performed in different scenarios, covering normal situations up to more extreme cases.

Communications over power lines can be affected by transmission medium characteristics: attenuation and noise. Furthermore, BPL technology makes it possible to offer other services as well on the same medium, resulting in a competition between GAD and the other services to obtain the shared medium.

Different simulated scenarios show how these difficulties can affect GAD in-home communications, leading to the following conclusions:

- Traffic generated by GAD service is very scarce in comparison to the bandwidth provided by BPL technology, making it possible to coexist with other services.
- Interfering traffic from other communication services through power lines won't affect in a significant way, just by adding slight delays in medium access.
- Channel noise and attenuation may be the main cause of packet losses inside the network, but simulations show that these losses will only happen in extreme situations of both factors.
- Simulations over real hardware have made it possible to check the approximations done during channel and devices modeling, giving more veracity to results.

5. AKNOWLEDGEMENTS

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Morever, fourteen Spanish research organizations are collaborating. CITIC is one of the R&D Centers working in the GAD Project. Its task inside this project is related to the communication group, working for Ericsson as research organization.

The acronym CITIC stands for ***Centro Andaluz de Innovación y Tecnologías de la Información y las Comunicaciones*** (Andalusian Centre of Innovation and Information and Communication Technologies)**.** The strategy adopted by CITIC consists in acting as a link between the knowledge of the university and the necessities of society and industry. This enables CITIC to realize R&D projects, transfer developed technology and favor the implantation into society through the Technology Transfer Office (TTO).

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