

Building the simulation model of a PLC network in the NS-3 environment

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Abstract

The method of simulation modelling is widely used to study data transmission protocols. The purpose of the work is to develop a model of the PLC-network topology of a multistoried building and to demonstrate the process of its construction with subsequent analysis of the operation, which is carried out by identifying the dependence of transmission speed on the distance between the network node and the server and of data transmission time on the packet size. In the process of modelling the topology of the PLC network we build the functional diagram of the network model, where the mathematical model of the channel is presented as transfer functions that are calculated for the entire network and for each node separately in the network simulator. The model showed the inverse dependence of the data transfer rate on the distance and the number of nodes in the network, and the direct dependence of the time of data transfer from the host to the server on the packet size during the process of simulating data transfer from the network nodes to the server. The results obtained empirically in the NS-3 environment correspond to the theoretical concepts of the object.

Keywords: Simulation Modelling, NS-3 Network Simulator, Topology, PLC Network.

1 Introduction

The high cost of equipment for testing new protocols, solving architecture optimization problems, and selecting certain topologies to apply in new network solutions is one of the common problems in the research of telecommunication systems [1]. That is why network simulation has become widespread. It is more convenient compared to the construction of real networks, as it has low cost, requires less time and allows the repetition of different experiments with different parameters, without affecting the accuracy and visibility of the result.

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There exist a large number of network simulation programs that allow you to create network models and provide results in a variety of data formats. NS-2, NS-3, OPNET, OMNeT++, QualNet, AnyLogic, GTNetS, and NetSim are some popular examples among them [2]. The main difference between them is the availability of libraries, the level of support, scalability, execution speed, the complexity of use, etc. The most popular among researchers is the network simulator NS-3. This simulator is a flexible and powerful tool for modelling information and communication networks. This is due to the possibility of using the built-in C++ and Python programming languages when creating models [3].

The NS-3 simulator is used to study heterogeneous communication systems. But the systems with different types of communication channels have one big problem, i.e. it is difficult to coordinate different data communication protocols.

Simulation of heterogeneous systems with a PLC-channel has gained interest in scientific circles with the development of PLC-technology. To study the PLC-channel and to build models of the network, there exist the developed modules of PLC-channels. These modules are described in scientific papers of the authors [4, 5]. Herewith, there is no description of the process of building a model of a PLC-network. The network model built in C++ builder with the use of OMNeT++ and its submodule INET is presented in the work [5]. The operation principles and capabilities of the PLC module developed in C++ for NS-3 are described in the publication [4]. The work [6] investigates the dependence of the transmission speed on the distance for the point-to-point connection on the basis of the PLC module [4]. The research report [7] considers the dependence of the PLC channel carrier capacity on the distance in the NS-3 network simulator, without taking into account the network topology. The article [8] presents the algorithm for assessing the state of the PLC-channel between the endpoints of the network, which is aimed at choosing the topology of the network in which data transmission will be implemented.

The purpose of this work is to develop a model of the PLC-network topology of a multistoried building and to demonstrate the process of its construction with subsequent analysis of the operation, which is carried out by identifying the dependence of data transmission speed on the distance between the network node and the server and of data transmission time on the packet size.

2 Features of a PLC network model in NS-3

NS-3 simulation environment does not contain a base module to work with PLC-based networks. In this regard, we used a third-party PLC module which allows simulating a PLC network in the NS-3 environment [4].

The PLC network model can be built using such parameters as:

- types of physical connections used;
- drawing up a network diagram;
- defining the positions of network devices;
- determining the spectral model values.

Let us consider the main components of the PLC network [9] in an NS-3, which allow you to create network models with the characteristics close to the conditions of the real world. These components include: node unit, transmitting channel, and noise.

Abstraction of a network device on a node is implemented in C++ by means of the NetDevice class. The network device in the NS-3 simulator allows you to control connections to other objects using data channels and can be defined and used by the user within the framework of the object-oriented programming paradigm.

The model of a power line is considered as a black box described by the transfer function. The method of modelling the transfer function of the PLC channel uses parameter matrices which describe the relationship between the input and output voltage and the current of the dual-port network [9].

The general model of background noise with a low spectral density of signal power (PSD) is used to match the real environment of signal propagation along the power lines. PLS module libraries have two methods of adding noise to the data channel:

- adding white noise that does not exceed the signal amplitude;
- adding pulse disturbance.

In a model, noise can be realized in the form of noise background in the channel or as a noise source for separate node units. To represent the cumulative effect of many noise sources, there is one function which is a white background noise at a certain level [10, 11].

3 Description of the object for modelling

Power Line Communications is a technology aimed at using the cable infrastructure of power grids as a physical medium for information transmission. As a result, the topology of the communication network depends largely on the topology of the electrical network.

The structure of power lines in a multi-storied residential building is a wired non-uniform network with the topology of the "common bus". This creates interferences typical for a PLC-network such as multipath propagation, exposure to white noise and impulse interference. They result in signal distortion and increase data transfer time. The realistic model of a PLC-network is formed on the basis of analyzing the topology of the all-house electric power grid, taking into account the characteristics of the transmission channel and the research of interferences.

The object for modelling is a nine-storied residential building. On each floor of the house, there are four PLC-modems which are designed to generate data packets and are the nodes of the PLC-network. All units are separately connected to one common electrical cable with mains voltage equal to 220 V. To connect nodes to the common network, as well as to transfer data packets to the data acquisition and transmission device (DATD) and subsequently to the network server, there are 3 types of cables. The first is an electric cable with a cross-sectional area of $50 \cdot 10^{-6} \text{ m}^2$ designed to connect PLC modems to a common cable. The second is the Ethernet cable that connects the DATD and the general network server. The third is an electric cable with a cross-sectional area of the conductor of $150 \cdot 10^{-6} \text{ m}^2$. This cable is a kind of "common bus" to which the nodes of the network are connected. DATD is a separate node that is able to both transmit and receive information from all other nodes of the network.

The shared network server is on the first floor of the house, together with DATD. During the process of simulating the PLC-network we also considered data transfer from a selected node to the DATD. It is assumed that the data package has already been generated and is ready to be sent. The packet size is assumed to be 256 bytes by default.

4 Building a simulation model of a PLC network

The mathematical model of the channel is presented as transfer functions, which are calculated for the entire network and for each node separately [9, 12]. To create the model, we used standard C++ libraries and NS-3 environment modules. All output information containing data on the process of modelling has seven levels of detail:

- LOG_ERROR – fail log (macro: NS_LOG_ERROR);
- LOG_WARN – alert log (macro: NS_LOG_WARN);
- LOG_DEBUG – debug message log (related by macro: NS_LOG_DEBUG);
- LOG_INFO – information message log (macro: NS_LOG_INFO);
- LOG_FUNCTION – registration message log with the description of each function (two associated macros: NS_LOG_FUNCTION, used for component functions, and NS_LOG_FUNCTION_NOARGS, used for static functions);
- LOG_LOGIC – registration message log describing the logical structure within the function (macro: NS_LOG_LOGIC);
- LOG_ALL – the log includes all of the above (not a macro).

Each level of detail can be requested individually or in the aggregate. Thus, logging can be started using the NS_LOG shell environment variable. Enabling the logging option requires calling the LOG_LEVEL_ALL function, which specifies the parameters to be displayed when the program is executed. In this case, it is LOG_PREFIX_TIME and LOG_PREFIX_NODE. The first parameter displays events occurring with the passage of time in the simulator. The second one shows the processes taking place on a certain node, as well as its main characteristics that were set during the simulation. The LOG_LEVEL_INFO parameter is used to display information about the physical parameters of the environment specified in the simulation. This option displays only informational messages defined in the NS-3 environment.

Further on, we configured physical environment, spectrum model and transmission power. In particular, we set the spectral model of electric network frequency and the time interval. The data on physical environment and spectrum is specified according to the G3-PLC standard [13].

In the simulation we used cables of PLC_NAYY150SE and PLC_NAYY50SE types. The physical parameters of the cables are described in the PLC_Cable class and provide more detailed visualization of network device connections on the nodes. Based on the parameters of the distributed diagram, we calculated the characteristic impedance and the constant of propagation gamma [12, 14].

Then, we made the description of the network nodes in accordance with the required topology. The position coordinates in space are set for each node using the SetPosition(x, y, z) function. After the nodes were given names and positions, they needed to be connected by physical communication lines. Next, we created a container for keeping the described nodes. After adjusting all objects of the model, it was necessary to create the data channel. Initialization of nodes and assignment of the spectral density of signal propagation power were the last step in creating the model. Further, it was important to set the size of the package and to specify the simulation parameters. The simulation started after calling the Simulator::Run() function. The functional diagram of the model of the network is shown in Figure 1.

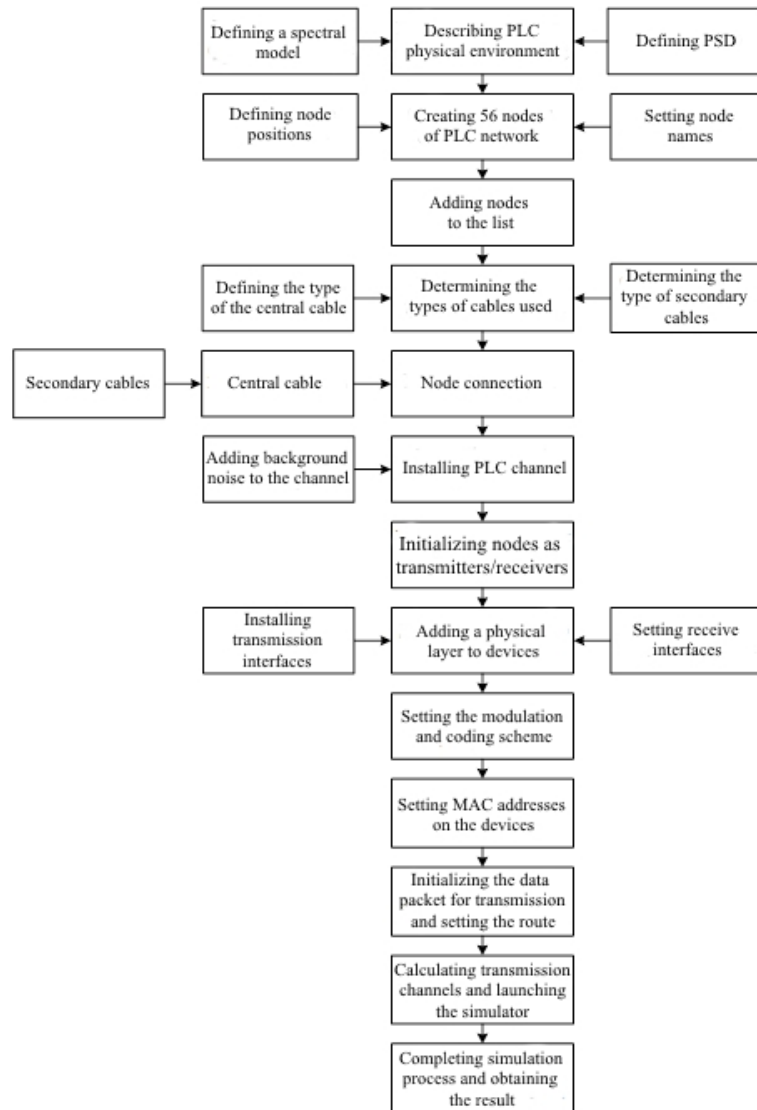


Figure 1: Functional diagram of the scenario

5 Simulation results

During the process of simulating data transfer from network nodes to the server, we determined a number of the dependencies:

- the dependence of the data transmission rate from the distance;
- the dependence of the time in which data is transferred from the network node to the server from the packet size.

The results of the simulation on the basis of which we can observe the dependence of the packet transfer rate on the distance are represented in table 1. The time of data transmission from a network node to the server in average equals 0.11724. Because of the fact that data transmission is run on 0 to 1 second, it is customary to assume that the measuring unit of speed equals the speed value multiplied by 10^3 meters per second. The maximum value of the data transmission rate equals $0.2004 \cdot 10^3$, and it corresponds to the communication node which is located 23.5 meters away from the server. The minimum speed value equals $0.0256 \cdot 10^3$ meters per second. The difference between the minimum and maximum results is due to the dependence of the data transfer rate on the amount of the network nodes.

Table 1: The results of simulating data transmission over the PLC channel

Name of the network node	$t, 10^{-3}$ s	S, m	$v, 10^3$ ms
PLC modem 36	117.251	23.5	0.2004
PLC modem 33	117.250	19.5	0.1663
PLC modem 32	117.249	21.5	0.1834
PLC modem 29	117.247	17.5	0.1493
PLC modem 28	117.245	15.5	0.1322
PLC modem 24	117.243	17.5	0.1493
PLC modem 21	117.242	13.5	0.1151
PLC modem 20	117.241	15.5	0.1322
PLC modem 17	117.239	11.5	0.0981
PLC modem 16	117.238	13.5	0.1152
PLC modem 13	117.237	9.5	0.0810
PLC modem 12	117.235	11.5	0.0981
PLC modem 9	117.234	7.5	0.0640
PLC modem 8	117.233	9.5	0.0810
PLC modem 5	117.231	5.5	0.0469
PLC modem 4	117.230	7.5	70.0640
PLC modem 1	117.229	3.5	0.0299
DATD	117.224	3.5	0.0256

Figure 2 represents the dependence of the data-transmission time on the data packet size. The packets were transmitted from 36th PLC modem.

Consequently, transmission of the packet with the maximum chosen size equal to 1024 bytes takes $284.5 \cdot 10^{-3}$ seconds. This time is the maximal result. It is due to the fact that the process of forming and preparing the packet with the size of 1024 bytes for transmission is more time-consuming. Therefore, when packet size is more than 1024 bytes, there will be a small time delay in data transmission over the PLC channel.

6 Conclusion

During the process of simulating data transfer from the network nodes to the server, the model showed the inverse dependence of the data transfer rate on the distance and the number of nodes in the network, and the direct dependence of the time of data transfer from the host to the server on the packet size. Therefore, when the packet size is more than 1024 bytes, a small time delay will be observed in data transmission over the PLC channel. These results correspond to the theoretical concepts of the object.

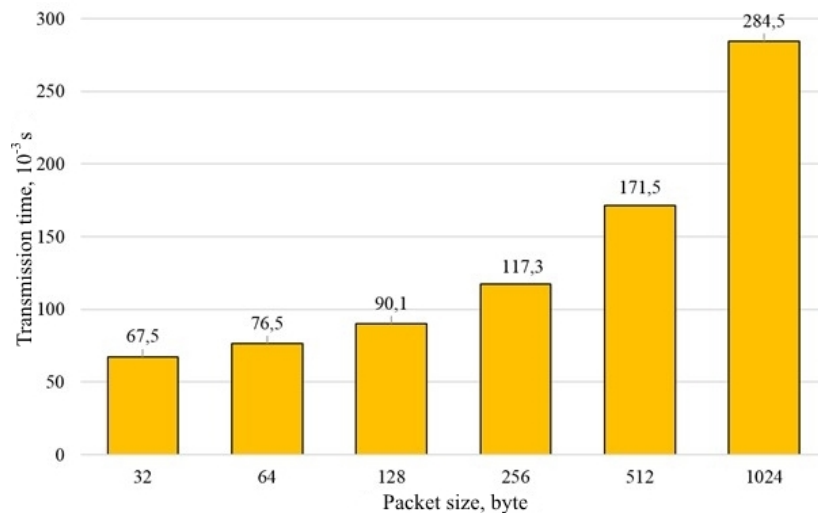


Figure 2: Diagram of data-transmission time depending on data packet size

Based on the results of the simulation it is necessary to note that the developed model of the PLC network topology is close to the real network topology of a multistoried building and can be used to study data transmission protocols. The modified and refined model will be used in the future in simulating a heterogeneous communication system, which will save time and financial costs associated with creating the system.

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