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Quality Analysis of Data Transferring Through the Process of Modeling WirelessHART Network

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Abstract— **The topology of WirelessHART network is changeable since a number of dynamic devices change, and all that requires a reorganization of the network, as well as finding new ways of routing data. Devices can fall out of the network due to destruction, failure, reduction or loss of electricity. On the other hand, it is possible to "refresh" the network with new devices and thus completely change the topology of the newly created network. This research analize the quality of data transferring in a WirelessHART network using two network topologies: Extended star network and Mesh network. The aim of this paper is to determine which network topology provides better quality of data transferring in a WirelessHART network on the basis of signal latency and Received Signal Strength Indicator (RSSI). To achieve this, experiments are performed using the equipment by the manufacturer Emerson Process Management: Gateway 1420, TT 648 and PT 3051 for the implementation of the network, as well as software tools for configuration, planning and management of wireless industrial networks, AMS Wireless SNAP-ON and AMS Intelligent Device Manager. The research results show several advantages of applying Mesh topology in a WirelessHART network: it is almost impossible to interrupt communication between devices in the network; there does not have to be optical visibility between the network devices; ease of installation and deinstallation; low application cost compared to Extended star network.**

Keywords- WirelessHART; Process industry; Mesh network; Sugnal Latency

I. INTRODUCTION

The WirelessHART protocol is controlled by a relatively low speed data transmission of 250 kbps and it operates at a frequency of 2.4 GHz in the ISM (Industrial Scientific and Medical) radio band [1].

The topology of WirelessHART network (Fig. 1) is changeable since a number of dynamic devices change, and all that requires a reorganization of the network, as well as finding new ways of routing data.

Devices can fall out of the network due to destruction, failure, reduction or loss of electricity. On the other hand, it is possible to "refresh" the network with new devices and thus completely change the topology of the newly created network [1], [2].

The aim of this paper is to determine which network topology (Extended star or Mesh) provides better quality of data transferring in a WirelessHART network on the basis of signal latency and Received Signal Strength Indicator (RSSI). To achieve this, the experimental research is carried out using the equipment by the manufacturer Emerson Process Management: Gateway 1420, TT 648 and PT 3051 for the implementation of the network, as well as software tools for configuration, planning and management of wireless industrial networks, AMS Wireless SNAP-ON and AMS Intelligent Device Manager.

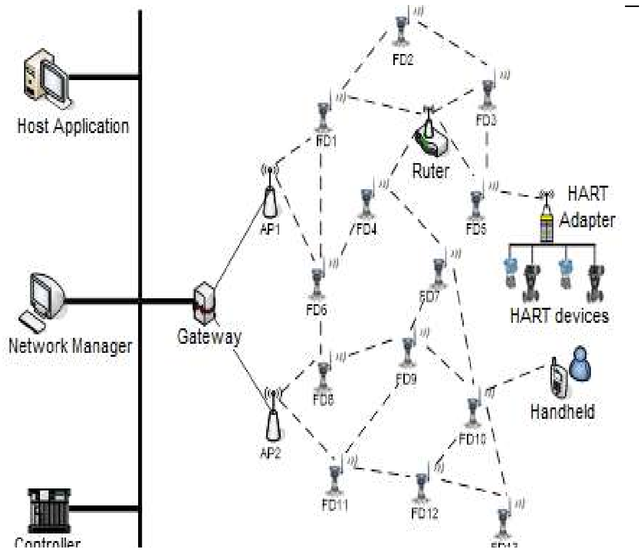

Figure 1. An architecture of wirelessHART network [1]

In addition to the introduction, the paper is structured in 5 sections, and at the end a list of used references is given (section VII). Section II deals with the network life cycle, which explains in more detail how devices connect to the network. Redundancy, which is present in all levels of the network (on the network Access Point, on the Gateway and in wireless sensor networks) is described in Section III. Section IV deals with network modeling, use of certain equipment and describing the process of connecting devices to the network through parameters configuration. A quality analysis of the data transferring in Extended star network and Mesh network topologies is given in Section V based on the signal latency and signal level RSSI. The conclusion is given in section VI.

II. LIFE CYCLE OF DEVICES ON THE NETWORK

A. Sequences of Joining

Devices are joined in the WirelessHART network by executing the sequence order of joining shown in Fig. 2 and in order to be joined they need to go through the following states [3], [4], [5]:

1. Configuration of Devices;
2. The Beginning of the Joining Process;
3. Getting the Session Key;
4. The Integration of the Device in the Network;
5. Quarantine State;
6. Active State.

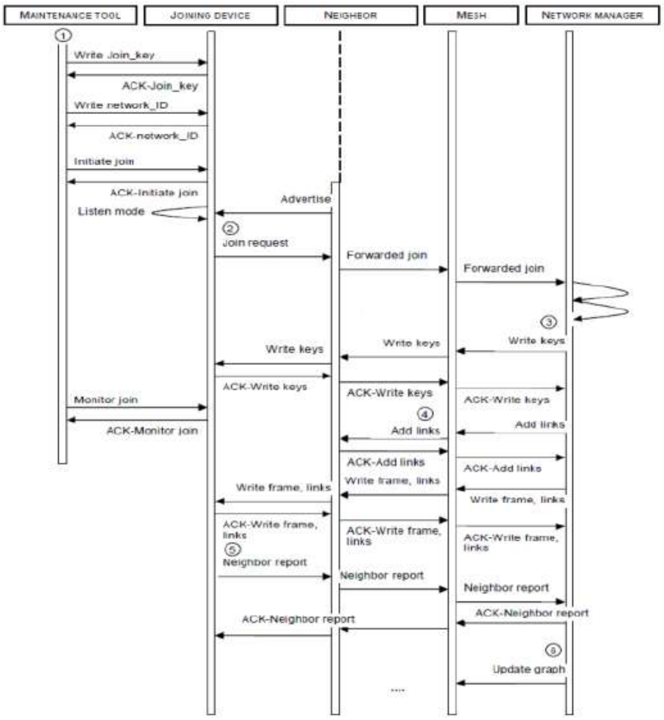

Figure 2. Joining sequence diagram [1]

1. Configuration of Devices

Before each new device becomes a part of wireless network, a device must have configured parameters for a wireless network. All devices in the WirelessHART network have two identical network parameters: Network ID and Join Key. These parameters must be configured to match the other devices on the network before installing a new device in the network. These configuration changes can be implemented by using a device for the field communication or program for wireless configuration. Devices within the WirelessHART network continuously send advertising packages that contain instructions for joining of new devices on to the same network. An advertising package contains priority for accepting new devices, which is based on three factors:

- a number of Gateway jumps,
- signal strength and
- battery wear.

2. The Beginning of the Joining Process

A new device can start with the process of joining when it receives at least one advertising package from a device in the WirelessHART network. If here is more than one device that enables joining of new device in the network, a priority has a device with the highest signal strength. After new device is synchronized with the network, a request for joining is passed on the Network Manager.

3. Getting the Session Key

When the network manager receives a request for joining a new device to a WirelessHART network, it must confirm that it received a request from the device which:

- has a reliable identity,
- uses matching key for joining and
- combines correctly device identity and joining key.

If a new device meets the above mentioned criteria for checking of device, then request for joining is considered authentic and Network Manager assigns a session key to it.

4. The Integration of the Device in the Network

Since the new device has a session key, it is able to communicate with the Network Manager. The Network Manager integrates the new device in the WirelessHART network by:

- giving an identity to the device and
- updating communication tables.

5. Quarantine State

The device will go into "quarantine" status if it has access to the network, and it has no established session with Gateway. In this state, the device communicates only with the Network Manager, and depending on the strategy of the Network Manager, it establishes a session with Gateway or device is retained in "quarantine" for a while. The device will remain in "quarantine" until a session, that allows communication with Gateway, is established.

6. Active State

The new device becomes active in the network after establishing a session with Gateway and in this way it receives enough communication resources to fulfill its obligations in the system of automatic process.

B. Disconnection

During operation of WirelessHART networks it may happen that some devices must be disconnected from the network. Disconnection can be caused by Network Managers by sending commands to the device for disconnection or device can disconnect by itself by sending messages for disconnection to all neighboring devices with which a device is connected [1], [4], [5].

Fig. 3 shows the interruptions sequence diagram of direct communication links between the devices A and B in the WirelessHART network when there is a physical obstacle that interferes their communication.

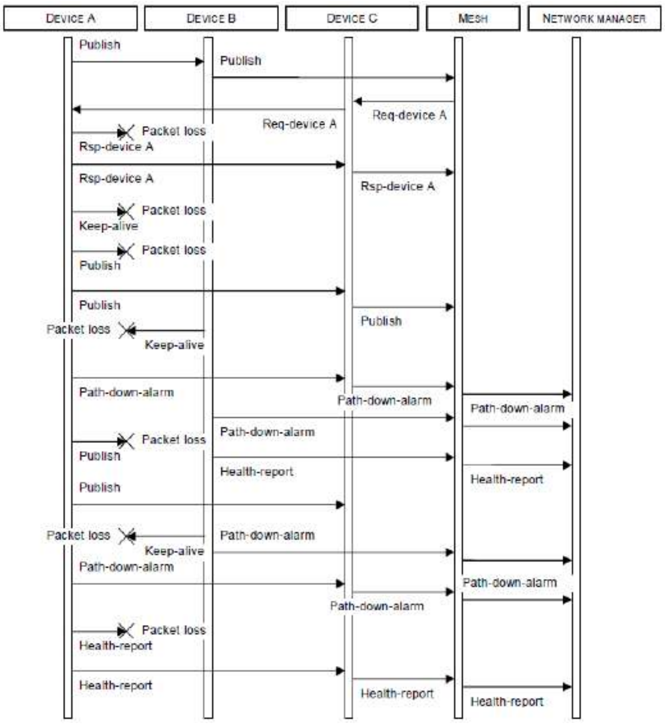

Figure 3. Interruptions sequence diagram of direct communication links [1]

III. REDUNDANCY IN A WIRELESSHART NETWORKS

In the process of automatization, operators make decisions based on the available data, and when one or more process variables are not available, and then operators must make decision without complete picture of what is going on in the control process. The same goes for management systems that do not have all necessary input data and also for the systems whose managing algorithm cannot provide the best control functionality over management process, and it can even lead to shutting down managing of the process. Management process sometimes uses a system of redundancy to minimize the probability of data loss [6]. Redundancy is important for processes where controlling data are critical or where failure of one of the components may result in loss of a large number of process variables [7], [8], [9]. WirelessHART network enables a lot of ways to improve redundancy, and it is available at all levels of the network system [10], [11]:

- on the network Access Point,
- on the Gateway and
- in wireless sensor networks.

A. A Redundancy on the Network Access Point

Access Point is a specialized device with high bandwidth range of communication channel towards the Gateway, which allows two-way communication to and from the Field Device. WirelessHART network allows using of multiple Access Points as it is shown in the Fig. 4. It allows additional network bandwidth and redundant communicational paths for Gateway.

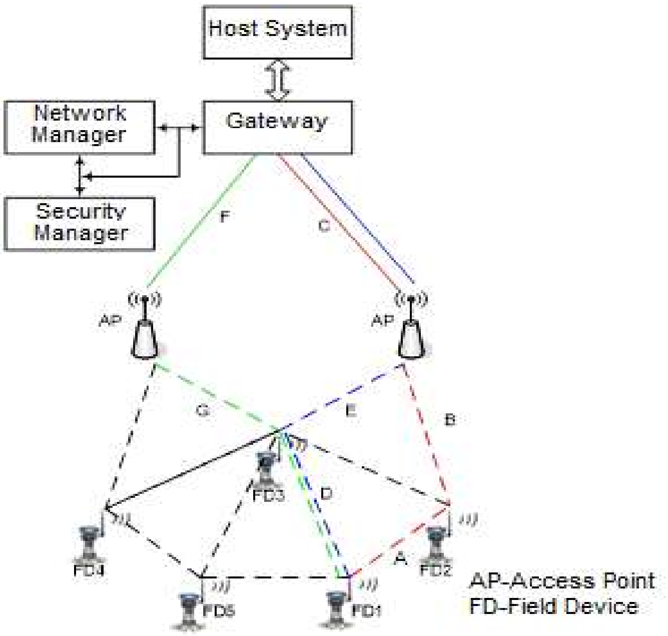

Figure 4. Redundancy of WirelessHART network [10]

B. Redundancy on the Gateway

WirelessHART components of the higher level are Gateway, Network and Security Manager which are shown in Fig. 5. Each of these components supports device redundancy, and one way of providing this approach is entering of controlling functions into the device and making identical copy of the device itself. This creates flexibility during controlling of the critical applications, because a user can decide which Network Manager is weaker and he can turn on redundancy of that component [4], [7], [10].

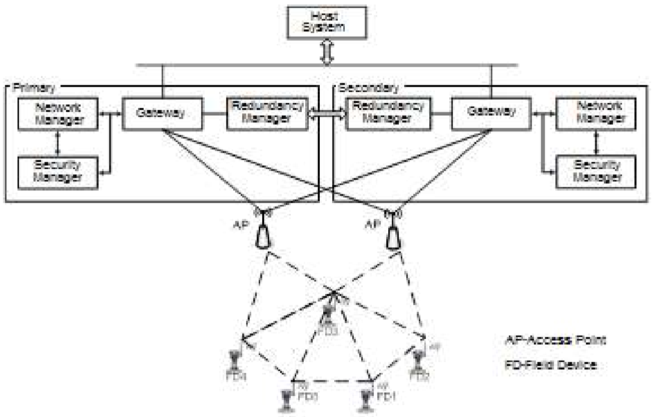

Figure 5. Redundancy on the Gateway [10]

According the Fig. 5, all three components (Gateway, Network and Security Manager) are set in the primary and secondary physical Gateway that communicate with each other over a redundant manager, thus providing synchronization in a network. If primary physical Gateway fails then the secondary will take over the job of the primary [7], [10].

C. The Redundancy in the Wireless Sensor Networks

WirelessHART protocol provides redundancy in wireless sensor networks through several mechanisms, and each communication can have [10]:

- multiple transmission paths between the device and Gateway,
- multiple portable radio channels and
- multiple possibilities of measuring time intervals.

Fig. 4 presents a system in which three ways of achieving communication are available towards some destination. The first method of establishing communication route from the FD1 to the Gateway goes over node A-B-C. However, if the device FD1 cannot establish this communication route, then it will, in a very short period, try to achieve a second communication route, for example D-E-C. If that does not happen, it will try to establish it over D-G-F. This shows that the redundancy is available in both directions, from the Gateway towards a FD1 device and vice versa.

IV. MODELING OF WIRELESSHART NETWORK

In this study, for the purpose of modeling different topologies of the WirelessHART network, the following process measurement equipment by the Rosemount manufacturer is used: two transmitters with pressures of 3051S (PT101, PT102), two temperature transmitters 648 (TT101, TT102), and one Smart Wireless Gateway 1420 [13].

The number of devices that can be connected to the WirelessHART via the Gateway depends on the interval of updating data that a device sends to the Gateway. For example, if each device in a WirelessHART network sends updated information every 60 seconds, then the Gateway can support up to 100 devices. The maximum allowed update interval is one hour. Update intervals that last less than 60 seconds are pre-defined into the exponentials of number two, such as four, eight, 16 or 32 seconds. These devices can adjust an update interval in order to gain the best compromise between a battery life and a latency signal. The devices that are sed for realization of different topologies of the WirelessHART networks are powered by a battery (9 V) and they have the ability to save energy by uploading and transferring data by adjusted interval updates. However, a shorter update leads to a shorter life span of the battery. Practically, the shortest update interval for this generation of equipment is eight seconds, although there is an option of choosing four, two or one second. These devices have the ability to estimate the remaining days of battery life on the basis of its current state of charge and energy consumption. Before devices become a part of the wireless network, they must have configured parameters for a WirelessHART network:

- ID network (up to 4 digits) and
- Join Key (4 groups of 8 hexadecimal digits).

After that, they can communicate with other devices on the network. Device parameters in the WirelessHART network are configured using an AMS Wireless Configurator or AMS Device Manager [14].

If parameters for the network access are configured and if an appropriate amount of time has passed since the network calling, then devices will be successfully connected to the WirelessHART network. In order to verify the connection of devices in the network, an interface of the Gateway is used as shown in Fig. 6. The green status indicator in Fig. 6 shows that the device is working properly, and if the indicator is red, then there is a problem with the device or the communication path. In order to fix the problem, an additional device is added to bridge the connection to the network.

Figure 6. A device status in the network

Network statistics about any device that is connected to the network can be obtained by clicking on its name in the HART Tag column [13].

V. RESULTS AND DISCUSSION

As a part of this survey, the quality of transferring data in a WirelessHART network is analyzed for four scenarios using two network topologies:

- Extended star network and
- Mesh network.

A quality analysis of the data transferring in implemented topologies of the WirelessHART network is given based on the following parameters [15], [16], [17], [18], [19]:

- Latency signal and
- Level of signal RSSI (Receive Signal Strength Indicator).

In the proposed scenarios, two topologies of the WirelessHART networks are analyzed. For the purpose of the quality data transferring research, the topologies were conducted in the area of the first floor of the Faculty of Transport, using software tools for configuration, planning and management of wireless industrial networks: AMS Wireless SNAP-ON and AMS Intelligent Device Manager [7], [20]. In this confined space, there are obstacles on the communication route between devices within the implemented network and those are walls made of brick and concrete.

1) The first scenario

Fig. 7 shows the architecture of the confined space with a marked position of Gateway and with numerically written positions of devices which are organized in an extended star network [8], [11], [21].

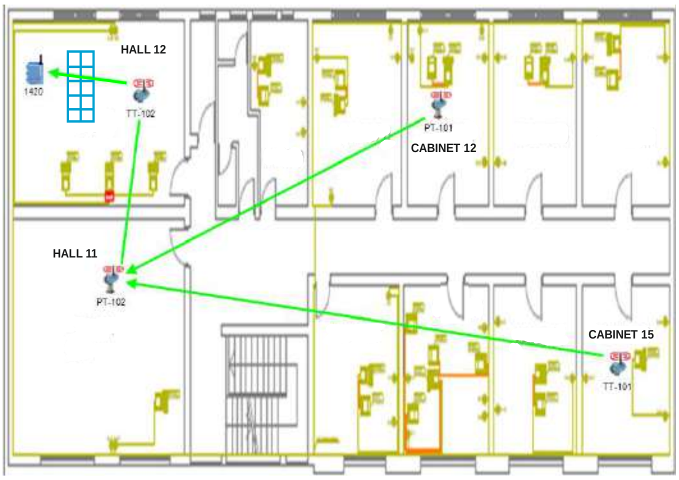

Figure 7. Extended star network

In this scenario, the central network device PT 102 is located in hall 11 and it is connected to the device TT102, which is located in a laboratory for electrical engineering at a distance of 10 meters with a partition wall between them. Then, the device TT102 is connected with Gateway 1420 at a distance of five meters with an obstacle made of iron construction between them, and, as a result of that, the level of signal is lower. The device PT101 is in cabinet 12 and it is connected with the central device PT 102 at a distance of 20 meters with four partition walls of brick and concrete between them. The fourth device in this scenario of the network TT101 is in cabinet 15 and it is connected to the central device PT102 at a distance of 30 meters with five partition walls between them.

According to the network in Fig. 7, the diagram given in Fig. 8 is obtained, showing the latency of the WirelessHART network from devices TT101 and PT101 towards the Gateway, which is higher than for devices TT102 and PT102.

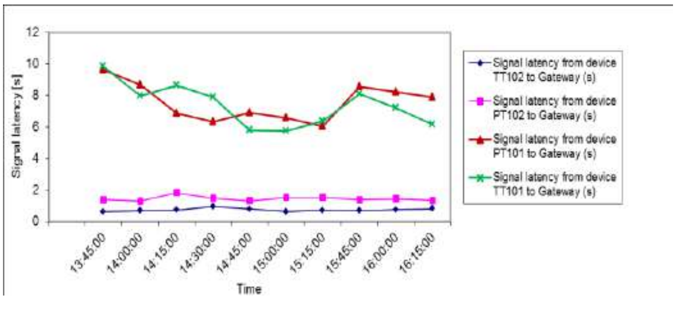

Figure 8. Latency of the WirelessHART network in the first scenario

They are located at a greater distance due to a large number of partition walls on the communication route towards the Gateway.

In addition, according to the network in Fig. 7, the diagram given in Fig. 9 is obtained, showing the level of signal between devices TT101 and PT101 and the central device, which is lower (25 ÷ 40) dB in relation to the signal level between devices PT102, TT102, TT102 and the Gateway since there is a larger number of partition walls on the communication route.

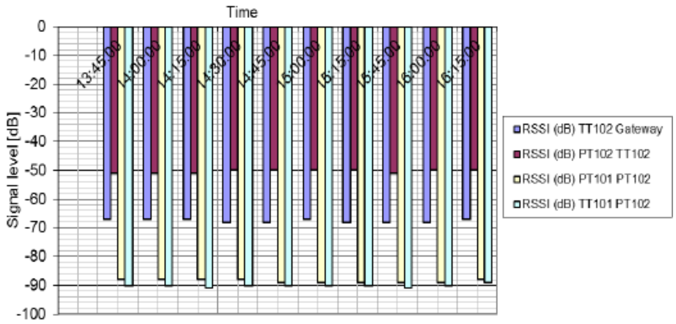

Figure 9. A signal level in the first scenario

Based on these diagrams, it can be concluded that besides a distance and a number of obstacles in a form of partition walls on the communication route, there is higher latency and a lower signal level as a consequence. The main disadvantage of this scenario is that the operational network depends on the central device PT102 since if it comes to a failure of this device, the entire network will no longer be operational.

2) The second scenario

Fig. 10 shows the architecture of the confined space with a marked position of Gateway and with an exact number of device positions which are organized in a Mesh network. In Mesh networks - fixed type, there is a typical hierarchical routing, as it is the case with this scenario which is based on the tree where the Gateway is a root of the tree and in charge for starting the process of finding and maintaining the communication path [10].

Figure 10. Mesh network

The Gateway periodically sends broadcast packages to the devices in the network as a reminder to update the values that are related to metrics of routing or the number of jumps through which the package moves on its communication path towards the Gateway and also its bandwidth power which shows a capacity of connection. Each device after updating the values chooses the best parent for its communication towards the Gateway and it keeps the list of all other potentially good parents. If it happens that the communication towards the parent fails, the device chooses a new parent from the list of potentially good parents and it informs children about it. After that, the device sends a request to the Gateway in order to remind other devices to update their values that are related to the metrics of routing.

According to the network in Fig. 10, the diagram given in Fig. 11 is obtained. The level of signal from devices TT101, PT101, PT102 and TT102 towards the Gateway is lower compared to the same devices in the first scenario since data are sent through a Mesh network using an optimal communication path even when the individual devices in the network are blocked or they lose their signal.

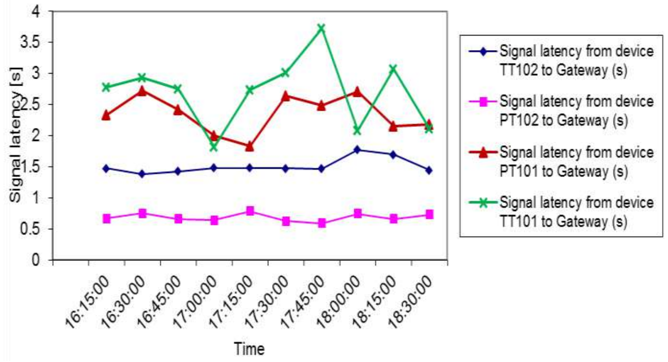

Figure 11. Latency of the WirelessHART network in the second scenario

An implemented Mesh network prevents congestion of the channels between devices, so that data packages do not have to travel to a central device in the network as it is the case in the first scenario. Data packages which are distributed through the Mesh network in Fig. 10, on its communication path, may pass through one or up to maximum four devices to a Gateway. This type of network ensures that devices that are closer to the Gateway (as far as the number of jumps takes place) do not use a wider range of transmission than those which are farther away. Due to the possibility of wireless package distribution, the speed of data transfer increases since the jumps between devices in the network are mainly "short", i.e. the distance between the antennas of these two devices is shorter.

Additionally, according to the network in Fig. 10, the diagram given in Fig. 12 is obtained, showing the signal level between individual devices and the Gateway. A signal level in the second scenario ranges from -54 to -87 dB, which is almost the same as the level in the first scenario. Based on the implemented network in Fig. 10, it can be concluded that the value of the signal level between the devices primarily depends on the number of partition walls on their communication routes.

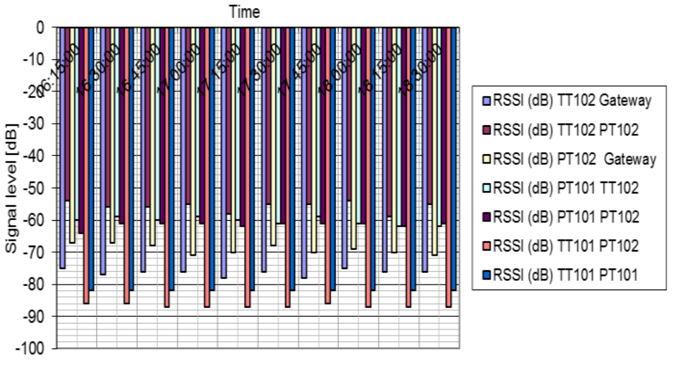

Figure 12. A signal level in the second scenario

In order to provide the ability to transfer data through a Mesh network, the so-called Self-Healing algorithms are used. The algorithms continuously send a small amount of test data through the network and thus determines possible errors in individual devices. If they identify an error, they reshape the path, and ensure that the data in its transfer bypasses a device with an error. This kind of communication is quite safe because it allows additional network bandwidth and multiple redundant communication paths for transferring data from the device to the Gateway [16]. As a part of implemented Mesh network, a quality of data transferring from devices TT101 to the Gateway is analyzed for the following scenarios when there is:

- Redundancy of communication paths for transferring data via PT102 and
- Redundancy of communication paths for transferring data via PT101.

3) The third scenario

Fig. 13 shows the architecture of a confined space with a marked position of Gateway and numerically written device positions that are organized in the Mesh network. In addition, a redundancy of communication paths for transferring data from devices TT101 via the device PT102 to the Gateway is observed.

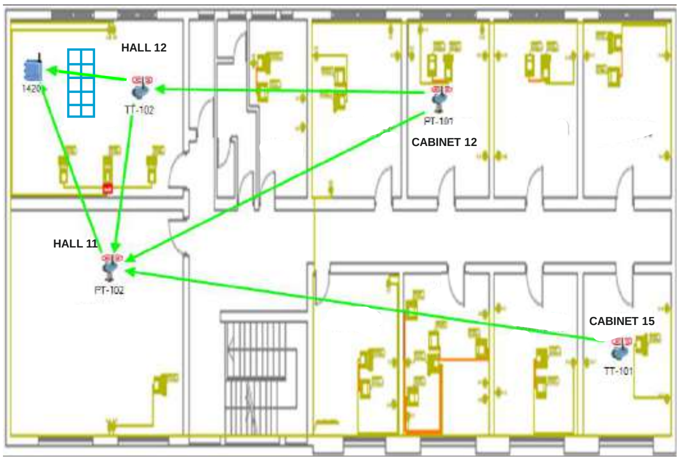

Figure 13. Redundancy of communication path via PT102

According to the network in Fig. 13, the diagram given in Fig. 14 is obtained, illustrating the latency of the WirelessHART network along the communication route from the device PT102 to the Gateway, which is approximately the same as in the Mesh network in the second scenario. The latency of the WirelessHART network for a communication route from the device TT101 over devices PT102 to the Gateway is twice larger than in the second scenario due to processing delays in the device PT102 over which a communication route from devices PT101 and TT102 takes place.

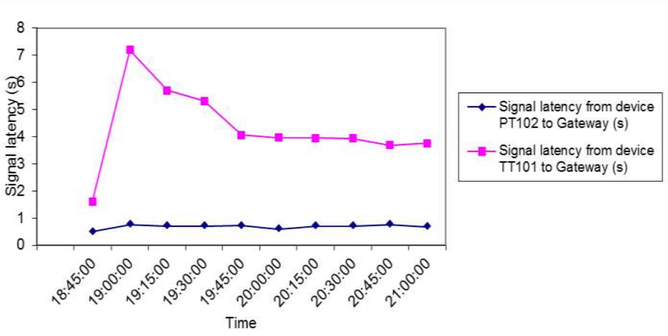

Figure 14. Latency of the WirelessHART network in the third scenario

4) *The fourt scenario*

Fig. 15 shows the architecture of a confined space with a marked position of Gateway and numerically written device positions that are organized in the Mesh network and the redundancy of communication paths for transferring data from devices TT101 via the device PT101 to the Gateway is observed.

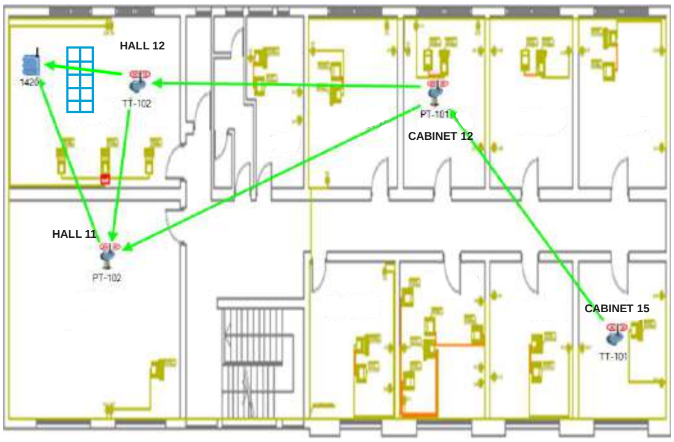

Figure 15. Redundancy of communication path via PT101

According to the network in Fig. 15, the diagram given in Fig. 16 is obtained, illustrating the latency of the WirelessHART network along the communication route from the device TT101 to the Gateway that requires three or four jumps and approximately it is the same as in the Mesh network in the third scenario where two jumps are required.

The latency of the WirelessHART network for communication route of the remained three devices to the Gateway is almost the same as in the Mesh network in the second scenario.

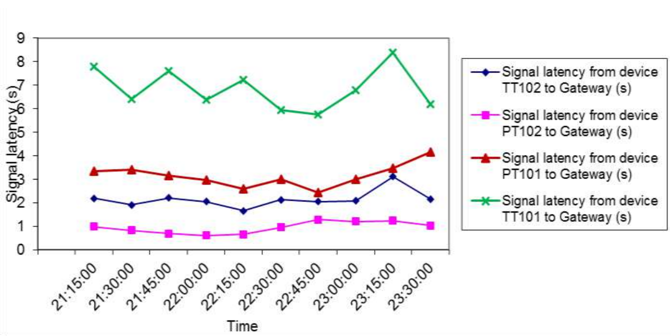

Figure 16. Latency of the WirelessHART network in the fourth scenario

VI. CONCLUSIONS

On the basis of the research results for the quality of the data transferring in two topologies of the WirelessHART network, an extended star network and Mesh network, we can conclude the following:

- The lack of an extended star network is operational part of the network which depends on the central device since if it fails, the entire network will no longer be operational, and therefore a Mesh topology is preferred in order to implement the wireless communication network based on the HART Protocol.
- The main advantages of Mesh topology wireless communication network based on the HART Protocol in relation to the extended star network is its ability to be applied to the environment to which it suits most since the environment is constantly changing and it is almost impossible to interrupt communication between devices in the network.
- Mesh topology of the WirelessHART network is a good alternative in areas where classical architecture networks for wireless distribution of data packages, as it is the case with the extended star network, have a problem in the efficiency of delivering data due to the absence of an optical route between antennas on the devices in the network.

Due to relatively easy installation and uninstallation of wireless devices, a Mesh topology of WirelessHART network can be easily adapted to new requirements and the cost of applying it to new areas is much lower than the cost of an extended star network.

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