1. Introduction

Over the past few decades, the number of natural disasters caused by global climate change on Earth has been increasing worldwide:

- frequency of hydrometeorological disasters is growing: floods, droughts, heat and cold waves, hurricanes and storms [1, 2];
- frequency of geological disasters is growing: landslides, avalanches, soil erosion [2, 3];
- frequency and prevalence of fires is growing in savannas and forests [2, 4].

Such extreme events periodically occur in each of the regions of the world. The economic damage from them is measured in huge amounts [3].

It is noted that the most threatening consequences of warming for the regions of the world are waiting for the seafood industry, agriculture, tourism, insurance companies; in addition, coastal settlements sensitive to sea level rise [3].

The increase in the number of disasters caused by global climate change, determine the need to develop recommendations for the protection of one of the main sectors of modern production - telecommunications, for example [5–9].

However, the variability of the modern natural-anthropogenic environment can cause changes in the intensity, power and the list of threats. Global warming is one of the factors that accelerates the invasive process, the available information about the “aggression” of invasive species in relation to the local environment [10]. The seismicity of the regions is largely determined by microseismic oscillations of the lithosphere, which are caused by a shift in the frequency spectrum of natural oscillations of water bodies, in turn, depend on the water level [11].

This state of affairs forces to review the list of threats, analyze their effect, and develop protective measures.
2. Literature review and problem statement

The Recommendation of the Telecommunication Standardization Sector of the International Telecommunication Union (ITU) ITU-T L.92 (10/2012) presents the most devastating natural disasters threatening telecommunications [6].

Their statistics are given in ITU-T Recommendations L.1502 (11/2015). These are floods (25%); strong winds (22%); earthquakes (22%); forest fires (13%); landslides (6%); severe frosts (6%); others (precipitation and heavy rainfall, increased atmospheric moisture content, severe frost and intense heat, heavy snowfall, heavy ice, etc. – 6%) [7].

The effects of hazards on telecommunications determine the resources of the telecommunications network (TCN). Fig. 1 presents a matrix of environmental factors caused by natural disasters and the stability of TCN hardware resources to this action. Elements of the matrix represent the degree of influence of the factor on the resource: insignificant (I), moderate (M) and significant (S).

Table 1 shows typical effects of natural disasters on TCN elements in more detail.

| Disaster | Effects | G | Protection Measures |
|----------|---------|---|---------------------|
| High water | Flooding of cable ducts; potential damage to cables | P | Restrictions on the location of telecommunication facilities in areas of possible flooding; the establishment of heavy concrete structures in places of possible post-mortem swelling of the soil; the establishment of retaining structures between external objects and steep landslide hazardous slopes |
| Tsunami | Damage to external telecommunications facilities; damage to coastal energy systems | P | Placemant of telecommunication facilities and linear cable structures (LCS) on a hill; compliance with the conditions for the spatial separation of the main and backup communication lines (CL) by transmission media; giving preference to laying communication cables in gas pipelines for maintaining cables under low pressure (GMCLP) along the river bottom compared to laying along the bridge (near the mouth of the river) to provide power to telecommunication facilities by duplicating power sources and power supply cables |
| Hurricanes/tornadoes/typhoons/wind storms/strong wind | Collapse of the supports of the overhead communication line (OCL), radio towers; rush; damage to the OCL | P | Strong wind protection |
| Earthquake | Destruction of external telecommunication facilities; GKKNT breaks and cable breaks | P | Earthquake-resistant construction; construction restrictions within seismically active tectonic faults; increasing the resistance of materials used in external telecommunication facilities to earthquakes |
| Wildfire | OCL firing support; damage to the OCL | P | Use of fire protection (isolation with clean stripes of land – mainly in rural areas) |
| | | C | Protection of external telecommunications facilities using non-combustible or flame retardant materials; the use of non-combustible materials in cable structures |
| | | M | Installation of emergency detection systems |
The precautionary measures to reduce losses from natural disasters for TCN, proposed in accordance with ITU-T Recommendations L.92, are divided into groups (Table 1). Separately, groups of measures (G) for the prevention of natural disasters were identified: preventive measures (P), countermeasures (C), and monitoring (M) [6].

ITU recommendations [6, 7] are limited to the list of the most destructive dangers to date and how to protect against their action. However, they do not address other potential dangers for telecommunications.

An extended list of natural disasters in the amount of 38 items that may occur in Ukraine in various sectors of the national economy of the country is given in the National Classifier DK 019:2010 “Classifier of emergency situations” (from 11.10.2010, No. 457). However, in DK 019:2010 there are no “indicative” dangers of the global warming period: temperature rise [7, 8], sea level rise [7, 8], and changes in precipitation regimes [8]. In addition, the document does not discuss how to protect a telecommunication network.

The performed analysis of the literature shows the feasibility of conducting a study devoted to examining the growing threats of the telecommunication network as a result of global warming, analyzing their impact on network hardware resources and developing countermeasures.

3. The aim and objectives of research

The aim of research is to develop measures to reduce the losses of the telecommunication network from the effects of natural disasters in general, and new threats of global warming in particular.

To achieve this aim it is necessary to solve the following objectives:

- determine the list of threats to the hardware resources of the telecommunications network, which may be stipulated by global warming;
- analyze the effect of threats on the telecommunications network;
- develop countermeasures.

4. Method of developing measures to protect the telecommunications network from the effects of natural disasters

The research material is a natural and anthropogenic environment, which is exposed to natural disasters.

A method to achieve this aim is technology, which should end with reasonable proposals for protecting the telecommunications network from the effects of natural disasters.

The developed method for developing measures to protect the telecommunications network from the effects of natural disasters includes the phased collection of information about the effects of natural disasters on the hardware resources of the telecommunications network, their analysis, and the development of appropriate countermeasures.

At the initial stage, a list of threats is determined, the occurrence of which can be caused by processes that accompany global warming of the climate on Earth.

At the second stage, an analysis is made of the influence of observations of the effects of natural disasters on the functioning of the telecommunication network.

At the final stage, a synthesis of possible measures to reduce losses from certain threats is performed.

5. Synthesis of measures to reduce losses from natural disasters

5.1. Threats, the occurrence of which may be caused by processes that accompany global warming on Earth

The stability of hardware resources in natural threats is ensured provided that the onset of the limiting state is not allowed [12]:

\[ S(\mathbf{r}, t) \geq V(\mathbf{r}, t) \]  \hspace{1cm} (1)

where \( S(\mathbf{r}, t) \) – value of the resistance criterion to the action of the damaging factor (DF), \( \mathbf{r} \) – radius vector of the point of the DF field; \( t \) – time; \( V(\mathbf{r}, t) \) – DF value.

Table 2 is a list of the damaging factors of natural emergencies, the nature of their actions and manifestations, according to the RF standard GOST R 22.0.06-95.

The damaging factors form a matrix, the rows of which are their names in alphabetical order, and the columns are the characters of action and manifestation in decreasing order of frequency of occurrence in the list. The matrix elements are denoted in the form \( F_{n,f} \) where \( n \) – the number in order of DF name, \( f \) – the number in order of the characteristic action and manifestation of the damaging factor in a variety of items. A fragment of the matrix is shown in Fig. 2.
## Table 2
The nature of the actions and manifestations of the damaging factors of natural emergencies [13]

| Emergency source | DF name/designation | The nature of DF action and manifestations |
|------------------|---------------------|------------------------------------------|
| **Earthquake**   |                     |                                          |
|                  | Dynamic/F₆₂          | Earth shake                              |
|                  | Dynamic/F₆₄          | Earth deformation                        |
|                  | Dynamic/F₆₁₁         | Ejection, loss of eruption products       |
|                  | Dynamic/F₆₁₃         | Movement of lava, mud, stone flows        |
|                  | Dynamic/F₆₁₂         | Rock gravity displacement                 |
|                  | Thermal/F₆₅          | Burning cloud                            |
|                  | Thermal/F₆₂          | Lava, tephra, steam, gases                |
|                  | Chemical/F₆₁₂        | Pollution of the atmosphere, soil, hydrosphere |
|                  | Thermophysical/F₆₁₁  | Pollution of the atmosphere, soil, hydrosphere |
|                  | Physical/F₆₁₁        | Lightning discharges                     |
|                  | Dynamic/F₆₂          | Displacement (movement) of rocks          |
|                  | Gravitational/F₆₂₂   | Displacement (movement) of rocks          |
|                  | Dynamic/F₆₅          | Earth shake                              |
|                  | Gravitational/F₆₃₂   | Earth shake                              |
|                  | Dynamic/F₆₆          | Dynamic, mechanical pressure of displaced masses |
|                  | Gravitational/F₆₆₆   | Dynamic, mechanical pressure of displaced masses |
|                  | Dynamic/F₆₆₁         | Hit                                      |
|                  | Gravitational/F₆₆₁   | Hit                                      |
|                  | Chemical/F₆₁₂        | Rock dissolution                         |
|                  | Hydrodynamic/F₆₉₉    | Rock dissolution                         |
|                  | Chemical/F₆₁₂        | Destruction of rock structure            |
|                  | Hydrodynamic/F₆₁₀    | Destruction of rock structure            |
|                  | Chemical/F₆₁₂        | Movement (leaching) of rock particles     |
|                  | Hydrodynamic/F₆₇₇    | Movement (leaching) of rock particles     |
|                  | Gravitational/F₆₁₂   | Displacement (collapse) of rocks         |
|                  | Gravitational/F₆₄₄   | Earth deformation                        |
|                  | Gravitational/F₆₄₄   | Earth deformation                        |
|                  | Gravitational/F₆₄₁₁  | Soil deformation                         |
|                  | Hydrodynamic/F₆₁₃    | Wave beat                                |
|                  | Hydrodynamic/F₆₈₈    | Soil erosion (destruction)               |
|                  | Hydrodynamic/F₆₂₁₇   | Soil particle transfer                   |
|                  | Gravitational/F₆₂₁₃  | Displacement (collapse) of rocks in the coastal part |
|                  | Gravitational/F₆₁₅   | Groundwater level rise                   |
|                  | Hydrodynamic/F₆₂₁₅   | Groundwater flow hydrodynamic pressure    |
|                  | Hydrochemical/F₆₃₄   | Soil pollution (salinization)             |
|                  | Hydrochemical/F₆₄₄   | Corrosion of underground metal structures |
|                  | Hydrodynamic/F₆₃₃    | Hydrodynamic pressure                    |
|                  | Hydrodynamic/F₆₃₄    | River bed deformation                    |
|                  | Hydrodynamic/F₆₂₁₃   | Wave beat                                |
|                  | Hydrodynamic/F₆₃₃    | Hydrodynamic pressure                    |
|                  | Hydrodynamic/F₆₈₈    | Soil erosion (destruction)               |
|                  | Hydrodynamic/F₆₂₁₆   | Flooding (ES code 20590)                 |
|                  | Hydrodynamic/F₆₂₁₉   | River water uptake                       |
Continuation of Table 2

| 1                                           | 2                                           | 3                                           |
|----------------------------------------------|----------------------------------------------|----------------------------------------------|
| Mudflow                                      | Dynamic/F6_2                                 | Displacement (movement) of rocks              |
|                                              | Gravitational/F5_2                           | Displacement (movement) of rocks              |
|                                              | Dynamic/F6_1                                 | Hit                                          |
|                                              | Gravitational/F5_1                           | Hit                                          |
|                                              | Dynamic/F6_8                                 | Mechanical pressure of the mudflow           |
|                                              | Gravitational/F5_8                           | Mechanical pressure of the mudflow           |
|                                              | Hydrodynamic/F2_16                           | Mudflow hydrodynamic pressure                |
|                                              | Aerodynamic/F1_11                            | Shock wave                                   |
| High water level (floods)                    | Hydrodynamic/F2_1                            | Water flow                                   |
|                                              | Hydrochemical/F4_1                           | Water flow                                   |
|                                              | Hydrodynamic/F2_5                            | Hydrosphere, soil pollution                  |
|                                              | Hydrochemical/F4_2                           | Hydrosphere, soil pollution                  |
| Jams, ice jams                               | Hydrodynamic/F2_18                           | Water level rise                             |
|                                              | Hydrodynamic/F2_14                           | Hydrodynamic pressure of water               |
| Snow avalanche                                | Gravitational/F5_7                           | Displacement (movement) of snow masses       |
|                                              | Dynamic/F6_7                                 | Displacement (movement) of snow masses       |
|                                              | Gravitational/F5_1                           | Hit                                          |
|                                              | Dynamic/F6_1                                 | Hit                                          |
|                                              | Gravitational/F5_10                          | Pressure of displaced snow masses            |
|                                              | Dynamic/F6_10                                | Pressure of displaced snow masses            |
|                                              | Aerodynamic/F1_10                            | Shock wave                                   |
|                                              | Aerodynamic/F1_8                            | Sonic boom                                   |
| Strong winds, including squalls and tornadoes, incl. hurricanes, typhoons, wind storms | Aerodynamic/F1_7                            | Wind flow                                    |
|                                              | Aerodynamic/F1_3                            | Wind load                                    |
|                                              | Aerodynamic/F1_4                            | Aerodynamic pressure                         |
|                                              | Aerodynamic/F1_1                            | Vibration                                    |
|                                              | Aerodynamic/F1_8                            | Strong air discharge                         |
|                                              | Aerodynamic/F1_6                            | Whirlwind                                    |
| Heavy dust storm                             | Aerodynamic/F1_5                            | Blowing and filling of topsoil               |
| Heavy rain                                   | Hydrodynamic/F2_1                            | Water flow                                   |
|                                              | Hydrodynamic/F2_6                            | Flooding (ES code 20590)                    |
| Very heavy snowfall                          | Hydrodynamic/F2_11                           | Snow load                                    |
|                                              | Hydrodynamic/F2_12                           | Snow drifts (ES code 20335)                 |
| Strong snowstorm                             | Hydrodynamic/F2_11                           | Snow load                                    |
|                                              | Hydrodynamic/F2_2                            | Wind load                                    |
|                                              | Hydrodynamic/F2_12                           | Snow drifts (ES code 20335)                 |
| Heavy ice                                    | Gravitational/F5_9                           | Ice load                                     |
|                                              | Dynamic/F6_9                                 | Ice load                                     |
|                                              | Gravitational/F5_3                           | Vibration                                    |
|                                              | Dynamic/F6_3                                 | Vibration                                    |
| Large hail                                   | Dynamic/F6_1                                | Hit                                         |
| Heavy fog                                    | Thermophysical/F10_2                         | Reduced visibility (cloudy air)              |
| Very severe frost                            | Thermal/F5_4                                | Soil, air cooling                            |
| Very intense heat                            | Thermal/F5_3                                | Soil, air heating                            |
| Low water/drought                            | Aerodynamic/F1_2                            | Soil drying                                  |
|                                              | Thermal/F5_1                                | Soil drying                                  |
| Lightning strikes                            | Electrophysical/F2_1                         | Electric discharges                          |
| Wildfire, steppe, field, peat bog            | Thermophysical/F10_5                         | Flame                                       |
|                                              | Thermophysical/F10_3                         | Heat flow                                    |
|                                              | Thermophysical/F10_7                         | Heatstroke                                   |
|                                              | Thermophysical/F10_6                         | Clouding of air                              |
|                                              | Thermophysical/F10_4                         | Hazardous smoke                              |
|                                              | Chemical/F12_1                              | Pollution of the atmosphere, soil, hydrosphere |
Table 3 provides a list of natural disasters that could lead to emergencies. The National Classifier DK 019:2010 was taken as the basis. The table is supplemented by phenomena that were not included in the classifier: from the matrix of environmental factors caused by climate change and the hardware resources of the telecommunication network, Fig. 1 [7]; Table 1 “Typical consequences of natural disasters and possible measures to reduce damage from them” [6]; from Table 2 “The nature of the actions and manifestations of the damaging factors of natural emergencies” [13].

| ES code. Title                                      | The effect of the natural threat on hardware | Protection Measures |
|----------------------------------------------------|---------------------------------------------|---------------------|
| 20100. GEOPHYSICAL PHENOMENA                       |                                             |                     |
| 20110. Earthquake                                  | See Table 1, Table 2                       |                     |
| 20120. Solar flare                                 | See Table 1, Fig. 3, cable protection from EMF exposure ($F_{11,2}$) can be carried out by insulating coatings, tread, cathode or drainage installations, line-protective grounding [14]; to protect cables from the effects of EMF ($F_{11,2}$), calibration, cascade protection and grounding of CL, the installation of arresters and fuses are used; the establishment of lightning rods on OCL and cables – on CL [15] |                     |
| 20200. GEOLOGICAL PHENOMENA                        |                                             |                     |
| 20210. Eruption of a mud volcano                   | See Table 2                                |                     |
| 20230. Collapse or talus                           | See Table 1, Table 1, 2                   |                     |
| 20240. Deposition (failure) of the earth’s surface | See Table 2                                |                     |
| 20260. Rising groundwater table (flooding)        | See Fig. 2                                 |                     |
| 20300. METEOROLOGICAL PHENOMENA                    |                                             |                     |
| 20310. Precipitation-related phenomena             | Flooding, flooding [8]                     |                     |
| 20311. Heavy rain                                  | See Fig. 1, Table 2                       |                     |
| 20312. Large hail                                  | See Table 2                                |                     |
| 20313. Very heavy snow                             | See Table 1, Table 1, 2                   |                     |
| 20314. Very heavy rain (rain and sleet)            | The combined effect of heavy rain (code 20311) and very heavy snowfall (code 20313) |                     |
| Change in precipitation patterns                   | May cause precipitation (abyss) of the earth’s surface (code 20240) [8] |                     |

Fig. 2. Fragment of the matrix of the nature of actions and manifestations of the damaging factors of natural emergencies
Continuation of Table 3

| 1 | 2 |
|---|---|
| **20320. Meteorological temperature** | |
| **20321. Very severe frost** | See Table 1, 2 |
| | See Table 1 |
| **20322. Very intense heat** | See Table 1, 2 |
| | See Table 1 |
| **Temperature increase** | See Fig. 1, may cause equipment overheating [8] |
| | Application of ventilation and air conditioning systems [7, 8]; revision of equipment protection requirements [8] |
| **20330. Meteorological, other** | |
| **20331. Strong wind, including squalls and tornadoes, hurricanes, typhoons, wind storms** | See Fig. 1, Table 1, 2 |
| | See Table 1 |
| **20332. Severe dust storm** | See Table 2; overvoltage on the VLAN wires [15] |
| | From the EMF action \( F_{11} \) - as in an earthquake (code 20110) |
| **20333. Strong sticking of snow** | The action is similar to the action of strong ice (code 20334) |
| | According to Fig. 1, as for strong ice |
| **20334. Heavy ice, incl. as a result of an ice storm** | See Table 1, 2, Fig. 1 |
| | See Table 1, monitoring of guttering; methods aimed at preventing guttering; Methods associated with the removal of ice formed [18] |
| **20335. Snow drifts** | See Table 2 |
| | See Table 1 |
| **20336. Snowstorm** | See Table 2; overvoltage on the OCL wires [15] |
| | See Fig. 3, from the action of EMF - as in an earthquake (code 20110) |
| **20337. Heavy fog** | See Table 2 |
| | Not found |
| Increased atmospheric moisture [7] | See Fig. 1, can accelerate hardware corrosion [8] |
| | View equipment protection requirements; condensate monitoring [8] |
| **Lightning strikes [7, 13]** | See Fig. 3, Table 2; the lead sheath of the underground cable melts, the jute braid burns out, the insulation burns, the cable conductors melt, etc. [15] |
| | Cable protection from electrical discharges \( F_7 \) can be carried out by insulating coatings, tread, cathode or drainage systems, line-protective grounding [14]; protection of equipment from direct lightning strikes is carried out using an external lightning protection system [19]; shielding, connections of metal elements, grounding, surge protection devices are used to protect against secondary effects of lightning [19] |
| **20400. HYDROLOGICAL MARINE PHENOMENA** | |
| **20410. Strong (high) unrest of the sea and the reservoir** | The action is similar to the effect of a high water level (high water, high water) (code 20510) special foundations \( F_{123} \) are assigned for OCL supports [20] |
| | High sea level action similar to high water level action (code 20510) low sea level action similar to low water/drought action (code 20520) |
| | Accordingly, for the case of high sea level - as for high water level for the case of low sea level – as for low water/drought |
| **Sea level rise [7]** | See Fig. 1, corrosion acceleration of coastal infrastructure, flooding [8] |
| | Viewing the heights of reference points for some calculations of telecommunication equipment [8] |
| **20430. Early freeze-up or fast ice** | Undefined |
| | Undefined |
| **20440. Threatening icing of ships** | Undefined |
| | Undefined |
| Tsunami. Storm surge of water [13] | See Table 1, 2 |
| | See Table 1, Fig. 3, special foundations \( F_{123} \) [20] are assigned for protection against wave impacts for OCL supports |
| **20500. HYDROLOGICAL PHENOMENA OF SURFACE WATERS** | |
| **20510. High level of water (floods, floods), including flash floods** | See Fig. 1, Table 1, 2 |
| | See Table 1, Fig. 3 |
| **20520. Low water level/drought (low water level)** | See Table 2 |
| | Undefined |
| **20530. Jams, ice jams** | See Table 2 |
| | Undefined |
| **20540. Mudflow** | See Table 2 |
| | See Fig. 3 |
The resulting registry (Table 3) includes both a detailed list of telecommunications network threats and a description of their impact on hardware and related countermeasures.

5.2. Analysis of observations of the effects of natural disasters on the functioning of the telecommunication network

Characteristic actions and manifestations of damaging factors that affect the performance of the hardware were found (Table 3), but are not mentioned in the list of Table 2 “The nature of the actions and manifestations of the damaging factors of natural emergencies”, namely:

– for phenomena related to precipitation (code 20310), to flooding ($F_{2,6}$, code 20590) of linear-cable structures of telecommunication transport networks located in lowlands, inspection and inspection wells, as well as underground structures and data centers located in the coast and on urban lands, the risks of flooding are added (increase in groundwater level $F_{3,1}$, hydrodynamic pressure of the groundwater

| 1                        | 2                                                                 |
|--------------------------|-------------------------------------------------------------------|
| 20550. Snow avalanche     | See Table 2                                                       |
|                          | See Fig. 3                                                        |
| 20560. Low water         | The action is similar to the action of low water/drought (code 20520) |
|                          | How to protect against water shortage/drought                    |
| 20570. Early ice formation and the appearance of ice in navigable water bodies and rivers | Undefined |
|                          | Undefined                                                        |
| 20580. Intensive ice drift | Damage to the OLC supports [20]                                  |
|                          | On floodplains with severe ice conditions, special foundations are assigned to the OLC supports [20] |
| 20590. Flooding          | See Table 2                                                       |
|                          | See Fig. 3                                                        |
| Shore processing [13]    | See Table 2                                                       |
|                          | See Fig. 3                                                        |
| Channel erosion [13]     | See Table 2                                                       |
|                          | Undefined                                                        |
| **20600. PHENOMENA ASSOCIATED WITH FIRES IN NATURAL ECOLOGICAL SYSTEMS** | |
| 20610. Forest fire       | See Table 1, 2                                                   |
|                          | See Table 1                                                       |
| 20620. Steppe fire       | See Table 1, 2                                                   |
|                          | See Table 1                                                       |
| 20630. Field fire (on agricultural land) | See Table 1, 2 |
|                          | See Table 1                                                       |
| 20640. Peat bog fire     | See Table 1, 2                                                   |
|                          | See Table 1                                                       |

**20700. BIOMEDICAL PHENOMENA**

Contact mechanical failure:
– collisions See Table 4 [21]
  See Table 5
– gnawing See Table 4 [21]
  See Table 5
– destruction See Table 4 [21]
  See Table 5

Performance degradation:
– biocontamination See Table 4 [21]
  Cleaning leaves and debris in the OCL locations [8]
– bioobstruction See Table 4 [21]
  Cleaning leaves and debris in the OCL locations [8]
– biofouling See Table 4 [21]: the defeat of underground cables by a lightning current that flows along the roots of trees [15]
  Cleaning leaves and debris in the OCL locations [8]

Biochemical destruction:
– bio-consumption in the process of nutrition See Table 4 [21]
  See Table 5
– chem. action of released substances See Table 4 [21]
  See Table 5

Biocorrosion See Table 4 [21]
  See Table 5
flow $F_{2.15}$, soil contamination (salinization) $F_4.3$, corrosion of underground metal structures $F_{4.4}$, code 20260) [8];

- in cases of a strong dust storm (blowing and filling of the topsoil $F_{1.5}$, code 20332) and a strong snowstorm (snow load $F_{2.11}$, wind load $F_{2.2}$, snow drifts $F_{2.12}$, code 20336) small grains of sand and ice crystals flying at high speed above the ground as a result of friction, they receive electric charges that they give to hanging wires in a collision with the latter. As a result, overvoltages are created on overhead lines;

- the thermal damaging factor “Heat flow” $F_{10.3}$ is assigned to the phenomena associated with fires in natural ecological systems (code 20600). At the same time, the consequences of strong heating of the underground cable can be a lightning strike;

- the physical damaging factor “Electromagnetic field” ($F_{11.2}$) is assigned to the phenomena associated with the earthquake (code 20110). At the same time, as a result of changes in the magnetic field of the Earth, they can be caused by a magnetic storm caused by a solar flare;

- the physical damaging factor “Electromagnetic field” ($F_{11.2}$) is assigned to the phenomena associated with the earthquake (code 20110). At the same time, overvoltages on the OCL overhead wires, caused by the action of an electromagnetic field, are created as a result of climbing over small grains of sand (strong dust storm, code 20332) and ice crystals (strong snowstorm, code 20336).

Identified natural threats to hardware that are not included in the table include the “Register of natural threats to telecommunications network hardware”.

1. In the “traditional” for global warming, an increase in temperature, an increase in the atmospheric moisture content, changes in precipitation regimes and an increase in sea level are attached:

- severe ice due to an ice storm (let’s note that only in the USA during 1949–2000. Ice storms led to 87 large-scale accidents, causing damage in the amount of 16.3 billion USD [22]);

- solar flares (for example: September 1–2, 1859 disabling telegraph networks in Europe and America; August 4, 1972 – the telephone network of the state of Illinois (USA), it is noted that significant differences arising from a sharp change in the Earth's magnetic field due to a magnetic storm potentials between points on the earth’s surface that are remote from each other affect the operation of single-core communication circuits (remote supply via wire-to-ground system, signaling circuits, etc.) [16]. For long-term passage along the circuit, earth currents can lead to damage in electronic equipment [15]);

- lightning strikes [15].

2. There is evidence of biological attacks on communication cables [10]:

- high humidity and temperature contribute to the growth of molds, which reduce the strength of the protective covers of the cable and change the properties of water-blocking materials;

- termites, ants, tree bugs and larvae damage the protective cover of the cable; ants and termites release active acid secretion, which, when in contact with the cable, can cause corrosion of metal elements;

- overhead cables damage birds; in addition, their livelihoods are characterized by a high content of chemically and biologically active substances, which are aggressive environments for cable sheaths.

The development and behavior of native species in the context of global warming, their impact on telecommunication equipment requires a detailed study. Invasive species require even more calculated attention.

Known methods for disrupting the operational state of electronic and electronic computing devices that can cause a combination of organisms or their communities are given in Table 4.

### Table 4

| Biodeterioration type | Explanation |
|----------------------|-------------|
| 1. Mechanical failure upon contact (caused mainly by macroorganisms having dimensions comparable to product dimensions): |
| collisions | birds with radio antennas |
| gnawing | materials by rodents, or species |
| destruction | usually occurs in the process of feeding organisms |
| 2. Deterioration of operational parameters: |
| allocation of organisms and their metabolic products, the action of which as a result of wetting with water or absorbing moisture from the air leads to a change in product parameters |
| 3. Biochemical destruction (caused mainly by microorganisms that are microscopic in size and invisible to the naked eye): |
| biological consumption during nutrition | associated with preliminary chemical destruction by the enzymes of the starting material, sometimes only one component (usually a low molecular weight compound, for example a plasticizer, stabilizer). Such destruction opens the way for physical and chemical corrosion, leads to a deterioration in the thermodynamic properties of the material and its mechanical destruction under the action of operational loads |
| 4. Biocorrosion | biocorrosion on the face of the material-organism is due to the action of amino and organic acids, as well as hydrolysis products; it is based on electrochemical processes of metal corrosion under the action of microorganisms |

Note: * – lightning currents that flow along the roots of plants can cause damage to the underground cable [15]. The fact that an increase in temperature stimulates their growth is noted in [8].

In the literature accessible to the authors, no data were found on the effects on the hardware of a telecommunication network of the following natural threats:

- early ice formation or fast ice (code 20430);
- threatening icing of ships (code 20440);
- early ice formation and the appearance of ice in navigable water bodies and rivers (code 20570).

### 5.3. Synthesis of possible measures to reduce losses from certain threats

Specific measures known from the literature for protecting telecommunications network hardware from certain
natural hazards are summarized in the Register (Table 3). The generalized measures are described further and are reduced to recommendations for the protection of linear cable structures and organizational measures.

Practical recommendations for protecting key telecommunications facilities, communication cables, from some pests are given in Table 5.

| Pest                  | Protection element                                      |
|-----------------------|--------------------------------------------------------|
| Rodents               | Armored steel wire, aramid yarns or fiberglass rods     |
| Birds                 | Steel sheath or steel laminated tape                    |
| Ants and termites     | Polyamide sheath                                        |
| Woodpeckers and termites | Armor-curved steel or brass bands                      |
| Wood insects and their larvae | Protective cover from steel strips with a thickness of 0.2 mm with a bituminous composition |

To protect the line-cable structures from atmospheric and hydrological threats, it is proposed to lay them underground. Fig. 3 presents examples of enhanced measures to protect underground linear cable structures.

To protect hardware from natural threats (Table 3), the following organizational measures are proposed:

– to protect against geophysical (code 20100) and geological phenomena – to maintain the readiness of monitoring, forecasting, warning systems; decide on the feasibility of building in hazardous areas; maintain the readiness of forces and means to eliminate the consequences of the action;

– for protection against meteorological phenomena (code 20300) – to identify precursors, detect disasters; notify the population; establish a strict procedure for building codes in high-risk areas; develop emergency plans in high-risk areas;

– for protection against hydrological marine phenomena (code 20400) – conduct and refine risk assessments and hazard identification; organize a centralized monitoring and control system; identify and specify areas with the most dangerous and frequent anomalies and determine the risks of emergencies in them; strengthen measures to protect territories in hazardous areas; create a reserve of funds and equipment for recovery;

– to the extent possible, eliminate or minimize the linking of communication infrastructure to the electricity network infrastructure, providing backup power through diesel generators, autonomous wind and solar power plants.

When assessing the reliability of a telecommunication channel, its resistance to threats is determined by the channel availability coefficient, which is calculated by the formula [24]:

\[ k = \frac{t_w}{t_w + t_d}, \]  

where \( t_w \), \( t_d \) – the duration, respectively, of the work and disability of the channel, the stability of which is determined by inequality (1), after a certain control time interval \( t_w + t_d \).

Fig. 3. Examples of measures to protect underground line-cable structures from the experience of Japanese telecommunications experts [6]: 1 — sliding joint for manholes (a gas pipe connection); 2 — sliding joint for gas pipelines; 3 — sliding connection with a stopper; 4 — flexible connection for sinking the wall of the cable shaft; 5 — flexible connection of cable channels; 6 — flexible connection of sections of the gas pipeline for penetration into the building; 7 — flexible connection; 8 — sliding joint+coupling; 9 — sliding connection with a stopper+concrete cable tray; 10 — sliding connection with a stopper+connecting sleeve; 11 — reinforced concrete manhole cover; 12 — building user services; 13 — cable channel; 14 — cable shaft; 15 — cable duct; 16 — sinking bridge; 17 — inspection well (IW); 18 — revision well (RW); 19 — normal soil; 20 — water-saturated soils; 21 — directions of displacements; 22 — wall of the building; 23 — flexible corrugated gas pipeline.
According to existing experience, the hardware resources of a telecommunication network must comply with the principle of redundancy, in which an operational reconfiguration is performed. It is proposed to apply reservation of communication lines due to alternative technologies, for example, optical transmission technology in free space, high-frequency communication over power lines. All this, first of all, concerns the transport network common for telecommunication services users.

Fig. 4 shows the functional diagram of the network, the increase in resources of which is carried out due to three-level multiplexing with mutually independent multiplexing levels. The principle of independence is also supported within the levels: due to the frequency and time separation of signals, separation of signals by physical nature (electrical, optical), separation by media (free space, artificial guides).

Fig. 4. Functional diagram of a multichannel communication system: I - level of multiplexing channels with frequency and time signal separation; II - level of multiplexing channels with separation of signals by physical nature $f(E)$; III - level of multiplexing of channels with separation of signals with transmission medium $f(x,y,z)$, where $k, l, m, n$ - corresponding channels; MX - modulator, DMX - demodulator [25]

The availability factor of the proposed communication system, built from $n$ duplicated channels of the telecommunication network, is calculated by the formula:

$$k_{av} = 100 \times \left[ 1 - \prod_{i=1}^{n} \left( 1 - \frac{k_i}{100} \right) \right], \quad i = 1,2,3,...,n$$

where $k_i$ - availability factor of the $i$-th communication channel.

6. Discussion of the results of the study of natural threats to the telecommunications network and measures to reduce damage from them

As a result of studies, characteristic actions and manifestations of damaging factors that were not included in the Table 2 “The nature of the actions and manifestations of the damaging factors of natural emergencies” were revealed, but the effect of which affects the operability of hardware (Table 3) - 6 positions of emergency sources. Natural threats to hardware were identified that were not included in the register of natural threats to telecommunication network hardware (Table 3) - 13 positions of emergency sources. No data were revealed on the impacts on the hardware of the telecommunications threat network - 3 positions of emergency sources.

Global warming is one of the factors that accelerates the invasive process. Available information on the “aggression” of invasive species in relation to local flora and fauna. The danger catalyst can be anthropogenic impact, which is distinguished by the promotion of climate change, the artificial modification of the environment. There is evidence of attacks on communication cables, electronic and electronic computing tools that can cause invasive and indigenous populations of organisms or their communities, plants under global warming.

The limited amount of work, the variability of both natural and anthropogenic (artificial) environments do not allow, firstly, to provide reasonable, systematized actions and manifestations of damaging factors in detail and their compliance with certain natural threats, and secondly, a complete list of protective actions that has become would be a panacea for all ills and forever.

Therefore, no data has been identified on the protection of hardware from a number of actions and manifestations. To protect the TCN, in addition to organizational measures, cable laying and installation of linear cable structures underground is proposed. Recommendations are given on protecting communication cables from rodents, birds, ants and termites, woodpeckers, wood insects and their larvae.

According to existing experience, the hardware resources of a telecommunication network must comply with the principle of redundancy, in which an operational reconfiguration is performed. It is proposed to apply the reservation of communication lines by three-level multiplexing with mutually independent multiplexing levels. The principle of independence is also supported within the levels: due to the frequency and time separation of signals, separation of signals by physical nature (electrical, optical), separation by media (free space, artificial guides).

As a result of the study, the ES sources have been identified; they constitute natural threats to hardware, but are not mentioned in the National Classifier of Ukraine DK 019:2010. The global warming process has amplified the harmful effects of known dangers and identified a number of new ones that are proposed to be classified. A significant threat to the telecommunications network is the accelerated evolution of bio-vision in a changing natural environment. The “catalyst” of the danger can be anthropogenic impact, which is distinguished by the promotion of climate change, artificial modification of the environment.

The study is a continuation, firstly, of ITU’s research to identify threats inherent in global warming, and secondly, to identify measures to protect telecommunication network resources from them. Future research should continue to identify possible “latest” threats, acting on their prevention. This will prevent emergency situations, in particular in the field of telecommunications. Another area of future research is a deeper analysis of the effects of natural disasters. As practice shows, they can have a significant list of damaging factors, which requires advancing additional requirements for the stability of hardware resources.

7. Conclusions

1. A method has been developed to develop measures to protect the telecommunications network from the effects of natural disasters. The method is easily formalized and algorithmized, and includes a phased collection of informa-
tion about the effects of natural disasters on the hardware resources of the telecommunication network, their analysis and the development of appropriate countermeasures. The method can be used in the formation of orders for information and communication research, in studies of a wide range of extreme impacts on the natural and anthropogenic environment, in particular those that have departmental and regional directions, in developing measures to counter impacts, in developing relevant strategic and current research plans programs.

2. A register of natural threats to the telecommunication network hardware has been developed, containing data on the impact of the hazard and measures to protect it. The main position of the registry is that measures to protect any resource of a telecommunication network are adequate influential phenomena on the resource, and are directly dependent on the nature of the action and the manifestations of threats that form the appropriate matrix.

3. To protect the telecommunications network from natural threats of global warming, it is proposed to use a network whose resources are increased through three-level multiplexing with multiplexing levels that are independent of each other. Three-level multiplexing allows to optimize the telecommunications network at the design and modernization stages, in particular, duplicated network resources in the conditions of established restrictions.

References

1. Bondarenko, L. V., Maslova, O. V., Belkina, A. V., Sukhareva, K. V. (2018). Global climate changing and its after-effects. Vestnik of the Plekhanov Russian University of Economics, 2 (98), 84–93. doi: https://doi.org/10.21686/2413-8213-2018-2-84-93

2. Banholzer, S., Kossin, J., Donner, S. (2014). The Impact of Climate Change on Natural Disasters. Reducing Disaster: Early Warning Systems For Climate Change, 21–49. doi: https://doi.org/10.1007/978-94-017-8598-3_2

3. Safonov, G. V. (2006). Ospaye posledstviya global’nogo izmenenia klimata. Munecips: RREC, GO, WWF Rossii, 20.

4. Pate nationalne povidomlennya Ukrainy z pytan zmyny klimatu, pidhotovlene na vykonannia statti 4 ta 12 Ramkovoi konventsii OON pro zmiu klimatu ta statti 7 Kiotskogo protokolu (proekt) (2009). Kyiv, 281.

5. Weather and Climate Services in Europe and Central Asia. A Regional Review. World Bank Working Paper No. 151. Washington, D.C. doi: https://doi.org/10.1596/978-0-8213-7585-3

6. Recommendation ITU-T L.92 (2012). Series L: construction, installation and protection of cables and other elements of outside plant. Disaster management for outside plant facilities.

7. Recommendation ITU-T L.1502 (2015). Adapting information and communication technology infrastructure to the effects of climate change.

8. Ospina, A. V., Faulkner, D., Dickerson, K., Bueti, C. (2014). Resilient pathways: the adaptation of the ICT sector to climate change. ITU, 62.

9. ITU-D Study Group 2. Question 6/2: ICT and climate change. Final Report (2017). Geneva, 64.

10. Katok, V., Koytun, A., Rudenko, I. (2005). Biologicheskaya ataka na kabel’. Seti i telekommunikacii, 11, 68–71.

11. Anakhov, P. V. (2016). Triggering of earthquakes of Azov-Black Sea basin by seiche deformation of the ground. Geodynamics, 1, 155–161. doi: https://doi.org/10.23939/jgd2016.01.155

12. Shobotov, V. M. (2004). Tsyvilna oborona. Kyiv: «Tsentr navchalnoi literatury», 438.

13. GOST R 22.0.06-95. Bezopasnost’ v chrezvychaynyh situatsiyah. Istochniki prirodnih chrezvychaynyh situatsiy. Porazhayuschie faktory. Nomenklatura parametrov porazhayuschih vozdeystviy.

14. Rekomendatsii po odnovremennoy zashchite kabeley svyazi ot korrozii, udarov molnii i elektromagnitnyh vliyaniy (1983). Moscow: Radio i svyaz’, 12.

15. Kozak, M. M.; Dobrochynskyi, S. B., Petrunchak, H. M. (Eds.) (2009). Liniini sporudy zviazku. Vinnytsia, 317.

16. Vladimirov, V. A., Chernyh, G. S. (2013). Analiz opasnostey u uzorg prirodnogo haraktera na sovremennom etape. Strategiya grazhdanskoy zaschity: problemy i issledovaniya, 3 (1), 24–38.

17. DBN V.1.1-25-2009. Inzhenernyi zakhyst terytoriy ta sporud vid pidtoplennia ta zatoplennia.

18. Zarubzhnyi dosvity epizootologii terytoriialnyh territoriy. Izd-vo Natsional’nogo universitetu Ukrainy im. Tarasa Shevchenka. Kiev, 2007.

19. DSTU B V.2.5-38:2008. Ulashtuvannia blyskavkozakhystu budivel i sporud (IEC 92305:2006, NEQ).

20. Proektatsiia dokumentatsyi. Seriya 3.407.1-139. Zaschita fundamentov opor VL 35–500 kV, sooruzhаемых na poyme ot ledovyh i naslediv ozheledi/NPTsR OES Ukrainy (2016). Kyiv, 74.

21. GOST R 52.0.06-95. Bezopasnost’ v chrezvychaynyh situatsiyah. Istochniki prirodnih chrezvychaynyh situatsiy. Porazhayuschie faktory. Nomenklatura parametrov porazhayuschih vozdeystviy.

22. Rekomendatsii po odnovremennoy zashchite kabeley svyazi ot korrozii, udarov molnii i elektromagnitnyh vliyaniy (1983). Moscow: Radio i svyaz’, 12.

23. Kozak, M. M.; Dobrochynskyi, S. B., Petrunchak, H. M. (Eds.) (2009). Liniini sporudy zviazku. Vinnytsia, 317.

24. Vladimirov, V. A., Chernyh, G. S. (2013). Analiz opasnostey u uzorg prirodnogo haraktera na sovremenном etape. Strategiya grazhdanskoy zaschity: problemy i issledovaniya, 3 (1), 24–38.

25. Anakhov, P. V. (2017). Increasing the channel capacity of a part of telecommunication network at the expense of space-energy multiplexing. Data Recording, Storage & Processing, 19 (1), 50–54. doi: https://doi.org/10.35681/1560-9189.2017.19.1.126493