Останнім часом у всьому світі зростає кількість катастроф природного характеру, які обумовлені зміною клімату на Землі. Для розробки заходів щодо захисту апаратних ресурсів від наслідків дії стихійних лих використано метод проєктів. Опрацьований згідно його положень метод включає поетапний збір відомостей щодо дії стихійних лих на апаратні ресурси телекомунікаційної мережі, їх аналіз і розробку відповідних протидій.

Виявлені дії і прояви вражаючих факторів, які не увійшли до сімейств відповідних вражаючих факторів переліку "Характер дій і проявів вражаючих факторів природних НС", але дія яких викликається визначеними джерелами потенційних НС і позначається на працездатності апаратних засобів. Розроблена матриця характеру дій і проявів вражаючих факторів природних НС.

На основі Класифікатора надзвичайних ситуацій України побудовано Реєстр природних загроз апаратним засобам телекомунікаційної мережі. Виявлені нові джерела НС, які становлять загрози апаратним засобам (13 позицій). Процес глобального потепління посилив шкідливу дію відомих небезпек і визначив низку нових, які пропонується класифікувати. "Каталізатором" небезпек може стати антропогенний вплив, який відрізняють сприяння змінам клімату, штучна модифікація середовища.

Мінливість природно-антропогенного середовища не дозволяє представити повністю обгрунтовані, детально систематизовані природні загрози, дії і прояви вражаючих факторів та відповідність їх визначеним загрозам. Перелік відомих захисних дій включає організаційні заходи і заходи протидії виявленим загрозам. Відповідно до існуючого досвіду, апаратні ресурси телекомунікаційної мережі мають відповідати принципу надмірності, за якого виконується оперативна реконфігурація. Пропонується застосовувати резервування ліній зв'язку шляхом трирівневого мультиплексування із взаємонезалежними між собою рівнями мультиплексування

Ключові слова: апаратний ресурс телекомунікаційної мережі, вражаючий фактор небезпеки, природна загроза, стихійне лихо, трирівневе мультиплексування каналів зв'язку

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PROTECTION OF TELECOMMUNICATION NETWORK FROM NATURAL HAZARDS OF GLOBAL WARMING

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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 savannahs 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.

Infrastructure \ Effect	Temperature rise	Humidity	Wind loading	Sea level rise	Rainfall	Floods	Landslides	Snow and Ice fall	Lightning strikes	Species damage
Tower	L	L	H	M	L	H	M	L	H	L
Antenna	M	M	H	L	H	M	M	H	H	L
Electronics	H	H	L	L	M	L	L	L	H	L
Equipment room	M	M	L	H	H	H	L	L	H	L
Fibre Optic	L	L	L	L	L[1]	L	H[1]	L	L	M
Twisted pair and coaxial cables	L	L	H	M[2]	M	H	H[2]	M	H	H
Grid supply	L[3]	L	L	M	M	H	M	M	H	M
Standby generators	L	L	L	M[2]	M	H	H[2]	H	M	L
Satellite Earth Stations	L	L	H	M	H/M	M	M	H	H	L
HVAC	H	M	L	L	L	L[2]	L	L	L	L

L: Low; M: Moderate; H: High

[1] The fibre optic installation should take note of the risk of landslides and heavy rainfall; their respective installation should avoid areas with a high risk of landslides.

[2] Location dependent.

[3] Demands on grid supply may increase beyond its capacity when temperatures rise due to more requirements for cooling.

Fig. 1. The effect of environmental factors due to climate change on the hardware resources of a telecommunication network [7]

Table 1

Typical consequences of natural disasters and possible measures to reduce damage from them [6]

Disaster	Effects	G	Protection Measures
1	2	3	4
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-mortal swelling of the soil; the establishment of retaining structures between external objects and steep landslide hazardous slopes
		C	Installation of waterproof doors and water pumps; sealing the ends of plastic pipes (in hatches/shafts of the underground infrastructure) with foam filler; installation of drainage pumps and waterproof partitions in cable ducts
		M	Installation of flood sensors and control systems for cable ducts; installation of systems for early detection of emergency situations
Tsunami	Damage to external telecommunications facilities; damage to coastal energy systems	*P*	Placement 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
		C	Installation of additional structures for compensating wind loads (vertical struts, cable braces) at an expected wind speed of more than 40 m/s with steel wires; use of fastening between poles; attaching artificial dampers to protect cables from vibration
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
		C	The use of rubber gland seals for penetration into cable ducts, the adoption of measures to ensure the tightness of the hatch cover to the neck of the cable well, the use of flexible joint joints for GMCLP and seismic modeling; Install vibration sensors or damping systems
		M	Installation of emergency detection systems
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

Continuation of Table 1

1	2	3	4
Landslide	Destruction of underground GKNT; LCS damage	*P*	Construction restrictions in landslide hazardous places; assignment of telecommunication facilities from landslide hazardous slopes; increasing the stability of landslide hazardous slopes
		C	Periodic inspection installation of monitoring systems, monitoring by measurement
		M	Installation of emergency detection systems
Severe frost, snow, ice or heat	Equipment destruction	*P*	For the trouble-free operation of telecommunications equipment subject to extreme heat or cold, appropriate countermeasures should be provided; for the trouble-free operation of telecommunication equipment located in places with sharp temperature fluctuations, appropriate countermeasures must be provided
		C	Protection of cable sewers from snow penetration by sewer manholes and the use of antifreeze as a coolant in GMCLP

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), 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]:

$$S(\vec{r},t) \geq F(\vec{r},t), \qquad (1)$$

where $S(\vec{r},t)$ – value of the resistance criterion to the action of the damaging factor (DF), $\vec{r}$ – radius vector of the point of the DF field; t – time; $F(\vec{r},t)$ – 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
1	2	3
Earthquake	Seismic/F_{8_6}	Seismic shock
	Seismic/F_{8_4}	Rock deformation
	Seismic/F_{8_2}	Blast wave
	Seismic/F_{6_5}, $F_{6\_4...}$	Volcanic eruption (see Source: ES «Volcanic Eruption»)
	Seismic/F_{2_13}, $F_{2\_3...}$	Surge of waves (tsunamis) (see Source: ES «Tsunami. Storm surge of water»)
	Seismic/F_{8_3}	Gravitational displacement of rocks, snow masses, glaciers
	Seismic F_{8_5}	Surface water flooding
	Seismic/F_{8_1}	River bed deformation
	Physical/F_{11_2}	Electromagnetic field (EMF)
Eruption	Dynamic/F_{6_5}	Earth shake
	Dynamic/F_{6_4}	Earth deformation
	Dynamic/F_{6_11}	Ejection, loss of eruption products
	Dynamic/F_{6_13}	Movement of lava, mud, stone flows
	Dynamic/F_{6_12}	Rock gravity displacement
	Thermal/F_{9_5}	Burning cloud
	Thermal/F_{9_2}	Lava, tephra, steam, gases
	Chemical/F_{12_1}	Pollution of the atmosphere, soil, hydrosphere
	Thermophysical/F_{10_1}	Pollution of the atmosphere, soil, hydrosphere
	Physical/F_{11_1}	Lightning discharges
Landslide. Landslide or talus	Dynamic/F_{6_2}	Displacement (movement) of rocks
	Gravitational/F_{5_2}	Displacement (movement) of rocks
	Dynamic/F_{6_5}	Earth shake
	Gravitational/F_{5_5}	Earth shake
	Dynamic/F_{6_6}	Dynamic, mechanical pressure of displaced masses
	Gravitational/F_{5_6}	Dynamic, mechanical pressure of displaced masses
	Dynamic/F_{6_1}	Hit
	Gravitational/F_{5_1}	Hit
Karst dips	Chemical/F_{12_3}	Rock dissolution
	Hydrodynamic/F_{2_9}	Rock dissolution
	Chemical/F_{12_4}	Destruction of rock structure
	Hydrodynamic/F_{2_10}	Destruction of rock structure
	Chemical/F_{12_2}	Movement (leaching) of rock particles
	Hydrodynamic/F_{2_7}	Movement (leaching) of rock particles
	Gravitational/F_{5_12}	Displacement (collapse) of rocks
	Gravitational/F_{5_4}	Earth deformation
Deposition (failure) fo the soil	Gravitational/F_{5_4}	Earth deformation
	Gravitational/F_{5_11}	Soil deformation
Coastal processing	Hydrodynamic/F_{2_13}	Wave beat
	Hydrodynamic/F_{2_8}	Soil erosion (destruction)
	Hydrodynamic/F_{2_17}	Soil particle transfer
	Gravitational/F_{5_13}	Displacement (collapse) of rocks in the coastal part
Groundwater level rise (flooding)	Gravitational/F_{3_1}	Groundwater level rise
	Hydrodynamic/F_{2_15}	Groundwater flow hydrodynamic pressure
	Hydrochemical/F_{4_3}	Soil pollution (salinization)
	Hydrochemical/F_{4_4}	Corrosion of underground metal structures
Channel erosion	Hydrodynamic F_{2_3}	Hydrodynamic pressure
	Hydrodynamic/F_{2_4}	River bed deformation
Tsunami. Water storm surge	Hydrodynamic/F_{2_13}	Wave beat
	Hydrodynamic/F_{2_3}	Hydrodynamic pressure
	Hydrodynamic/F_{2_8}	Soil erosion (destruction)
	Hydrodynamic/F_{2_6}	Flooding (ES code 20590)
	Hydrodynamic/F_{2_19}	River water uptake

Continuation of Table 2

1	2	3
Mudflow	Dynamic/F_{6_2}	Displacement (movement) of rocks
	Gravitational/F_{5_2}	Displacement (movement) of rocks
	Dynamic/F_{6_1}	Hit
	Gravitational/F_{5_1}	Hit
	Dynamic/F_{6_8}	Mechanical pressure of the mudflow
	Gravitational/F_{5_8}	Mechanical pressure of the mudflow
	Hydrodynamic/F_{2_16}	Mudflow hydrodynamic pressure
	Aerodynamic/F_{1_11}	Shock wave
High water level (floods)	Hydrodynamic/F_{2_1}	Water flow
	Hydrochemical/F_{4_1}	Water flow
	Hydrodynamic/F_{2_5}	Hydrosphere, soil pollution
	Hydrochemical/F_{4_2}	Hydrosphere, soil pollution
Jams, ice jams	Hydrodynamic F_{2_18}	Water level rise
	Hydrodynamic/F_{2_14}	Hydrodynamic pressure of water
Snow avalanche	Gravitational/F_{5_7}	Displacement (movement) of snow masses
	Dynamic/F_{6_7}	Displacement (movement) of snow masses
	Gravitational/F_{5_1}	Hit
	Dynamic/F_{6_1}	Hit
	Gravitational/F_{5_10}	Pressure of displaced snow masses
	Dynamic/F_{6_10}	Pressure of displaced snow masses
	Aerodynamic/F_{1_10}	Shock wave
	Aerodynamic/F_{1_8}	Sonic boom
Strong winds, including squalls and tornadoes, incl. hurricanes, typhoons, wind storms	Aerodynamic/F_{1_7}	Wind flow
	Aerodynamic/F_{1_3}	Wind load
	Aerodynamic/F_{1_4}	Aerodynamic pressure
	Aerodynamic/F_{1_1}	Vibration
	Aerodynamic/F_{1_9}	Strong air discharge
	Aerodynamic/F_{1_6}	Whirlwind
Heavy dust storm	Aerodynamic/F_{1_5}	Blowing and filling of topsoil
Heavy rain	Hydrodynamic/F_{2_1}	Water flow
	Hydrodynamic/F_{2_6}	Flooding (ES code 20590)
Very heavy snowfall	Hydrodynamic/F_{2_11}	Snow load
	Hydrodynamic/F_{2_12}	Snow drifts (ES code 20335)
Strong snowstorm	Hydrodynamic/F_{2_11}	Snow load
	Hydrodynamic/F_{2_2}	Wind load
	Hydrodynamic/F_{2_12}	Snow drifts (ES code 20335)
Heavy ice	Gravitational/F_{5_9}	Ice load
	Dynamic/F_{6_9}	Ice load
	Gravitational/F_{5_3}	Vibration
	Dynamic/F_{6_3}	Vibration
Large hail	Dynamic/F_{6_1}	Hit
Heavy fog	Thermophysical/F_{10_2}	Reduced visibility (cloudy air)
Very severe frost	Thermal/F_{9_4}	Soil, air cooling
Very intense heat	Thermal/F_{9_3}	Soil, air heating
Low water/drought	Aerodynamic/F_{1_2}	Soil drying
	Thermal/F_{9_1}	Soil drying
Lightning strikes	Electrophysical/F_{7_1}	Electric discharges
Wildfire, steppe, field, peat bog	Thermophysical/F_{10_5}	Flame
	Thermophysical/F_{10_3}	Heat flow
	Thermophysical/F_{10_7}	Heatstroke
	Thermophysical/F_{10_6}	Clouding of air
	Thermophysical/F_{10_4}	Hazardous smoke
	Chemical/F_{12_1}	Pollution of the atmosphere, soil, hydrosphere

	Effect of danger				
	1 aerodynamic	**…**	**7 electrophysical**	**…**	**12 chemical**
1	Vibration DF_{1_1}		Electric discharges DF_{7_1}		Pollution of the atmosphere, soils, hydrosphere DF_{12_1}
2	Soil drying DF_{1_2}		-		Movement (leaching) of particles of rock DF_{12_2}
3	Wind load DF_{1_3}		-		Dissolution of rocks DF_{12_3}
4	Aerodynamic pressure DF_{1_4}		-		Destruction of rock structure DF_{12_4}
⋮	Blowing and backfilling		-		-

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

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].

Table 3

Register of natural threats to telecommunications network hardware

ES code. Title	The effect of th natural threat on hardware / Protection Measures
1	2
20100. GEOPHYSICAL PHENOMENA	
20110. Earthquake	See Table 1, Table. 2
	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]
Solar flare	Radio emissions, increasing magnetic field strength [15, 16]
	Alerts, changes in regulations and standards that determine the parameters of equipment operation, the creation of a reserve of necessary facilities and equipment, and the training of forces for restoration (repair) [16]; from the EMF action (F_{11_2}) – as in an earthquake (code 20110)
20200. GEOLOGICAL PHENOMENA	
20210. Eruption of a mud volcano	See Table 2
	See Fig. 3 [6]
20220. Landslide	See Fig. 1, Table 1, 2
	See Table 1, Fig. 3
20230. Collapse or talus	See Fig. 1, Table 1, 2
	See Table 1, Fig. 3
20240. Deposition (failure) of the earth's surface	See Table 2
	See Fig. 3
20250. Karst dips	See Table 2
	See Fig. 3
20260. Rising groundwater table (flooding))	See Table 2
	See Fig. 3, protection of underground metal structures from corrosion (F_{4_4}) can be carried out by insulating coatings, tread, cathode or electrodrainage installations, line-protective grounding [14]; restrictions on the location of telecommunication facilities in areas of possible flooding [8, 9]; artificial increase of planning marks of the surface of the territory; normative compaction of the soil when filling of pits and trenches; ensuring proper drainage of surface water, the construction of protective structures [17]
20300. METEOROLOGICAL PHENOMENA	
20310. Precipitation-related phenomena	Flooding, flooding [8]
	As for cases of flooding (code 20260), flooding (code 20590)
20311. Heavy rain	See Fig. 1, Table 2
	See Fig. 3
20312. Large hail	See Table 2
	Undefined
20313. Very heavy snow	See Fig. 1, Table 1, 2
	See Table 1, Fig. 3
20314. Very heavy rain (rain and sleet)	The combined effect of heavy rain (code 20311) and very heavy snowfall (code 20313)
	Accordingly, as for heavy rain and very heavy snowfall
Change in precipitation patterns	May cause precipitation (abyss) of the earth's surface (code 20240) [8]
	Accordingly, measures – as in the case of precipitation (abyss) of the earth's surface

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_2}) - as in an earthquake (code 20110)
20333. Strong sticking of snow	The action is similar to the action of strong ice (code 20334)
	Accordingly, 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_1}) 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_{2_13}) are assigned for OCL supports [20]
20420. High or low sea level	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_{2_13}) [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

Continuation of Table 3

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

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 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 base table "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

Classification of biological damage to electronic and electronic computing devices [21]

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:	
– biocontamination	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
– bioobstruction	spores of fungi and bacteria, plant seeds, parts of mycelium of fungi, bird droppings, excreta of organisms, dying organisms
– biofouling *	bacteria, fungi, sponges, mollusks and other organisms, enhances metal corrosion
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
– chemical effects of released substances	the chemical effect of the products of the exchange of microorganisms, which increases the aggressiveness of the environment, stimulates corrosion processes
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.

Table 5

Protection of communication cables from pests [23]

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 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]:

$$k = t_w / \left(t_w + t_{\bar{w}}\right), \qquad (2)$$

where t_w, $t_{\bar{w}}$ – 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 $\left(t_w + t_{\bar{w}}\right)$.

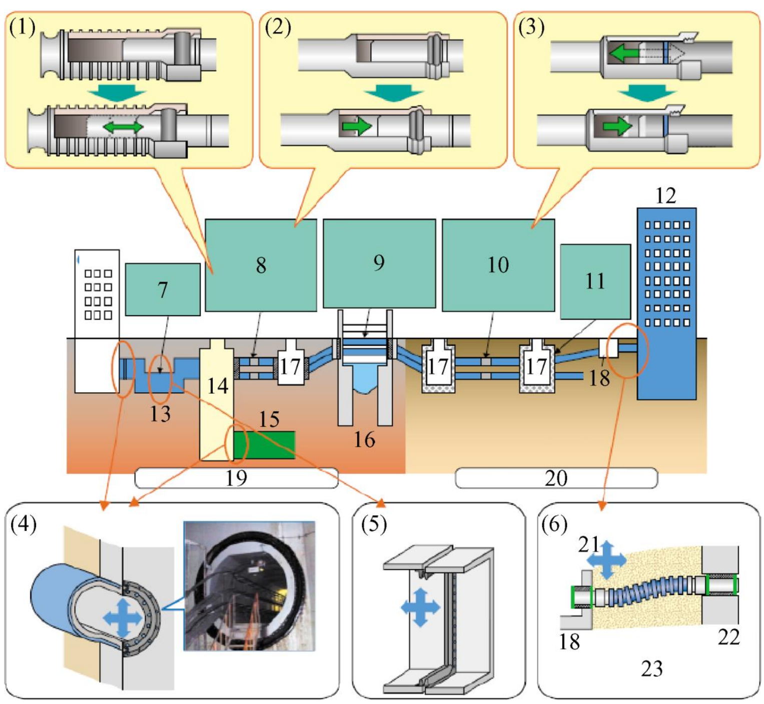

Fig. 3. Examples of measures to protect underground line-cable structures from the experience of Japanese telecommunications experts [6]: 1 — sliding joint for manholes (a gas pipe connection); 2 — sliding joint for gas pipelines; 3 — sliding connection with a stopper; 4 — flexible connection for sinking 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).

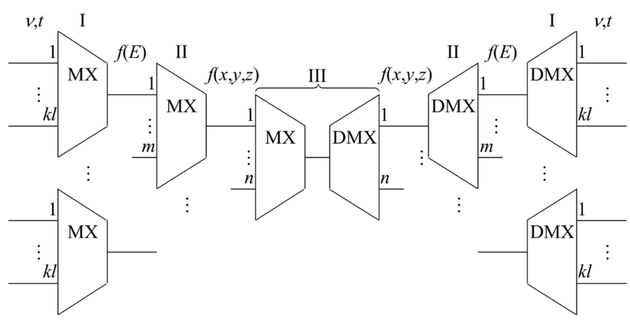

Fig. 4. Functional diagram of a multichannel communication system: I – level of multiplexing channels with frequency ν and time *t* signal separation; II – level of multiplexing channels with separation of signals by physical nature $f(E)$; III – level of multiplexing of channels with separation of signals 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:

$$k_{res} = 100 \times \left[1 - \prod_{1}^{i=n} \left(1 - k_i / 100 \right) \right], \quad i = 1,2,3,\ldots,n, \qquad (3)$$

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.

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