Tuchola County Broadband Network (TCBN)

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In memory of Professor Antoni Zabłudowski

Professor Antoni Jan Zabłudowski
(1947-2012)

In June of this year, passed away Professor Antoni Zabłudowski, Dean of the Faculty of Telecommunications and Electrical Engineering, the author of 76 articles and 15 unpublished works, 5 monographs, member of the Technical Cybernetics Polish Academy of Sciences, Section of Electronics and Telecommunications of the Polish Academy of Sciences and the Scientific Society of Bydgoszcz. Promoter of over 150 masters engineers, about 40 engineers, three doctors, two doctoral supervisor under the PhD, reviewer of 8 doctoral dissertations and two postdoctoral works.
Almost all his science life Professor Zabłudowski was associated with the current University, initially College of Engineering, later transformed in 1974 into the Academy of Technology and Agriculture, and in 2006 into the University of Technology and Life Sciences.

In the year of 1964 professor Zabłudowski started to study in College of Engineering on the department of telecommunications and Electrical Engineering which he graduated in 1968 with a electrical engineer degree. Already during studies he was fascinated with most advanced modern electronics what he proved writing his thesis titled "Digital frequency meter". He designed and constructed this meter on his own basing on transistors. In the beginning of his career, for a short time he was working in Department of Electronic Engineering of Computing as a hardware conservator. After 6 months he comes back to University. During work as an Assistant at the same time he was studying mathematics on Nicolaus Copernicus University in Torun. Acquired theoretical and practical knowledge and experience gained in the work allowed him to prepare and defend a master thesis "Probabilistic automats languages". Further scientific career of Professor Zabşudowski is related to the analysis and optimization of telecommunications networks. Her first step was to obtain the title of doctor of technical sciences, given to him by Gdansk University of Technology with a thesis "Optimization of telecommunication networks with alternative routes selection rule". Collaboration with Professor Seidler led to the preparation of postdoctoral degree thesis "Algorithms of network optimization topological structures", so he obtained a title of assistant professor specializing in telecommunications.
Regardless of the theoretical work related to telecommunications networks and computing, a significant part of his activities in the 80-ies of the last century, he devoted to the practical application and implementation work carried out for the industry. As examples of his activities can serve the following projects:

- Selected aspects of computer network design methodology. Research work carried out as part of the departmental problem RI-14;
- Digital subscriber line system 2B + D ISDN system to work with the subscriber's telephone exchange. Work carried out in the target project funded by the KBN (Polish Comity of sciences research) No. 8 8,404 91 C;
- Project of a diagnostic tool for assess of the sustainability of switching-extinguishing systems of HV circuit breakers, made and implemented to operate on behalf of the Northern District of Energy;
- Tester of programmable switching field module made for Telkom-Telfa.

An important area of theoretical work carried out at that time under the direction of Professor Zabłudowski, was the analysis of the properties of multilevel pseudo-random number sequences generated over the body of Galois GF (2^k) and GF (p).
In the early 90's, Professor Zabłudowski received from the Ministry of Defense proposal to build a dispatch-conference system for the military. This system had to meet the following functions - transmission, switching and computing. To meet this challenge Professor Zabłudowski decided that it is necessary to create a competent team consisted of the young graduates of the University. As a result, it seemed, by hazardous idea, its objective has been achieved, as evidenced by the fact that the system CDK has been designed, built and implemented, and, despite the passage of years, it is working successfully in the armed forces till today.
On the basis of the experiences achieved during CDK system design, the communication system for railways was created. This system joined the old analog communication system with the new digital one. At the request of the Town Hall of Bydgoszcz the team has participated in the development and implementation of the "Safe City" project, which allows the monitoring and controlling operations of municipal services in crisis situations.
At the same time, at the request of the Military Institute of Communications, a team led by Professor Zabłudowski made a model of electronic switch for internal communication of mobile means of transport for audio and data transmission.
In 2003 Kuiawian-Pomeranian Information Network (KPSI) was established, whose mission was to build a broadband network for Kuiawian-Pomeranian region. Vice President of the company was Professor Zabłudowski, who represented both the University of Technology and Life Sciences, and served as project manager and technical supervisor of its implementation.
By working with KPSI the team participated in a number of projects related to the design of broadband networks for Kuiawian-Pomeranian and Mazovia regions. Developed the concept of building WiMax radio network in the province of Kuiawian-Pomeranian implemented under the Regional Operational Project. Developed an analysis of the use of fiber optics in distribution network district - municipality for the construction of the access network in the district of Chełmno and performed a case study of installation for Wimax in the county of Tuchola, prepared fiber optic network project with the feasibility study and the functional utility program for the city Wąbrzeźno and fiber network project with feasibility study and functional-utility program for the district of Tuchola with Tuchola town.
Experience with the design methodology of regional networks has been collected and published in the form of papers which are a kind of handbook for designers for this type of networks.
In recent years the scope of the work of his team was expanded to include issues of wireless sensor networks.
In addition to the practical tasks, Professor Zabłudowski run the theoretical research related to the modeling of telecommunication networks with the help of regular graphs. The result of analysis and research are several papers. Interest in this subject has also resulted establishing close cooperation with the University of Aalborg. For several years, regular meetings and workshops, which made the exchange of experiences, there are set the way forward on issues of interest to both parties. The result of these meetings, are a number of joint publications published in journals or presented at international conferences. How close is the cooperation and how sincerely enjoyed Professor Zabłudowski person was evidenced by the fact that he was invited to provide lecture at doctoral study, as well as he was a member of the commission of doctoral dissertation at the University of Aalborg, issuing opinions on applications for the position of Associate Professor. Planning was also the issue of releasing of a textbook for students discussing the methodology of designing networks.
Unfortunately, the premature death meant that left us an outstanding scientist and magnificent man of whom we will always remember.

TUCHOLA COUNTY BROADBAND NETWORK (TCBN)

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Abstract. In the paper the designing project (plan) of Tuchola City broadband IP optical network has been presented. The extended version of network plan constitute technical part of network Feasibility Study, that it is expected to be implemented in Tuchola and be financed from European Regional Development Funds. The network plan presented in the paper contains both topological structure of fiber optic network as well as the active equipment for the network. In the project described in the paper it has been suggested to use Modular Cable System - MCS for passive infrastructure and Metro Ethernet technology for active equipment. The presented solution provides low cost of construction (CAPEX), ease of implementation of the network and low operating cost (OPEX). Moreover the parameters of installed Metro Ethernet switches in the network guarantee the scalability of the network for at least 10 years.

1 Introduction

The total volume of traffic carried in broadband IP network is determined by the usage of different applications implemented in the network. All services offered to the users in the highest technology network impact on the one hand on the network layers realization and on the other one on income gained from network operation. Starting with 2008, Cisco has issued three successive reports [1, 2, 3] that concerns to IP traffic estimation. These reports analyze all segments of IP traffic and show the tendency of traffic changes. The reports show that the greatest increase of total traffic concerns to residential users. Moreover reports show that:

1. In 2014, the Internet will be four times larger (in traffic sense) than it was in 2009.

2. Global IP traffic will quadruple from 2009 to 2014. Overall, IP traffic will grow at a compound annual growth rate (CAGR) of 34 percent.

3. Annual global IP traffic will exceed three-quarters of a zettabyte (767 exabytes per year or 64 exabytes per

month) in the year 2014.

4. Global Internet video traffic will surpass global peer-to-peer (P2P) traffic by the end of 2010, so P2P traffic will not be the largest Internet traffic type. The global online video community will surpass 1 billion users by the end of 2010.

5. Video communications traffic growth is accelerating and will increase sevenfold from 2009 to 2014.

6. Real-time video is growing in importance. By 2014, Internet TV will be over 8 percent of consumer Internet traffic, and ambient video will be an additional 5 percent of consumer Internet traffic. Live TV has gained substantial ground in the past few years. Consumer IPTV and CATV traffic will grow at a 33 percent CAGR between 2009 and 2014.

7. Globally, mobile data traffic will double every year through 2014, increasing 39 times between 2009 and 2014. Mobile data traffic will grow at a compound annual growth rate (CAGR) of 108 percent between 2009 and 2014, reaching 3.6 exabytes per month by 2014. Almost 66 percent of the world's mobile data traffic will be video by 2014.

The expectations for total transferred volume traffic in actual broadband IP network discussed above impacts mainly on the structure of such network. Such huge volume traffic requires efficient backbone network for traffic transfer from one hand, and high bandwidth access lines from the other one. Currently, Telecomm Operators invest gigantic funds to improve backbone infrastructure, i.e. switching and transport layers of broadband IP network. Only few of them however invest money into access layer of the network, as improvement of this network layer requires investment expenses.

OECD statistics [9] for 2nd quarter of year 2010 shows that Poland broadband infrastructure seen as the penetration of broadband access lines locates Poland on one of the last places among OECD countries regarding. The average penetration of broadband access lines in Poland is 12 lines per 100 citizens where 7 ones of them are implemented in ADSL technology and 4 of them are implemented in DOCSIS technology (cable TV). In Polish network there are almost no FTTH technology access lines. It is result of very limited investments in fiber infrastructure in all layers of the network. In Fig. 1 there has been shown six years historical series of broadband access lines penetration for two most advanced counties, namely Korea and Japan, Poland for comparison with Korea and Japan, and OECD as an average of all OECD countries [10].

Currently, the broadband networks, co-financed with the European funds, are starting to be deployed in many different regions of Poland. In previous financing period, that has took place in years 2004÷2006, the only Kujawsko-Pomorskie region broadband network, has been successfully implemented [9]. In current financing period (2007÷2013) the broadband networks are intended to be implemented in some other regions of Poland. The main goal of the regional broadband networks implementation in Poland is to fulfill the gap which has appeared as a lack of investment in broadband networks infrastructure. Broadband Internet is the basis for the development of all modern networks and first of all consists a base for the construction of NGN networks.

Broadband Internet infrastructure is treated now as fundamental factor affecting on rapid development of all European countries. So, that was the reason of announcing on May 2010 special Digital Agenda where European Commission declare the policy oriented towards broadband Internet [4]. As the future economy will be a network-based knowledge economy with the internet at its centre, the actual EC policy requires additional support to improve modern Internet network - especially network infrastructure. The Europe 2020 Strategy has underlined the importance of broadband deployment to promote so-

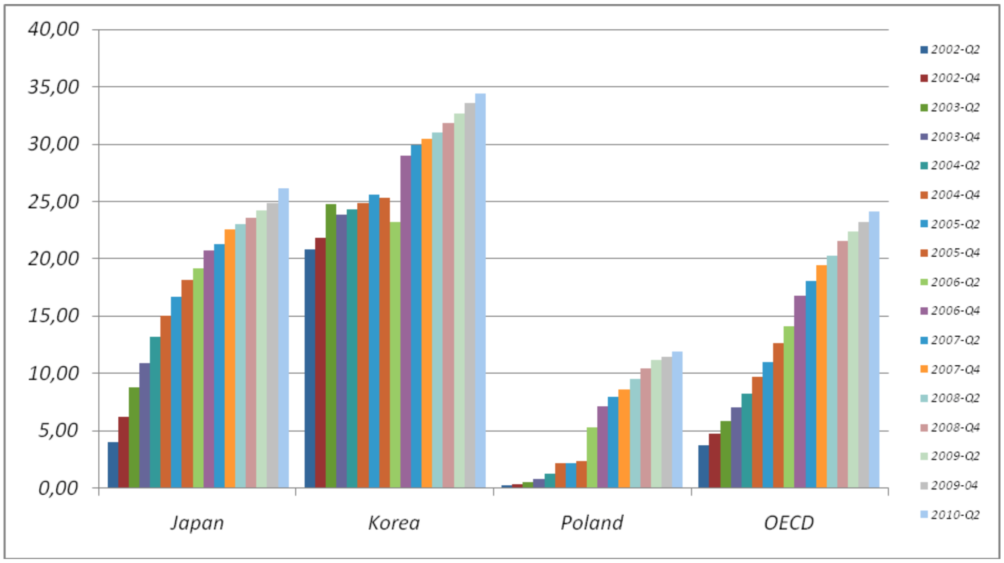

Fig. 1: Six year historical time series, broadband lines penetration (June 2010) for Japan, Korea, Poland and OECD, as an average for all OECD countries

cial inclusion and competitiveness in the EU. It restated the objective to bring basic broadband to all Europeans by 2013 and seeks to en sure that, by 2020:

- all Europeans have access to much higher internet speeds of above 30 Mbps,
- 50% or more of European households subscribe to internet connections above 100 Mbps.

The only solution of 100 Mbps access line bandwidth is to built it as the optical access, i.e. to implement in access network layer FITL technology (Fiber In The Loop) and especially FTTH (Fiber To The Home) technology. Rapid deployment of FITL technology into telecom networks is currently realized in Korea and Japan (on the world) and in Sweden and Denmark on Europe [9]. However the FTTH lines penetration is usually very low in many countries (in Poland is less than 1), what is depicted in Fig. 2 [4].

From Fig. 2 it follows that the level of FTTH lines penetration is very low in Europe, putting Europe far back towards Japan and Korea. Implementation of specialize services in European networks show that some of them could not be successfully offered in wires broadband access lines (for example healthcare systems) [11]. So, many European countries invest or intend to invest in FTTH infrastructure improving existing telecomm operators networks. The Netherlands intends to reach 19% penetration (about 1,5 millions lines) of all homes lines with FTTH technology by 2014 [5] and the French government plans to invest 2 billion € and cover 100 % of its citizens with fiber by the year 2025 [6].

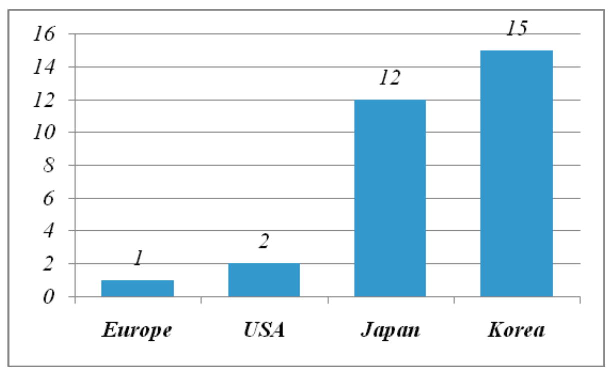

Fig. 2: Fiber to the Home (FTTH) penetration in July 2009

Poland is far back not only towards Korea and Japan but also towards almost all European countries. Changing this situation requires a lot of investment in existing network infrastructure, especially in access network layer. Currently, some Polish regions uses European Regional Funds (ERDF) to improve access network layer and implement FTTH technology in access layer networks. Usually, built in FTTH technology access network layers possesses functionality as the NGA.

Fiber To The Home is one of several methods for delivering Broadband to residential subscribers. With FTTH, the architectural distinctions between types of carriers disappear. All these carriers deploy virtually identical architectures once they are delivering services with FTTH, and the only remaining differences are largely due to legacy system support. As FTTH is one of the different access versions, so the others can be commonly used. Those other are as follows [7]:

- FTTB - Fiber to the Building, usually a multi-tenant building, with Digital Subscriber Line (DSL) or Ethernet delivered to each subscriber.
- FTTC - Fiber to the Curb, typically with some form of DSL connecting to the subscribers.
- FTTN - Fiber to the Node, typically with ADSL2+ or VDSL2 from an OutSide Plant (OSP) cross-connect to the subscribers.
- FTTP - Fiber to the Premises, where the premises could be a business or a residence.

The Authorities of Tuchola County decided to build the modern IP network, that cover entire Tuchola region. This network was to be financed from ERDF funds of actual financing period. Before to apply for ERDF funds the Feasibility Study should be prepared, where one of part of it was the network project. Tuchola County network project has been done by the staff of Computer Communication Division Institute of Telecommunication UTP.

2 Topology of Tuchola County Optical Network

Considering all the possible services expected by network users, i.e. Internet access, digital TV, VoD, P2P, videoconferencing, monitoring, controlling, VoIP services as well as the tendency in IP network development we decided to implement this regional network as the optical network. The network project (network plan) required to define, at the beginning topology of the network, but the network topology has been followed from Tuchola County Authorities requirements.

One of the main requirement from Tuchola County Authorities was that each node of the network should be located in the town or village in County that is the capital of commune. So the ducts with optical cables should connect all these places. The ducts has constituted the backbone layer of planned network. In order to improve network reliability, it has been assumed that backbone layer is formed from two optical fibers and operates as bi-directional ring. It has been assumed that the fibers should be ended in municipal offices located in capital of commune. The planned network should operate as aggregation/distribution layer with FTTN functionality.

During network planning process it has been decided also that optical fibers passing villages and towns situated on the route of chosen course of fibers, will be ended in the areas where the greater number of people live. The villages that belong to smaller districts called parishes should be connected to the nodes of backbone layer located in communes capital, with one link constituting star topology.

The terrains of Tuchola's County region are in majority rural and forest areas. The small business located here is mainly set on food processing activity. There is also furniture, mechanical and construction business here. The main part of this institutions is located in Tuchola. The number of small and medium enterprises, which are interested with the access to the network, has been estimated at 15% of whole enterprises.

Tourism also plays an important role for the region development. Although it has seasonal character the demand for this sector has been also included. In view of lack of information regarding exact localization of the business entities it has been assumed that they are located in community nodes, which should not have an direct impact on calculations results, as information from this type of users flow to this nodes.

For estimation of global bandwidth demands it has been assumed that the following public institutions will be connected to Tuchola County broadband information network:

- Primary schools, gymnasium, secondary schools, other educational institutions.
- Hospitals and health institutions.
- Police and municipal police.
- Fire departments.
- Commune and district offices.

It has been assumed that all educational, local government and health institutions, as well as police and fire departments, municipal and community offices are predicted to have an access to the broadband network. The topology of cable ducts for Tuchola County broadband network, both for backbone as well as for access is depicted in Fig. 3.

In Fig. 4 the connection structure for TCBN network has been depicted. Fig. 4 shows that most of lines that connects backbone nodes of TCBN network with nodes located in parishes are direct lines. Only small part of those line passes via intermediate nodes located in other parishes. Using separated fibers for each connection (this method will be discussed in detail in the next part), it is easy however to connect each parish node directly to backbone one. From Fig. 3 follows that total length of all cable ducts for TCBN is equal to 266,9 km, where:

- the length of backbone layer network is equal to 116, 9 km,
- the length of all connections to parishes is equal to 139 km,
- the length of ducts in Tuchola is equal to 11 km.

The project of the passive physical network layer (fiber optic network) involves the construction of the network using Modular Cable System (MCS) technology with the usage of one pipe equipped with three micro pipes. The assumptions about the construction of passive infrastructure are as follows:

- The fibers optical cables are done based on the MCS system.
- MCS cables (pipes) that are used for network construction are suitable for digging directly in the ground. Every pipe is equipped with 3 micro pipes. The fiber cable can be blown into each of micro pipe.
- In the first stage of project implementation to one of three micro pipes fiber cable is blown. The cable contains 96 fibers on the basis of 8 micro cables with 12 fibers in each micro cable.
- For network transmission capacity extension in the future, at each 1 km cable distance the cable bunkers are placed.

For estimation in rural area of investment cost of 1 km MCS cabling infrastructure it has been assumed that:

- Excavation for the cables - 24,0 thousands PLN.
- Cost of cable including MCS cables - 9,0 thousands PLN.
- Optical cable with 96 fibers - 11,0 thousands PLN.

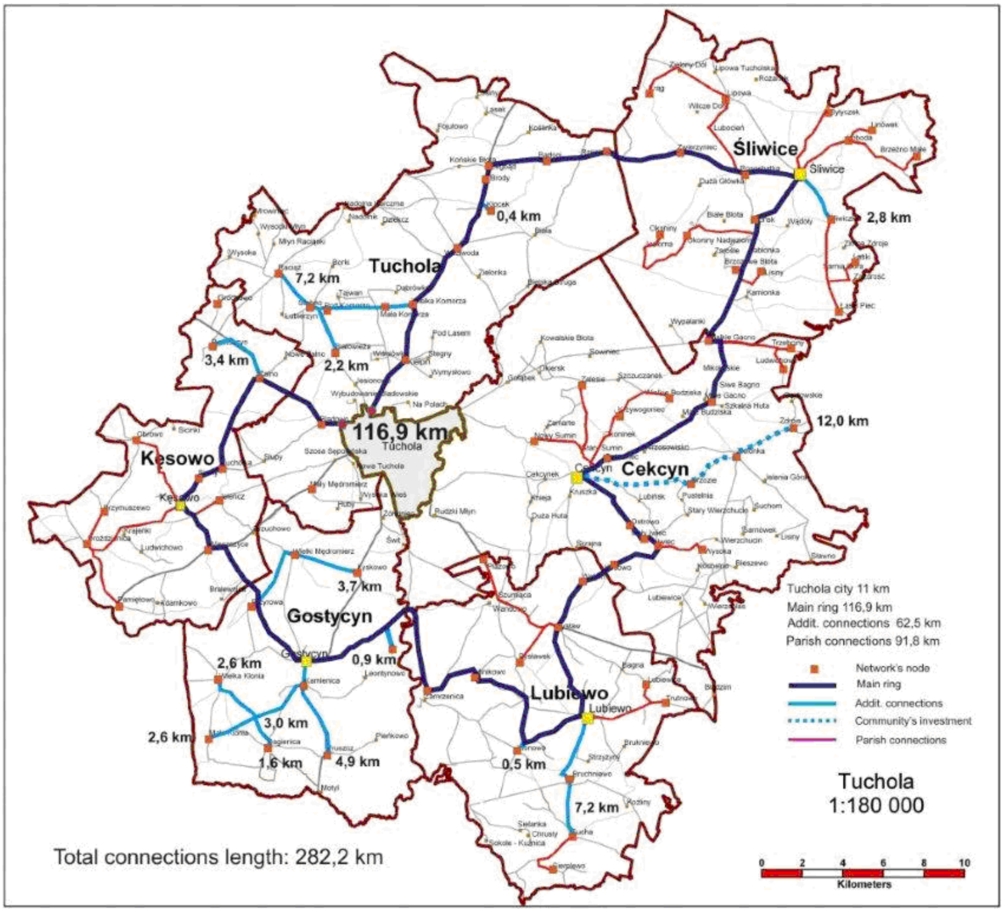

Fig. 3: Topology of cabling infrastructure for Tuchola's County Broadband Network

- Blowing the cable - 2,5 thousands PLN.
- Cabling bunkers - 2.0 thousands PLN.
- Welds - 2,5 thousands PLN.
- Measurements - 1,0 thousand PLN.
- Project - 6,5 thousands PLN.
- Fibers tray - 1,0 thousand PLN.
- Accessories - 0,5 thousand PLN.

Prices used for estimation of 1 km MCS investment cost were taken as an average of prices from different companies that build optical cabling network.

The total cost of 1 km of optical fiber in rural area was estimated on the level of 60 thousands PLN, so the total investment cost of Tuchola County Optical Network passive infrastructure has been calculated and was equal to **15.354 thousands PLN**.

3 Topology of Tuchola City Optical Network

The TCBN project contains also separate project for Tuchola City, i.e. the city that is the capital of County. As it was in the case of TCBN, the optical network in Tuchola City was designed in FTTN technology. Topological structure of Tuchola City network passive fiber optic

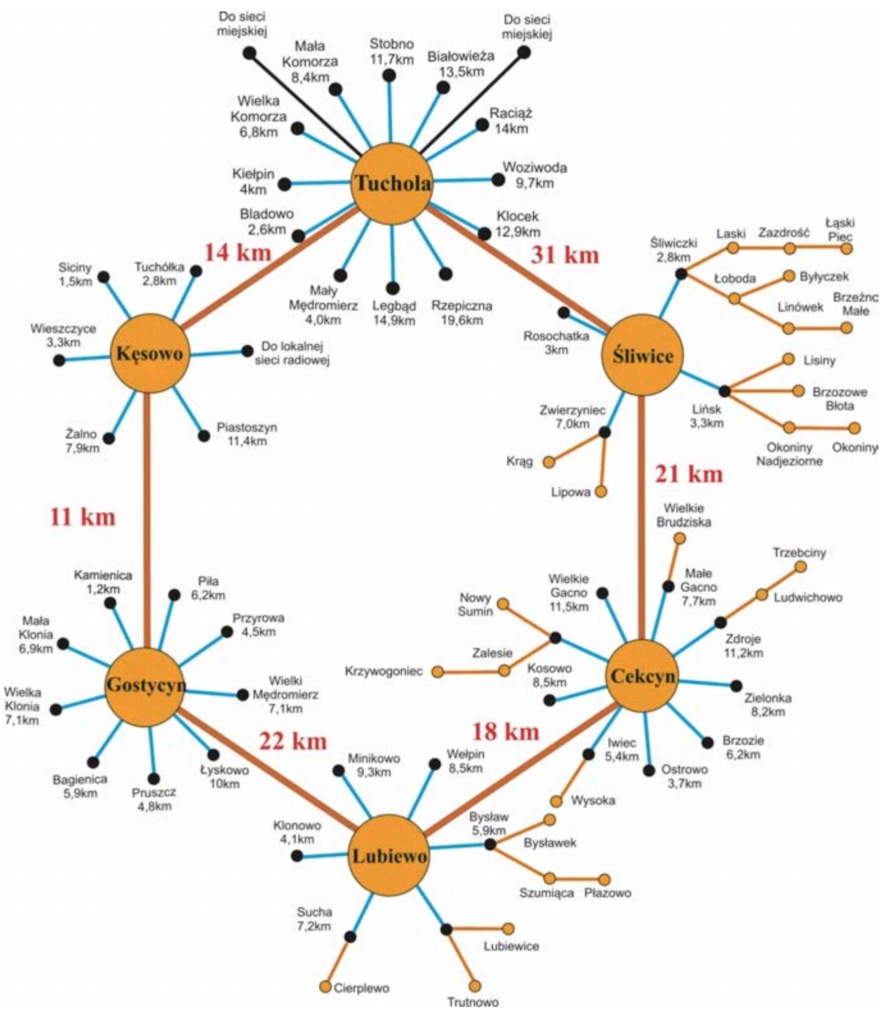

Fig. 4: The logical topology of the TBN Network

physical layer is shown in Fig. 4. This structure shows layout of all build, under the ongoing project, fiber optic cables, both for backbone and access network. In table 1, Tuchola City network node locations and characteristic of those nodes has been depicted.

In turns, Fig. 5 shows a topology structure of network nodes and links connections between the nodes depicted in Fig. 4, that was created on the basis of fibers cable physical layout. The diagram presented in Fig. 5, has been used for a mapping of physical topology depicted in Fig. 1 into logical network topology shown in Fig. 4. In planned Tuchola City IP network it has been assumed that 3 nodes (BN_1, BN_2, BN_3) function as the distribution/ aggregation nodes and the other ones as the access nodes.

Distribution/aggregation nodes of Tuchola City network plays the role of backbone layer network nodes connected together by the fiber links. The backbone layer of every network should be characterized by high level of network reliability. So, over designing process of physical topology Tuchola City network structure, it has been assumed that distribution/aggregation nodes will be connected with double fiber rings. Double ring topology structures are used very often as the topology of backbone layer, as on the one hand this topology ensures high level of network reliability but on the other one, simplifies the management process of traffic transfer in the network.

The way of increasing reliability level of traffic transfer in the ring structure it uses one of well known methods of link or path protection [8]. The main principle of protection lies in fact that all selected pairs of nodes, that communicate with each other, are connected by two disjoint routes. In double fiber optical ring, each of these paths uses single optical fiber. One path is called working path and the second one, protecting path, They are implemented with the use of disjoint rings. Traffic transmitted from any two nodes in backbone must pass through all intermediate nodes lying between those nodes. As in Tuchola City network three backbone nodes are connected without any optical system, so communication between any two nodes, in working or protecting paths, are always done via the third node (in working or protecting paths).

On the basis of fiber rings layout depicted in Fig. 4, real physical network structure of Tuchola City has been modified to "traffic oriented network" [12]. Modified Tuchola City physical network infrastructure includes two unidirectional fibers rings (or one bidirectional), that join three backbone nodes denoted as BN_1, BN_2, BN_3, and also links joining 16 access nodes to backbone ones. So, the modified physical fiber cables structure of Tuchola City IP network is implemented in the form of double fibers ring connecting distribution/aggregation nodes (backbone layer), and branches (spurs), joining backbone nodes with access ones located in the city. Thus the real structure of Tuchola City network topology, build on a physical basis of topological structure presented in Fig. 4, is shown in Fig. 5. From Fig. 5 results that two backbone nodes BN_2 and BN_3 are connected to regional (K-PSI) network via IXP. Two connections of Tuchola City network with regional network has been assumed to increase the level of reliable transfer to the global Internet via nodes A_{13} and A_{21}.

To be able to realize the topological structure of planned network the suitable usage of optical fibers is needed. The main idea of fibers usage is shown below in Fig. 6. Access nodes located on the spurs of network structure are connected with dedicated fibers to the ring, and then using dedicated ring fibers, to backbone nodes. Access nodes located in the ring has been connected to backbone nodes using fibers in the ring. Connections of access nodes located in the ring are realized out as follows: in each relation (optical cable joining neighboring nodes) one pair of fibers (let us take the pair marked with red color) is used for connection of backbone nodes. The other pairs of fibers in analyzed relation can be used for

Tab. 1: Node location and their characteristics

Node	Node Type	Location
Starostwo Powiatowe	**Backbone (BN1)**	Pocztowa st.
NZOZ Hospital	Access (A1)	Nowodworskiego st.
Marketplace	Access (A2)	Marketplace
Secondary school	Access (A3)	Pocztowa st.
Primary school num. 3	Access (A4)	Pocztowa st.
Sport and recreation	Access (A5)	Warszawska st.
Kindergartner	Access (A6)	Piastowska st.
Speciality School	**Backbone (BN2)**	Piastowska st.
Middle school	Access (A7)	Piastowska st.
Tuchola hospital	Access (A8)	Świecka st.
Przedsiębiorstwo Komunalne	Access (A9)	Świecka st.
Kindergartner num. 1	Access (A10)	Bydgoska st.
High school and techinical school	Access (A11)	Świecka st.
Primary school num. 5	Access (A12)	Świecka st.
Regional network	Access (A13)	Główna st.
KPSI	IXP	Przemysłowa st.
Fire Department	**Backbone (BN3)**	Sępoleńska st.
Police	Access (A14)	Świecka st..
Court	Access (A15)	Dworcowa st.
Promary school num. 1	Access (A16)	Szkolna st.
Medical center	Access (A17)	Świecka st.
City hall	Access (A18)	Plac Zamkowy st.
Tax office	Access (A19)	Plac Zamkowy st.
Cultural Centre	Access (A20)	Plac Zamkowy st.
Regional network	Access (A21)	Główna st.
KPSI	IXP	Przemysłowa st.

Fig. 5: The map of planned optical fiber ducts for Tuchola City network

connection of access nodes located in this relation with the nearest (and only one) backbone node. To connect each access node, the described idea requires to use separate pair of fibers. Obviously, similar situation is when connecting access nodes on spurs, as in the ring the fibers for joining spur nodes are chosen in the same way as the fibers for connection of access nodes lying in the ring.

However, to reduce the number of needed fibers, it has been assumed that the pair of fibers in the cable with the same number can be used repeatedly, however, two access nodes located in the network ring can be connected, with the same number of fibers pair, to different backbone nodes. For example, in Fig. 6 it has been shown that the pair of fiber marked with a green color (let us assume fiber pair with i-number) connects, in the same cable relation, A3 with BN1 and A6 with BN2. The described above method of fibers reuse, gives topology required minimal number of fiber pairs usage. For network presented in Fig. 5, the construction of this network requires only four pairs of fibers. In this way the logical structure of all connections is depicted in Fig. 7, where each Node (installed in access node) is join directly with one backbone node. The described method of fiber reuse has been also used in TCBN network for connecting communities and parishes

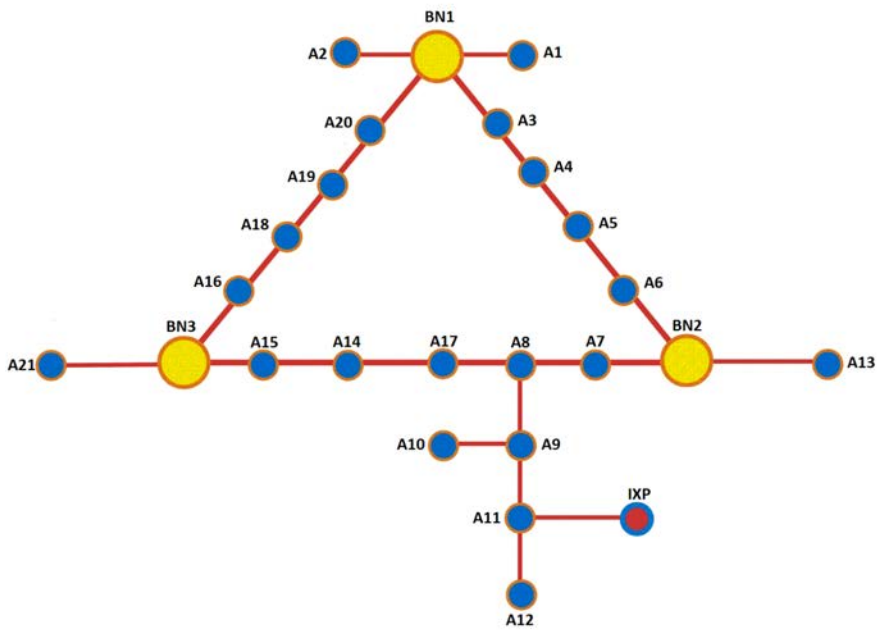

Fig. 6: Physical connection scheme following from network structure shown in Fig. 4

in Tuchola County.

Estimation of 1 km MCS cabling infrastructure investment cost in Tuchola City is based under the same assumption as for rural area, with the only difference that concerns to cost of excavation for the cables. Usually, in cities this cost is much higher than in rural area, so we have assumed that instead of 24,0 thousands PLN, this cost in Tuchola City is equal to 74 thousands PLN. Thus the average cost of 1 km fiber cable implementation in Tuchola City is around 110 thousands PLN. As the total length of fiber infrastructure in Tuchola city is about 11 km long, so the total cost of Tuchola City network passive infrastructure (fiber cabling) was calculated as 1,22 millions PLN.

Before the necessary choice of the equipment it is essential to evaluate the total volume of traffic generated in Tuchola City network. The traffic in this network has been calculated in accordance with the procedure outlined in the paper [12]. For traffic evaluation the following assumptions has been taken:

1. around 20% of all households in Tuchola city will be connected (via ISP networks) to planned Tuchola City Network. Average capacity of user access line will be 6 Mb/s;

2. around 15% of total number of SME companies (Small and Medium Enterprises) will be connected to planned network. Average capacity of business user access line will be 20 Mb/s;

3. all educational institutions, government, and local government agencies, health care, police department, fire department, municipal and county offices will be connected to designed network. Average capacity of access line for institutional users will be 10 Mb/s;

4. overbooking factor is assumed as:

    - 20 for residential users,
    - 10 for business user;

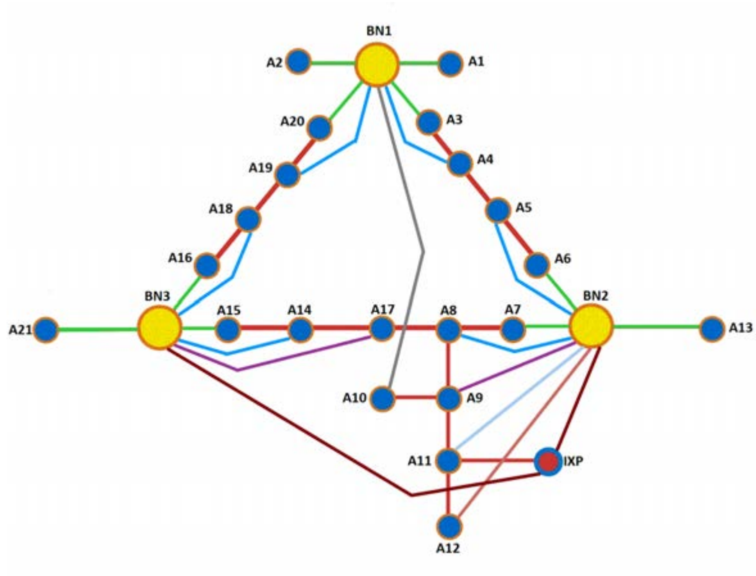

Fig. 7: Physical fibers connections for backbone and access network implementation

- 6 for institutional ones.

Taking into account the assumptions presented above, the total volume of traffic generated in Tuchola City has been estimated equal to 700 Mb/s.

4 Active infrastructure for Tuchola County Broadband Network

In TCBN network the same active equipment has been used. Before the concrete active equipment has been chosen there was made necessary calculation to evaluate equipment efficiency (performance) in the sense of total traffic volume served in the network. The total traffic volume generated in TCBN network has been made according to the procedure proposed in [12].

As an active equipment option for TCBN network, there has been chosen Metro Ethernet switches with path protection. This option is both, cost effective (allows to build the network with minimal cost) and bandwidth effective (ensures high throughput). The details requirements for Metro Ethernet switches installed in TCBN network are given below:

- Two neighboring backbone nodes connected (on double fiber rings) to the third one are using 2 optical links with capacity of 10 Gb/s. Such high capacity of backbone connections will allow to operate TCBN City, ensuring network scalability for at least 10 years and guaranteeing the appropriate level of services offered in the network. Switches ports of 10 Gb/s capacity should be equipped with optical interfaces ensuring proper transmission even on 40 km range. Every Metro Ethernet switch installed in backbone layer node additionally should support MPLS protocol, as the protection functions in the backbone are provided by MPLS protocol. MPLS protocol ensures traffic switching into protecting path in the case of working path failure.

- Each backbone node is equipped with 24 optical ports with 1 Gb/s capacity, through which these nodes are connected to lower level access nodes, located throughout the city. Similarly to the specification of backbone ports, also 1 Gb/s access ports should provide efficient transmission of up to 70 km

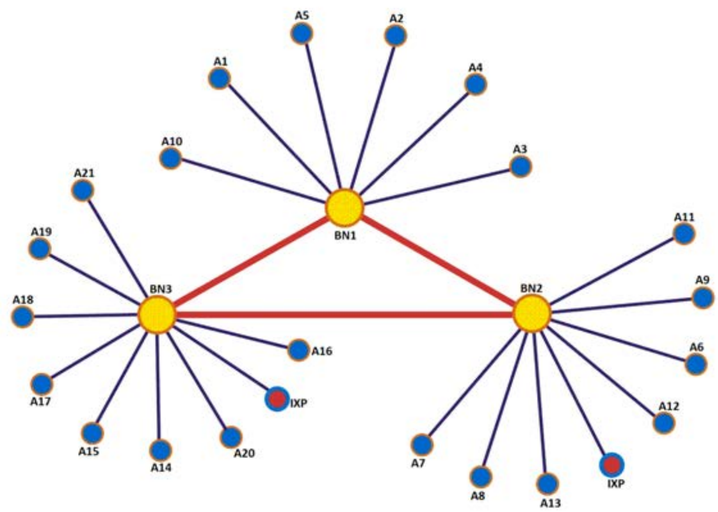

Fig. 8: Logical topological structure of Tuchola City IP network

distance.

- In access nodes the switches are equipped with one 1 Gb/s optical port (for connection with backbone node) and at least 6 wire ports (for user connection) with capacity 1 Gb/s.

- It has been assumed that active equipments of backbone nodes are installed mostly in the indoor cabinets. The cabinets are equipped with power supply unit, air condition device and UPS module. The outdoor cabinets are only located at the police station, hospital, fire department and City Hall, as there is no possibility to install indoor ones. Outdoor cabinets are also equipped with air condition devices, power supply unit as well as UPS.

In designed TCBN network the backbone nodes have been located in community capital (for rural areas) or in three main locations (District Office, Speciality School and Fire Department) for Tuchola City network. It should be noted however that described network would operate in future as Carrier of Carriers network type, where the users (both residential and business) going to be join to the network via local ISP networks. So, in the planned here network do not exist access lines connecting end users, as in fact this city network is "last mile before" network.

The switches for backbone nodes connections, both in rural area as well as in Tuchola city has been chosen on the basis of the following assumption: all backbone nodes in TCBN network, i.e. towns or villages where the commune headquarters are located, and backbone nodes in Tuchola City network are connected with through links with a capacity of 10 Gb/s. As all backbone nodes are connected physically by the double optical ring Metro Ethernet switches joining backbone nodes possesses built in functionality of increasing network reliability. Each ME switch, installed in backbone node, is equipped with two 10 GbE ports connected to two separate fibers. In the case of the fiber failure, traffic transfer among every pair of backbone node can be realized with the use of one or second fiber. 10 Gbps links capacity allows to operate the network for next couple of years with the assurance of high level of services offered by the network (high network scalability). As, in rural part of TCBN, the backbone nodes are located even several dozen kilometers each other, 10Gb/s Metro Ethernet ports have to be equipped with the inserts which allow the optical propagation of the signal at distance of 40 km. For switches installed in Tuchola City network backbone nodes the inserts allow the optical propagation of the signal at distance of 10 km.

Both for rural and city parts, the network has been planned to ensure wide scalability. It has been assumed that the main nodes of the network (backbone ones), are to be connected to each other using links with transmission capacity of 10 Gb/s, while the access nodes has been joined to the backbone nodes using links with 1 Gb/s transmission capacity. Logically, the access nodes together with backbone one, forms a star topology (the optimal topology for "traffic oriented network") with backbone nodes as the main star nodes. Functionally, both the backbone and access nodes of TCBN network meet mainly distribution (aggregation) functions, as their role is traffic transfer, to (from) main (backbone) nodes, from (to) access nodes and further to (from) regional network and thence to (from) global Internet. All access nodes lying both, on network ring or outside network ring are connected with dedicated fiber to only one backbone node. Admittedly, the star structure of access network does not guarantee high level of reliability, but it is the cheapest structure, that allow efficient traffic transfer. In fact, the damage of a fiber optic link will affect only the small group of users.

The switches installed in backbone nodes are also equipped with at least 12 ports with a total throughput of 1 Gb/s each. These ports are used to connect the parish (in rural area) or access (in city) nodes within the backbone nodes. All these 1Gb/s ports have optical interfaces that allow to traffic transfer at distance of 10 km or 70 km.

The price of the 10Gb/s equipment is estimated as follows: backbone ports - 112 thous. PLN and access ports has been calculated using the relation: n10 * 2,4 thousands PLN for the 10 km transmission or n70 * 8,6 thousands PLN for the 70 km transmission, where nx means the number of these kind of ports. It is assumed that devices in rural area the backbone nodes are installed in indoor cabinets. These cabinets are equipped with an UPS battery in case of power failure. The estimated cost of the cabinet including UPS system is 10 thousands PLN. In Tuchola City network backbone node equipment is also installed in indoor cabinets.

In parishes (in rural areas) and in access nodes (in Tuchola city) the direct access to optical network (to backbone nodes) is realized by switches equipped with 1Gb/s optical port. These switches are also equipped with at least 6 GE wire ports. The cost of the nodes in parishes (in rural area) and access nodes (in Tuchola city) include the cost of switch and transmission inserts. The cost of the switch with 6 GE ports is estimated at 3,0 thousands PLN whereas for optical 1Gb/s insert with a range of transmission at 10 km - 2,4 thousands PLN and at 70 km - 8,6 thousands PLN.

The parishes devices are installed in indoor cabinets. No UPS battery support system is predicted there. The cost of such cabinet is estimated at 3 thousands PLN. If there is no possibility to place indoor cabinets the outdoor cabinets are predicted to be used instead. The outdoor cabinets are equipped with AC and ventilation system. The cost of such cabinet is estimated at 16 thousands PLN. It has been suggested that the Tuchola County Broadband Network should be connected to the global Internet via Kuyavia-Pomerania Regional Broadband (K-PSI) network. The Internet Exchange Point with K-PSI network is installed in two backbone nodes located in a Main Power of Tuchola. The connection between TCBN and K-PSI regional network is going to be implemented for every node through two links with 1 Gb/s each (all together 4 Gb/s).

The total cost of network infrastructure (including active and passive equipment) installed in entire Tuchola County Broadband Network equals to: 13272 thousands

PLN. The total cost of network infrastructure installed in Tuchola City network has been estimated on 1914 thousands PLN.

5 Conclusions

The paper is devoted to the designing project (plan) of Tuchola County Broadband Network (TCBN). In the paper, the topological structure of fiber optic network as well as the final solution for active layer of the network has been presented. For construction of passive infrastructure the technology of Modular Cable System - MCS has been suggested. Within this technology the fairly wide range scalability and cost effective network has been provided.

For the construction of TCBN network active layer the Metro Ethernet technology is used. Metro Ethernet technology provides a low cost of construction (CAPEX), ease of implementation of the network and low operating cost (OPEX). The parameters of installed network switches (switches) Metro Ethernet guarantee the scalability of the network for at least 10 years. The project assume also, that the city network in Tuchola cooperate with the regional K-PSI network (TCBN network and K-PSI network exchange traffic via common IXP point).

Total network investment cost in Tuchola County is estimated on 15,2 million PLN.

References

[1] Cisco Visual Networking Index: Forecast and Methodology, 2007-2012, June 2008.

[2] Cisco Visual Networking Index: Forecast and Methodology, 2008-2013, June 2009.

[3] Cisco Visual Networking Index: Forecast and Methodology, 2008-2013, June 2010.

[4] A Digital Agenda for Europe. Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels, 19.05.2010.

[5] Dutch FTTH penetration to reach 19% of households by 2014. `http://www.telecompaper.com/news/dutch-ftth-penetration-to-reach-19-of-households-by-2014`

[6] French government pledges €2 bn for FTTH. `http://www.ftthcouncil.eu/home/latest-news/french-government-pledges-2bn-for-ftth?news_id=3205&back=/home`

[7] FTTH Overview and Update. `http://www.fttxtra.com/ftth/ftth-overview-update/`

[8] Ming-Jun Li and other. Transparent Optical Protection Ring Architectures and Applications. Journal of Lightwave Technology.

[9] Nowak. K., Zabłudowski A., Regionalna szerokopasmowa sieć teleinformatyczna regionu kujawsko-pomorskiego. Przegląd Telekomunikacyjny i Wiadomości Telekomunikacyjne, 2005, 8-9.

[10] OECD Broadband statistics: OECD historical fixed (wired) broadband penetration rates, April 2011.

[11] Only FTTH can save Europe's healthcare systems. `http://www.ftthcouncil.eu/documents/Opinions/2011/eHealth_Final.pdf`

[12] Zabłudowski A: Broadband IP Networks Development. Image Processing & Communications Challenges, Academy Publishing House EXIT 2009, pp.417-434

USAGE OF DIGITAL IMAGE CORRELATION IN ANALYSIS OF CRACKING PROCESSES

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Abstract. In this paper, the analysis of the possibilities of using Digital Image Correlation (DIC) based on Graphics Processing Unit (GPU) for strain analysis in fatigue cracking processes is presented. The basic assumption for the discussed displacement and strain measurement method under time variable loads was obtaining high measurement sensitivity by simultaneously minimizing the measurement time consumption. For this purpose special computing procedures based on multiprocessor graphic cards were developed, which significantly reduced the total time of displacement and strain analysis. The developed digital procedure for correlation of images has been used for an example of displacement analysis in the method of fatigue crack propagation testing in airplane riveted joints. In this paper are presented the results of the researches of the team run by professor Antoni Zabłudowski.

1 Introduction

The possibility of application of digital image correlation method to analyze and strain has been an exceptionally attractive choice in the mechanics of solids [1, 2]. However, due to technological limitations, its practical application is far from being satisfactory, especially for an analysis of small strain values, typical for operating loads of structures and materials with high stiffness, for example, steel. Measurement of small displacements, which later provide basis for determination of strains, requires the use of very high resolution digital video cameras (even when sub-pixel interpolation methods are used) and this involves a necessity of transmission and processing of a huge amount of data in a very short time.

The complexity of applying strain determination methods based on analyzing the object's surface image appears to be high for time variable loads. Long lasting cyclical loads involve a significant increase in the amount of data to be processed with further reduction of the analysis time and a considerably higher probability of the method decorrelation.

Despite these inconveniences, the authors' experience in fatigue investigations and experimental methods provides good background with numerous for applying possibilities strain determination methods in many different fields, especially where other measurement techniques such a whole-field ones cannot be used, eg. due to impossibility of having direct access to the object or the object's dimensions are reduced and measurement sensors such as extensometers cannot be mounted.

The remainder of this paper presents a method of displacement and strain determination in the fatigue cracking zone, illustrated by examples of test carried out on aluminum samples of airplane structures.

2 Background

The image correlation methods, developed in the 80s, involve comparing a sample image before and after exposing the object to strain in the form of lighting with white light or laser light (spot methods) [3, 4, 5].

Displacements of characteristic points of the sample surface allow determining the strain values within the analyzed area. The sensitivity of this method depends on the parameters obtained using image observation methods such as dimensions of the observation field or the image geometric resolution. In case of many objects, measurements can be realized with the use of their natural roughness, thus, there is no necessity to previous prepare the surface to be analyzed. Another method of obtainment of random points on the sample surface is marking them by means of surface machining techniques, including painting. Image's surface points are recorded on PC (personal computer), before and after exposing the object to strain. This enables correlation of these images on the basis of intensity recorded for each pixel by CCD matrix or a different type of the image sensor. The usage of interpolation functions increases accuracy as compared to a strictly digital analysis carried out for a pixel grid. Also methods of artificial intelligence, including genetic algorithms, are used for the analysis of the image spot.

Development of the image digital correlation techniques is connected with the progress in optoelectronics. Constantly increasing resolution of video cameras makes it possible to obtain more and more accurate measurements. However, it should be remembered that in order to avoid the image de-correlation effect for cyclically variable loads, more frequent record of the image is required. An increasing resolution of video cameras and application of the image digital transmission systems involve a necessity of transmission of a huge amount of data in a very short time. This significantly limits the possibilities of DIC methods for time variable loads.

Nowadays, applications using DIC method can be found in experimental mechanics of solids, mainly for analyzing objects made of low stiffness materials which after being loaded usually reveal usually undergo big strains, thus this usage of lower resolution video cameras. For instance, in [2] presents results of tests performed in conditions of strong strain gradients: in a flat sample made of laminate near an opening, at the top of a crack in an alloy of TiAL (titanium-aluminide) and within the neck occurred in a polymer sample after stretching.

3 Digital Image Correlation method based on Graphics Processing Unit

The basic assumption for the discussed strain measurement method with time variable loads was obtaining high measurement sensitivity by simultaneous minimizing the measurement time. For this purpose special computing procedures based on multi-processor graphic cards (PGC) were developed. Analyzing displacements based on the assessment of the value of cross correlation coefficient C is one of the basic solutions used in the image cross correlation methods. The cross-correlation coefficient is determined for a chosen point of an environment $P[x, y]$, as follows:

$$C(u,v)=\sum_{i=a}^{b}\sum_{j=c}^{d}[I_n(x_i,y_j)I_m(x_i,y_j)] \quad (1)$$

and for a standardized version

$$C(u,v)=\sum_{i=a}^{b}\sum_{j=c}^{d}\left[\frac{I_n(x_i,y_j)I_m(x_i,y_j)}{\bar{f}\cdot\bar{g}}\right] \quad (2)$$

where $\bar{f}$ and $\bar{g}$ are respectively:

$$\bar{f}=\sqrt{\sum_{i=a}^{b}\sum_{j=c}^{d}[I_n(x_i,y_j)]^2} \quad (3)$$

$$\bar{g}=\sqrt{\sum_{i=a}^{b}\sum_{j=c}^{d}[I_m(x_i,y_j)]^2} \quad (4)$$

where: a, b - initial and final values of the correlated image coordinate x index, c, d - initial and final values of the correlated image coordinate y index, $In(x_i, y_j)$ - the image intensity in the point with coordinates xy, recorded in the phase of loading, $Im(x_i, y_j)$ - the image intensity in the point with coordinates xy, recorded in the phase of loading.

The value of coefficient C can change in the range from 1 to 0. When $C = 1$, the images of point P is in environment recorded in phases n and m are entirely consistent, and when $C = 0$ they are entirely different.

In order to define a displacement of a chosen point P, basing on images recorded in two phases of loading n and m, sub-area O covering point P is separated from image n and m it is displaced in relation to the analogical area in image n. The value of cross-correlation coefficient C is calculated for each location of sub-area O_n.

Due to low efficiency of standard functions to determine coefficient C, eg. those available in OpenCV library, an original algorithm of correlative search of the image similar areas has been developed. The implementation was performed by means of CUDA library in version 3.2, facilitated by NVidia Company [6, 7]. Since there are two known ways of obtainment of a resultant matrix of the pattern adjustment to the searched image (correlation matrix), it is necessary to make a choice in the initial phase, between the method utilizing Fourier transforms (used by Open CV library) and the method to directly determine values of the correlation function. It has been assumed that the pattern area dimension are: 20×20 to 40×40 points. For such dimensions the approach using transforms loses its efficiency because of a higher number of successive stages of computing. Therefore it was decided to carry out own implementation of the algorithm determining the correlation function according to the version directly defined by dependence 2.

Due to the fact that loading data into the global graphic card memory is one of the most time consuming operations affecting the general efficiency of the implemented algorithm, it was decided to carry out calculation threads connected with one line of searched image **I** in a block. For this line, there were performed all connected with it combinations of multiplications by the image of pattern **T**.

Therefore it is possible to avoid next loading the same data for image **I**, at the cost of reloading the pattern data (the pattern area is assumed to be smaller than the searched one). Since the data concerning points of the one image line represents successive memory cells, physically adjacent to each other, thus certain n of the data reading operations (typically including 128 bytes) can be combined into a single operation.

Examples of matrixes corresponding to the searched fragment of image **I** of size 9 and pattern **T** of size 3, are shown in Fig. 1. Thus, operations of partial sums of products belonging to different displacements of the pattern image are carried out by a single block of threads, which has been shown in Fig. 2.

For instance, in Fig. 3, the calculations performed by the third block of threads (connected with the 3rd line of

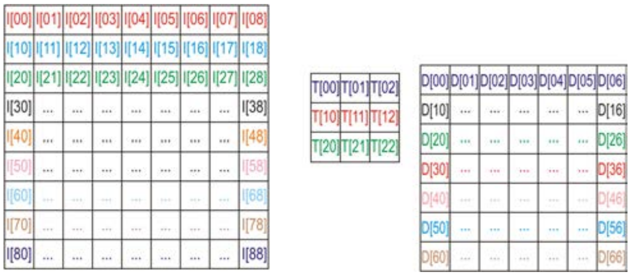


Fig. 1: Matrixes of searched image **I**, looked for pattern **T**, resultant **D**

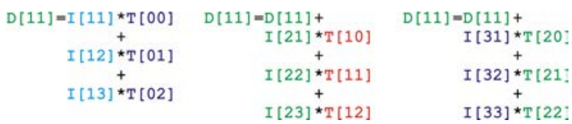


Fig. 2: Example obtaining the correlation function values between image **I** and pattern **T** for point (1,1) of a resultant matrix

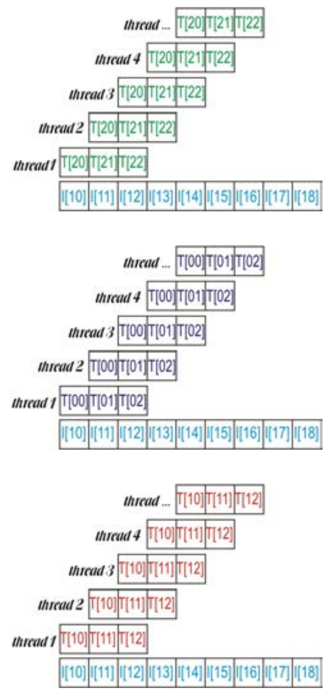


Fig. 3: Calculations performed by the block of threads connected with the third line of image **I**

matrix **I**) have been demonstrated in the successive phases of the algorithm. In the first step, thread 1 calculates the sums of products of the first pattern row through corresponding to it image points, for displacement D(2,0), simultaneously, these sums are calculated by thread 2, for displacement 2D(2,1), and sums for maximal, possible for X axis, displacement D(2,6), are calculated for exemplary parameters by the last thread. The following step of the algorithm involves loading the next line of pattern T (points T(1,0), ..., (91,2)) and multiplying it by the same line of the image data, thus, obtaining a part of the products sum necessary for determination of displacement (1,0) for thread 1, displacement (1,1) for thread 2 etc.

The first and last z of image **I**, where z means the size of matrix **T** are special cases. For instance, Fig. 4 shows how the block of threads for second line of image **I**. In this case, multiplication of the third line of pattern **T** is not performed, as such a displacement of the pattern would mean crossing the range of searched image **I**.

Since there is no possibility of synchronizing particular blocks of threats with each other, it is necessary to use the operation of atomic (indivisible) addition in order to avoid potential errors of indirect results recording. Such functionality is available, for floating point data type, merely in the new CUDA (version 2.0 - platform FERMI - *atomicAdd*). Tests were carried out comparing operational speed of algorithms using *atomicAdd* with a normal addition operation (this version returned results burdened with resulting from the collision of reading operations with the recording ones). These tests revealed a decrease in the operation speed by less than 2%. In order to ensure maximal grouping coefficient of the reading and recording operations, the allocation of global memory blocks GPU, was performed by means of function *cuMemAlocPitch* providing a proper arrangement (adjustment) of the allocated memory blocks within the GPU address space.

For this version of algorithm tests were carried out tests comparing the performance with its possibly maximally optimized equivalent, taken from OpenCV library. Thus, the developed implementation, computing the functions of correlation without normalization on GPU, was com-

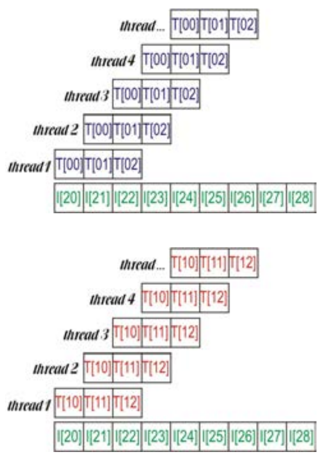


Fig. 4: Calculations performed by a sample block of threads - the image initial line

pared with a multi-thread OpenCV implementation on CPU and GPU. Tests were carried out for a constant ratio of pattern area **T** in relation to searched image **I**, being 1:3 when both areas were square. The results of comparison tests are shown in figure 5 where "CPU" is the algorithm with simplest implementation performed on GPU (one thread), "GPU" is the tested implementation of algorithm performed on GPU, "CPU-CV" represents an algorithm using OpenCV library in a multithread manner, "GPU-CV" is utilization of Open CV library in GPU version.

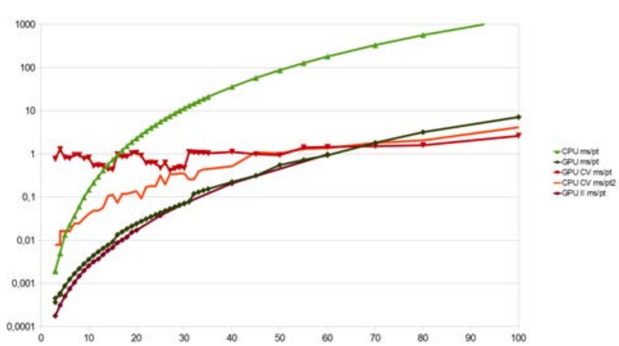


Fig. 5: Results of the correlation algorithm efficiency tests on GPU

The authors' implementation on GPU is more efficient than the other solutions for **T** pattern dimensions not exceeding 65 × 65 points. For **T** pattern dimensions 30 × 30 points, computation speed achieved was ten times faster.

Tab. 1: Occupancy of GPU resources for different sizes of **T** pattern area

T size	threads/block	sh mem/block	GPU occupacy %	registers/thread
15	31	90	17	18
30	61	180	33	18
60	121	360	67	18
100	201	600	88	18

Further optimization of the algorithm's speed was accomplished based on analyzing the theoretical load of GPU (Tab. 1). The usage of GPU resources using the algorithm operation, for the pattern dimension 15 × 15 points, reached 18%. The small number of threads triggered within a single block was the cause of limited usage of GPU.

The documentation available from NVIDIA shows that it is necessary to aim at approximately 60 of GPU occupancy which in case of the developed procedures, meant the pattern dimensions is supposed to be 60 × 60 points.

Thus, an increase in GPU resources occupancy was obtained through a simultaneous computing of products sums for a few lines in a single block of threads. An optimal number of simultaneously computed lines ranges from 7 for **T** size = 14 × 14 points to 3 for **T** = 60. For bigger sizes of **T**, increasing the number of threads per block (with increasing complexity the algorithm used) did not improve the results. The effects of GPU resources occupancy optimization are demonstrated in Fig. 6. Additionally, increasing the number of registers used by the block (for instance connected with the algorithm complexity) already caused a drop in GPU resources occupancy.

The above operations caused an increase of computing speed for **T** sizes 20 points, even by 100%. The effects of how this version of the algorithm works are presented in Fig. 5 as GPU II.

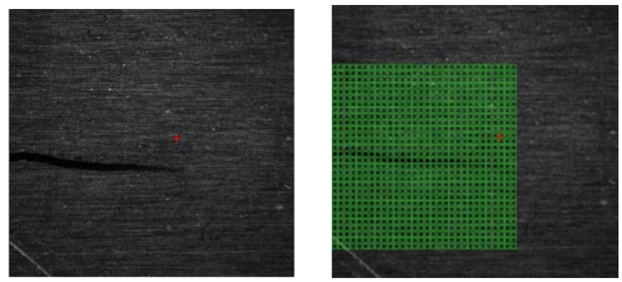
By copying a group of blocks of threads which computes the best match for a single area in the searched image, a simultaneous calculation of these matches became possible for the whole matrix of the searched areas (earlier defined by the user). The possibility of defining both blocks and threads performing the assigned program (kernel) in the form of a multi-dimension grid appears to be very helpful. As in Fig. 6, inside blocks, threads are organized bi-dimensional, i.e. the first dimension corresponds to columns of determined matrix D, the second dimension corresponds to the analyzed line of image I (optimization increasing the number of threads per block). The best method to organize a block would be a three-dimensional organization, unfortunately, for the available version of CUDA library, an application of only two dimensions was possible, where the first dimension are verses of analyzed image **I**, and the second dimension is represented by successive processed areas of the image with x and y coordinates of a given area appropriately coded.

The last phase of the algorithm optimization involved the use of textures memory for storing the pattern and searched images data. The main advantage of the textures memory is the so called 2D cache - cache memory taking into consideration the image mutual adjacency of both horizontal and vertical axes points. Other advantages include hardware conversion between the integer and floating-point types and a possibility of hardware, bilinear interpolation of the values between the image points. By using the memory of textures the algorithm's efficiency was improved by about 25%, regardless of pattern area T.

4 Example results of strain analysis in fatigue crack zone

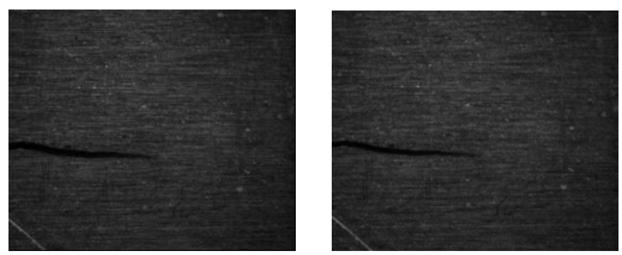
The developed digital procedure for correlation of images has been used for an example of a displacement analysis in the method of fatigue crack propagation testing in airplane riveted joints.

In Fig. 7 a sample made of aluminum alloy 2024-T3 with a propagated crack, which was exposed to a constant amplitude of nominal stress and the stress ration R = 0, has been presented.



(a) (b)

Fig. 7: Sample with a crack (a) and crack image with analysis pattern (b)



(a) (b)

Fig. 8: Images of the sample surface in chosen phases of the load cycle (a) minimal value of loading cycle, (b) maximal value of loading cycle

A digital video camera with resolution 2448 × 2050 pixels and set of lens with 50 mm area of view was used for sample image recording. The sample surface image was recorded on computer PC memory, equipped with GPU card MVIDIA GTX480 by means of Giga Ethernet card with maximal frequency 17 Hz.

Measurement sensitivity s = 0.0025 mm was obtained for the applied resolution of the video camera, the matrix size and lens zoom.

In Fig. 8 the sample images have been shown in chosen phases of a time variable load cycle. Determined on their basis, distributions of displacements within the crack environment are demonstrated in Fig. 9.

Further, the course of the crack length changes was de-

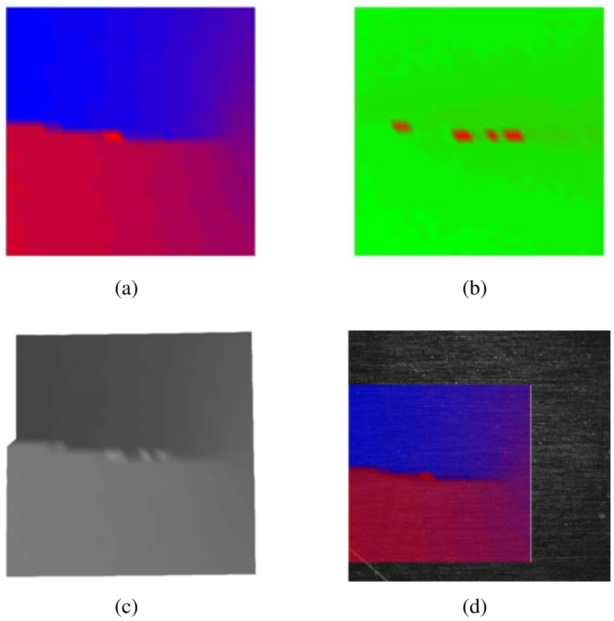


Fig. 9: Distributions of displacements within the crack zone: (a) in loading direction v, (b) perpendicular to loading direction u, (c) resultant = (u2+ v2)1/2, (d) displacement map in loading direction against the background of specimen image

termined on the base of obtained displacement distributions in a function of the load cycle number, for the discussed tests example.

5 Conclusions

The considered analysis method of displacements with the use of image digital correlation technique supported by GPU technology enables its application in displacement and strain tests for objects exposed to time variable loads. By applying modern optoelectronic and IT solutions, the image analysis algorithms developed for the equipment configuration used in this work was able to determine the strain distribution in an 2448×2050 pixels image, with the size of a matrix of searched patterns 30×30 elements and the pattern size 20×20 pixels, in less than 0.2 sec. Further shortening of the analysis time is possible for GPU cards with a higher number of cores.

In the case of displacement analysis in decreased areas of interest, reducing the time of the analysis offers the possibility of applying of developed method in fatigue life testing with controlled strain value.

References

[1] Pilch A., Mahajan A., Chu T. - Measurement of whole-field surface displacements and strain using a genetic algorithm based intelligent image correlation method, Journal of Dynamic Systems, Measurement, and Control, v. 126, 3, 479-488. 2004.

[2] Lagattu F., Brillaud J., Lafarie-Frenot M.C. - High strain gradient measurements by using digital image correlation technique. Materials Characterization 53,17-28. 2004

[3] PC Hung, AS Voloshin - In-plane Strain Measurement by Digital Image Correlation. Journal of the Brasilian Society of Mechanic Sciences & Engineering. Vol.XXV No. 3/215. 2003

[4] Sutton M.A., McNeil S.R., Helm J.D. Chao Y.J. - Advances in 2-D and 3-D Computer Vision for Shape and Deformation Measurements. Photomechanics. Topics in Applied Physics, 2000. Volume 77/2000, 323-372

[5] Siebert T., Crompton M.J. - Application of High Speed Digital Image Correlation for Vibration Mode Shape Analysis. Proceedings of SEM Annual Conference 2010 Indianapolis

[6] Gembris, M. Neeb, M. Gipp, A. Kugel, R. Manner - Correlation analysis on GPU systems using NVIDIA's CUDA. Journal of Real-Time Image Processing. Volume 6 Issue 4, December 2011, 275-280

[7] Kirk, W. Hwu - Programming Massively Parallel Processors a Hands-on Approach. Elsevier 2010. ISBN: 978-0-12-381472-2

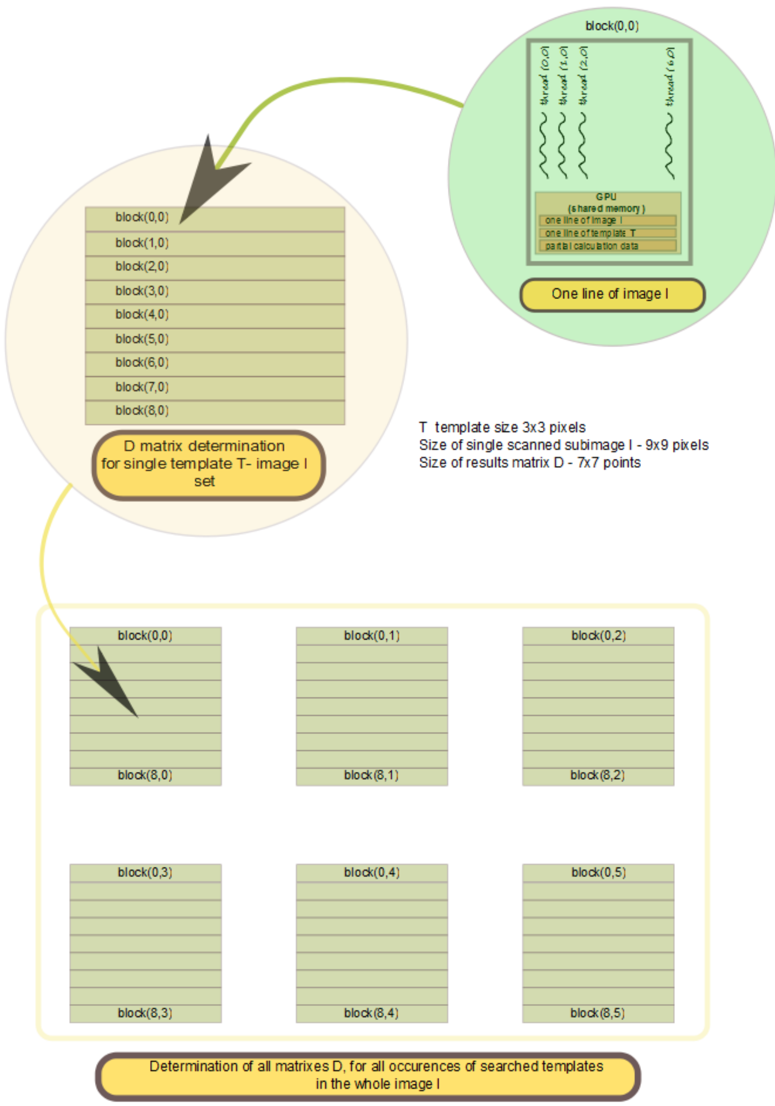


Fig. 6: Organization of the algorithm to determine the correlation function, searching for the displacements of the pattern matrixes with dimensions equal to 3 columns per 2 lines

MODIFIED NDR STRUCTURES

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Abstract. In this paper, the analysis of the properties of modified Network double Ring (NdR) topologies has been presented. The special type of these structures, namely optimal and ideal graph, has been defined. The basic parameters (diameter and average path length) were calculated and described by formulas which make possible evaluate these parameters for any NdR graph without experiments, next the comparison of the analyzing structures has been carry out.

1 Introduction

The choosing of the interconnection network topology has the biggest impact on efficiency, speed, reliability and cost of the telecommunications or computer systems [1]. These networks can be modeled by symmetric digraphs, i.e., a directed graph $\mathbf{G}$ with vertex set $\mathbf{V}(\mathbf{G})$ and edge set $\mathbf{E}(\mathbf{G})$, such that, if $[v_i, v_j]$ is in $\mathbf{E}(\mathbf{G})$, then $[v_j, v_i]$ is also in $\mathbf{E}(\mathbf{G})$. So any edge of digraph connecting vertices v_i and v_j can be replaced by two directed edges $[v_i, v_j]$ and $[v_j, v_i]$ [2]. It is obvious that the best service and reliability parameters one can obtain by forming complete networks (described by a complete graph), but only small networks can be built in this way. In [3], a survey of known topologies has been presented. Among the analyzed topologies that would be used in designing the distributed structures, the authors of this paper have chosen rings as they are very simple and extensible. They are not expensive (number of edges is equal to the number of nodes), are regular and symmetric, but possess poor transmission parameters. A modification of this type graphs are chordal ring structure [4, 5]. The chordal ring is a ring with additional chords. It is defined by pair $(p, \mathbf{Q})$, where p is the number of nodes of the ring and $\mathbf{Q}$ is the set of chords. Each chord connects every pair of nodes of the ring that are at distance q_i in the ring.

The application of chordal rings in computer systems [3, 6], Time Domain Multiplexing (TDM) networks (communication between distributed switching modules) [7], core optical networks [8, 9, 10, 11, 12, 13], and optical access networks [14, 15, 16, 17, 18] has been analyzed. The authors of this paper, in their earlier works on modeling of telecommunication and computer networks, present an analysis of chordal rings [18, 19, 20, 21, 22, 23]. The authors were encouraged to go deeper into the subject of NdR type structures that can be used, first of all, for building Fiber to the Home (FTTH) distribution networks and computer networks but also in communications systems with topology control that use shared medium, where increased reliability is required e.g. communications systems for smart grid or smart metering.

Application of the proposed method, in many areas of telecommunications, is possible only a few years because of the development of new technologies such as: Density Wave Domain Multiplexing (DWDM) and Optical Add Drop Multiplexers (OADM) or wireless communication and Orthogonal Frequency Division Multiplexing (OFDM) dedicated to Power Line Communications (PLC). The Authors can see two main areas of usage the NdR, they are:

- Fast and reliable optical networks with protection of links and nodes,
- Dense sensor networks with topology control.

As it follows from experiences the big impact on the transmission properties of networks have its diameter and average path length.

The network diameter is the largest value among all the shortest path lengths between all pair of nodes.

$$d(G) = \max_{v_i v_j}\{d_{\min}(v_i, v_j)\} \tag{1}$$

The average length of the paths between all the pair of nodes is defined by the following formula:

$$d_{av} = \frac{1}{p(p-1)}\sum_{i=0}^{p-1}\sum_{j=0}^{p-1} d_{\min}(v_i, v_j) \tag{2}$$

In order to find lower limit of the analyzed type structures parameters, the theoretical calculated two reference topologies were defined. The first one is called the ideal graph and the second one - optimal graph. In fact these graphs exist only in particular cases, but they are useful as reference models for evaluation expected parameters of tested graphs.

Definition 1 *The ideal graph is the regular graph were the total number of nodes pi is described by the formula:*

$$p_i = 1 + \sum_{d=1}^{D(G)-1} |p_d| + \left|p_{D(G)}\right| \tag{3}$$

where p_d means the number of nodes that belong to the d-th layer (the layer is the subset of nodes that are at a distance d from the source node), while $p_{\mathbf{D(G)}}$ denotes the number of the remaining nodes which appear in the last layer, $\mathbf{D}(\mathbf{G})$ means diameter of analysed graph. For ideal rings, for every n and $m < \mathbf{D}(\mathbf{G}) p_n \cap p_m = \emptyset$. If for certain $\mathbf{D}(\mathbf{G})$ the subset $p_{D(G)}$ of chordal ring reaches the maximal possible value, then such a ring is called the optimal ring (optimal graph).

For ideal graphs the average path length d_{avi} is expressed as:

$$d_{avi} = \frac{1}{p_i - 1}\sum_{d=1}^{d(G)-1} d\,|p_d| + D(G)\left|p_{d(G)}\right| \tag{4}$$

whereas for the optimal graph the average path length d_{avo} is equal to:

$$d_{avo} = \frac{1}{p_o - 1}\sum_{d=1}^{d(G)} d p_d \tag{5}$$

where d - layer number, p_d - number of nodes in d-th layer, p_o - number of nodes in optimal graph.

NdR structures are the subset of generalized Petersen graphs, and they are interesting due to shorter diameter and average path length than double rings and third-degree chordal rings.

The remainder of the paper is organized as follows. In section 2 the basic properties of NdR structures. In section 3 the definition of Reference Graph is presented and the analytical reviews of modified NdR topologies. At the last part comparison of proposed modifications are given.

2 NdR structures

The subject of the analysis is structure of double rings named NdR. A regular third degree network topology which consists of two rings: inner and outer having the same number of nodes is described as NdR structure. Each node of the outer ring is connected to the one by additive link node. It can be used in real networks as redundant connection which increases reliability of them. It is used as a backup in case the primary ring fails. In these configurations, data moves in opposite directions around the rings. Each ring is independent of the other until the primary ring fails and the two rings are connected to continue the flow of data traffic. This topology is shown in Fig. 1.

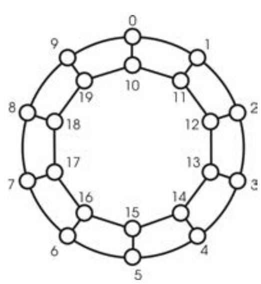


Fig. 1: Basic NdR(20) structure

This structure can be described by the following definition:

Definition 2 *Two rings, each containing p nodes, form the NdR structure:*

- *outer ring, in which each node ok is connected with two adjacent nodes $o_{k-1(mod\,p)}$ and $o_{k+1(mod\,p)}$;*
- *inner ring, in which each node i_{k+p} is connected with two adjacent nodes $i_{k+p-1(mod\,2p)}$ and $i_{k+p+1(mod\,2p)}$;*
- *each of the nodes of the inner ring i_{k+p} is connected with a corresponding node of the outer ring o_k.*

The degree of each node of the graph is equal to 3. This structure is described as follows- NdR($2p$).

On the basis of obtained results of calculations the theoretical total number of nodes forming optimal NdR graphs with the diameter $D(G)$ is defined by:

$$2p_o = 4D(G) \tag{6}$$

The theoretical diameter of NdR structure is given by expression:

$$D(G) = \left\lceil \frac{2p}{4} \right\rceil \tag{7}$$

The theoretical average path length in optimal graph is described by the following expression:

$$\begin{array}{ll} \text{when} & D(G) = 1 \\ & d_{av} = 1 \\ \text{when} & D(G) > 1 \\ & d_{av} = \frac{2D(G)^2+2D(G)-1}{4D(G)-1} = \frac{p_o+2p_o-2}{2(2p_o-1)} \end{array} \tag{8}$$

The structures NdR($2p$) is "inflexible" - their parameters are fixed, so in order to remove this disadvantage it introduced modification of them [20].

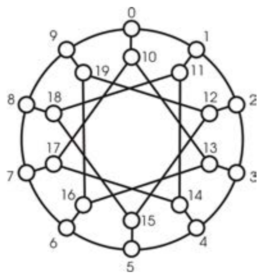
Definition 3 *Two rings, each containing p nodes, form the NdRm structure:*

- *outer ring, in which each node o_k is connected with two adjacent nodes $o_{k-1(mod\,p)}$ and $o_{k+1(mod\,p)}$;*
- *inner ring, in which each node ik+p is connected with two adjacent nodes $i_{k+p-q(mod\,2p)}$ and $i_{k+p+q(mod\,2p)}$; by chords q of equal lengths, which are a multiplicity of the outer, ring chord length;*
- *each of the nodes of the inner ring i_{k+p} is connected with a corresponding node of the outer ring o_k.*

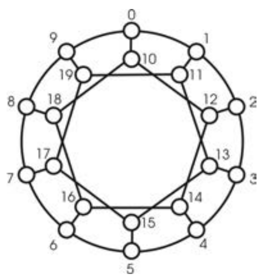
This structure is described in the following way - NdRm($2p, q$). The degree of each node of the graph is equal to 3.

Examples of them are shown in Fig. 2.

These NdRm structures can be distinguished into two classes:



(a)



(b)

Fig. 2: Examples of the graphs belonging to two classes of NdRm structures

- First class in which the chords of both the outer and inner rings form Hamilton cycles. To belong to this class, the number of nodes in a ring and the chord length must be relatively prime (Fig. 2(a)).
- Second class in which the Hamilton cycle is characterized by the property $j = i \oplus 1 \bmod p$ and a certain set of disjointed cycles of equal length formed from a number of nodes smaller than p (Fig. 2(b)).

It is easy to notice that distributions of nodes equally distant from a randomly chosen source node are different depending on whether the source node is on the inner or outer ring. This must be taken into account when calculating average distance and diameter. Assuming that these are measured only from a source node in the outer ring, this can be done as shown in (7):

$$d_{avNdR} = \frac{d_{avNdRq} + d_{avNdRq^*}}{2} \tag{9}$$

where d_{avNdRq} means the average length of the paths in the initial graph and $d_{avNdRq*}$ the average length of the paths of transformed graph, both measured from an outer-ring node or inner-ring. It can find the cases when $d_{avNdrq} = d_{avNdrq*}$ - these structures are automorphic.

An optimal graph such as NdR structure in which layers reach maximal power, forming a sequence, is described by the expression:

$$p_d = \begin{cases} 3 & \text{when} \quad d = 1 \\ 6 & \text{when} \quad d = 2 \\ 12 + 8(d-3) & \text{when} \quad d \geqslant 3 \end{cases} \tag{10}$$

On the basis of obtained results the theoretical total number of nodes forming optimal graphs with the diameter $D(G)$ was defined by:

$$2p_o = 2\left[2D(G)^2 - 4D(G) + 5\right] \text{ if } D(G) \geqslant 2 \tag{11}$$

where $2p_o$ denotes the sum of all the nodes of NdRm optimal structure.

The diameter of the optimal graphs is described by formula:

$$\begin{aligned} &\text{when} \quad p_0 > 3 \\ &D(G) = \tfrac{8+4\sqrt{(2p_o-6)}}{8} = 1 + \sqrt{\tfrac{p_o-3}{2}} \end{aligned} \tag{12}$$

The average length of the paths is equal to:

$$d_{avo} = \frac{8D(G)^3 - 6D(G)^2 - 14D(G) + 33}{3(4D(G)^2 - 8D(G) + 9)} \tag{13}$$

The only realized in reality the optimal graph is Petersen's graph having 10 nodes (see Fig. 3).

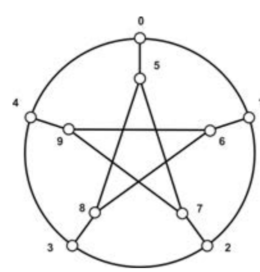


Fig. 3: Petersen graph

The optimal graphs are a particular case of ideal graphs.

Definition 4 *Ideal graph was referred to as an automor-*

phic NdRm structure with the number of nodes higher than 10, in which the numbers of nodes in the layers is equal to:

$$\begin{aligned} &\textit{when} \quad d < D(G) \\ &\quad \textit{then } p_{di} = \begin{cases} 3 \textit{ if } d = 1 \\ 6 \textit{ if } d = 2 \\ 12 + 8(d-3) \textit{ when } d \geqslant 3 \end{cases} \\ &\textit{when} \quad d = D(G) \\ &\quad \textit{then } p_{di} = p_i - p_{o(D(G)_i - 1)} \end{aligned} \tag{14}$$

where p_{di} denotes the number of nodes in d-th layer of an ideal graph, whereas, $p_{o(D(G)_i-1)}$ indicated the total number of nodes in an optimal graph with its diameter smaller than 1 from a theoretically calculated diameter of an ideal graph. The exception of this rule is NdRm structure having 3 nodes in each layer.

The diameter can be calculated using formula:

$$D(G) = \left\lceil \frac{2 + \sqrt{(p_i - 6)}}{2} \right\rceil \text{ when } p_i > 6 \tag{15}$$

The average length of the paths connecting a randomly chosen source node with the remaining nodes is described by the formula:

$$d_{avi} = \frac{8D(G)^3 - 28D(G)^2 + 22D(G) + 33}{3(2p_i - 1)} + \frac{3D(G)\left(p_i - p_{o(D(G)_i-1)}\right)}{3(2p_i - 1)} \tag{16}$$

For a chosen number of nodes forming a graph, parameters of an ideal structure are lower limits of these parameters values, with which the examined graphs features would be compared. Analyzing the NdRm structures belonging to second group, where the chord length is not prime in respect of number of nodes in ring, they did not find any ideal graph, but during analyzed the node distributions in particular layers of NdRm structures, a group of graphs having parameters closed to ideal ones, has been discovered.

Characteristic features of this type of graphs are:

Tab. 1: Distributions of nodes in the layers of analyzed graphs

p_{qi}	q_i	$D(G)_t$	$D(G)_{qi}$	d_{av}	Distribution of the nodes in the layers
14 nodes	4	4	5	2.81	3 6 12 5 1
26 nodes	10	5	6	3.57	3 6 12 20 9 1
42 nodes	16	6	7	4.28	3 6 12 20 28 13 1
62 nodes	26	7	8	4.99	3 6 12 20 28 36 17 1
86 nodes	36	8	9	5.68	3 6 12 20 28 36 44 21 1
114 nodes	50	9	10	6.37	3 6 12 20 28 36 44 52 25 1
146 nodes	64	10	11	7.05	3 6 12 20 28 36 44 52 60 29 1
182 nodes	82	11	12	7.73	3 6 12 20 28 36 44 52 60 68 33 1

- their diameters $d(G)$ are equal to $d(G)_t + 1$, where $d(G)_t$ denotes the theoretically calculated diameter of an ideal graph;
- in the first $d(G)_t - 1$ layers all sets of nodes equally distant from the source node reach maximal power;
- in the last layer there is only 1 node;
- they are automorphic structures;
- in the inner ring there always appear two subcycles of length $p/2$.

Examples of distributions of nodes in this type of graphs are presented in Table 1.

$D(G)_t$ means the theoretical diameter, $D(G)_{qi}$ - real diameter. These structures are depicted by the following formulas:

- Number of nodes in each ring can be calculated using (17):

$$p_{qi} = 2\left[D(G)_t^2 - 3D(G)_t + 3\right] \tag{17}$$

- Length of the chord of inner ring q_i:

$$\begin{aligned} &\text{when} \quad D(G)_t \text{ is even} \\ &\quad q_i = D(G)_t^2 - 4D(G)_t + 4 \\ &\text{when} \quad D(G)_t \text{ is odd} \\ &\quad q_i = D(G)_t^2 - 4D(G)_t + 5 \end{aligned} \tag{18}$$

- The diameter can be described by expression:

$$D(G)_t = \frac{3 + \sqrt{2p_{qi} - 3}}{2} \tag{19}$$

- Number of nodes in last but one layer:

$$p_{D(G)t} = 4D(G)_t - 11 \tag{20}$$

- Average path length:

  when $D(G)_t > 4$

$$d_{avi} = \frac{2}{3}\frac{4D(G)\big(D(G)^2-1\big)-9\big(D(G)^2-2\big)}{4D(G)^2-12D(G)+11} \tag{21}$$

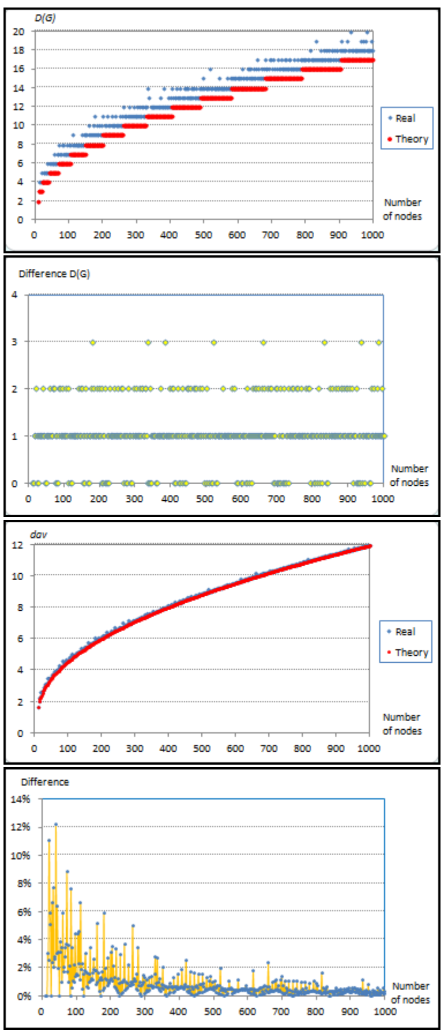


Fig. 4: Parameter's difference between theoretical ideal and real graph

As summing-up in Fig. 4 the juxtaposition of the parameters of the best real structures NdRm belonging to both meaning groups in respect to theoretical calculated ideal graphs are shown.

From these charts it follows that the difference of the real graphs diameters do not exceed more than 3, but average path length is very close to characteristic of reference graphs.

In order to find real best reference parameters of third degree graphs they defined Reference Graph. It represents lower bounds for average distance and diameter for all these graphs, but since it is in many cases "virtual graph" these bounds may not always be achievable.

The Reference Graph possesses parameters as follows:

1. The number of nodes p_{dRG} in d-th layer is determined by formula:

$$p_{dRG} = 3 \cdot 2^{(d-1)} \tag{22}$$

2. Total number of nodes $p_{D(G)RG}$ versus graph diameter is described by expression:

$$p_{D(G)RG} = 3 \cdot 2^{D(G)RG} - 2 \tag{23}$$

3. Value of diameter versus total number of nodes is given can be calculated following formula:

$$D(G) = \left\lfloor \log_2 \frac{p_{D(G)RG} + 2}{3} \right\rfloor \tag{24}$$

4. Average path length d_{avr} in function of diameter is equal to:

$$d_{avRG} = \frac{3 \cdot (D(G) - 1) \cdot 2^{D(G)} + 1}{3 \cdot \left(2^{D(G)} - 1\right)} \tag{25}$$

5. This graph is symmetrical, all of its parameters are equal regardless from which node they are calculated.

In Fig. 5 comparison of basic parameters of NdRm structure and Reference Graph is shown.

From these pictures it follows that the parameters of NdRm structures in significant degree are different from

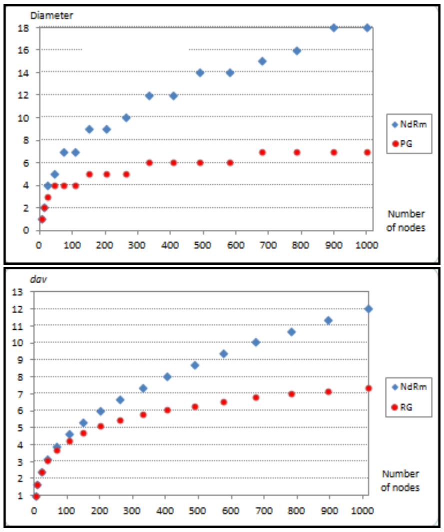


Fig. 5: Comparison of basic parameters NdRm structure and Reference Graph

Reference Graph, so authors of presented paper decided to try to find similar structures having better properties.

3 Modification of NdR Structure

In this part of the paper other, proposed by authors, modification of NdR topologies will be presented.

3.1 NdRa structure

Definition 5 *NdRa forms the structure consisted of:*

- *outer ring has p nodes (p has to be divisible by 4), in which each node o_k is connected with two adjacent nodes $o_{k-1(mod p)}$ and $o_{k+1(mod p)}$;*
- *inner ring or rings which have in total p nodes. Each even node i_{2k+p} is connected with two adjacent nodes $i_{2k+p+q1(mod 2p)}$ and $i_{2k+q2(mod 2p)}$ and each odd node i_{2k+1+p} is connected with two adjacent nodes $i_{2k+1+p-q1(mod 2p)}$ and $i_{2k+1+q2(mod 2p)}$;*
- *each node of the inner ring i_{k+p} is connected with a corresponding node of the outer ring o_k.*

Parameter q_1 must be odd; q_2 is even and equal to $p/2$. They are meaning the lengths of the chords. This structure is describing in the following way - NdRa$(2p; q1, q2)$.

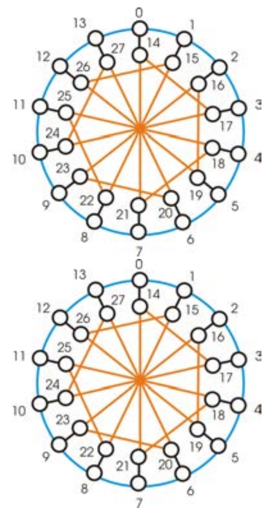


Fig. 6: Examples of analyzed structures

In the beginning the distribution of the nodes in the layers was analyzed.

As it follows from Table 2 the nodes distribution depends of the numbers of them creating the structure. If

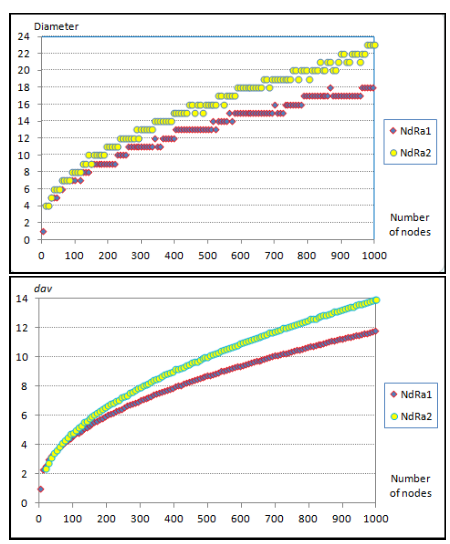


Fig. 7: Comparison of basic graph parameters in dependence of number of nodes

the number of nodes in a graph is not divisible by 8 than

Tab. 2: Maximal number of nodes in the layers

d	1	2	3	4	5	6	7	8	9	10	Node	Number of nodes	
p_{do}	3	6	12	22	30	38	46	54	62	70	In/Out	p notl8	NdRa1
	3	5	9	16	22	27	33	38	42	47	In	pl8	NdRa2
	3	6	11	17	23	28	32	37	43	48	Out		

it does not matter how to choose a source node (inner or outer ring) of optimal graph, both parameters - diameter and average path length can reach the same value, in the second case it is impossible.

In Fig. 7 the results obtained in experimental way are shown.

In the first case in inner ring the edges create Hamilton cycle, chord q_2 connects even and odd node, in turn odd node is connected to even node by chord q_1 etc.

In second case chord q_2 connects two even or odd node, so when source node has number i, it will obtain cycle which creates sequence of numbers $-i + p/2mod(p)$; $i + p/2 + q_1 mod(p)$; $i + p/2 + q_1 + p/2mod(p) \equiv i + q_1$; $i + q_1 - q_1 \equiv i$. Then always a subcycle consisting of 4 edges will be obtained.

In dependence of number of nodes creating analyzing structures, is it divisible by 8 or not, the distribution of nodes in successive layer of optimal graph can be described as follows:

when $2p_o$ **is not divisible by** 8

$$p_d = \begin{cases} \frac{d^3+3d^2+2d+2}{6} & \textbf{when } d \le 4 \\ 4(2d-5) & \textbf{when } d > 4 \end{cases}$$

when $2p_o$ **is divisible by** 8 **and source node belongs to outer ring**

$$p_d = \begin{cases} \frac{-d^3+12d^2-11d+18}{6} & \textbf{when } d \le 4 \\ 5d-2 & \textbf{when } d=1 \textbf{ or } d=2 \pmod 4 \textbf{ and } d>4 \\ 5d-3 & \textbf{when } d=3 \textbf{ or } d=4 \pmod 4 \textbf{ and } d>4 \end{cases}$$

when $2p_o$ **is divisible by** 8 **and source node belongs to inner ring**

$$p_d = \begin{cases} \frac{d^3+5d+12}{6} & \textbf{when } d \le 4 \\ 5d-3 & \textbf{when } d=1 \textbf{ or } d=2 \pmod 4 \textbf{ and } d>4 \\ 5d-2 & \textbf{when } d=3 \textbf{ or } d=4 \pmod 4 \textbf{ and } d>4 \end{cases} \quad (26)$$

On the basis of obtained results the theoretical total number of nodes forming optimal graphs with the diameter $D(G)$ was defined by:

when $2p_o$ **is not divisible by** 8

$$2p_o = \begin{cases} 2(3D(G)-1) & \textbf{when } D(G) \le 2 \\ 2(2D(G)^2-3D(G)+2) & \textbf{when } D(G) > 2 \end{cases}$$

when $2p_o$ **is divisible by** 8 **and source node belongs to inner ring**

$$2p_o = \begin{cases} \frac{D(G)^3-2D(G)^2+9D(G)}{2} & \textbf{when } D(G) \le 4 \\ \frac{5D(G)^2-3}{2} & \textbf{when } D(G)=1 \pmod 4 \textbf{ or } D(G)=3 \pmod 4 \textbf{ and } D(G)>4 \\ \frac{5D(G)^2-2}{2} & \textbf{when } D(G)=2 \pmod 4 \textbf{ and } D(G)>4 \\ \frac{5D(G)^2-4}{2} & \textbf{when } D(G)=0 \pmod 4 \textbf{ and } D(G)>4 \end{cases}$$

when $2p_o$ **is divisible by** 8 **and source node belongs to outer ring**

$$2p_o = \begin{cases} \frac{D(G)^3+9D(G)^2+2D(G)+12}{6} & \textbf{when } D(G) \le 4 \\ \frac{5D(G)^2-13}{2} & \textbf{when } D(G)=1 \pmod 4 \textbf{ or } D(G)=3 \pmod 4 \textbf{ and } D(G)>4 \\ \frac{5D(G)^2-14}{2} & \textbf{when } D(G)=2 \pmod 4 \textbf{ and } D(G)>4 \\ \frac{5D(G)^2-12}{2} & \textbf{when } D(G)=0 \pmod 4 \textbf{ and } D(G)>4 \end{cases} \quad (27)$$

where $2p_o$ denotes the sum of all the nodes of NdR optimal structure.

The average length path of optimal graphs is describing by expressions:

When $2p_o$ **is not divisible by** 8

$$d_{avo} = \begin{cases} \frac{4D(G)-3}{2D(G)-1} & \textbf{when } D(G) \le 2 \\ \frac{8D(G)^3-3D(G)^2-10D(G)-3}{4D(G)^2-6D(G)+1} & \textbf{when } D(G) > 2 \end{cases} \quad (28)$$

Tab. 3: Total numbers of nodes forming optimal graphs versus diameter

$D(G)$	1	2	3	4	5	6	7	8	9	10	Node	Number of nodes
$2p_o$	4	10	22	44	74	112	158	212	274	344	In/Out	not p|8
	4	9	18	34	56	83	116	154	196	243	In	p|8
	4	10	21	38	61	89	121	158	201	249	Out	

When $2p_o$ is divisible by 8 and source node belongs to inner ring

$$d_{avo\,in}=\begin{cases}\dfrac{20D(G)^3-69D(G)^2+122D(G)-60}{3\left(D(G)^3-2D(G)^2+9D(G)-2\right)} & \textbf{when } D(G)\le 4\\[2ex] \dfrac{20D(G)^3+15D(G)^2-5(G)-180+\begin{cases}\frac{17}{2} & \textbf{when } D(G)=1\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ \frac{D(G)+17}{2} & \textbf{when } D(G)=2\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ 8 & \textbf{when } D(G)=3\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ \frac{D(G)+17}{2} & \textbf{when } D(G)=0\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\end{cases}}{12\cdot\begin{pmatrix}\frac{5D(G)^2-5}{2} & \textbf{when } D(G)=1\ (\mathrm{mod}\,4)\ \textbf{or } D(G)=3\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ \frac{5D(G)^2-4}{2} & \textbf{when } D(G)=2\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ \frac{5D(G)^2-6}{2} & \textbf{when } D(G)=0\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\end{pmatrix}} & \end{cases}$$

when $2p_o$ is divisible by 8 and source node belongs to outer ring

$$d_{avo\,out}=\begin{cases}\dfrac{14D(G)^3-21D(G)^2+37D(G)-12}{D(G)^3+9D(G)^2+2D(G)+6} & \textbf{when } D(G)\le 4\\[2ex] \dfrac{20D(G)^3+15D(G)^2-5(G)-180-\begin{cases}\frac{17}{2} & \textbf{when } D(G)=1\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ \frac{D(G)+17}{2} & \textbf{when } D(G)=2\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ 8 & \textbf{when } D(G)=3\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ \frac{D(G)+17}{2} & \textbf{when } D(G)=0\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\end{cases}}{12\cdot\begin{pmatrix}\frac{5D(G)^2-15}{2} & \textbf{when } D(G)=1\ (\mathrm{mod}\,4)\ \textbf{or } D(G)=3\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ \frac{5D(G)^2-16}{2} & \textbf{when } D(G)=2\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\\ \frac{5D(G)^2-14}{2} & \textbf{when } D(G)=0\ (\mathrm{mod}\,4)\ \textbf{and } D(G)>4\end{pmatrix}} & \end{cases} \tag{29}$$

In second case the average path length has to be counted as average value of d_{avo} out and d_{avo} in.

In Fig. 8 and 9 the comparison of parameters both type of graphs are shown.

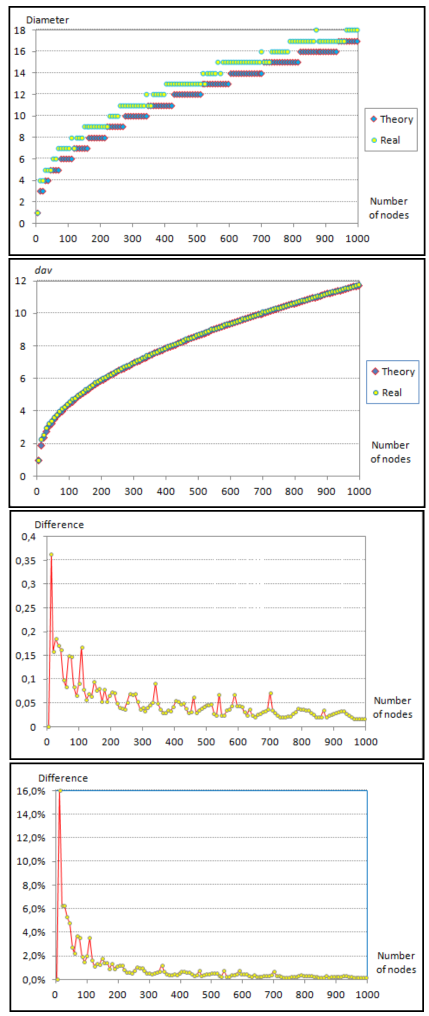


Fig. 8: Comparison of basic parameters real and theoretical graphs in dependence of number of nodes when the number of nodes is not divisible by 8

3.2 NdRb structure

Definition 6 *Two rings, each containing p nodes (p has to be divisible by 4), form the NdRb structure:*

- *outer ring, in which each node o_k is connected with two adjacent nodes $o_{k-1(mod p)}$ and $o_{k+1(mod p)}$;*
- *inner ring, in which each even node i_{2k+p} is connected with two adjacent nodes $i_{2k+p+q1(mod 2p)}$ and $i_{2k+p+q2(mod 2p)}$ and each odd node i_{2k+1+p} is connected with two adjacent nodes $i_{2k+p-q1(mod 2p)}$ and $i_{2k+p-q2(mod 2p)}$;*
- *each node of the inner ring i_{k+p} is connected with a*

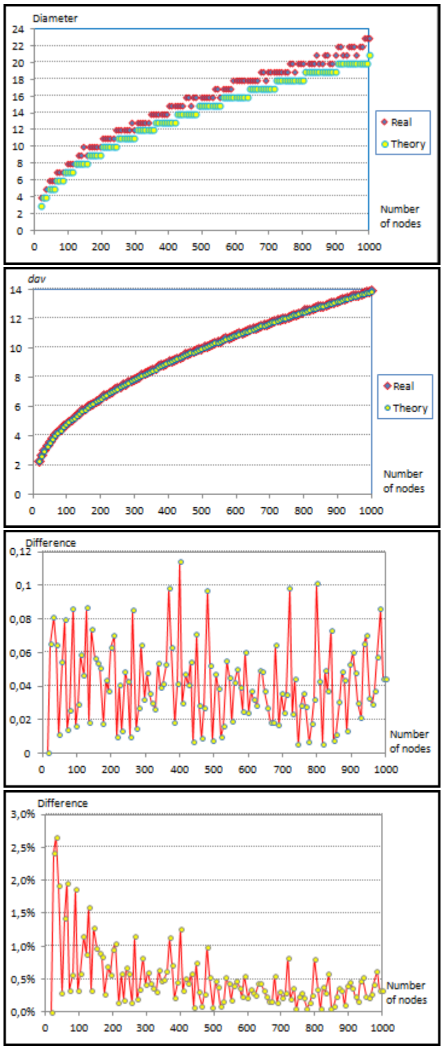


Fig. 9: Comparison of basic parameters real and theoretical graphs in dependence of number of nodes when the number of nodes is divisible by 8

corresponding node of the outer ring o_k.

Parameters q_1 and q_2 must be odd, they are meaning the lengths of the chords and describing this structure in the following way - NdRb($p; q_1, q_2$).

In the Table 4 the distribution of nodes in successive layers of optimal, virtual graph, obtained in experimental way, is shown.

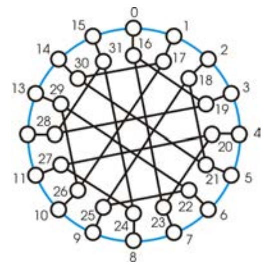


Fig. 10: Example of NdRb structure

This distribution of the nodes in dependence of the distance calculated from any source node is given by:

$$p_d = \begin{cases} 3 & \text{when } d = 1 \\ 3(d^2 - 3d + 4) & \text{when } 1 < d \le 4 \\ \frac{13d^2 - 21}{8} & \text{when } d > 4 \text{ and odd} \\ \frac{13d^2 - 20}{8} & \text{when } d > 4 \text{ and even and not divisible by } 8 \\ \frac{13d^2 - 16}{8} & \text{when } d > 4 \text{ and even and divisible by } 8 \end{cases} \quad (30)$$

On the basis of these results the total number of nodes can be calculated and described by (31) (Table 5).

Tab. 5: Maximal number of nodes in the layers

$D(G)$	1	2	3	4	5	6	7	8
2_{po}	4	10	22	46	84	140	217	319

$$p_o = \begin{cases} D(G)^3 - 3D(G)^2 + 8D(G) - 2 & \text{when } D(G) \le 4 \\ \frac{1}{48}\left(26D(G)^3 + 39D(G)^2 - 104D(G) + 327\right) & \text{when } D(G) = 1 \mod 4 \\ \frac{1}{48}\left(26D(G)^3 + 39D(G)^2 - 104D(G) + 324\right) & \text{when } D(G) = 2 \mod 4 \\ \frac{1}{48}\left(26D(G)^3 + 39D(G)^2 - 104D(G) + 315\right) & \text{when } D(G) = 3 \mod 4 \\ \frac{1}{48}\left(26D(G)^3 + 39D(G)^2 - 104D(G) + 336\right) & \text{when } D(G) = 0 \mod 4 \end{cases} \quad (31)$$

The average path length can be calculated using expressions as it follows:

$$d_{av\,o} = \begin{cases} 3\frac{2D(G)^3 - 8D(G)^2 + 14D(G) - 7}{D(G)^3 - 3D(G)^2 + 8D(G) - 3} & \text{when } D(G) \le 4 \\ \frac{3\left(13D(G)^4 + 26D(G)^3 - 26D(G)^2 - 38D(G) + 249\right)}{2\left(26D(G)^3 + 39D(G)^2 - 104D(G) + 279\right)} & \text{when } D(G) = 1 \mod 4 \\ \frac{3\left(13D(G)^4 + 26D(G)^3 - 26D(G)^2 - 40D(G) + 248\right)}{2\left(26D(G)^3 + 39D(G)^2 - 104D(G) + 276\right)} & \text{when } D(G) = 2 \mod 4 \\ \frac{3\left(13D(G)^4 + 26D(G)^3 - 26D(G)^2 - 46D(G) + 249\right)}{2\left(26D(G)^3 + 39D(G)^2 - 104D(G) + 267\right)} & \text{when } D(G) = 3 \mod 4 \\ \frac{3\left(13D(G)^4 + 26D(G)^3 - 26D(G)^2 - 32D(G) + 256\right)}{2\left(26D(G)^3 + 39D(G)^2 - 104D(G) + 288\right)} & \text{when } D(G) = 0 \mod 4 \end{cases} \quad (32)$$

Tab. 4: Maximal number of nodes in the layers

d	1	2	3	4	5	6	7	8	9	10
p_{do}	3	6	12	24	38	56	77	102	129	160

The obtained results of comparison of optimal and real graphs in Fig. 11 are shown.

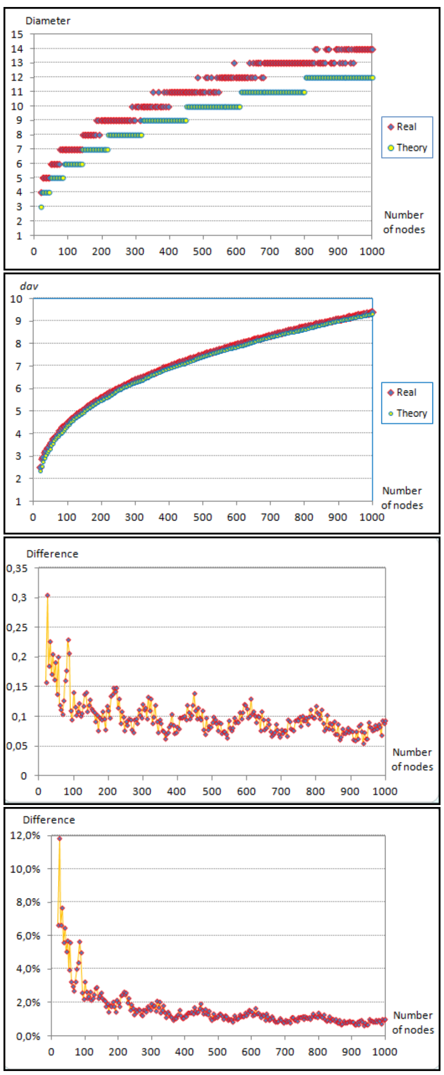


Fig. 11: Comparison of basic parameters real and theoretical graphs in dependence of number of nodes

3.3 NdRc structure

Definition 7 *Two rings, each containing p nodes (p has to be divisible by 2), form the NdRc structure:*

- *outer ring, in which each node o_k is connected with two adjacent nodes $o_{k-1(modp)}$ and $o_{k+1(modp)}$;*
- *inner ring, in which each even node i_{2k+p} is connected with two adjacent nodes $i_{2k+p-q1(mod2p)}$ and $i_{2k+p+q1(mod2p)}$ and each odd node i_{2k+1+p} is connected with two adjacent nodes $i_{2k+p-q2(mod2p)}$ and $i_{2k+p+q2(mod2p)}$;*
- *each node of the inner ring i_{k+p} is connected with a corresponding node of the outer ring o_k.*

Parameters q_1 and q_2 must be even, they are meaning the lengths of the chords and describing this structure in the following way - NdRc(p; q_1, q_2).

Example of this structure in Fig. 12 is show.

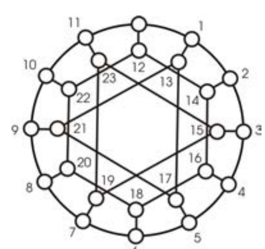


Fig. 12: Example of chordal ring NDRc(24; 2,4)

Distribution of nodes in the layers in dependence of source node location is shown in Table 6.

Tab. 6: Distribution of nodes in the layers

d	1	2	3	4	5	6	7	8	9	10	ring
p_{do}	3	6	12	24	44	78	132	204	292	396	Inner
	3	6	12	24	42	68	112	176	256	352	Outer

These sequences can be described by expression (33):

$$\begin{aligned}&\textbf{when}\quad d<5\\ &p_d=\frac{d\left(d^2-3d+8\right)}{2}\\ &\textbf{when}\quad 4<d<7\\ &p_{din}=2(17d-63)\quad p_{dout}=2(13d-44)\\ &\textbf{when}\quad 6<d\\ &p_{din}=4\left(2d^2-12d+19\right)\quad p_{din}=8\left(d^2-7d+14\right)\end{aligned}\tag{33}$$

where p_{din} and p_{dout} means the number of nodes counting of nodes belonging to the inner or outer ring accordingly.

Theoretical total number of nodes in optimal graphs calculated in dependence of source nodes location is shown in Table 7.

The optimal graphs do not exist in reality but the total number of nodes in dependence of source nodes location can be given by expressions:

$$\begin{aligned}&\textbf{when}\quad D(G)\leq 5\\ &p_{D(G)in}=\frac{D(G)}{12}\left(D(G)^3+2D(G)^2-D(G)+46\right)\\ &p_{D(G)out}=D(G)^3-3D(G)^2+8D(G)-2\\ &\textbf{when}\quad D(G)>5\\ &p_{D(G)in}=\frac{4}{3}\left(2D(G)^3-15D(G)^2+40D(G)-6\right)\\ &p_{D(G)out}=\frac{2}{3}\left(4D(G)^3-36D(G)^2+128D(G)-99\right)\end{aligned}\tag{34}$$

The theoretical average path lengths calculated using formula $d_{avNDRb}=\frac{d_{aviNDRb}+d_{avoNDRb}}{2}$ are equal to (35):

$$\begin{aligned}&\text{when}\quad D(G)<5\\ &d_{avo}=\frac{7D(G)^3-27D(G)^2+50D(G)-24}{2\left(D(G)^3-3D(G)^2+8D(G)-3\right)}\\ &\text{when}\quad 4<D(G)<7\\ &d_{avoin}=4\frac{62D(G)-255}{78D(G)-299}\quad d_{avoout}=2\frac{99D(G)-390}{68D(G)-251}\\ &\text{when}\quad 6<d\\ &d_{avoin}=12\frac{2D(G)^3-12D(G)^2+19D(G)}{8D(G)^3-60D(G)^2+160D(G)-27}\\ &d_{avoout}=24\frac{D(G)^3-7D(G)^2+14D(G)}{8D(G)^3-72D(G)^2+256D(G)-207}\end{aligned}\tag{35}$$

The difference between real and theoretical calculated parameters of NdRc structures is shown in Fig. 13.

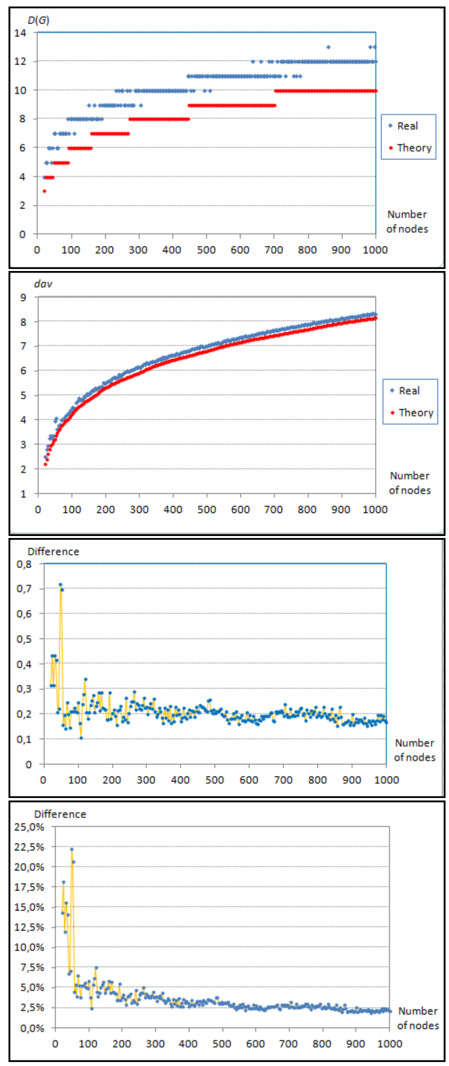


Fig. 13: Difference between parameters of real and virtual structures NdRc

Tab. 7: Total number of nodes versus graph diameter

$D(G)$	1	2	3	4	5	6	7	8	9	10	ring
$P_{D(G)o}$	4	10	22	46	90	168	300	504	796	1192	Inner
	4	10	22	46	88	156	268	444	700	1052	Outer

3.4 NdRd structures

Definition 8 *Two rings, each containing p nodes (p has to be divisible by 4), form the NdRd structure:*

- *outer ring, in which each node o_k is connected with two adjacent nodes $o_{k-1(mod p)}$ and $o_{k+1(mod p)}$;*
- *inner ring, in which each even node $i_{(2k+p)=0(mod4)}$ is connected with two adjacent nodes $i_{2k+p+q1(mod2p)}$ and $i_{2k+p+q2(mod2p)}$, each even node $i_{(2k+p)=2(mod4)}$ is connected to nodes $i_{2k+p+q1(mod2p)}$ and $i_{2k+p-q2(mod2p)}$ and each odd node $i_{2k+1+p=1(mod4)}$ is connected to two adjacent nodes $i_{2k+p-q1(mod2p)}$ and $i_{2k+p+q3(mod2p)}$ and node $i_{2k+1+p=3(mod4)}$ is connected to nodes $i_{2k+p-q1(mod2p)}$ and $i_{2k+p-q3(mod2p)}$;*
- *each node of the inner ring i_{k+p} is connected with a corresponding node of the outer ring o_k.*

Parameters q_1 must be odd but q_2 and q_3 - even, they are meaning the lengths of the chords. This structure is describing by - NdRd($p; q_1, q_2, q_3$).

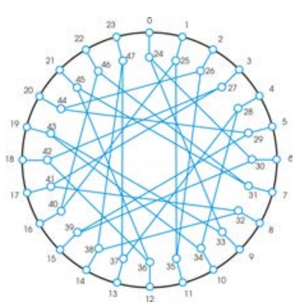


Fig. 14: Example of chordal ring NdRd(24; 9,6,10)

An example of these structures is shown in Fig. 14. Distribution of nodes in the layers in dependence of source nodes location is shown in Table 8.

The distribution of nodes in the first six layers can be described by expression:

$$\text{when} \quad d \le 6$$
$$p_d = \frac{4d^5 - 65d^4 + 420d^3 - 1165d^2 + 1585d + 600}{60} \tag{36}$$

Theoretical total number of nodes in optimal graphs calculated in dependence of diameter is shown in Table 9.

In this case it can calculate the total number of nodes in dependence of graph diameter (if it is not bigger than 6) using formula:

$$\text{when} \quad D(G) \le 6$$
$$p_o = \frac{6D(G)^5 - 85D(G)^4 + 580D(G)^3 - 1535D(G)^2 + 2354D(G) - 840}{120} \tag{37}$$

and the average path length of optimal graph is equal to:

$$\text{when} \quad D(G) \le 6$$
$$d_{avo} = 5\frac{8D(G)^5 - 97D(G)^4 + 594D(G)^3 - 1571D(G)^2 + 2050D(G) - 912}{6D(G)^5 - 85D(G)^4 + 580D(G)^3 - 1535D(G)^2 + 2354D(G) - 960} \tag{38}$$

It did not find any simple formulas describing distributions of nodes in higher layers, total number of nodes in NdRd structures and what is follows from this situation - average path length.

The difference between real and theoretical calculated parameters of NdRd structures is shown in Fig. 15.

3.5 Summing-up of the analysis

In the previous parts of this chapter an analysis of modified topological structures was presented. As a base for the creation of these topologies NdR structure was using. This analysis concentrated on two parameters: the diameter and average path length, which were used as a measure

Tab. 8: Distribution of nodes in the first layers

d	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Ring
p_{do}	3	6	12	24	43	76	125	179	247	344	460	583	732	924	1150	Inner
	3	6	12	24	43	76	123	181	249	340	459	583	736	924	1143	Outer

Tab. 9: Total number of nodes in optimal graphs

$D(G)$	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Ring
p_o	4	10	22	46	89	165	290	469	716	1060	1520	2103	2835	3759	4909	Inner
	4	10	22	46	89	165	288	469	718	1058	1517	2100	2836	3760	4903	Outer

of properties of the transmission networks modeled with the help of this type of graphs. In order to facilitate the estimation of these parameters expression for calculation of theoretical values characteristic for the graphs of optimal and ideal were given. In the diagrams the values of these parameters calculated theoretically and obtained experimentally for the real graph as a function of the number of nodes making up these structures were given.

The obtained results showed that the diameters of graphs NdRa1, NdRa2, NdRd in function of the number of nodes, are different from the theoretically calculated no more than 2. In the case of graphs NdRb they found one instance of the difference equal to 3, while such differences often appear in the structures of NdRc. In order to better visualize the differences of the average length of paths that appear in the real structures in respect to theoretical calculations in absolute terms and relative rates in the additional diagrams are given.

It was stated that differences of average path length decreases with the increase of the number of nodes forming the graphs and in any considered case slightly exceed or are less than 2% when the number of nodes exceeds 200.

In Fig. 16 the comparison of the both basic parameters of all analyzed structures is shown. From the charts it follows that the best properties possess graphs NdRc and NdRd but when structure consists of number of nodes greater than 150, in this case the difference between all analyzed topologies is significant. The disadvantage of NdRd structure is fact that it can be constructed when the number of nodes is equal or greater than 40 and only in this case this number is divisible by 8. This structure is quite complicated and additionally they did not find any polynomial describing the distribution of nodes in layers when the distance of source node is greater than 6. The drawback of NdRc is a difference between parameters value in dependence of the location of a source node (it belongs to outer or inner ring and has odd or even number). NdRa2 (when global number of nodes is divisible by 8) possesses the worst properties, while NdRa1 has parameters similar to basic structure NdR.

From the application point of view it seems that NdRb structures are the optimal solution for modelling optical network of type NdR. These structures are simple in construction, have a quite good basic parameters and these parameters are equal regardless of the source node they are calculated.

4 Conclusions

In this paper, in first part an analysis of NdR structures has been carried out. In this paper the authors proposed a few structures which are the modification of basic NdR graphs and presented their properties and formulas which can be used to facilitate process of choice of optimal network based on NdR structures.

A general conclusion that can be drawn from the presented analysis is that using structures of the NdR type for building extended computer networks is advisable and

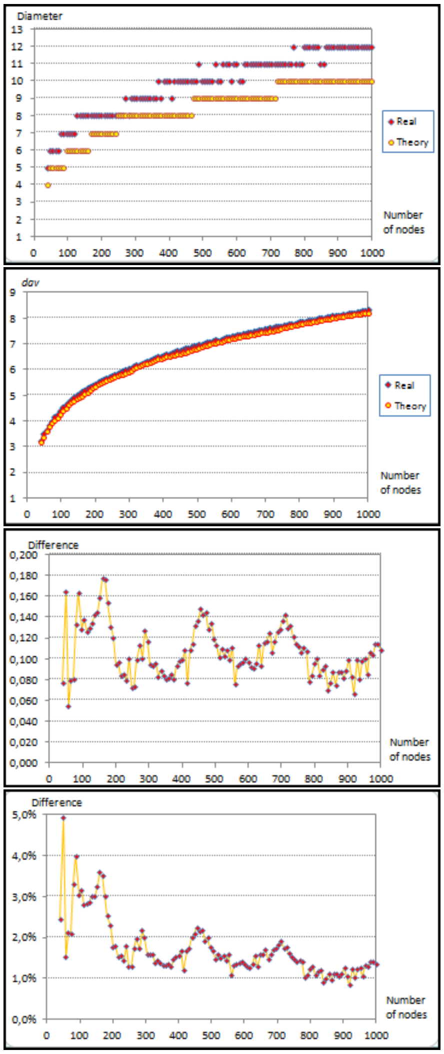


Fig. 15: Difference between parameters of real and virtual structures NdRd

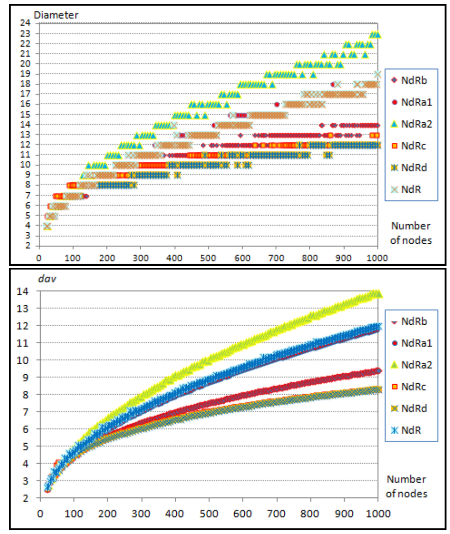


Fig. 16: Comparison of analyzed structures

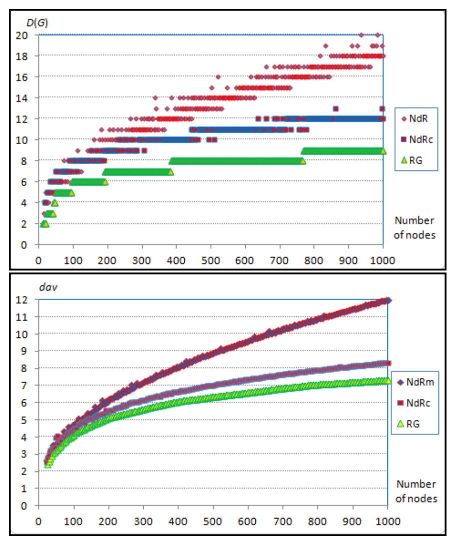


Fig. 17: Comparison of parameters of basic NdRm, real NdRc and Reference graphs in function of number of nodes

technologically justified due to their speed (resulting from a small diameter and the average path length), low degree of forming the network nodes, and good extensibility.

In Fig. 17 comparison of diameters and average path length of the best structure created on the base of NdR graph and Reference graph is shown. From this picture it follows that NdRc has parameters more close to Reference graph parameters but they are different of the ideal, so the future works, doing by authors, will be concentrate on searching the structures having parameters equal or minimal different from mentioning above relation graph.

Shown results are used, by the authors, in the designing of broadband networks based on DWDM technology and also were implemented in the algorithms for selecting the best neighbours in Wireless Sensor Networks (WSN) in order to ensure high efficiency readings in Automatic Meter Reading (AMR) system dedicated for acquisition and distribution of data from/to watt-hour-meters.

References

[1] L. N. Bhuyan - Interconnection Networks for Parallel and Distributed Processing. IEEE Computer Vol. 20 No. 6 pp. 9-12, 1987

[2] L. Narayanan, J. Opatrny, D. Sotteau - All-To-All Optical Routing in Chordal Rings of Degree 4. Algorithmica Vol. 31, pp. 155-178, 2001

[3] G. Kotsis - Interconnection Topologies and Routing for Parallel Processing Systems. ACPC, Technical Report Series, ACPC/TR92-19, 1992

[4] W. Arden, H. Lee - Analysis of Chordal Ring Network. IEEE Transactions on Computers Vol. 30 No. 4 pp. 291-295, 1981

[5] Cyril Gavoille "A Survey on Internal Routing" - http://deptinfo.labri.ubordeaux.fr/~gavoille/article/survey/node28.html

[6] B. Mans - On the Interval Routing of Chordal Rings. ISPAN '99 IEEE - International Symposium on Parallel Architectures, Algorithms and Networks, Fremantle, Australia, 1999, ss. 16-21

[7] S. Bujnowski - Analysis & Synthesis Homogeneous Structure Networks Connecting Communications Modules - PhD Thesis, UTP,Bydgoszcz, 2003.

[8] M.M. Freire, H.J.A. da Silva - Influence of Wavelength on Blocking Performance of Wavelength Routed Chordal Ring Networks. Proceedings of 3rd Conference on Telecommunications, Figueira da Foz, 2001

[9] M.M. Freire, H.J.A. da Silva - Performance Comparison of Wavelength Routing Optical Networks with Chordal Ring and Mesh-Torus Topologies. ICN (1), ss. 358-367, 2001

[10] M.M. Freire and H.J.A. da Silva - Assessment of Blocking Performance in Bidirectional WDM Ring Networks with Node-to-Node and Full-Mesh Connectivity. European Conference on Networks and Optical Communications (NOC'99), Delft, 1999

[11] A.L. Liestman, J. Opatrny, M. Zaragoza - Network Properties of Double and Triple Fixed Step Graphs. International Journal of Foundations of Computer Science 9, ss. 57-76, 1998

[12] L. Narayanan, J. Opatrny - Compact Routing on Chordal Rings of Degree Four. Algorithmica, Vol. 23, ss. 72-96, 1999

[13] L. Narayanan, J. Opatrny, D. Sotteau - All-to-All Optical Routing in Chordal Rings of Degree 4. Algorithmica Vol. 31, ss. 155-178, 2001

[14] Jens Myrup Pedersen, Structural Quality of Service in Large-Scale Networks. PhD. Thesis Aalborg University, April 2005

[15] Jens Myrup Pedersen, Ahmed Patel, Thomas Phillip Knudsen, Ole Brun Madsen, Generalized Double Ring Network Structures. Proc. of SCI 2004, The 8th World Multi-Conference On Systemics, Cybernetics and Informatics. Vol. 8, Pages 47-51. Orlando, USA, July 2004.

[16] Jens Myrup Pedersen, Thomas Phillip Knudsen, Ole Brun Madsen, Comparing and Selecting Generalized Double Ring Network Structures. Proc. of IASTED CCN 2004, The Second IASTED International Conference Communication and Computer Networks. Pages 375-380. Cambridge, USA, November 2004.

[17] Jens Myrup Pedersen, M. Tahir Riaz, Ole Brun Madsen, Distances in Generalized Double Rings and De-

gree Three Chordal Rings. Proc. of IASTED PDCN 2005, The IASTED International Conference on Parallel and Distributed Computing and Networks. Pages 153-158. Innsbruck, Austria, February 2005.

[18] Sławomir Bujnowski, Bożydar Dubalski, Jens M. Pedersen, Antoni Zabłudowski - Struktury topologiczne CR3m oraz NdRm. Przegląd Telekomunikacyjny LXXXI, nr8/9 2008, ss. 1133 - 1141.

[19] Bożydar Dubalski, Antoni Zabłudowski, Sşawomir Bujnowski, Jens M. Pedersen - Comparison of Modified Chordal Rings Fourth Degree to Chordal Rings Sixth Degree. Proceedings of Electronics in Marine, ELMAR 2008, Zadar, Croatia. Volume 2: ss. 597-600

[20] Jens M. Pedersen, Jose M. Gutierrez, Tomasz Marciniak, Bożydar Dubalski, Antoni Zabłudowski - "Describing N2R Properties Using Ideal Graphs". Advances in Mesh Networks, MESH 2009. The Second International Conference on Advances in Mesh Networks. ISBN: 978-0-7695-3667-5, ss. 150-154

[21] Sławomir Bujnowski, Bożydar Dubalski, Antoni Zabłudowski, Damian Ledziński, Tomasz Marciniak, Jens M. Pedersen - Comparison of Modified 6 Degree Chordal Rings. Image Processing and Communications. Challenges 2. 2010, ISSN 1867-5662. ss. 435 - 446

[22] Bożydar Dubalski, Antoni Zabłudowski, Damian Ledziński, Jens M. Pedersen, Tahir M. Riaz - Evaluation Of Modified Degree 5 Chordal Rings for Network Topologies. Proceedings of 2010 Australasian Telecommunication Networks and Applications Conference. Auckland - New Zealand, ISBN 978-1-4244-8171-2, ss. 66-71

[23] B. Dubalski, S. Bujnowski, D. Ledziński, A. Zabłudowski, P. Kiedrowski - Analysis of Modified Fifth Degree Chordal Rings. New Frontiers in Graph Theory. InTech 2012. ISBN 978-953-51-0115-4, ss. 43-88

CONTROL ALGORITHMS IN MULTI-AGENT ENVIRONMENT

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Abstract. Abstract: In this paper the general information regarding controlling multi-agent systems has been given. The simulation results of using algorithms, proposed by authors, used for controlling groups of robots servicing the virtual library has been presented. These simulations concerned estimation of following parameters: number of iterations needed to complete a task, average customer service time and average customer awaiting service time in function of number of robots, size of library and number of exchange points.

1 Introduction

The multi-agent systems are the dynamically developing branch of science which is deeply explored now days because of its big potential of usage. Systems like these can be used both in supporting of life science and humanistic science and widely understood informatics. The usage of those systems in modern informatics allows upgrading computer systems performance, upgrading of their parameters and resolving very complex problems which without the usage of those systems would be very difficult to resolve. The most important field where multi-agent systems can be used is robotics, where are using to creation and controlling of the group of robots. In this case single robot is able to work independently. It can communicate with other robots sharing information about surrounding environment and to realize specified goal. This allows for replacing or relieve humans protecting our health and live for instance in emergency situations, industry or battlefield.

The goal of the following paper is to present the achieved results of the simulation allowing for examine of the abilities of the usage and evaluation of the efficiency of the proposed algorithms of controlling the multi-agent system supporting library which allows for choosing the most optimal organization of this system.

2 Background

The intensive development of the informatics causes the need of searching new solutions in creating systems, which are reliable and efficient in usage. It is found that the development of information processing is largely dependent of the new application in informatics systems, the better utilization of the networks capabilities and distributed systems which are characterized by realization of the processes being done in parallel by multiple machines using shared resources.

The multi-agent system [1] is a form of complex computer applications which realize in parallel and distribute specified tasks with decentralized data containing [2]:

- A set of agents $A = a_1, a_2, \ldots, a_n$, where a_x is an agent which does not have complete information and is autonomous,
- Environment V, that is the place of performance of the algorithm, in which agents are located. The environment contains some ingredients that are processed by the agent,
- A set of R rules defining the relationships and interactions of agent - environment.

K. Centarowicz in his work [3] laid down the expectations of a new approach to information systems, such as multi-agent systems:

- Increase the flexibility in systems - systems can be easily adapted to carry out new tasks under varying conditions to a much greater extent than in systems that do not use agents;
- Increase the reliability of systems - enabling the creation and use of new tools that allow for better protection of complex computer systems;
- Improving the efficiency of systems - improving the time parameters, the implementation of new capabilities - combining features of different systems and obtaining new properties (eg. self-organization, self-adaptation).

The application of multi-agent systems will allow the creation of systems that enable the development of construction technology systems that will create and use systems difficult or impossible to achieve without the use of an agent (e.g. due to the complexity or to work under conditions of incomplete information about the problem), and the process creation of decentralized systems (problem analysis, design, programming and implementation) may be simpler, cheaper and more reliable [3].

Multi-agent systems are used in areas such as: support for solving optimization tasks and tasks that require the use of constraint programming, software engineering, computer networks, such as network management, security for information systems, robotics, modeling and simulation aspects of the natural sciences and the humanities [2].

The term agent is understood as a computer program in a sufficiently precise operating environment, which is the active component, with the necessary information about his condition, the ability to use certain resources and the ability to make independent decisions, adapted to current conditions, taking steps to achieve that goal.

Features agent regards two types of information [3]:

- The flow of the information agent - environment
  Each autonomous agent acting in their environment makes certain observations of the environment to retrieve the information necessary for its operation. Agent may have memory and ability to learn on the basis of the observed changes in the environment, and previous decisions. State of the environment and the actions of other agents have a direct impact on the decisions and behavior of the agent, and all his actions directly affect the environment. The agent should be able to use the often contradictory information coming from different sources, and dynamically changing environment should not affect the effectiveness of the agent is and the accuracy of his assessment of the situation.
- The flow of the information agent - agent

During operation, agents invoking certain events can communicate with each other to provide the information necessary to complete a task. Between agents can be distinguished the following relations: coexistence - the agent should be able to do its job without the help of other agents, however, there are possible conflicts between the agents, co-operation - the agent to perform a task must necessarily interact with other agents, cooperation - to complete a task only one agent is necessary, but in the environment, there are many potential contractors (in this case, cooperation is essential for agents, which leads to the emergence of an agent - the contractor); distributed performance - for the job you need a group of agents.

In multi-agent systems, there are two types of agents. This division is based on the method of decision-making based on the method of perception: a purely reactive agent - decisions are the result of current knowledge about the environment, the agent does not use or analyze information on the previous states of the environment, an agent with internal parameter - the agent to make decisions using the knowledge of the former states of the environment.

Agents to make decisions are using the decision-making functions. Depending on the implementation of the architecture these are as follows [4]:

- Logic-based architecture - is characterized by clarity, simplicity approach and high computational complexity, which is often the result of prolonged decision-making. Agent receives information about the environment stored in a symbolic way, which then updates, and all decisions are made on the basis of logical deduction.

- Reactive architecture - this architecture abandoned token entry environment, all decisions are made on the basis of direct communication agent - the environment, and the final behavior is the sum of simple agent behaviors.

- The BDI (Belief Desire Intention) type architecture is intuitive. Its main objective is to decide what you want to achieve and how. According to this architecture, an agent at each step determines what must to do to carry out their task goal.

- Layered architectures - these are all types of architectures that have at least two layers. There are of two types: parallel and serial. In the parallel architectures all layers receive and process the signals appearing at the input, and generate an output signal. Operations using this method are fast, but they need a special mechanism for deciding which layer at a time should do its decision function. In the serial type, data are received by one layer, and then sent to the next layer, which results that the system is simpler, does not require a master decision mechanism, but because of the elongated path of information flow is slower.

In multi-agent systems there are many ways to implement the decision-making mechanism. In terms of the decision-making multi-agent systems are divided into [5]:

- Centralized structure, where decisions are taken by one agent, designated as the leader (coordinator). Coordinator has full information about the environment, it can collect and store and transmit orders to other agents. In this way it is easy to implement predictive and optimization functions. An additional advantage of this system is to simplify the decision-making - there is no negotiations mechanism. The main disadvantages of this solution is its low reliability (failure of the coordinator causes the crash of whole system) and the dependence of the reaction rate on the size of the system.

- Hierarchical structure, where the structure of the system consists of agents connected with relationships at different levels of the hierarchy. Main process is divided into smaller, related subprocesses. The advantage of this approach is easier and simpler to implement, which can be introduced gradually - due to the modular configuration. The disadvantage of this system is its low scalability (even small changes in the environment may require intervention at several levels of the hierarchy), the difficulty of access to higher levels of hierarchy and limited fault tolerance.

- Hybrid structure which combines the features of hierarchical and centralized structures. In this system, the system distinguishes agents whose task is to optimize decisions, and other agents of limited influence on decision making. The advantages of this structure are usually all the positive features of both architectures (centralized and hierarchical). The major disadvantages include quite small scalability and limited resistance to a system crash.

- Distributed structure, where each agent has full decision-making capacity, and by the relevant transactions with other agents can realize their goals. The main advantage of this architecture is a high resistance to failure - in case of failure of the agent, the rest of the system continues to run, because other agents can take over tasks undone by faulty agent. Taking into account the software implementation, the system is easier to develop, because the software will be similar for each of the agents. Good scalability and ease of deployment of self-organization, are characteristic of this architecture. The main disadvantage of this solution is difficult to achieve the objective imposed on the system due to the need for continuous exchange of information between agents who speak about their immediate environment. Without this exchange of such data, complicating the construction of an agent, the system could not perform the tasks previously assigned.

The decision on the next step and about how to meet this target, the agent takes on the basis of observations of the environment. So the agent to be able to act in accordance with their algorithm needs to be placed in the environment. Environment can be classified as follows [4]:

- Available / unavailable - the availability of environmental says the number of the information about it. Determines the level of accessibility to the complexity of the construction of the agent, the more information, the easier it is to build an agent;

- Deterministic / non-deterministic, if the environment is deterministic, it means that all actions of the agent environment responds uniquely;

- Episodic / non episodic. Episodic environment means that the changes that occur in the environment of the particular agent it does not depend on the actions of other agents on the other stages;

- Static / dynamic - static environment allows the agent to perform only a finite number of actions;

The environment can be divided into different parts because of its availability [3]:

- Far environment - a collection of data that is indirectly within the perception of the agent.

- Close environment - an environment that the agent using the procedures of perception is only within his observation.

- Surrounding - part of the environment (close), in which the causative agent is not possible, for which the agent can act, process it and change it.

- The neighborhood is part of the surrounding in which the agent can act with more power than the other agents.

- Own environment - the part of the neighborhood, which can only be modified by the algorithm, so-called owner and other algorithms can make changes to this part of the environment only through and with the consent of the owner.

When creating multi-agent system it is very important to choose the right environment for agents and their activities. A very practical application to the environment based on graphs, called graph similar environments [5]. They are characterized by the simplicity of the implementation and large and highly complex theoretical background. Due to the large number of available algorithms to find paths in the graph, the agents in the environment, moving around the nodes of a graph may find be the most optimal route to get there.

3 The use of multi-agent systems in robotics

Robots are found in many areas of human life, often replacing humans and doing various jobs for him. With the development of science, which is the robotics, you need to control not only the individual robots, but also a group of robots. One of the main applications of multi-agent systems is to use them in a distributed robotics, which may be understood as directing a group of autonomous robots working together to carry out tasks with varying (dynamic) parameters, and the environment [6, 7, 8].

Tasks performed by a team of robots can be divided into two main groups [4]. The first one has a task that can be successfully performed by a single robot, but the use of several robots significantly shorten the duration of the entire task or the use of one agent will be less effective. The second group consists of tasks that cannot be performed by a single robot, and only allow the use of several agents to perform the activity.

The three main areas of application of the team of robots are: transport - in the case of items that prevent transport from one robot (with large size, high weight) or when one robot performs the task more slowly, the exploration - gathering information about the area - a group of robots will do the job faster, furthermore it is possible to start exploring the different places in different directions, inspection - patrolling the area, an example may be searching for minutes by robots, collecting scattered elements - in this case, a team of agents has undoubted advantages over a single robot, because a group of robots can search a much larger area than a single robot, so that patrolling will be done accurately.

Multi-agent systems can be used to perform diverse types of tasks [3]. Examples are as follows:

- Sweep - understood to perform certain activities in certain areas (vacuuming, painting, cleaning, inspection);
- Search of the environment, quite similar to the previously described sweep. The problem of searching the destroyed areas requires a different approach to designing systems based on a group of rescue robots that need to respond flexibly to a greater amount of information to make more complex decisions to address emerging problems and also be more resistant to failures. The unpredictability of the environment and shorten the time of operation of robots are the main problems faced by the designers of such systems;
- Motion control, which can be understood in two ways: as a robot motion control (that is, ensuring that the group of robots moving in a top-down set taking into account the co-operation between robots) as well as motion control for robots (eg. in factories, where all the stages of production must be done in the right order at the right time).
- Emergency medical services. Robots are used to test the emergency response strategy, team work coordination, collection, analysis and processing of information. According to the assumptions in the future work of this type to replace the emergency services and minimize the risk of emergency workers, disaster victims to be giving the their health status and, if

necessary, to provide for those in need of food and means of communication.

Multi-agent systems are not only used in robotics for scientific and industrial, but also for entertainment, for example, to popularize the issues related to robotics and artificial intelligence created RoboCup competitions [4, 9]. Summing up, groups of robots can be used in many ways to perform various operations and solving various problems.

In the further part of this article is present an analysis using a group of robots, controlled by multi-agents algorithms that support virtual library [10].

The results of the use of a team of robotic control algorithms will be presented in terms of evaluation of the following parameters:

- The number of iterations of the algorithm, i.e. the number of actions that robots have to perform to achieve the goal;
- Average customer service time, i.e. the number of units of time in which the client gave and received all the books;
- Average customer waiting time to the entrance to the library, i.e. the number of units of time, during which customer waited from the entering the queue to until the start of its operation.

4 Description of proposed algorithms

The subject of this paper is to present the possibility of using multi-agent systems to control the group of robots team on the example of a group that supports virtual library.

For the analysis the following assumptions ware undertaken: clients coming to the library put in exchange points (system inputs) books for return and a list of "wishes"

Fig. 1: Diagram of exemplary analyze library

containing a list of items to borrow, The task of a group of robots is to return books to the shelves which ware returned to library and bring back the ordered (output system) books.

Research on the performance and application of multi-agent algorithms were performed on a simulation environment [11] that has been shown in the Fig. 1. It is a two-dimensional environment, graph similar, where robots move between nodes in the graph along the paths of latitudinal-meridian system (freely selectable distance of two points is the sum of the absolute values differences in their coordinates), and change of the direction of movement of the robot is possible only in nodes.

In each simulation step the robot can perform one action, such as changing the position, download books, waiting for a job.

Robots use Dijkstra's algorithm to find the shortest path. The main aim of authors was to select the algorithm for working robots, which will output with a shortest time of customer service.

Non collision algorithms were analyzed, namely those in which the robots will not be able to detect a collision, i.e. simultaneously occupy the same graph node, and the same path, which corresponds to the situation that exists independent of the road on which the robots move. It was assumed that there is a possibility of free parameters matching the library:

- Number of robots servicing the library;
- Transport capacity of the robot, the number of books

that the robot can carry when performing one task;

- Number of positions available to customers;
- Limit of books that can be put on the point;
- Number of rows of books;
- Number of segments in the bilateral row;
- Number of shelves on one side of the segment.

Among couple of algorithms which have considered, after analysis [11] for further tests one algorithm with distributed structure and two algorithms with hybrid structure were chosen. Below are characteristics and description of every one of each.

Environment and algorithms have been implemented using the Java programming technology.

4.1 RI Algorithm

When developing the RI algorithm, the following assumptions where done. It has a distributed structure, which means that each robot independently decides what to do in the next step. Robot in a single task can carry only one book. In each step of the algorithm, before any action is performed robot checks if it has an empty pocket, where he puts the book. If it do not currently support any task, it executes viewing positions in the library - this step always begins with the desktop that is closest to the entrance to the library. First, it is checked whether the positions are not on a list of "wishes". If a particular position is found on the list it moves the book to the exchange point and if not it decides to put the carried book on the shelf. The Fig. 2 shows a block diagram of the algorithm RI.

4.2 H1 Algorithm

The H1 algorithm is characterized by a hybrid structure - assignment of jobs is the coordinator responsibility, and each robot can decide what steps to do to achieve the goal. Coordinator allocates the robot to handle a specific job position and the number of volumes that are on it, or are to be delivered, how the robot is able to transport at one time. Coordinator begins its operation by creating a list of available positions in the library. During the search task is selected first position in the list, then the number is moved to the end of the queue, to avoid build-up tasks for selected positions. In determining the position of the manual, it is checked whether they are on the books to return or list of "wishes". If the position is not empty, it begins to determine the stage of the robot to handle the position. Management algorithm checks whether any of the agents at the moment waiting to be assigned a task, and when found, assign it to a specific position.

Robots supporting work stations can download as many books as they can carry in their pocket. Robot starting work reports it to coordinator that he expects the task, and checks whether or not he has been assigned a exchange point to handle. After receiving the order, first it checks to see if in the exchange point can be found books to return, and if it finds any it puts it in his pocket until it is full or until all books are collected. Once the pocket is full, the agent starts offload items to the shelves. If the robot has already put all the volumes or did not find any, it checks if the exchange point has any a list of "wishes". Locating the list starts downloading procurement phase of the shelves, which lasts up to fill robots pocket or handle all of the books that the customer wants to borrow. In the next step, the robot carries owned books, and when they are delivered the task is assumed as completed and reports the coordinator the transition to the stand-by mode (Fig. 3).

4.3 H2 Algorithm

The H2 algorithm is hybrid structure algorithm. Like the H1, coordinator operation is to select tasks and assign job to support them. Robot gets the job from the coordinator or waiting to be assigned to. After downloading the task the robot decide on its own what steps need to do

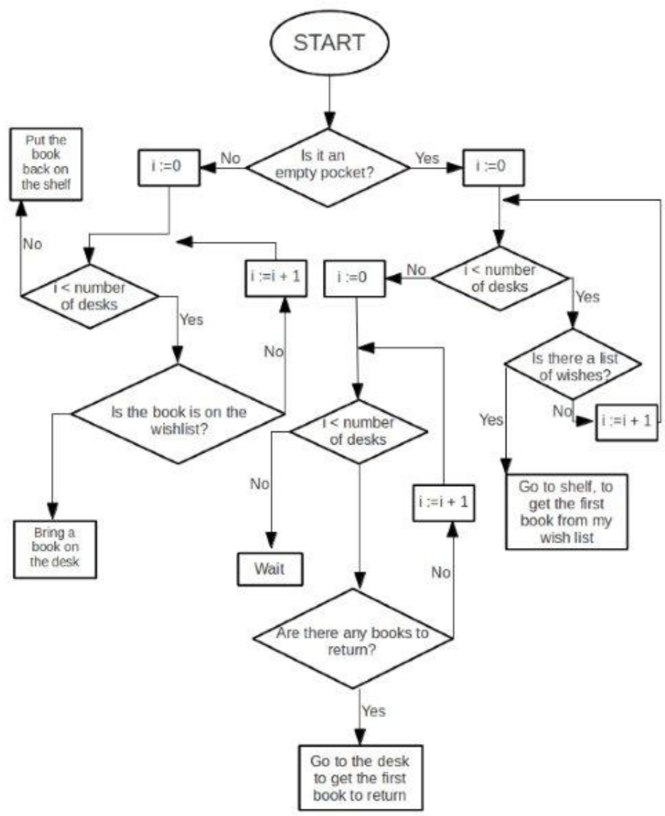

Fig. 2: Block diagram of the algorithm RI

to achieve the goal. The algorithm distinguishes between two types of tasks - to provide books to the position (DELIVER_TO_DESK) and take books out of exchange point (TAKE_FROM_DESK).

For each task can it be assigned more than one book, but the maximum number of them may not exceed a capacity of robot pocket. The agent can perform only one order at a time only and it cannot be disrupted or replaced by other during its lifetime. Depending on the type of task, the robot behavior is different. In the case of delivery to the exchange point more than two books, the robot looks for the position of a book that is closest to its current position. In this way, the travel time to the shelves is minimized. However, there is also the ability to deliver books without analysis of their position by changing the order in your pocket (books are arranged from the earliest located in exchange point to the latest). Coordinator first assign tasks to related to delivery of the books - this impacts on the improvement of the library service - customers who want to return a book do not wait and after hanging books

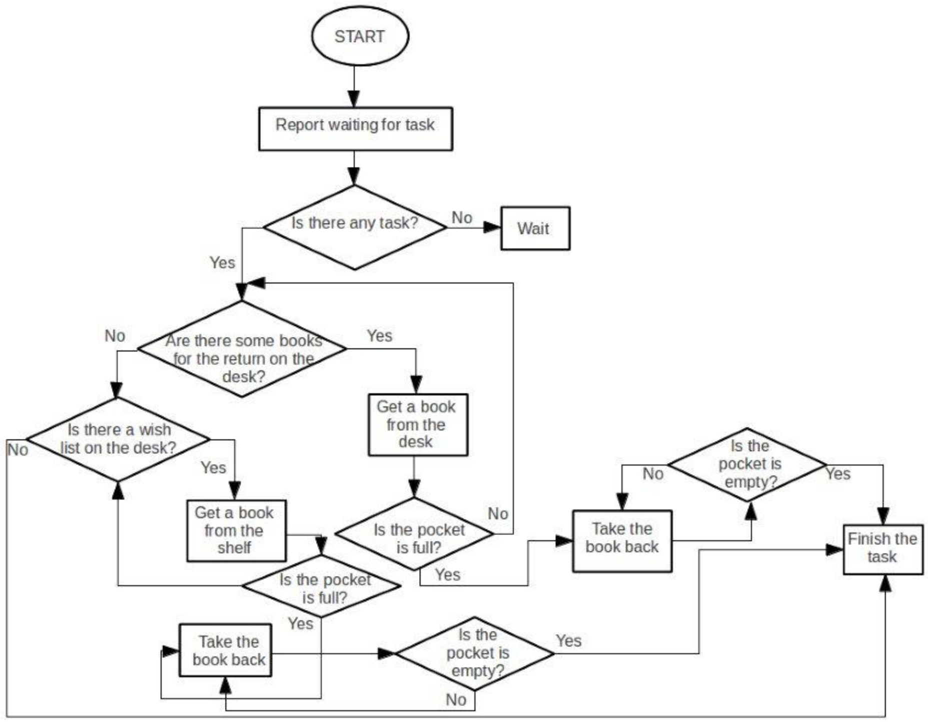

Fig. 3: Block diagram of the algorithm H1

leave the library, reducing average handle time.

The algorithm of the robot at the beginning retrieves information about a task that coordinator assigned. In the algorithm has been used flags - these are variables which can store information about the task details. Initially, each robot has set its variable in the "WAIT". When the robot performs the next step it is checked the number of bibliographic position, which the agent has not yet handled. If the size of the list is equal to one, the robot changes the flag to the next task in the queue, doing task which it found earlier. Finishing the job, after all books are delivered, robot reports it to coordinator, which changes the information status of the robot - set it as available to assign tasks (Fig. 4).

Coordinator its algorithm starts with operation of finding robots ready to take the books from the exchange points. It then searches the exchange points, in search of tasks, and when it detects a new job reported by the exchange point algorithm terminates its action, selects free agent and assigns him the task type, titles of books and number of positions (Fig. 5).

5 Simulation analysis of the proposed algorithms

The above-described algorithms were tested determining the number of iterations, the average customer service time and average waiting time for customer service. The simulations were performed for the following environmental variables: the library served by one to three robots that due to the limitation of the algorithm, in one task robot can carry only one book. In the library for students were available from one to six exchange points, which may at one time have up to five books. In the environment

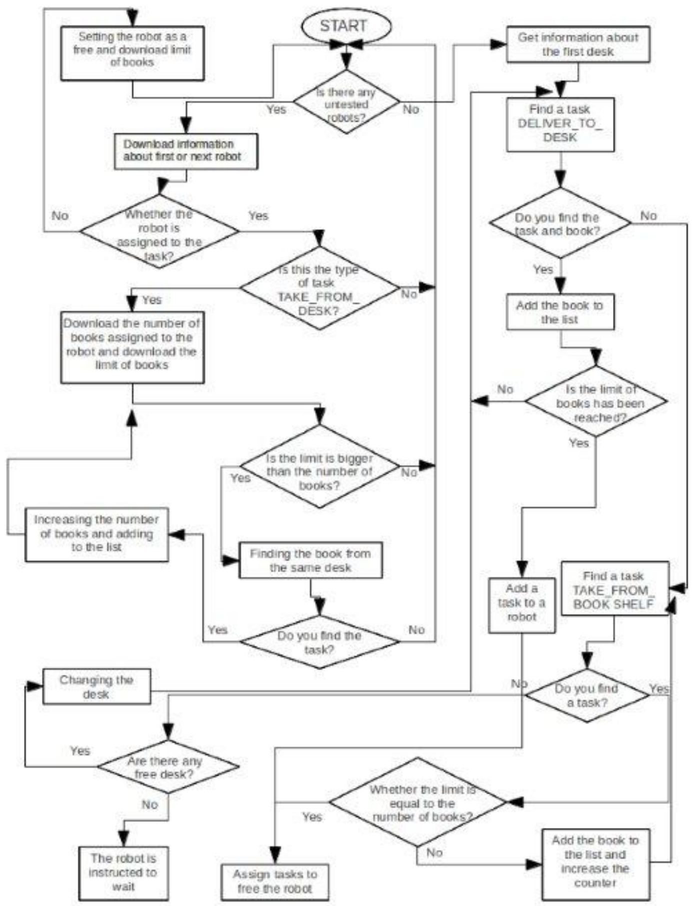

Fig. 4: Block diagram of the algorithm H2a

are placed two, three or four segments, and the number of bilateral segments is equal to the number of rows. In each segment, there were five racks. In order to bring more transparency in the parameter "number of rows" is defined as the size of the library. The research was conducted under the assumption handling thousand of clients.

In the charts presented below is shown the results of the simulation.

5.0.1 Number of iterations

From presented above diagrams (Fig. 6, 7) it results that if library is serviced by one robot then the sort of control robot algorithm and the size of library does not have any special impact. However if the library is serviced by more than one robot than hybrid algorithms gives better results although if number of exchange points is more than four than the difference between iterations in H1 and H2 algorithms can be omitted regardless of the size of the library.

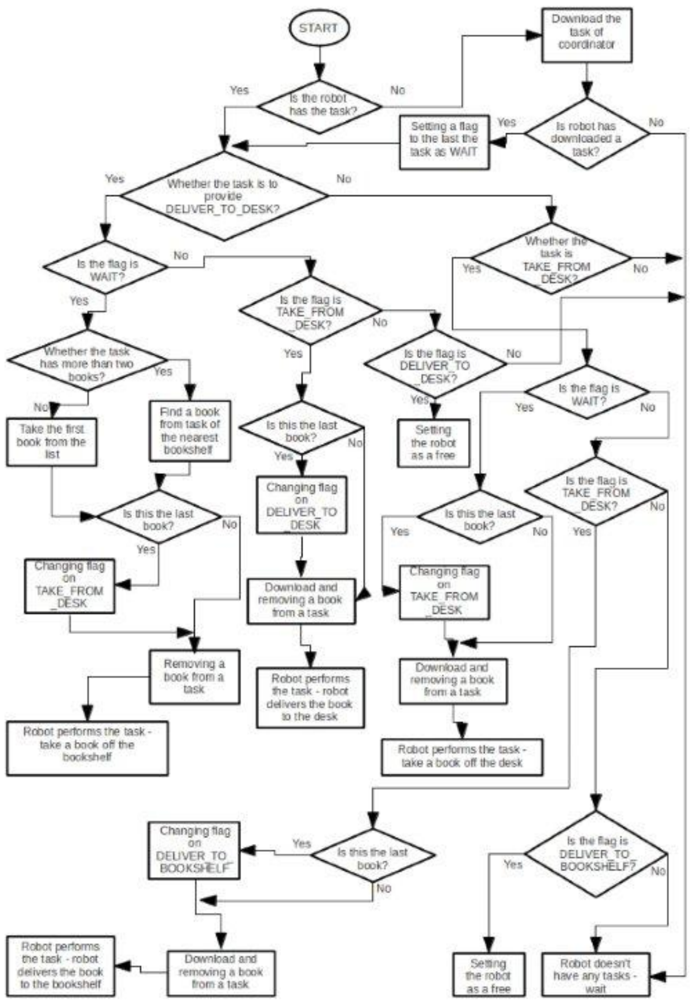

Fig. 5: Block diagram of the algorithm H2b

5.0.2 Average customer service time

Just as it did in the case of the study the number of iterations that if the library implements one service robot, the robot control algorithm type and size of the library has no special meaning. If the library supports more than one robot, the hybrid algorithms provide much shorter customer service time but if the number of the positions is greater than four then difference between those times obtained through the use of algorithms for H1 and H2 is not much regardless of the size of the library (Fig. 8, 9).

5.0.3 Customer service awaiting time

With regard to the examination of customer waiting time for service, it is just like it was in previously analyzed results of the estimation of the parameters, selection of the type of robot control algorithm and library size does not matter if you the library is serviced by one robot. If the library supports more than one robot, the hybrid algorithms provide a much shorter waiting for customer service time, but the difference between those obtained by using algorithms H1 and H2 is significant regardless of the size of

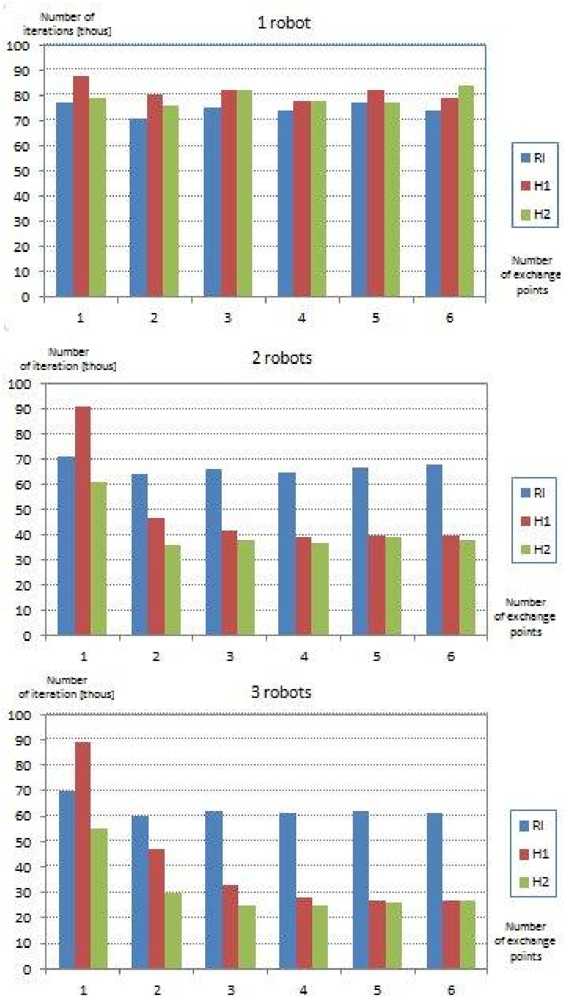

Fig. 6: The results of used algorithms in terms of the number of iterations performed as a function of the number of exchange points serving customers, assuming a variable number of robots that support a library of size 2 (RI - distributed algorithm, H_i - hybrid algorithms)

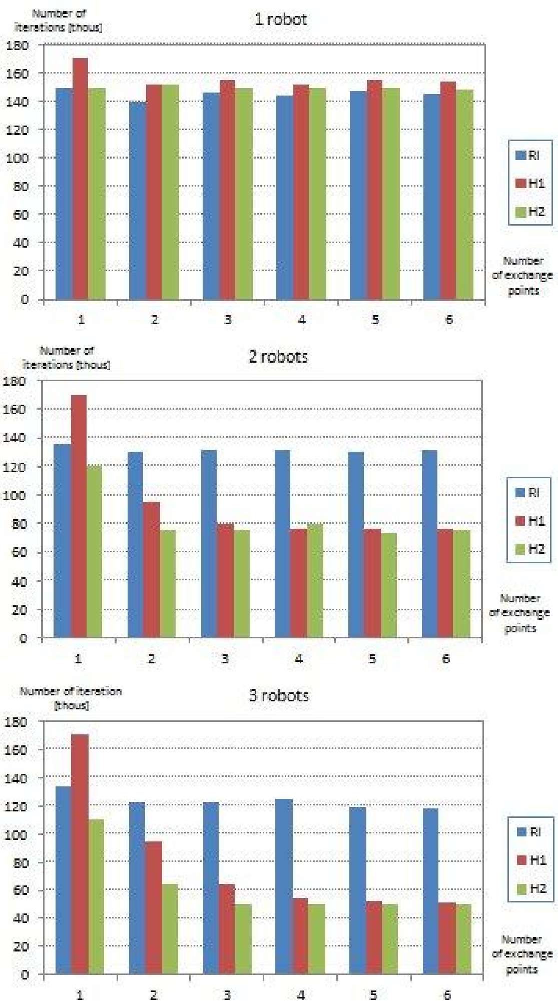

Fig. 7: The results of examination of used algorithms in terms of completed number of iterations in function of servicing the clients and the number of servicing robots assuming that the size of library is 4

the library (Fig. 10, 11).

Based on the obtained results, it was found that the parameters of the algorithm on a distributed structure significantly different from the results of typical hybrid structures, an additional simulation has been done for algorithms H1 and H2 in order to determine their effectiveness for handling 3 books at one time. These tests were carried out for the library size of 4. The obtained results are presented in summary charts below.

- Number of iterations

  The chart presented above (Fig. 12) confirms previous results and observations but we can see that if library is served by more than one robot than the difference of number of iterations using H1 and H2 algorithms impacts the number of exchange points.

- Average customer service time

  Fig. 12. The results of examination of H1 and H2 algorithms In terms of average customer service type

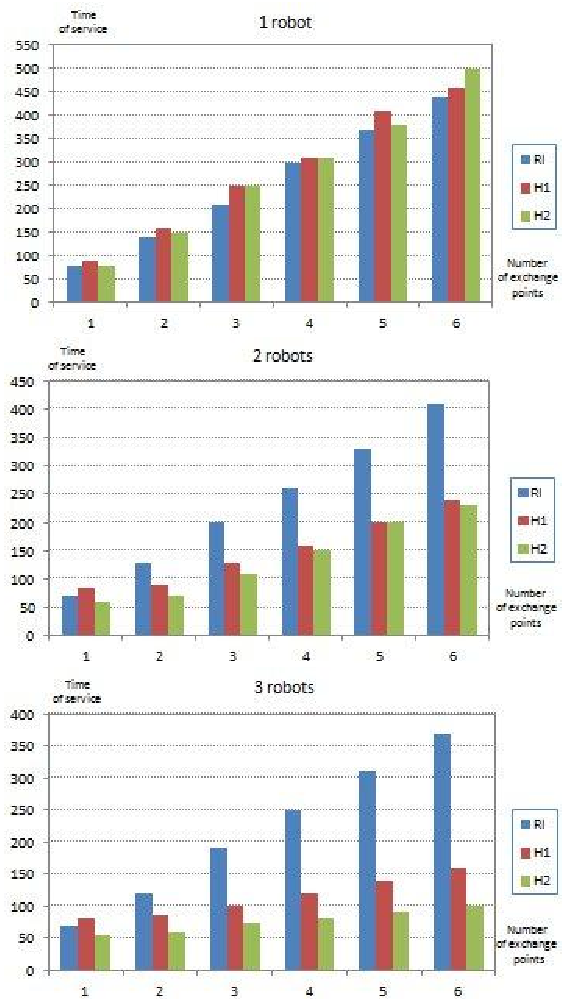

Fig. 8: The results of examination of used algorithms in terms of customer average service time in function of number of exchanging points servicing the clients assuming that the size of library is 2

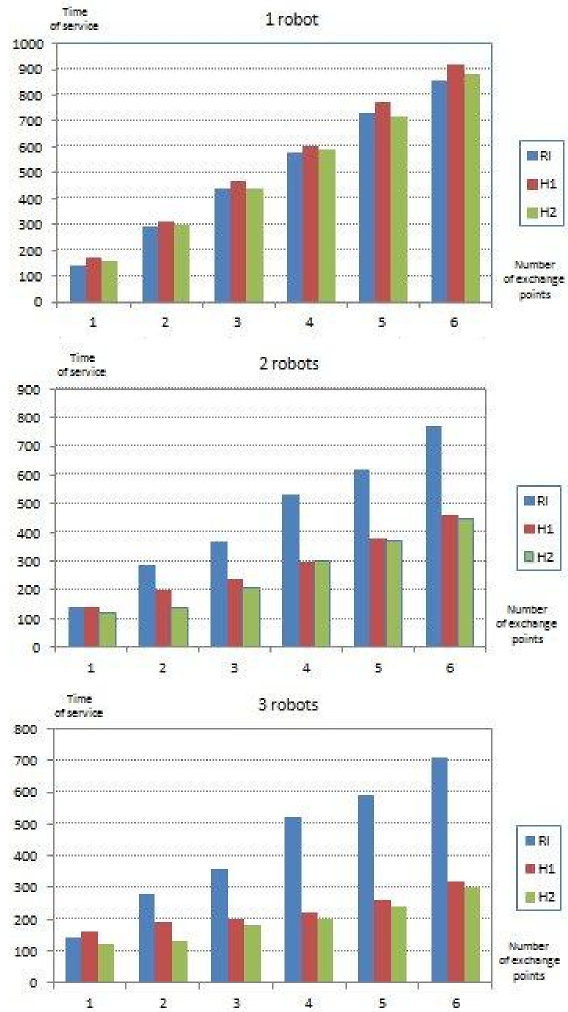

Fig. 9: The results of examination of used algorithms in terms of customer average service time in function of number of exchanging points servicing the clients assuming that the size of library is 4

in function of number of exchange points servicing the clients assuming increasing number of carried books by robot to 3. From the chart (Fig. 13) given above it can conclude that if library is served by more than one robot than the average customer service time together with the increase of number of exchange points is similar no matter what type of algorithm was used.

- Service awaiting time

Presented above results confirm previous observations that H2 algorithm guarantee shorter customer service awaiting time and this difference maintains approximately at the same level no matter what is the number of exchange points for customers (Fig. 14).

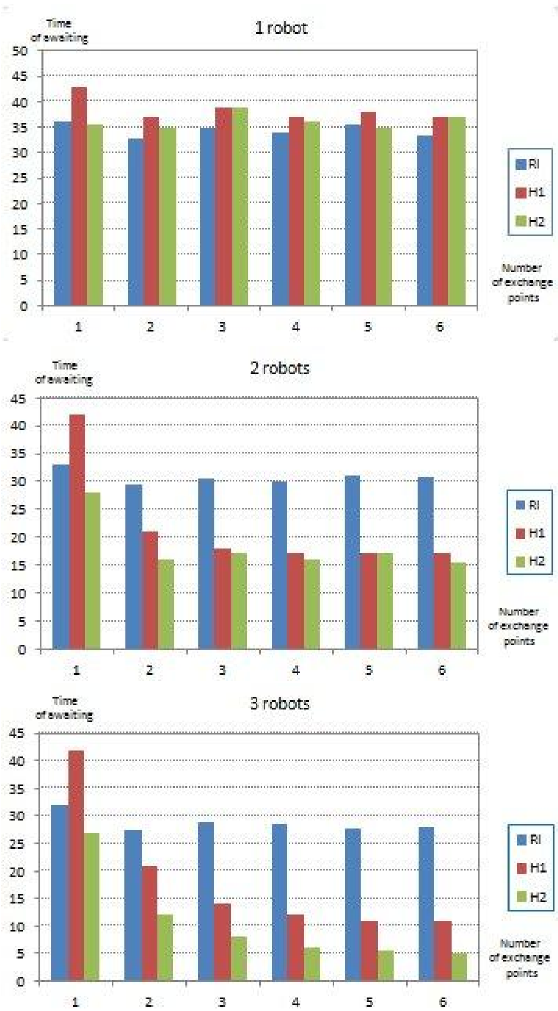

Fig. 10: The results of examination of used algorithms in terms of average customer service waiting time in function of number of exchange points servicing the clients assuming that the size of library is B = 2

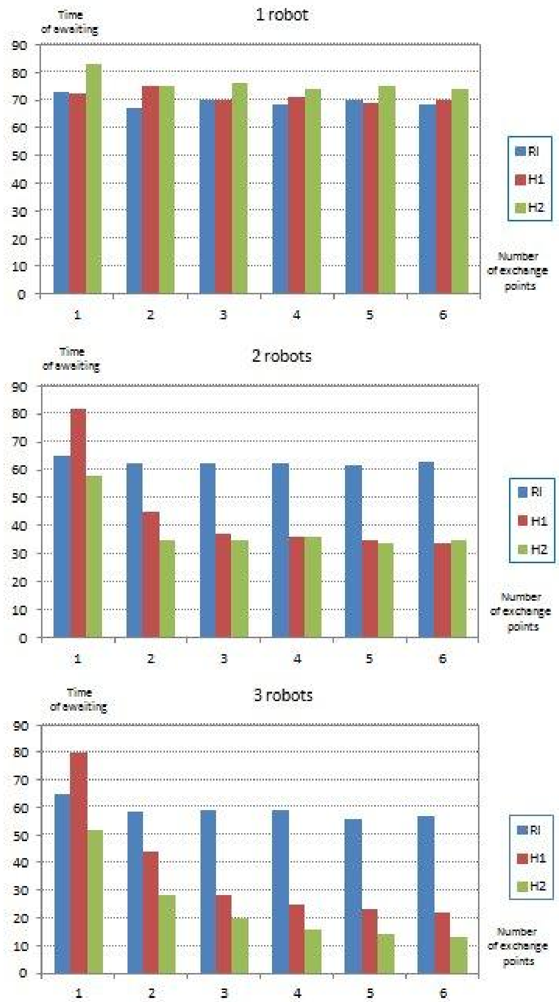

Fig. 11: The results of test of used algorithms in terms of average customer service waiting time in function of number of exchanging points servicing the clients assuming that the size of library is B = 4

6 Conclusions

In this paper, in its first part it provided basic information on multi-agent systems. The following sections describe the principles of operation of the proposed algorithms, and show the results of analysis of proposed by the authors control algorithms to control the systems that support virtual library. Based on the simulations regarding the number of iterations required to perform the tasks, the average customer service time and the average waiting time for customer service in function of the number of robots used, the library size and the number of exchange points, it was found that the systems that use teams of robots are much more effective than systems operated by single robot regardless of the algorithm used. Among the proposed algorithms on the basis of the results found that the best performance is a hybrid algorithm H2, because it guarantees minimum customer expectations for service, if the robot takes only one copy of the book, and if robot

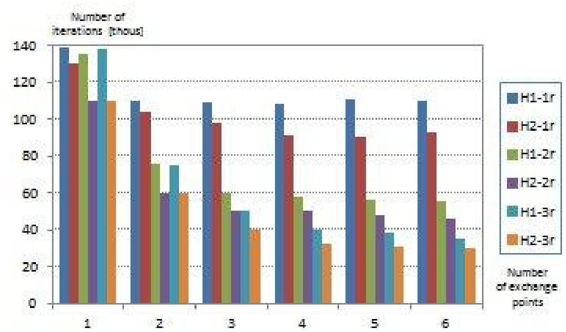

Fig. 12: The results of examination of H1 and H2 algorithms in terms of completed number of iterations in function of number of exchange points servicing the clients assuming increasing number of carried books by robots (Hi - type of algorithm, jr - number of robots)

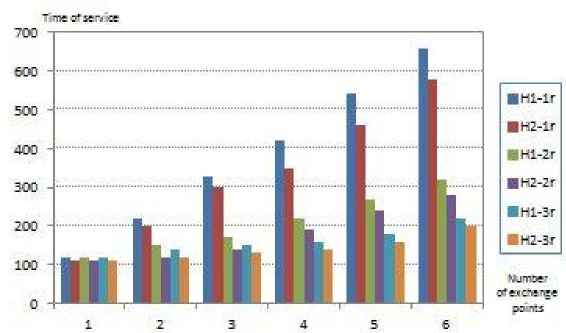

Fig. 13: The results of examination of H1 and H2 algorithms In terms of average customer service type in function of number of exchange points servicing the clients assuming increasing number of carried books by robot to 3

can carry a larger number of books also the number of iterations necessary to handle the task.

It should be noted that the analysis of collision algorithms, which do not detect a collision occurring during the movement in the libraries, can simultaneously occupy the same exchange point, and the path of the graph. This problem is similar to the problem described in [12].

The second type of multi-agents control systems are collision algorithms, in which environment is implemented mechanism of collision detection, booking paths and predictions of interdependence when choosing routes. This type of algorithms will be the subject of further re-

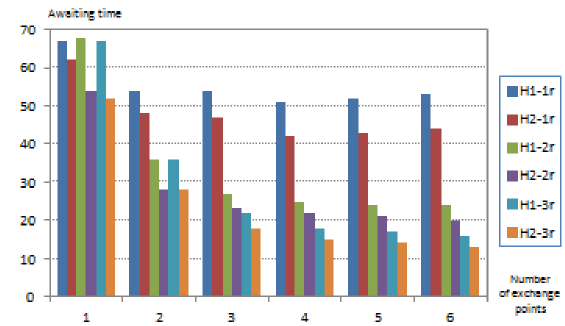

Fig. 14: The results of examination of H1 and H2 algorithms in terms of average customer service awaiting time in function of number of exchange points servicing the clients assuming increasing number of carried books by robot to 3

search conducted by the authors of this paper.

References

[1] P. Wołoszyn. Modelowanie dynamiki chaotycznych systemów biologicznych z użyciem metod multiagentowych. Ph. D. Thesis, Akademia Górniczo-Hutnicza, Kraków, 2004

[2] A. Biernacki. Systemy wieloagentowe jako narzędzie do symulacji systemów złożonych. Politechnika Śląska, 2005

[3] K. Centarowicz. Problemy projektowania i realizacji systemów wieloagentowych. Rozprawy Monografie 80, AGH Uczelniane Wydawnictwo Naukowo- Dydaktyczne, Kraków, 1999

[4] M. Gnatowski. Wykorzystanie systemów wieloagentowych we współdziałaniu robotów mobilnych. Ph. D. Thesis, Polska Akademia Nauk Instytut Podstawowych Problemów Techniki, Warszawa, 2005

[5] Chaohui Gong; Tully, S.; Kantor, G.; Choset, H. Multi-agent deterministic graph mapping via robotrendezvous. Robotics and Automation (ICRA), 2012 IEEE International Conference on Robotics &

Control Systems. 10.1109/ICRA.2012.6225274, pp. 1278 - 1283

[6] Cai Luo; Espinosa, A.P.; De Gloria, A.; Sgherri, R. - Air-ground multi-agent robot team coordination. Robotics and Automation (ICRA), 2011 IEEE International Conference on Robotics & Control Systems. 10.1109/ICRA.2011.5980582, pp. 6588 - 6591

[7] Nishiyama, H.; Yamazaki, W.; Mizoguchi, F. Nishiyama. Negotiation protocol for proof of realization of cooperativetask in multi-agent robot systems. Systems, Man, and Cybernetics, 2000 IEEE International Conference on Robotics and Automation. 10.1109/ICSMC.2000.886350, pp. 1685 - 1690 vol.3

[8] J. Zajźc. Wieloagentowe sterowanie zrobotyzowanymi systemami produkcyjnymi. Politechnika Krakowska, Instytut Technologii Maszyn i Automatyzacji Produkcji, 2006

[9] `www.RoboCup`, `http://www.robocup.org/`

[10] Qin Cen; Yiru Ye; Lina Liu; Xi Ye. On the application of the multi-agent based on robot system inbook classification for library. Natural Computation (ICNC), 2010 Sixth International Conference on Computing & Processing (Hardware/Software). 10.1109/ICNC.2010.5584886, pp. 4109 - 4113

[11] K. Makowiecka, M. Marasz. Wieloagentowe systemy sterowania. Engineering Thesis, UTP Bydgoszcz, 2012

[12] P. Kiedrowski, B. Boryna: Wpływ kolizji na skuteczność odczytów liczników energii elektrycznej, Zeszyty Naukowe Nr l , 2007, WETiI Politechniki Gda nskiej, Seria: Radiokomunikacja, Radiofonia i Telewizja pp. 147-150.

A SURVEY ON CHORDAL RINGS, N2R AND OTHER RELATED TOPOLOGIES

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Abstract. In this short paper we summarize the main results of 10 years of research on network topologies carried out jointly at Aalborg University (AAU), Aalborg, Denmark, and University of Life Science (UTP), Bydgoszcz, Poland. The starting points are the Chordal Rings, which were mainly studied in UTP, and the N2R which were studied at AAU. From here the universities have collaborated intensely, and studied a number of alternatives and variations of the original topologies, based on methodologies developed both independently and jointly over time. This paper gives an overview of the work done, and provides appropriate references to the work for further details. The paper is presented as a tribute to Professor and Dean Antoni Zabłudowski who passed away during 2012.

1 Introduction

Our society is becoming increasingly dependent on communication infrastructures, including broadband networks, and they are used for many aspects of our lives; Enterprises are relying on them for operating their businesses, contact with the public sector is increasingly based on self-service and digital platforms, and many services are (or are becoming) dependent on reliable high-capacity broadband connections, including services within health care, elderly care, education and homebased workplaces. In addition, there are several projects on managing other infrastructures using communication networks in different forms, such as the Smart Grid and Intelligent Transportation Systems. This is changing the requirements for our digital infrastructure, where it is not only a matter of being able to connect to the Internet, but also of reliability and quality of the connections. This increased focus can also be seen from various projects on Internet Quality, where the most prominent is the European benchmark on Network Quality carried out by SamKnowns [1].

The study of network topologies is crucial in this regard, at multiple levels: The physical layout of the (mainly wired) networks is basically limiting what can be done at the higher layers, in terms of connectivity and distances even if the network is suffering from one or more failures, and it is important to choose wisely the optical layout in order to get the right tradeoff between reliability/availability and cost.

The research on CR at University of Life Science (UTP), Bydgoszcz, Poland, started with research projects regarding switching systems, such as the analysis of distributed structures of telecommunication servers done in [4]. A distributed telecommunication server consists of a number of identical, sophisticated, switching modules that communicate each other with the use of interconnection network. It is obvious, that the telecommunication servers provide for their subscribers the same functions and services as the large switches do. The main problem which has appeared during analysis of such the systems was the problem of choosing the interconnection network structure that links the telecommunication modules. The solutions from distributed computer systems, especially the interconnection network structure for telecommunication servers have been studied. Also here, it is obvious that the distributed computer systems are very similar in concept to the studied distributed telecommunication server, and similarly that the topology of interconnection network determines the efficiency of the entire system [5], both in distributed computer system and distributed telecommunication server. The interconnection network structure should provide very high level of reliability as well as the level of service quality. Among the analyzed regular interconnection structures (i.e. hypercubes, meshes, Cayley's graphs, rings etc.) the rings are the cheapest and the easiest to implement ones, but they have the lowest connectivity and the highest diameter [6].

The situation is similar for communication networks, where optical networks are usually constructed on basis of rings. Optical transmission systems allow for designing high-bandwidth, error-free communication networks, with the capacities that have higher orders of magnitude than the traditional networks [7, 8]. The high data transmission rate is achieved by transmitting information through optical signals, and maintaining the signal in optical form, thus avoiding the necessity of converting it into electronic form temporarily. The application of fibers, Optical Add/Drop Multiplexers and Optical Cross-Connects gives a possibility to create all-optical networks [9, 10]. In these systems different messages may use the same link concurrently if they are assigned to distinct wavelengths, but if the messages are assigned to the same wavelength then they must use edge-disjoint paths. Using DWDM technology one can create virtual networks which can be modelled by the symmetric directed graphs (digraphs). i.e., a directed graph G with vertex set **V(G)** and edge set **E(G)**, such that, if $[v_i, v_j]$ is in **E(G)**, then $[v_j, v_i]$ is also in **E(G)**. So any edge of digraph connecting vertices v_i and v_j can be replaced by two directed edges $[v_i, v_j]$ and $[v_j, v_i]$ [11].

The research on $N2R$ at Aalborg University (AAU), Denmark, took its starting point in problems from planning of broadband networks, in search for better alternatives to tree and ring based structures, which are vulnerable to single and double failures respectively. Moreover, as stated above, the availability and performance of broadband networks is getting increasingly critical for the modern society. It turned out that many of the concept and problems are similar to those of distributed systems, which also became an important source of inspiration [6], as well those of optical networks as described above.

Throughout the years AAU and UTP have done a good amount of research on network topologies, taking the starting point in Chordal Rings (CR) and $N2R$ topologies. This paper gives an overview of the work done over the last decade. It does not go in deep with the different topologies, but provides references for further readings.

The remainder of the paper is divided into four sections. Section 2 provides the basic notation, and explains basic definitions, parameters and metrics used. The topologies based on $N2R$ are then described in Section 3, and the topologies based on CR are described in Section 4. Further work on the topologies, of which a large amount is done jointly, is described in Section 5. Section 6 finalizes the paper with conclusion and outlook.

2 Basic notation and definitions

A topology can be represented as a directed or undirected graph, where in the following we will assume that the graphs are undirected unless stated otherwise. Moreover, we shall always assume that the graphs and networks are connected.

Each graph consists of a set of nodes (also called vertices) connected by a set of lines (also called edges), so that edge line interconnects exactly two nodes. Since the graphs are directed we assume that if two nodes (u, v) are connected, so are (v, u). A path from a source node u to a destination node v is a set of nodes and lines $(u = u_0), e_1, u_1, e_2, u_2, e_{n-1}, u_{n-1}, e_n, (u_n = v)$, where every line e_i connects the nodes u_{i-1} and u_i. The path length is determined by the number of lines between the source and destination node; In the previous case, the path is of length n. The distance between two nodes u and v is written $d(u, v)$ and is determined by the length of the shortest path between them. For a node u, the set of nodes v such that $d(u, v) = 1$ is said to be the neighbours of u. Two nodes are said to be connected if and only if they are neighbours. An important characteristic of a node is its degree, which describes how many neighbours it has. If all nodes in a graph has the same degree (say n), then the graph is said to be regular, or more precisely n-regular.

In general, we will mainly evaluate the topologies on their average distance and diameter, where the average distance is the average of the distance, taken over all pairs

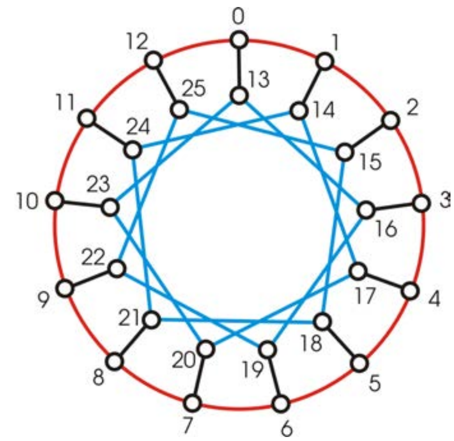

Fig. 1: Example of N2R structure

of nodes, and the diameter is the maximum of the distance, taken over all pairs of nodes.

Obviously, these metrics only describe properties of topologies when there are no failure situations. In order to also quantify how a given topology performs under failure, we can also measure the k-average distances and k-diameters, based on the length of the 2nd, 3rd or k'th disjoint paths. More details and exact definitions can be found in [22]. Here, we shall just state that a key concept is the use of disjoint paths, i.e. paths which either share no lines (or no lines and no nodes), and the length of first, second and third paths. This reflects the use of path protection. Alternatively, it is also possible to make a statistical analysis, where the average distance and diameter is calculated for all possible fault scenarios of 1-2 failures, possibly with a certain probability of failure associated to each line/node (e.g. depending on the physical length of a line).

3 N2R

$N2R$ means Network of 2 Rings, and was first described as such in [2]. However they are subsets of the Generalized Petersen Graphs, which were first described back in 1950 [3]. As shown in Fig. 1, they consist of two rings, each of size p: The outer ring, where nodes are connected as a classical ring, lines between every node in the outer ring and the corresponding node in the inner ring, and lines of the inner ring which connect every q'th node to each other. By selecting q so that p and q are relatively prime, it is guaranteed that the inner ring is actually a ring. Such a topology can be written $N2R(p;q)$. The distances of this topology were studied in [28], which also describes other properties including their isomorphisms, symmetries and table-free routing schemes.

[23] described how the parameters p and q could be chosen in order to minimize the distances for networks with a given number of nodes. One of the conclusions was that it is in most cases possible to minimize average distance and diameter at the same time, and in the remaining cases minimizing first diameter and then average distance will also give average distances very close to the minimum values. A slightly later study from the same year [24] was dealing with the distribution of traffic load on the different links in the network. Yet another study introduces the "tube" as a more pratical way of deploying the $N2R$ topologies, and compares the reliability of single, double, $N2R$ and $N2R$ tube structures by introducing up to two faults in the network. The results show that even when errors are introduced in the network structures, the $N2R$ structure remain superior. Furthermore, this is also valid with a smaller margin for the $N2R$ tube structures. [25] introduces a simple routing scheme for N2R network structures is proposed. It is essentially table-free, routing decisions are based on node addresses, and only few calculations are needed in each node. While it does not always result in shortest paths being chosen, it is quite efficient since the chosen paths are only slightly longer than shortest paths, in particular when q is small compared to p. It is also shown that for most values of p it is possible to find small values of q which gives minimal or nearly minimal distances in the resulting network. A later paper [26] takes this observation a step further, and discusses different techniques for selecting $N2R$ topologies which result in short distances given the proposed routing scheme. Another enhancement of the topological routing proposed previously can be found in [27].

4 Chordal Rings

The transmissions properties of the networks which are constructed of basis simple rings (we take the probability of call rejection as the of quality parameter) are quite poor in comparison with the other types of graphs. The simplest possible method of improvement of transmission properties of meaning interconnection structures is the use of additional edges called chords. The rings with additional edges linking nodes are denoted in the literature the chordal rings, which are quite simple, extensible and have good transmission abilities [12]. Moreover, using regular and symmetric topologies makes it possible to reduce the complexity of routing and restoration schemes, making network planning and management easier.

Chordal ring is a ring with additional arcs called chords. Chordal ring is defined by the pair (p, Q), where w denotes the number of nodes of the ring and Q denotes the set of chord lengths $Q \subseteq \{1, 2, \ldots, \lfloor p/2 \rfloor\}$. Each chord of length $q \in Q$ connects every two nodes of the ring that are at distance q. The chordal ring will be further denoted as $G(p; 1, q_1, \ldots, q_i)$, $q_1 < \cdots < q_i$. In general, the degree of chordal rings is 2_i, unless there is a chord of length $p/2$. In this case w should be even and rings' degree is $2_i - 1$ [6].

The authors in own publication [13, 14, 15] have analyzed parameters and properties of many chordal rings in dependence of its nodes degrees. After establishing the cooperation with Aalborg University, the common research were concentrated on searching how to transform basic chordal rings in order to obtain new, modified regular structures possessing better transmission properties as described in the following section.

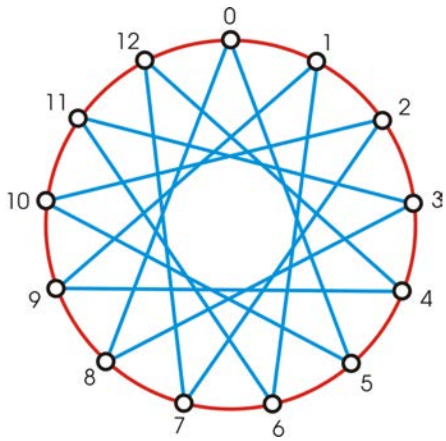

Fig. 2: Example of CR structure

5 Further works

After getting to know the related work on CR and $N2R$ the collaboration between the two universities started to take off. A study was conducted comparing the distances in $N2R$ and CR, which showed that the $N2R$ generally had lower distances than CR for topologies with the same number of nodes, especially for topologies with large or very large numbers of nodes. In addition to the usual distance measures, also k-average distance and k-diameter was calculated for k up to 3.

A further decrease in distances of $N2R$ was proposed by having two inner rings instead of just one. By having different jump lengths of these two inner rings it is shown that the distances are significantly reducedwhile the topologies are still 3-regular and 3-connected. It is a minor drawback that these new topologies are less symmetric, but we show that the distance parameters are quite similar regardless of which node in the network they are measured from [29]. A similar scheme was proposed for the CR, and the results compared to those of $N2R$ [30]. This work also lead to one of the first joint papers between the researchers in Aalborg and Bydgoszcz, namely [16]. This paper analyses degree 4 CR with two different chord lengths. Formulas for approximating diameters and average path lengths are provided and verified, and it is shown that the distances in these are significantly smaller than in traditional CR and $N2R$, and also smaller than modified $N2R$ for topologies with up to 1500 nodes. Despite the proposed topology being of degree 4, and the modified $N2R$ of degree 3, they may be better suited for the optical level of fiber rings, due to its easy mapping onto the ring. It seems to be superior also to the traditional CR, but it is not node symmetric. The work was also continued in another joint paper, namely [31].

In addition to the ongoing work on distances, a good amount of research in Aalborg was dealing with reliability in $N2R$ networks, specifically on protection and restoration mechanisms [32] [33].

The joint work at this point was now focusing more on describing more variants of both CR and $N2R$, and describing their characteristics mainly in terms of distances. This was to a large extend based on the concept of ideal and optimal graphs, which was first used by the researchers from Bydgoszcz [34]. This methodology was also applied to the $N2R$ topologies in [35]. At the same time the concept of Topological Routing, which was mainly used in Aalborg was also applied to the CR topologies in [36] as well as for other degree 3 networks [37].

[17] extends the work on CR by comparing 4th degree CR to 6th degree CR, focusing on topologies with different chord lengths. It is shown that, as expected, significantly shorter distances can be obtained when the node degrees are higher. Also, more comparative studies were done together, such as [18] where optimal and ideal graphs were used in deriving expressions for average distances and diameters for $N2R$ and CR with degree 3 and two different chord lenghts. Based on this a comparative study was made, showing that especially for large graphs this gives shorter distances than the original CR and $N2R$.

The same methods were used for evaluation of degree 5 CR with different chord lengths [20] [21] and for comparing different degree 6 CR [19].

6 Conclusion and Discussion

In this paper we have summarized highlights of the work on Chordal Rings, $N2R$, and a number of other topologies derived from these. It gives an overview of many of the topologies that we have studied, and an introduction to the most important methods used during the studies. While focus has been on providing the overview, references are provided for more in-depth descriptions of the results.

The paper is a tribute to Professor and Dean Antoni Zabłudowski, who was a main driver for the work and collaboration, and an important source of inspiration for the researchers involved. The work started out from different perspectives, i.e. planning of broadband networks at AAU, and telecommunication/optical networks at UTP. However, it turns out that the problems related to network topologies are very similar. In addition to a large amount of joint work on the topologies, the universities have also collaborated on application fields such as broadband planning and optical networks

In the future, work will continue on describing and comparing potential network topologies. However, making the theoretical results obtained useful in practical scenarios is another important problem currently being addressed, including the development of automatic and semi automatic tools for network planning and design.

References

[1] http://samknows.com

[2] O.B. Madsen, J.D. Nielsen, H. Schioler, ”Convergence”, *Proceedings of RTLIA 2002*, Wien, 2002

[3] H.S.M. Coxeter, Self-dual configurations and regular graphs, *Bulletin of the American Mathematical Society*, Vol. 56, 413-455, 1950.

[4] S. Bujnowski, Analysis & Synthesis Homogeneous Structure Networks Connecting Communications Modules - Ph. D. Thesis, ATR Bydgoszcz 2003

[5] L. N. Bhuyan, Interconnection Networks for Parallel and Distributed Processing. IEEE Computer Vol. 20 No. 6 pp. 9-12, 1987

[6] G. Kotsis, Interconnection Topologies and Routing for Parallel Processing Systems. ACPC, Technical Report Series, ACPC/TR92-19, 1992

[7] G. Yanovsky, Evolution and Convergence in Telecommunications, www.ssgrr.it/en/ssgrr2002s/papers/262.pdf

[8] J. M. Pedersen, Structural Quality of Service in Large-Scale Networks. Ph. D. Thesis. Aalborg University 2005

[9] http://www.ncs.gov/library/tech_bulletins/2000/tib_00-7

[10] A. Jajszczyk, Optyczne Sieci Szerokopasmowe. Szerokopasmowe sieci światłowodowe. XVI Krajowa Szkoşa Optoelektroniki. Z. 3, pp. 1-38, Zakopane 2001

[11] L. Narayanan, J. Opatrny, D. Sotteau, All-to-All Optical Routing in Chordal Rings of Degree 4. Algorithmica Vol. 31, pp. 155-178, 2001

[12] S. Bujnowski, B. Dubalski, A. Zabłudowski, Analysis of Chordal Rings. Mathematical Techniques and Problems in Telecommunications. Centro Internacional de Matematica, Tomar 2003, pp. 257-279

[13] S. Bujnowski, B. Dubalski, A. Zabłudowski, The Evaluation of Transmission Ability of 3rd Degree Chordal Rings with The Use of Adjacent Matrix. The Seventh INFORMS Telecommunications Conference. pp. 219-221, Boca Raton 2004

[14] S. Bujnowski, B. Dubalski, A. Zabłudowski, Analysis of 4th Degree Chordal Rings. Proceedings of International Conference on the Communications in Computing. Las Vegas, 2004 pp. 318 - 324

[15] S. Bujnowski, B. Dubalski, A. Zabłudowski, Analysis of Transmission Properties of 3rd Degree Chordal Rings. Kwartalnik Elektroniki i Telekomunikacji. 2005, 51, z.4, pp. 521 - 539

[16] B. Dubalski, S. Bujnowski, A. Zabłudowski, J. Pedersen, Introducing Modified Degree 4 Chordal Rings with Two Chord Lengths. Proceedings of the Fourth IASTED Asian Conference *Communication Systems and Networks*. Phuket 2007, ISBN CD: 978-0-88986-658-4, pp. 561-174 - 2

[17] B. Dubalski, A. Zabłudowski, S. Bujnowski, J. M. Pedersen, Comparison of Modified Chordal Rings Fourth Degree to Chordal Rings Sixth Degree, *Proceedings of Electronics in Marine*, ELMAR 2008, Zadar, Croatia. Volume 2: pp. 597-600

[18] S. Bujnowski, B. Dubalski, J. M. Pedersen, A. Zabłudowski, Analysis of Regular Structures Third Degree Based on Chordal Rings. *Image Processing and Communications*, Vol. 14, nr 1, pp. 13-24, 2009

[19] S. Bujnowski, B. Dubalski, A. Zabłudowski, D. Ledziński, T. Marciniak, J. M. Pedersen, Comparison of Modified 6 Degree Chordal Rings, *Image Processing and Communications. Challenges 2*, 2010, ISSN 1867-5662. pp. 435 - 446

[20] B. Dubalski, A. Zabłudowski, D. Ledziński, J. M. Pedersen, T. M. Riaz, Evaluation Of Modified Degree 5 Chordal Rings for Network Topologies, *Proceedings of 2010 Australasian Telecommunication Networks and Applications Conference*, Auckland - New Zealand, ISBN 978-1-4244-8171-2, pp. 66-71

[21] S. Bujnowski, B. Dubalski, A. Zabłudowski, J. M. Pedersen, T. Riaz, Analysis of Degree 5 Chordal Rings For Network Topologies, *Image Processing & Communications. Challenge 3*, 2011, Springer. ISSN 1867-5662, pp. 445-459

[22] T. Jørgensen, L. Pedersen, J. M. Pedersen. Reliability in Single, Double and N2R Ring Network Structuresm *Proceedings of the 2005 International Conference on Communications in Computing (CIC'05)*, 2005, pp. 375-380.

[23] J. M. Pedersen, T. P. Knudsen, O. B. Madsen, Comparing and Selecting Generalized Double Ring Network Structures. *Proceedings of the 2nd IASTED International Conference on Communication and Computer Networks*, 2004.

[24] J. M. Pedersen, T. M. Riaz, O. B. Madsen, Traffic Load on Interconnection Lines of Generalized Double Ring Network Structures. *Proceedings of the 7th International Conference on Advanced Communication Technology, ICACT 2005*. 2005, Vol. 2, pp. 1277-1282.

[25] J. M. Pedersen, T. M. Riaz, O. B. Madsen, A Simple, Efficient Routing Scheme for N2R Network Structures. *Proceedings of IT&T Annual Conference 2005*. 2005, pp. 69-80.

[26] J. M. Pedersen, T. M. Riaz, O. B. Madsen, Five Novel Section Policies for N2R Network Structures. *Proceedings of the 8th International Conference on Advanced Communication Technology, ICACT 2006*. 2006, Vol. 3, pp. 2174-2179.

[27] J. M. Gutierrez Lopez, R. Cuevas Rumin, J. M. Pedersen, O. B. Madsen, Improving Topological Routing in N2R Networks. *Combinatorial Aspects of Networking*, red. Pralat - Jeanette Pawel - Janssen. IEEE Computer Society press 2007, pp. 131-148 (Lecture Notes in Computer Science, Vol. 4852).

[28] J. M. Pedersen, A. Patel, T. P. Knudsen, O. B. Madsen, Generalized Double Ring Network Structures. *Proceedings of the 8th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2004)*. 2004, pp. 47-51.

[29] J. M. Pedersen, T. M. Riaz, R. H. Nielsen, O. B. Madsen, A Generalization of the Generalized Petersen Graphs and N2R Network Structures. *Proceedings of the Third IASTED International Conference on Communications and Computer Networks*. 2006, pp. 52-56.

[30] J. M. Pedersen, O. B. Madsen, A. Patel, Using Different Chord Lengths in Degree Three Chordal Rings and N2R Topologies. *Proceedings of SBRC 2007: 25th Brazilian Symposium on Computer Networks and Distributed Systems.*. 2007, pp. 557-566.

[31] S. Bujnowski, B. Dubalski, J. M. Pedersen, A. Zabłudowski, Struktury Topologicze CR3m oraz NdRm. *Przeglad Telekomunikacyjny i Wiadomosci Telekomunikacyjne*. 2008, pp. 1133-1141.

[32] J. M. Gutierrez Lopez, J. M. Pedersen, R. Cuevas, O. B. Madsen, Restoration Mechanisms for the N2R Topological Routing Algorithm. *Proceedings of the Seventh International Conference on Networking, ICN 2008*. IEEE, 2008.

[33] J. M. Gutierrez Lopez, J. M. Pedersen, R. Cuevas, O. B. Madsen, Protection Mechanism for the N2R Topological Routing Algorithm. *Proceedings of the 2008 International Conference on HighPerformance Switching and Routing (HPSR 2008)*. IEEE, 2008.

[34] S. Bujnowski - Analysis & Synthesis Homogeneous Structure Networks Connecting Communications Modules - Ph. D. Thesis, ATR Bydgoszcz 2003

[35] J. M. Pedersen, J. M. Gutierrez Lopez, T. Marciniak, B. Dubalski, A. Zabłudowski, Describing N2R Properties Using Ideal Graphs. *Proceedings of the Second International Conference on Advances in Mesh Networks, MESH 2009*. IEEE, 2009, pp. 150-154.

[36] J. M. Gutierrez Lopez, M. T. Riaz, J. M. Pedersen, S. L. Cecilio, O. B. Madsen, On Topological Routing On Degree 3 Chordal Rings. *Proceedings of the First International Conference on Image Processing & Communications*. Academy Publishing House EXIT, 2009.

[37] J. M. Gutierrez Lopez, M. T. Riaz, J. M. Pedersen, S. L. Cecilio, O. B. Madsen, Degree 3 Networks Topological Routing. *Image Processing & Communications*, Vol. 14, Nr. 4, 12.2009. pp. 35-48.

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