

Design of WDM Transmission System for Medical Data Exchange

Robert Cybulski and Krzysztof Perlicki

Faculty of Electronics and Information Technology, Warsaw University of Technology, Warsaw, Poland

Abstract—This paper describes design of the Wavelength Division Multiplexing (WDM) transmission system using Alien Wavelength channels for medical data exchange. Main purpose of such system is to develop variety of services for medical cases diagnostics in order to comply with modern standards in telemedicine. Those standards refer to photo or video data transmission produced by diagnostic devices used in radiological centers together with text data concerning medical case analysis and patient data. These features are delivered by Picture Archiving and Communication System (PACS). PACS describes intra-hospital network organization, which applies to constructing system data from raw graphical data and text information according to Digital Imaging and Communications in Medicine (DICOM) version 3.0 standard. This standard is used by authors to evaluate necessary bit rate concerning all types of services delivered by PACS and cumulative throughput of link connections between hospitals and databases. Organization of these connections in metropolitan WDM system using advantages of Alien Wavelength technique is this article the main goal. Difference between configurable and non-configurable 10 Gigabit Small Form Factor Pluggable (XFP) end devices for Alien Wavelength channels are analyzed and compared with the standard approach using transponder cards.

Keywords—Alien Wavelength, DICOM, PACS, telemedicine.

1. Introduction

Development of telemedicine may be obtained by means of inter-hospital exchange of medical picture and video data, produced by diagnostic devices like Computed Tomography (CT) or Magnetic Resonance (MR). This feature is supported by PACS described in [1]. In this system doctors are able to share and edit medical data stored in data bases called PACS servers. The possibility for exchange is delivered by connecting hospital network with those remote servers by different networking technologies depending on available resources.

Opportunity of using metropolitan WDM network allows dedicated optical channels deployment in Alien Wavelength (AW) technique for hospital or remote user in the system. This solution was previously used in Metropolitan Digital Imaging in Medicine (MEDIMED) [2], [3] in the Czech National Research and Education Network Operator (CESNET) network. MEDIMED project introduced PACS functionality with regard to different networking technologies, however if WDM access is possible, the AW is pri-

mary choice for interconnection [4]. In this work authors present analysis of difference between transmission system, using AW channels with configurable and non-configurable XFP optical modules and also standard approach, designed for Warsaw metropolis hospital data exchange.

This paper is organized as follows. Section 2 describes components of intra-hospital PACS organization, essential for medical data construction, as well as external connections with data bases. Section 3 presents Alien Wavelength technique and indicates possible architectures of optical channel. Section 4 concerns realization of medical data exchange for hospitals in Warsaw metropolis. For this purpose appropriate WDM channel grid has been established. In order to investigate the necessity of using optical amplifiers, attenuators or Dispersion Compensation Fiber (DCF) modules, power and chromatic dispersion calculations for existing links have been made. Results and methodology are presented in this section. Main part is cost analysis of three different optical channel architectures and their comparison which leads to optimum solution selection.

2. PACS

In most hospitals one can distinguish two kinds of devices important from medical data exchange point of view: sources of data and visualization stations, serving as working stations for hospital personnel. Each of these devices is connected to Hospital Information System (HIS) and Radiologic Information System (RIS), which contain necessary information about patient ID, history of case, etc. Altogether, the description data and visual data are combined in the way defined by DICOM 3.0 standard [5], [6]. It defines the amount of data necessary for objects, which represent medical multimedia data in procedure of information exchange. Organization of the PACS inside hospital is shown in Fig. 1. According to [1] choice of the intra-hospital network technology for the PACS devices may vary depending on the local situation thus it will not be discussed in further analysis. With regard to [2] redundancy of PACS servers is essential to obtain full time access to storage data. One of the servers acts as a primary unit and by default governs data exchange. The stored data is also maintained in the redundant server, which in case of failure of the primary server, intercept the primary unit functionality. Therefore dedicated channels must be obtained in relations between each hospital and both of the PACS databases. Depending on local situation concerning access to metropoli-

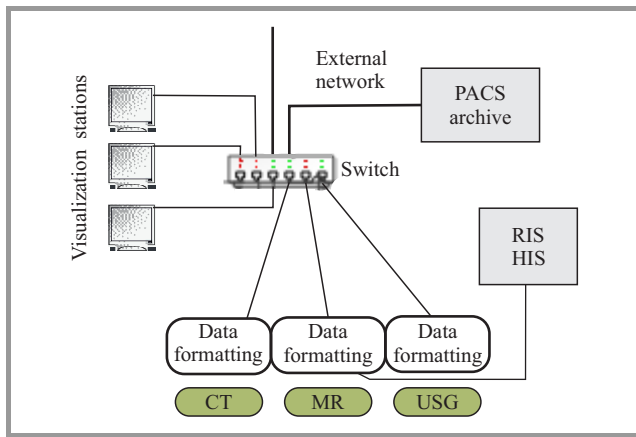


Fig. 1. Intra-hospital PACS scheme.

tan network, different kinds of technologies may be chosen, i.e., satellite communication, wireless, etc.

3. Alien Wavelength

3.1. General Idea of Alien Wavelength

Alien Wavelength may be described as dedicated “color” channels organization. In this solution optical signal is forwarded in WDM network with the same wavelength from the client source to destination device. This leads to two conclusions:

- optical signal must be transmitted and received at client devices at certain wavelength according to WDM spectral grid [7];
- there cannot be any Electric/Optical/Electric (E/O/E) signal conversion; it must be sent transparently across network devices.

In standard WDM channel realization, client’s signal transmitted to first network node has it’s wavelength chosen arbitrary not from frequency grid and it is usually set to either 1550 or 1310 nm. This approach is called grey wavelength

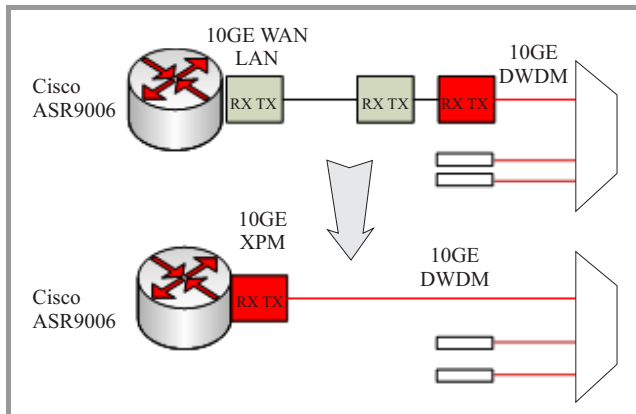


Fig. 2. Alien Wavelength general idea.

transmission. In the WDM node signal is recovered by means of 3R regeneration. It is also connected with E/O/E conversion and changing signal wavelength with regard to frequency grid. This functionality is served by transponder card, working as a receiver of client signal at WDM node. The Alien Wavelength concept is, therefore based on removing transponders and replacing those functionality by installing client optical pluggable devices, i.e. XFP’s [8]. This situation is presented in Fig. 2.

3.2. Motivation to Exploit AW Technique

Removing transponders is key advantage of AW solution, which is caused by the price of the these devices in comparison to XFP pluggable modules [4], [9]. Therefore main motivation to use AW technique for optical channels configuration is reducing system total cost exploiting this kind of connection. Apart from this AW technique complies with optical communication system general evolution, which moves in direction of all-optical signal processing, as there is no signal Optical/Electric/Optical (O/E/O) conversion.

3.3. Configurable and Non-configurable XFP’s

In order to deploy AW channels one can choose between two kinds of client optical pluggable modules: one with their parameters fixed on the production step and other one that allow to remotely change transmitted signals parameters. Distinguishing functionalities these devices gives opportunity to construct two kinds of transmission system. The configuration based on fixed XFP modules must use pair of unique devices, working on the same wavelength, for each relation. Apart from this system uses fixed number frequencies. On the other hand the reconfigurable system uses exactly the same XFP modules for each.

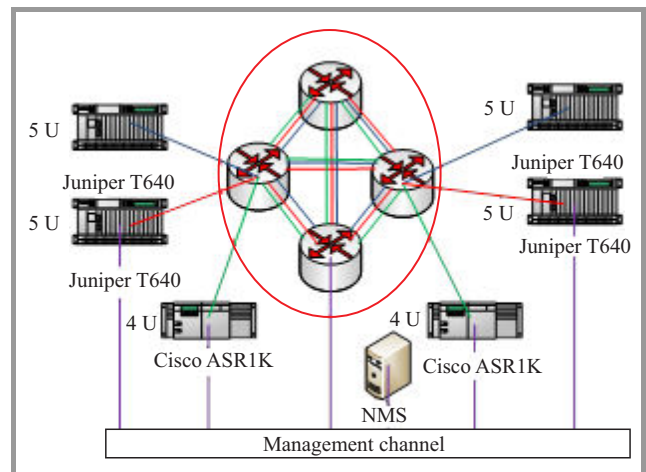


Fig. 3. WDM system management using configurable XFP’s modules set in Juniper T640’s and Cisco ASR1K’s core routers.

Management of WDM system using system uses exactly the same XFP modules for each relation. Changing configuration of these devices extends system flexibility.

Depending on the actual situation in WDM network, the used wavelengths set can be changed by external management system, which of course must be able to govern the work of client modules. Example of such organization is shown in Fig. 3.

It is clear that the system flexibility, which is its undisputed advantage, must be supported by appropriate control in order to avoid problems, i.e., different clients signals collision with the same wavelength selected. It could occur in optical multiplexer, if management system assigned the same wavelength for different client devices.

4. Using AW Channels for Medical Data Exchange

This section describes system transmission realization for medical data exchange between hospitals located in Warsaw metropolis [9]. Project takes under consideration 14 medical science institutes and hospitals in Warsaw and surroundings. This system is to be based on AW technique, thus the main goal is to evaluate the cost difference depending on chosen AW configuration. The usability of Alien Wavelength approach will be judged by comparing it to standard solution using transponder cards. It is assumed that costs connected with fiber cable installation and hospital devices are equal for all configurations. Power and chromatic dispersion calculations for existing connections shall give the answer, whether it is necessary to use optical amplifiers, attenuators or Dispersion Compensation Fiber (DCF) modules. Actual devices prices are taken from [10]. Usage of metropolitan WDM transmission system for establishing external hospital connections implies a necessity to organize channel grid corresponding to [7].

4.1. WDM Channel Grid

High number of medical institutions in the system takes the problem of channel allocation to selection of 14 wavelengths from C-band with specified channel spacing. Equality between hospitals number and chosen channels is reasoned by PACS structure and work of the medical data bases. Redundancy of PACS servers implies that only one link connection between each hospital and data bases is fully operational so that channels between particular hospital and these archives may have exactly the same wavelength. That kind of configuration is not supposed to produce any kind of collision in WDM system. The value of channel spacing was arbitrarily chosen for 100 GHz because of compatibility with used client end devices as well as availability of such channels. That problem comes out of obvious situation of occupation by already existing connections in WDM system. According to the network state of one of the network operators nearly 30% of channels are occupied, so that authors reject every third wavelength from the grid [7]. There is an additional problem of selective mismatch between channel grid and possible client end devices configuration. Some wavelength values cannot be

used with specified models according to product catalogue in [8]. This fact imposes that WDM 100 GHz frequency grid has to be additionally filtered and these particular un-operative channels are not supposed to be taken into account. Table 1 presents channel wavelengths/frequencies for defined link relations in the system.

Table 1
Channel wavelengths/frequencies for existing relations

Link relation to the PACS server	f [THz]	λ [nm]
Banacha 1 – Hospital at the Lindleya 4 st, Warsaw	193.1	1552.52
Banacha 1 – Hospital at the Nowogrodzka 59 st, Warsaw	193.2	1551.72
Banacha 1 – Hospital at the Kopernika 43 st, Warsaw	193.4	1550.12
Banacha 1 – Hospital at the Solidarności av. 67, Warsaw	193.6	1548.51
Banacha 1 – Hospital at the Wołoska 137 st, Warsaw	193.7	1547.72
Banacha 1 – Hospital at the Stepińska 19/25 st, Warsaw	193.8	1546.92
Banacha 1 – Hospital at the Płocka 26 st, Warsaw	193.9	1546.12
Banacha 1 – Hospital at the Szaserów 128 st, Warsaw-Rembertów	194.1	1544.53
Banacha 1 – Hospital at the Dzieci Polskich av. 20, Warsaw-Międzylesie	194.3	1542.94
Banacha 1 – Hospital at the Borowa 14/18 st, Otwock	194.4	1542.14
Banacha 1 – Hospital at the Narutowicza 80 st, Otwock	194.6	1540.56
Banacha 1 – Hospital at the Pomorska 1 st, Piaseczno	194.7	1539.77
Banacha 1 – Hospital at the Gdańska 1/3 st, Wołomin	194.9	1538.19
Banacha 1 – Hospital at the Warsztatowa 1 st, Pruszków	195.1	1536.61

4.2. Evaluation of Required Bitrate for Hospital Connection

Required bitrate is determined by DICOM 3.0 standard as well as total number of devices working in the PACS. According to [5], [6] there are special information objects data formats related to medical examinations in the system. Depending on that, information object include different data, therefore each case may vary in amount of necessary data to be stored or transmitted. In addition particular assumption must be made that total number of visualization stations and data producing devices is 32 and is equal for every hospital served by the system. This value is estimated on the example of Hospital at Banacha 1 street, Warsaw.

With regard to [1] each device must be able to access PACS server at any moment and to realize the most resource demanding service. In this case resource means sufficient bitrate for appropriate quality and service is transmission of data corresponding to particular medical examination. This bitrate is calculated from amount of data for each examination. The results are shown in Table 2.

Table 2
Sufficient bitrate for possible services

Type of examination	Bitrate [b/s]
Computed tomography	297,728,183
Computed radiography	143,357,805
Magnetic resonance	23,630,907
USG	50,809,193
Nuclear medicine	29,278,607
Endoscopy	200,000,000
Angiography	107,063,786

It is shown that computed tomography is the most demanding service. Therefore total hospital link capacity is 9.53 Gb/s, which is a result of simultaneous establishing of 32 CT service connections. This means that 10 GE link has to be created for relations between each hospital and both PACS servers. One should notice that Table 2 contain only mean values. Real values may vary depending images number.

4.3. Power and Chromatic Dispersion Calculations

Basic aspect of calculations in this subsection is to estimate fiber links lengths. For simplicity reasons specific distances were established assuming that fiber cables are installed inside ducts along main streets in Warsaw. Length L gives information on the total attenuation of the standard single mode fiber (G.652 [11]) as well as splices and their attenuation number. Splices are assumed to be made every 5 km. Every link is supplied with connectors at both ends imposing specific value power degradation. This calculations takes under consideration also fact of link exploitation, which is represented by necessity of additional connectors or splices during possible link reconstruction as well as optical fiber degradation. That impact is introduced by additional 0.1 of nominal parameter value. The last element in the power budget calculation are the devices parameters value change that may occur during system exploitation. They are represented by a MAR parameter. Equation (1) describes power level in receiver.

$$P_r = P_e - 1.1(\alpha L + 2\alpha_c + \frac{L}{5\text{km}} \alpha_s) - \text{MAR}, \quad (1)$$

where P_r is power level of received signal [dB], P_e is power level of emitted signal [dB], $\alpha = 0.25$ dB/km is the fiber attenuation coefficient, $\alpha_c = 0.25$ dB is the attenuation of the connector, $\alpha_s = 0.15$ dB is the splice attenuation and MAR = 3 dB is value of exploitation margin.

For proper signal detection the P_e value must be greater than minimum received power level ($P_{r,\min}$) and lower than maximum received power level ($P_{r,\max}$) which are the parameters of client end devices and depend on the configuration [8], [12].

Chromatic dispersion calculation is based on the fiber coefficient. In order to take care of equal chromatic dispersion compensation between different channels the D coefficient is calculated as presented in Eq. (2).

$$D(\lambda) = D_{1550} + S_{1550}(\lambda - 1550), \quad (2)$$

where $D_{1550} = 17 \frac{\text{ps}}{\text{nm}\cdot\text{km}}$ is the chromatic dispersion coefficient at 1550 nm wavelength, $S_{1550} = 0.056 \frac{\text{ps}}{\text{nm}^2\cdot\text{km}}$ is the chromatic dispersion slope value in the III optical window and λ is the signal wavelength. For defined length of the fiber L cumulative dispersion is calculated as follows.

$$D_{\text{Total}} = D(\lambda)L. \quad (3)$$

For proper signal detection value D_{Total} has to fit inside tolerance the receiver range corresponding to [8], [12]. Subsections below contain results of calculations in form quantity of necessary optical attenuators, amplifiers or DCF modules.

4.4. Fixed AW Configuration

Idealistic scheme of AW link connection using non-configurable XFP's modules is shown in Fig. 4.

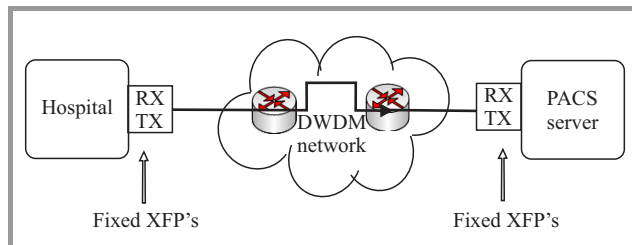


Fig. 4. Fixed AW channel realization block diagram.

This approach demands using 2 exactly the same DWDM XFP's transceiver modules, one of them installed in hospital location and the other one in PACS server place, which gives 42 XFP modules total quantity. Also there is necessity to provide hosting devices. In this case those will be Cisco ASR1k series router and Cisco 1-Port 10 Gigabit Ethernet Shared Port Adapter at client (hospital) side. On the other hand at the PACS servers locations it is necessary to install Cisco ASR900 chassis hosting 2 cards Cisco 8-Port 10GE High Queue Line Card to enable connectivity with each hospital. Moreover authors suggest to take into account spare elements for each device. This approach is described in [9] and assumes providing additional XFP module for each relation, one Cisco 8-Port 10GE High Queue Line Card and two Cisco 1-Port 10 Gigabit Ethernet Shared Port Adapters. Number of additional XFP's is caused by

fixed parameters of these devices, which enables to use specific module for particular connection. Power and dispersion calculations according to previously described model discovered that there is a necessity of installing attenuators for 7 existing relations, which gives total quantity of 14 devices TO-LC/5 dB plus 5 spares [8]. DCF modules are not needed for specified fiber links. Table 3 presents transmission devices cost for this configuration [9].

Table 3

Transmission devices cost for fixed AW configuration, xx.xx represent channel wavelength

Quantity of devices	Cost [PLN]
56 of Cisco 10BASE DWDM XFP (DWDM-XFP-xx.xx)	$56 \cdot 7,035 = 393,960$
16 of Cisco 1-Port 10 Gigabit Ethernet Shared Port Adapter, Version 2 (SPA-1X10GE-L-V2)	$16 \cdot 42,001 = 672,016$
5 of Cisco 8-Port 10GE High Queue Line Card (A9K-8T-E)+2 of ASR9006	$5 \cdot 336,010 + 2 \cdot 41,937 = 1,763,924$
14 of ASR1002 (ASR1002-10G-SHA/K9)	$14 \cdot 178,505 = 2,499,070$
19 of TO-LC/5 dB	$19 \cdot 149 = 2,831$
Total	5,533,589

4.5. Adjustable AW Configuration

The realization of reconfigurable AW channel is presented in Fig. 5. In this idea DWDM XFP optical modules used in each relation are identical, because of flexible their parameters change. Still there is a necessity of providing 42 XFP modules in order to realize all connections. Again Cisco ASR1k series router and Cisco 1-Port 10 Gigabit Ethernet Shared Port Adapter are used to establish connection from the hospital side and Cisco ASR900 chassis hosting 2 cards Cisco 8-Port 10GE High Queue Line Card at PACS servers locations. Difference in comparison to fixed configuration may be also noticed in the spare XFP modules. As a matter of fact full compatibility with each possible relation in the system, reduces total amount of spare XFP's and it has been estimated for 4 devices, which refer to 10% of necessary quantity. Despite of higher adjustable XFP unit price it is predicted that total cost will be lower. Proper calculation revealed that total number of 19 TO-LC/5 dB is

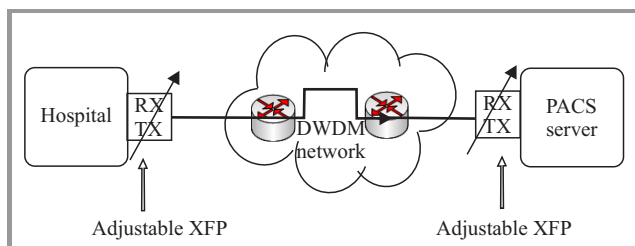


Fig. 5. Reconfigurable AW channel realization.

Table 4

Transmission devices cost for adjustable AW configuration

Quantity of devices	Cost [PLN]
46 of Cisco 10BASE DWDM XFP (DWDM-XFP-C)	$46 \cdot 8,000 = 368,000$
16 of Cisco 1-Port 10 Gigabit Ethernet Shared Port Adapter, Version 2 (SPA-1X10GE-L-V2)	$16 \cdot 42,001 = 672,016$
5 of Cisco 8-Port 10GE High Queue Line Card (A9K-8T-E)+2 of ASR9006	$5 \cdot 336,010 + 2 \cdot 41,937 = 1,763,924$
14 of ASR1002 (ASR1002-10G-SHA/K9)	$14 \cdot 178,505 = 2,499,070$
19 of TO-LC/5 dB	$19 \cdot 149 = 2,831$
Total	5,509,629

necessary and DCF modules are irrelevant because of short distance and nearly the same chromatic dispersion tolerance range [8]. Table 4 presents total system cost based on adjustable XFP optical modules.

4.6. Standard Approach Using Transponder Cards

The corresponding solution based on transponder usage in WDM nodes is presented in Fig. 6. It uses 2 Cisco ONS-XC-10G-I2 transceivers and 2 transceivers cards to realize "grey" wavelength transmission. As well as in former configuration using AW channels, supporting and hosting devices for transceivers must be taken into account. Thanks to compatibility Cisco 8-Port 10GE High Queue Line Cards and Cisco 1-Port 10 Gigabit Ethernet Shared Port Adapter with ONS modules, line cards and adapters may be identical in comparison to AW configurations.

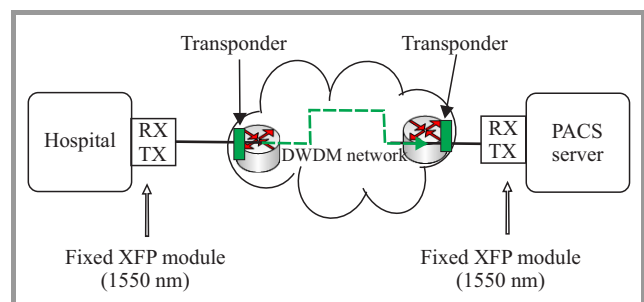


Fig. 6. Scheme of standard channel realization.

Cost analysis of this approach includes also transponders in WDM nodes price. This configuration implies necessity of installing total number 39 TO-LC/10DB attenuators plus 5 spares in total, because of higher signal power from client end devices and transponder cards according to [12], [13]. Despite of the narrower chromatic dispersion tolerances range of ONS-XC-10G-I2 there is no need to supply links with DCF modules. Table 5 presents total cost of described system.

Table 5

Transmission devices cost for standard approach system

Quantity of devices	Cost [PLN]
46 of Cisco ONS-XC-10G-12	$46 \cdot 9,743 = 368,000$
16 of Cisco 1-Port 10 Gigabit Ethernet Shared Port Adapter, Version 2 (SPA-1X10GE-L-V2)	$16 \cdot 42,001 = 672,016$
5 of Cisco 8-Port 10GE High Queue Line Card (A9K-8T-E)+2 of ASR9006	$5 \cdot 336,010 + 2 \cdot 41,937 = 1,763,924$
14 of ASR1002 (ASR1002-10G-SHA/K9)	$14 \cdot 178,505 = 2,499,070$
46 of Cisco 10-GBPS Multirate Transponder Card	$46 \cdot 69,000 = 3,174,000$
44 of TO-LC/10 dB	$44 \cdot 69,000 = 7,436$
Total	8,688,234

5. Conclusions

Presented cost analysis of three system configurations confirms former assumption about Alien Wavelength technique usability. It is clear that for medical data exchange system in Warsaw metropolis the most significant difference between standard approach and AW solution is induced by transponders. Apart from this adjustable AW configuration cost seems to be lower than in case of fixed solution, which gives possibility to choose more flexible solution.

References

- [1] H. K. Huang, O. Ratib, A. R. Bakker, and G. Witte, *Picture Archiving and Communication Systems (PACS) in Medicine*. Berlin: Springer, 1991.
- [2] K. Slavicek, O. Dostal, M. Javornik, and M. Drdla, "MeDiMed – regional centre for medicine multimedia data processing", in *Proc. 3rd Int. Con. Knowl. Discov. Data Mining*, Newport Beach, CA, USA, 2010, pp. 310–313.
- [3] K. Slavicek, O. Dostal, and M. Javornik, "MeDiMed – regional center for medicine multimedia data exchange", *J. Commun. Internet and Inform. Technol.*, vol. 5, no. 4, pp. 547–556, 2008.
- [4] K. Slavicek and V. Novak, "Introduction of Alien Wavelength into Cesnet DWDM Backbone", in *Proc. 6th Int. Conf. Inform., Commun. Sig. Proces.*, Singapore, 2007, pp. 977–981.
- [5] "Digital Imaging and Communication in Medicine (DICOM) Part 3: Information Object Definitions", Rosslyn (VA): National Electrical Manufacturers Association, 2011 (access: 26 March 2012) [Online]. Available: <http://www.medical.nema.org/>
- [6] "Digital Imaging and Communication in Medicine (DICOM) Part 5: Data Structure and Encoding", Rosslyn (VA): National Electrical Manufacturers Association, 2011 (access: 26 March 2012) [Online]. Available: <http://www.medical.nema.org/>
- [7] "Spectral grids for WDM applications: DWDM frequency grid", ITU-T Rec. G.694.1, Geneva, Switzerland 2/2012.
- [8] "Cisco 10GBASE Dense Wavelength-Division Multiplexing XFP Modules", San Jose (CA): Cisco Systems Inc., June 2012 (access: 29 Dec. 2012) [Online]. Available: http://www.cisco.com/en/US/prod/collateral/modules/ps5455/data_sheet_78-458530.pdf
- [9] R. Cybulski, "Projekt systemu transmisyjnego dla wymiany danych medycznych", Bachelor of science thesis, Institute of Telecommunications, Warsaw University of Technology, Warsaw, Poland, 2013 (in Polish).

- [10] Cisco Transceivers [Online]. Available: <http://www.ciscotransceivers.com>
- [11] "Spectral grids for WDM applications: Characteristics of a single-mode optical fiber and cable", ITU-T Rec. G.652, Geneva, Switzerland 11/2009.
- [12] "Cisco ONS Pluggable Optics Series Module for the Carrier Packet Transport (CPT) Platform", San Jose (CA): Cisco Systems Inc., March 2011 (access: 8 Jan. 2013) [Online]. Available: http://www.cisco.com/en/US/prod/collateral/optical/ps5724/ps2006/ps5320/product_data_sheet09186a00801849e7.pdf
- [13] "10-Gbps Multirate Transponder Card for the Cisco ONS 15454 Multiservice Transport Platform", San Jose (CA): Cisco Systems Inc., June 2006 (access: 5 January 2013) [Online]. Available: http://www.cisco.com/en/US/prod/collateral/optical/ps5724/ps2006/ps5320/product_data_sheet0900aecd80121bf7.pdf



Robert Cybulski received his B.Sc. degree in Telecommunication from Warsaw University of Technology, Faculty of Electronics and Information Technology, in 2013. His activities includes optical transmission systems and optical networks.

E-mail: rkcybulski@stud.elka.pw.edu.pl
 Faculty of Electronics and Information Technology
 Warsaw University of Technology
 Nowowiejska st 15/19
 00-665 Warsaw, Poland



Krzysztof Perlicki received his M.Sc., Ph.D. and D.Sc. from Warsaw University of Technology, Department of Electronics and Information Technology, Warsaw, Poland, in 1994, 1999, and 2010, respectively. Now he is a Professor at Institute of Telecommunications of Electronics and Information Technology, Warsaw University of

Technology, Poland. His scientific activities includes: high capacity optical transmission systems, optical access networks, attacks and security of physical layer in optical networks, test and measurement procedures for optical systems. He is an author of 80 scientific papers and 4 scientific books. Prof. Perlicki is a member of Optical Society of America, Federation of Telecommunications Engineers of the European Community.

E-mail: perlicki@tele.pw.edu.pl
 Faculty of Electronics and Information Technology
 Warsaw University of Technology
 Nowowiejska st 15/19
 00-665 Warsaw, Poland