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INCREASE OF OPTICAL TRANSFER MEDIUM TRANSPORT CAPACITY AND CONSEQUENT INCREASE OF SAFETY AND RELIABILITY OF TRAFFIC

ABSTRACT

Over the past few years we have been witnessing a rapid and undreamt of development in the communications field. Everyone wants to communicate with others all the time. Industry is a major generator of these changes. But users do not like fast and frequent changes because they usually mean nothing good. The majority is satisfied with basic necessities and there is a huge problem in trying to convince them into something new. There is a difference between technical and marketing sector. We are dealing with economy, promises, contracts. But industry wants more: new users, fresh money for new investments.

The aim of this article is to find a technical solution for increasing the existent optical cable capacities. The purpose is not to replace the existing cables but to use advanced technology and to improve economy, safety and reliability of all kinds of communications which use optical transmission medium.

KEY WORDS

communication, changes, services, optical infrastructure, upgrading, advance technology, optical multiplex, DWDM, CWDM, fixed network, traffic, reliability, security, bandwidth, experience, future

1. INTRODUCTION

More and more people use telecommunication services as groundwork or an instrument at the work they do. It is self-evident, that they always have the communication device or service they need at their disposal. This means that the needs for capacities, reliability and security grow irrepressibly. Therefore, we must satisfy the users by implementing technical solutions. Thus, the manufacturers of equipment, providers of services and maintaining engineers try hard to establish an optimal chain with stable "negative reverse binding".

One of the important infrastructural objects that offers and enables telecommunication connections to a wide number of users is the optical fiber. Because of their advantages the optical fibers are practically irreplaceable these days. They are perfectly suitable either for home or advanced use. But despite their remarkable transfer capabilities, the fiber optics have their limitations. These are shown in the end capacity/number of fibers inside an optical cable. As well as with other telecommunication investments, it is not possible to install optical cables and at the same time consider that they would satisfy the needs for ten or more years. That would be a highly uneconomical financial over-dimensioning of investment. Therefore, a pragmatic approach needs to be used to ensure the needed capacities by using technical solutions (pay-as-you-grow). In this way we will ensure dynamic evolution to a high degree as well as optimal utilization of resources for other purposes.

2. STATE OF THE ART

Optical networks

Investments in fiber optics infrastructure experienced a bloom and reached the highest point in the mid 90s. Over 70 million kilometers of fibers were installed yearly for the purposes of network expansion, more than 17 million kilometers of fibers in the 1998-2002 period (source: KMI, 2002) in Europe alone. We have learned from the past experiences that any kind of technology becomes obsolete after a certain period of time. In the sense of optical fibers this meant that despite enormous amount of installed capacities and virtually limitless transfer capacities (compared to copper cables) the problem of optical bottlenecks arose. In other words: a lack of transfer capacities on certain segments of fiber optics networks became a problem. Of course, there are several reasons for that:

- practically all signals in telecommunications today are digital,

- transfer demands today are far from static, they are highly dynamic,
- Internet expansion (factor 8 per year), increasing traffic with complex and highly variable content, new cellular telephony technologies.

The rest of the broadband services only worsened the situation. So we can easily talk about a paradox, that despite specified advantages of fiber optics those same advantages have remained unexploited because of the bottlenecks or intermediate section slowdowns.

3. DEFINITION OF THE PROBLEM

As we stated before, practically every communication device today is adapted for communication through optical interface. When we install terminal devices we usually do not ask ourselves how many free capacities we have. Everybody relies on the thought that the capacities of the existing infrastructure will easily handle it.

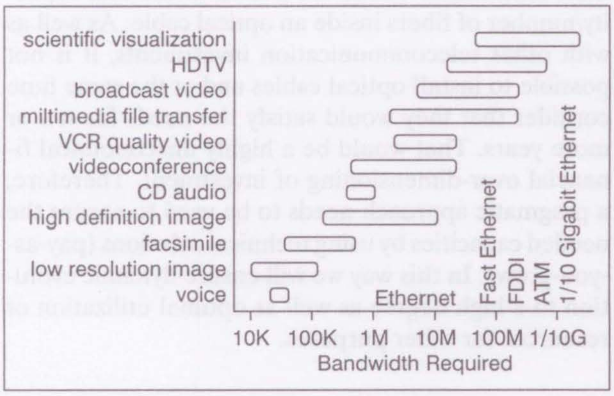

Figure 1 - Bandwidth requirements

Source: Miklavc A.: **Smernice za podatkovna hrbtenična omrežja**, SmartCOM, Ljubljana, 2003, Ljubljana, Dnevi odprtih vrat, April 2003.

Figure 1 shows the usage amount of bandwidth for common technologies of today. We have to admit that services intended for a wide spectrum of consumers are very wasteful regarding the bandwidth itself. Telecommunication demands of systems that interconnect separate devices are basically not that wasteful. But they require duplication or even triplication of connections in order to ensure security and reliability. Other than that, all this must be ensured via independent communication paths.

This fact inevitably leads to the lack of optical fibers. What now? New installations would be expensive and complicated. On the one hand we need new investments, financial funds and on the other hand we must start a new project and collect consensuses and permits. What's left is the implementation of innovative solutions that are financially competitive, simple to execute and timely acceptable.

4. DEFINITION OF SOLUTIONS

Solving the problem is not easy and short-lived. There are three possible solutions available:

1. Installation of new fibers according to ITU-T G. 652d standard – it is a suitable solution for new providers and those who consider a complete renewal of their optical network. This is by all means still the most expensive solution and it still does not enable the usage of free capacities of the existing fibers.
2. By increasing the transfer bit rate. With TDM technique of multiplexing we are momentarily capable of transferring information in the range from 2.5Gb/s to over 10Gb/s up to 40Gb/s through SDH and SONET networks. Despite of constant development of these technologies a growth factor of 1.5 is far from enough regarding demands stated above. Other than that we are limited at other QoS in demanding networks (ATM and real-time operation demands).
3. Wavelength division fiber optics multiplexing, which enables simultaneous transfer of several optical signals through the same optical fiber. With this technology it does not matter what type of signal we use or what its demanding speed is.

With the combination of the second and the third solution we are already reaching the transfer capacities of over 400 Gb/s and that is deep in the Tb/s area.

Wavelength division multiplexing

We must admit that the users only care about prices of transfer capacities but despite of that fact we

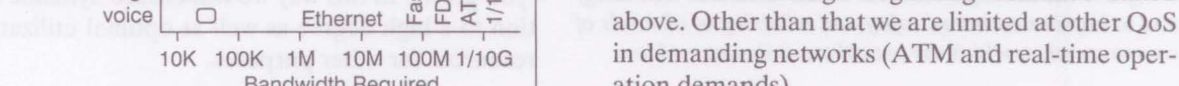

Figure 2 - WDM Wavelength Division Multiplexing

Source : Vižintin Z. : **Povečanje prenosne kapacitete optičnega vlakna**, Zbornik Seminar optične komunikacije, Fakulteta za elektrotehniko, Ljubljana, 2003, Ljubljana, January 2003, page 1.

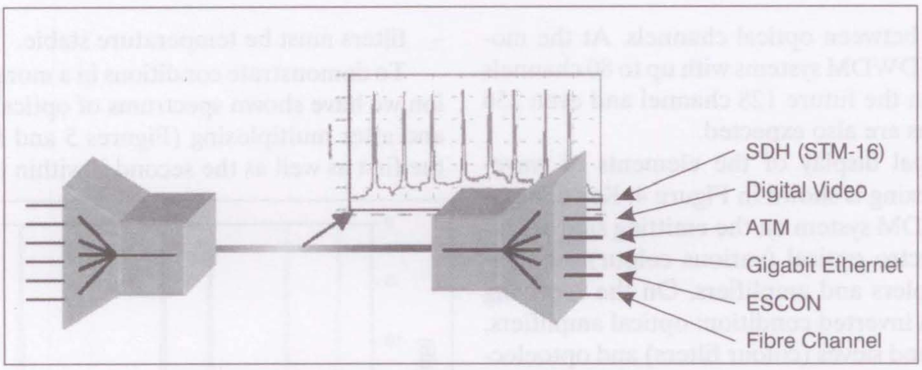

Figure 3 - Usefulness of optical system

Source: Vižintin Z.: **Povečanje prenosne kapacitete optičnega vlakna,** Proceedings: Seminar optične komunikacije, Fakulteta za elektrotehniko, Ljubljana, 2003, Ljubljana, January 2003, page 4.

must pay attention to the complexity and adaptability of the network that "satisfies" the user's needs. We can only reach that by developing and planning of all-optical – complete network. In this article we will show the way of increasing capacities of the existing optical infrastructure by using an innovative technical solution. We will also show that with that solution we can gain not only greater capacity but also reliability and security of transfers. We will present WDM, DWDM and CWDM technologies from the aspect of hardware and the possibilities of their implementation into the existing networks. A logical consequence for us is to indicate the guidelines of development that will cut out the evolution of optical networks.

The principle of wavelength division multiplexing is schematically shown in Figure 2.

Wave multiplex is an approach that uses enormous potentials of optical fiber bandwidth by requiring each end user to operate with its electric speed.

How does the whole system work?

The essence of the system is that numerous WDM channels of end users are multiplexed into one single fiber. With WDM technology the optical transfer spectrum is divided into several wavelengths (λ) or frequencies, where each λ supports one communication signal operating at the desirable speed. With the appropriate architecture, protocols and algorithms they enable adding and subtracting signals anywhere within the system.

We must accept the fact, that optical fiber is not an energetic medium and that we cannot speak about electric waves expansion, but the light itself (waving and total reflection).

Wave multiplexing[1] means combining of optical signals of different wavelengths into a single optical fiber. In reality, it is all about frequency multiplexing since we modulate optical carriers with independent electrical signals. In one optical fiber there is a possibility to use so many different wavelengths that the individual channels do not interfere with each other. To combine larger numbers of wavelengths we must use dense wavelength division multiplexing (DWDM)[2]. The usage of multiple channels gives us very large transfer capacities. WDM and DWDM enable simultaneous transfer of different protocols such as SDH, PDH, Ethernet, ATM, IP, FDDI and others. Optical signals with speed range from 0 to several Gb/s are being transferred through this technology. Figure 3 shows such a type of transfer:

Wavelength multiplexing can be used in the band of E, S and C.[3] New optical fibers can also be used in frame L, because the weakening is eliminated due to OH ions.[4] A number of channels depends on the nec-

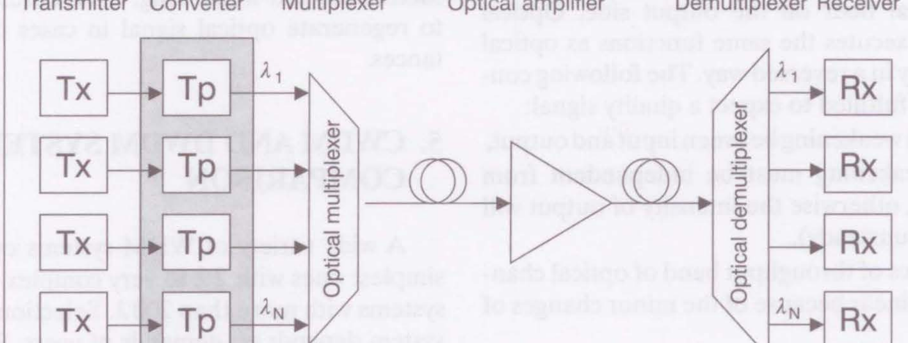

Figure 4 - WDM Elements of wavelength division multiplexing

essary spacing between optical channels. At the moment there are DWDM systems with up to 80 channels available, but in the future 128 channel and even 256 channel systems are also expected.

The principal display of the elements of wavelength multiplexing is shown in Figure 4. Key components of the WDM system on the emitting side are laser source, electro optical (various colour) modulators, opto-couplers and amplifiers. On the receiving side there is an inverted condition: optical amplifiers, splitters and band sieves (colour filters) and optoelectronic receivers (pin photodiodes).

Prior to multiplexing it is necessary to set an exact wavelength in the wavelength converter to each signal from transmitter. In cases where transmitters have adjustable emitting lasers, there is no need for the wavelength converter. In the optical multiplexer all signals join into optical fiber. If necessary, there are one or more optical amplifiers added to amplify the whole wavelength of all N channels. On the receiving side, it is first necessary to separate all N channels within demultiplexer and bring each signal to the receiver.

Elements of optical network with wavelength division multiplexing

For optical network with wavelength division multiplexing we need to have optical multiplexers with drop and repeated add function[5], optical cross-connectors[6] and optical amplifiers[7]. With these components we control the whole wavelength band, defined by ITU-T recommendations. OADM and OXC require new optical elements to fulfil those definitions. New elements enable connection between input and output WDM channels. The basic part of the optical nodal points is the optical switch matrix, which enables connection between input and output WDM channels. To implement OADM and OXC we also need adjustable optical filters, multiplexers, demultiplexers, adjustable laser sources, wavelength converters, amplifiers and regenerators.

Optical multiplexer and demultiplexer

N channels are connected to the input of optical multiplexer wherein all optical channels combine and enter the optical fiber on the output side. Optical demultiplexer executes the same functions as optical multiplexer, only in a reversed way. The following conditions must be fulfilled to expect a quality signal:

- low insertion weakening between input and output,
- insertion weakening must be independent from polarization, otherwise the intensity of output will be variable (unsteady),
- characteristics of throughput band of optical channel must be linear because of the minor changes of wavelength,
- filters must have a steep transitional zone to prevent interferences of neighbour channels,
- filters must be temperature stable.

To demonstrate conditions in a more realistic fashion we have shown spectrums of optical signal before and after multiplexing (Figures 5 and 6). The size of the first as well as the second is within the **coin class.**

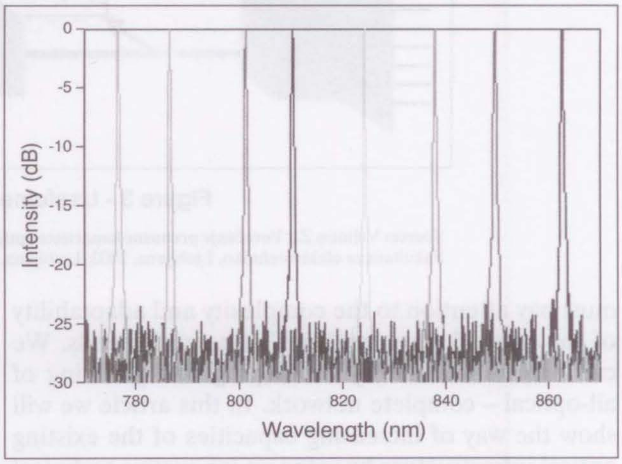

Figure 5 - 8 Channel CWDM optical multiplexing spectrum

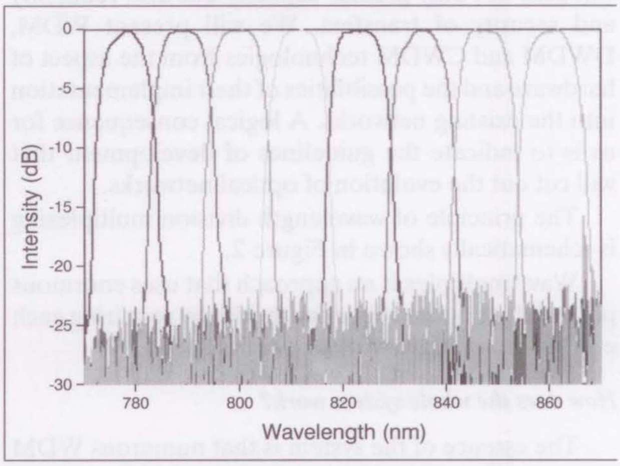

Figure 6 - 8 channel CWDM optical demultiplexing spectrum

We can see that the output spectrum is not entirely equal to the input spectrum. There are several reasons for that such as noise of multiplexers, medium characteristics and weakening. It is therefore, necessary to regenerate optical signal in cases of greater distances.

5. CWDM AND DWDM SYSTEMS COMPARISON

A wide variety of WDM systems exists, from the simplest ones with 2 λ to very complex and expensive systems with more than 200 λ. Selection of the proper system depends on demands of users. Price is usually not the prevailing factor; it is a proportion of price and capacity that is more and more important. Commercially there are two main technologies used: CWDM and DWDM. The former technology is used for local accesses and smaller networks and the latter for linking, transit and more powerful networks.

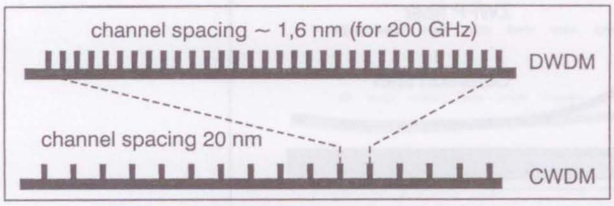

Figure 7 - CWDM and DWDM comparison

Source: Vižintin Z.: **Povečanje prenosne kapacitete optičnega vlakna,** Proceedings Seminar optične komunikacije, Fakulteta za elektrotehniko, Ljubljana, 2003, Ljubljana, January 2003, page 2.

CWDM systems are also called coarse systems, where the space between channels is 20nm. DWDM systems are also called dense systems with 1.6nm space between channels. Space between channels and consecutively large number of channels in the frequency band represent the final capacity – capacity of optical fiber. Needless to say, the same type of fiber is used in both cases. It is the matter of individual communication channel density within equivalent optical fiber.

Standardization

DWDM standardization of frequency network channels on S C and L [8] bands was carried out years ago (after recommendation of ITU G. 692) while CWDM standardization is still very young (ITU-T student group meeting, May 15th 2002 in Geneva, G. cwdm is ITU-T G. 694.2 DWDM). The sphere of standardization is a necessary (but not sufficient) condition for successful marketing. If we look back into the near past we can see that every non-standardized technology on the market failed to succeed. It is obvious because every manufacturer using that way is trying to offer something of his own, which is not necessarily good nor necessarily compatible with other systems.

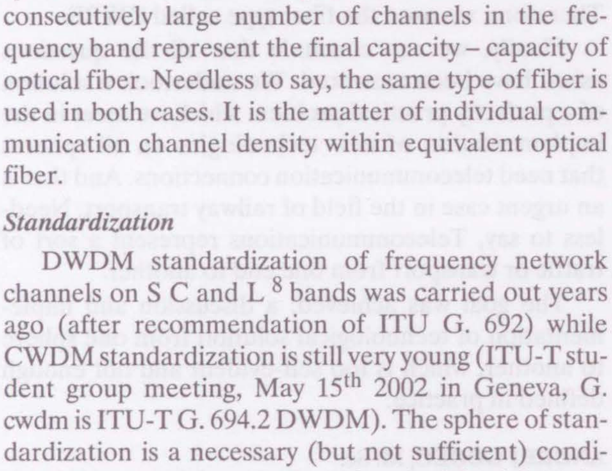

Figure 8 - DWDM and CWDM standardization

Source: Vižintin Z.: **Povečanje prenosne kapacitete optičnega vlakna,** Proceedings: Seminar optične komunikacije, Fakulteta za elektrotehniko, Ljubljana, 2003, Ljubljana, January 2003, page 2.

The largest deviation is noticeable at interconnection of different systems and in the sphere of supervision. The first step in the sphere of transfer systems technology was made with the standardization of SDH (time division multiplexing).

Limitations

DWDM systems doubtlessly offer the highest possible transfer capacity increase of the optical fiber, but they are technically demanding and expensive. For example: the temperature influence on the stability of individual output wavelength. Even a minor oscillation of daily environment temperature under uncontrolled conditions can disable the operation of DVDM system. Laser source is very sensitive to temperature changes. The temperature oscillation causes change of wavelength and interference with other communication channels because of great density and small spacing between communication channels. In this case the system is practically unusable. To avoid such situations we use special measures, the so-called specially cooled sources. Because of the required conditions they are noticeably more expensive and energetically wasteful compared to CWDM lasers without cooling.

Since the channel spacing is significantly larger, there are no such problems with CWDM[9], 10 to 15 times compared to DVDM. This means the usage of other technologies, which enable:

– wider optical spectrum,
– simpler laser units,
– greater temperature stability,
– cheaper filters and dividers.

But it is not only the transfer system that the final transfer capacity is dependent on. We need to consider the characteristics of the common optical fiber (G. 625).

Classic optical fiber has an extremely weak throughput (great attenuation) in the E band[10] (1360 -1460 nm), which is the consequence of water molecules in the optical fiber. This phenomenon is called "water peak". After several years of development the first fiber without water peak was developed in the laboratories. It was called ZWPF[11].

What do we gain with it?

We gain the whole E band for the commercial use, which means an increase in the transfer capabilities by over 50% and preserving of all the other standard qualities of the common fiber at the same time.

ZWPF fibers, which are backward compatible with common G. 652 fibers, are already standardized (G. 652. C and IEC 60793-2B1.3) and successfully tested for durable stability of transfer characteristic. Figure 9 shows comparison of the common and ZWPF fiber:

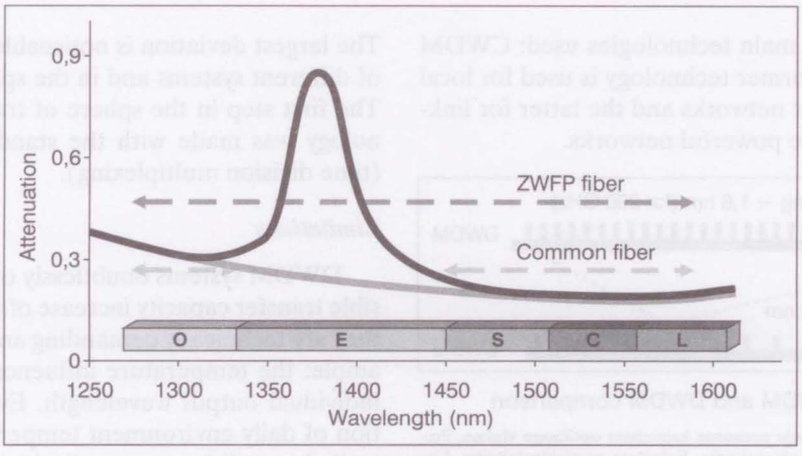

Figure 9 - Throughput characteristics

Source: Vižintin Z.: **Povečanje prenosne kapacitete optičnega vlakna**, Proceedings Seminar optične komunikacije, Fakulteta za elektrotehniko, Ljubljana, 2003, Ljubljana, January 2003, page 3.

6. CONCLUSION

In this article we have presented the problem and the solution of optical transfer media preoccupation as communication demands increase rapidly. Our starting point was the introduction of new technologies. Our motto was to avoid an increase in optical media capacity by installing new cables since this would mean excessively long and expensive procedure.

We searched and found an innovative technical solution which enables up to 250 times increase of existing transfer capacity with the help of wavelength division multiplexing into a single fiber. WDM technology enables a simple and graduate increase of the existing optical infrastructure. This means that the system is not built at once and not as a whole. When we need new transfer capacities, we add a new colour to the existing system.

The solution seems very simple and in fact it really is. Only a technological procedure of individual components manufacturing is complex. We saw two technologies which control the sphere today. Those technologies are CWDM and DWDM. The former represents coarse wavelength multiplexing and is designed for simple systems where we need a fast and reliable capacity increase. The latter enables dense multiplexing of signals and it is therefore a state-of-the-art of telecommunication technologies. Consequently, it is very sensitive to the temperature changes, it is more efficient and therefore, more expensive.

Both technologies offer enormous advantages compared to conventional systems. With the use of these technologies we can avoid harmful influences of electrical disturbances of the signal on the transmission path and practically eliminate the possibility of tapping and intrusion. The technologies operate transparently and independent from transfer protocols.

We discovered that the limitation factor of transfer capacity increase is the optical medium itself. Older optical fibers have a very distinctive weakening in cases where the wavelength multiplexing effect is weaker. Therefore, we used the fiber type called ZWPF.

Finally, we can conclude that all the questions asked have been answered. We undertook a solution of a perfectly practical problem which we meet in the implementation of new technologies on all spheres that need telecommunication connections. And that is an urgent case in the field of railway transport. Needless to say, Telecommunications represent a sort of traffic or transport from one end to another.

The goal was achieved: a discussion and implementation of technological solution from one sphere to another, which is too self-evident and not enough defined in practice.

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POVZETEK

POVEČANJE TRANSPORTNE KAPACITETE OPTIČNEGA PRENOSNEGA MEDIJA IN S TEM VARNOSTI TER ZANESLJIVOSTI PROMETA

Komunikacije so v zadnjih letih dosegle nesluten razvoj, tako v sociološkem kot tehničnem pogledu. Danes hoče praktično vsak komunicirati z vsakim ob vsakem času. Vsi se trudijo, da pri tem ne bi bilo ovir. Generator teh sprememb je v največji meri industrija, ki skrbi za razvoj komunikacij. Uporabniki pa se hitrim in pogostim spremembam v veliki večini izogibajo. Ko zadostijo osnovne komunikacijske potrebe, jih le stežka prepričamo v kaj novega. Od tu dalje pa tehnika ne igra več najpomembnejše vloge. Na vrsti je marketing, trgovanje, ponudbe in obljube.

Članek obravnava problematiko povečanja kapacitet že izgrajene optične infrastrukture in to z uporabo inovativnih

tehničnih rešitev. Uporabno vrednost tega lahko apliciramo povsod tam, kjer so kapacitete za prenos informacij že zasedene, uporabniki pa potrebujejo vedno nove storitve. Prednosti takšnega pristopa niso le ekonomske, temveč povečujejo obstoječe kapacitete, izboljšujejo varnost in zanesljivost vseh vrst komunikacij, kjer uporabljamo optične prenosne medije.

KLJUČNE BESEDE

komunikacije, spremembe, storitve, optična infrastruktura, nadgradnja, inovativne rešitve, optični multipleks, DWDM, CWDM, fiksna omrežja, promet, varnost, zanesljivost, pasovna širina, izkušnje, prihodnost

NOTES

1. WDM - wavelength division multiplexing
2. DWDM - dense wavelength division multiplexing
3. see Figure 8
4. see Figure 8
5. OADM - Optical Add/Drop Multiplexer,
6. OXC - Optical Cross Connect,
7. OFA - Optical Fiber Amplifier.
8. see Figure 8
9. see Figure 7
10. see Figure 8
11. zero Water Peak Fiber

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