WAVELENGTH DIVISION MULTIPLEXING AND ENERGY EFFICIENCY

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Abstract: Energy is hot topic in the improvements of the technology because energy efficiency topic is very important for future generations with the growing population in the world. Recently, hardware and functional structures in network are provided more data transmission with less energy and improvement the usage of communication tools on the internet. Telecommunications companies lean in to develop their infrastructure with energy efficiency. Hardware and functional routing methods are developed for energy efficiency and quality of service while fiber infrastructure with WDM networks is preferred to provide fast communication. This study gives information about Optical Circuit Switching (OCS), Optical Packet Switching (OPS), Optical Burst Switching (OBS), and Parallel Optical Burst Switching (POBS) in Wavelength Division Multiplexing (WDM) networks and their strategies, methods and studies to improve energy efficiency.

Keywords: Energy Efficiency, Wavelength Division Multiplexing (WDM), Optical Circuit Switching (OCS), Optical Packet Switching (OPS), Optical Burst Switching (OBS), Parallel Optical Burst Switching (POBS)

Introduction

Nowadays, communication on the internet are increasing, the economic and environmental impact of this situation has been discussed. According to a survey in United States, 1-7% of the electricity is consumed by internet tools (Tucker, 2009) and this rate increase about 50% in each year (Plepys, 2002). The usage of the internet is increasing 40% day by day in North America (Kilper, 2011). Increment of communication over the internet is seemed small scale now, but it is expected to reach significant number in the near future. As long as this increment is continued, energy consumption will be increase evenly.

The increment of the usage of internet means not only increment on network users but also increment of the bandwidth for each user (Tucker, 2012). Researchers start to improve more energy efficient system to balance energy consumption on the usage of internet. Also, they study with energy network technologies.

Nowadays, qualified and full time communication is very important. The means of more quickly communication is faster computer components and more energy consumption. The existing network infrastructure such as servers, amplifiers, routers, filters, storage devices and communication links must strengthen to ensure fast and quality communication. Although reinforcement of the network infrastructures provides desired bandwidth, it consumes more energy. This situation makes energy efficiency topic more popular among researchers.

Energy consumption originated from internet is increased day by day in developed and developing nations (Hinton, 2011). Society in economic growth is concerned to improve communication units with the same rate of increment on communication. This recovery means that function of the communication tools must improve and at the same time more energy is consumed for each developing units. As long as communication over internet is increasing, power consumption is increased.

Telecom companies make their infrastructures more suitable with new technology to provide fast data transmission. First choice of the telecom companies is optical network that provides faster data transmission. Network capacity can be increased with different wavelengths instead of placing more fiber lines. Therefore, wavelength division multiplexing are the most popular systems for telecom companies.

Energy is conserved 45% in wavelength division multiplexing (Shen, 2009). It can be possible with using wavelength grooming mechanism to transmit lightpaths in optical domain. It equals to save about 500 million dollars in a year for middle networks.

WAVELENGTH DIVISION MULTIPLEXING (WDM)

Wavelength Division Multiplexing is composed more than one different wavelength in a fiber. Each wavelength is accepted one channel. WDM includes multiplexer that gather signals, demultiplexer that separate signals and amplifiers.

Each light source has different wavelength output in WDM network. Optical signals, which come from different wavelength transmitters, are multiplexed to transmit one fiber by wavelength multiplexer (see Figure 1). On the other hand, wavelength multiplexed lights from fiber is separated to different wavelength by demultiplexer and each wavelength transmit to receiver. During the transmission, amplifier can be used to strengthen signals before demultiplexer and after multiplexer.

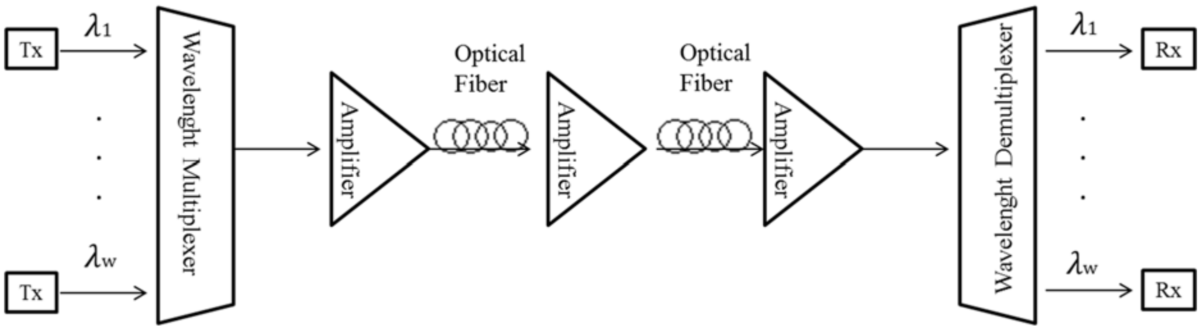

Figure 1. Wavelength Division Multiplexing (WDM)

Wavelength number on a fiber is increased with WDM network and it is the cheapest way for data transmission. Increasing fiber number is more expensive than increasing channel number in fiber (Aydın, 2009). So, WDM network is become popular among telecom companies and was established telecommunications backbone network. Telecom companies try to find cheaper solution inadequacy existing infrastructure to rapid development of the internet and incremental bandwidth requirements. Fast transmission with Wavelength Division Multiplexing communication systems is provided by using fiber infrastructure, improving network capacity is provided by wavelength with using little fiber cable.

Although working on WDM is complicate and expensive at the first time, to develop WDM network has become cheaper with the understanding of the dynamic structure of WDM. Bandwidth requirements in optical network have been solved with OCS (Optical Circuit Switching), OPS (Optical Packet Switching), and OBS (Optical Burst Switching).

OPTICAL CIRCUIT SWITCHING (OCS)

Lightpaths are built between network nodes in Optical Circuit Switching that is the one of optical network technologies (see Figure 2). There are different wavelengths in each lightpath. Packet in network is transferred in optical form from ingress node to egress node. Wavelengths are reserved to generate a lightpath to transmit packet from one node to another. Reserved path are released after packet is received. Not only same wavelength but also different wavelength is reserved between nodes. This can be with wavelength converter. If the wavelength converter does not exist, same wavelength can reserve.

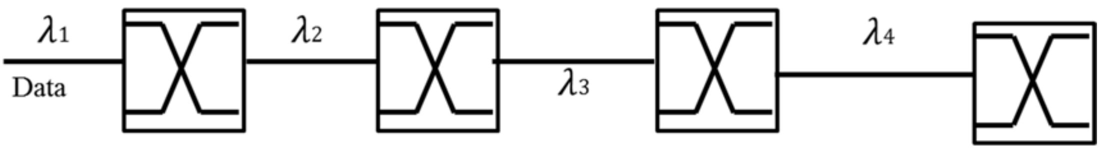

Figure 2. Lightpath in OCS

Lightpaths have static and stable bandwidth in OCS networks. Inefficient bandwidth allocation, reservation for short-term connection, low network usage in intensive data transmission, packet header must convert electrical to optical, optical to electrical. This situation does not prefer on existing communication systems so dynamic transmission on network is provided.

To make dynamic transmission on network is needed network status information system to direct network. As more than one lightpath is used to transmit packet, electrical to optical, optical to electrical will be increase because of header operation between nodes. This situation is caused to consume more network resources and transmission latency. The more energy is consumed, the more converters are used and the more packets are received late.

OPTICAL PACKET SWITCHING (OPS)
Data are switched in optical form in optical packet switching. OPS is fast and cheaper than OCS. Optical packet is consist data and header in OPS network. Data is processing in optical form; header is processing in electronic form. While header is processing, data is waited with Fiber Delay Line (FDL) in optical form. Switch Control Unit processes header. Optical packets transmit with its header and no need reservation. An important issue in OPS network is no buffering system to hold data while header is processing.

Semiconductor optical amplifiers based switch that is providing fast switching, must be preferred for packet delay because of switching in OPS. But this switches need signal that comes from optical multiplexer, is consume extra energy (Jue, 2005).

OPS is more preferable than OCS as optical network architecture is cheaper, more reliable and consumes less energy (Ramaswami, 2006). Although OPS is well designed and functional with network switching architecture, the biggest problem is lack of Random Access Memory (RAM) and wavelength converter and reproduction is expensive (Szczesniak, 2009).

OPTICAL BURST SWITCHING (OBS)
Optical Burst Switching is combination of OCS and OPS. Data transmission is provided with burst that consists of more than one IP packets in OBS networks. Burst has control packet (CP) and it is send separately (Aydın, 2009). Data consists of data burst (DB) which is packets with same ingress and egress node.

Control packet is produced for each data burst in OBS. Control packet has destination address, burst size, and time information (Sriram, 2003). Control packet is sent from different path to send data burst and it reserves path for burst. Then data burst is send from reserved path. If burst is send before reserve, the packet drops. After "offset time" data burst is send to minimize the lost packet number because there is no communication between control packet and data burst. Offset time must be well configured to prevent lost packet.

PARALLEL OPTICAL BURST SWITCHING (POBS)
Parallel Optical Burst Switching is a kind of switching method in Ultra Dense WDM and it is derived from Optical Burst Switching.

Each burst forms 2D Data Burst (2D-DB) that is named time and wavelength. Data Subbursts (DSBs) have fixed size. Meaning of this that time is fixed but wavelength has different size. Burst is processed in one wavelength channel in OBS network (see Figure 3), 2D-DB is processed multiple wavelength of one waveband (see Figure 4). B_1 burst (see Figure 3) is separated DSB_{11} (Data Subburst $_{11}$), DSB_{12} (Data Subburst $_{12}$), DSB_{13} (Data Subburst $_{13}$), B_2 burst is separated (Data Subburst $_{21}$), DSB_{22} (Data Subburst $_{22}$) data bursts in fixed size (m_{DSB}) and they is transmitted different wavelengths such as λ_1, λ_2, λ_3 (see Figure 4).

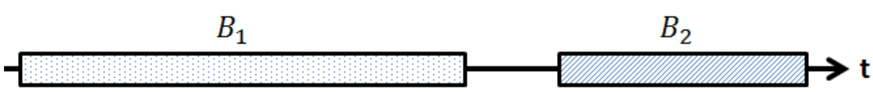

Figure 3. Transmission of the burst in OBS (Zaiter, 2014)

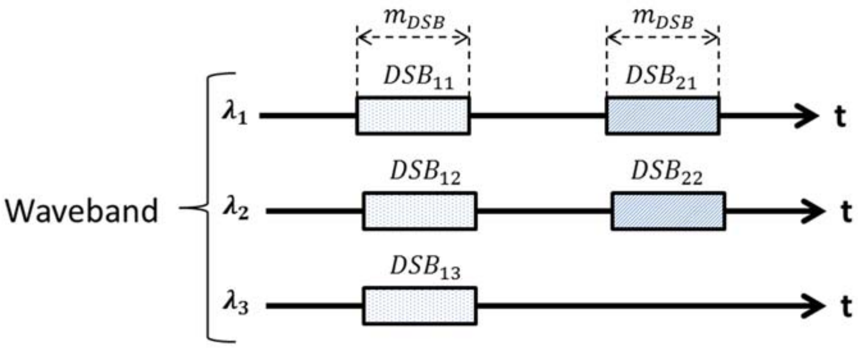

Figure 4. Transmission of the burst in POBS (Zaiter, 2014)

Optical Signal in fiber is analyzed B1, B2, ..., BM waveband with Fiber to Band (FTB) burst multiplexer (see Figure 5). B1, B2, ..., BM waveband with Band to Fiber (BTF) burst multiplexer is analyzed to exit fiber. Control packet is transmitted separately with Control Channel (λ_c). First of all, control packet converts optical to electrical (O\E) and then is processing in Switching Control Unit (SCU). Lastly, it is converts electrical to optical (E\O) to turn optical environment. Wavelengths with same source- destination node uses one port to switch multiple wavelengths are grouped in one waveband and exit from ingress node (Guo, 2009, Huang, 2007).

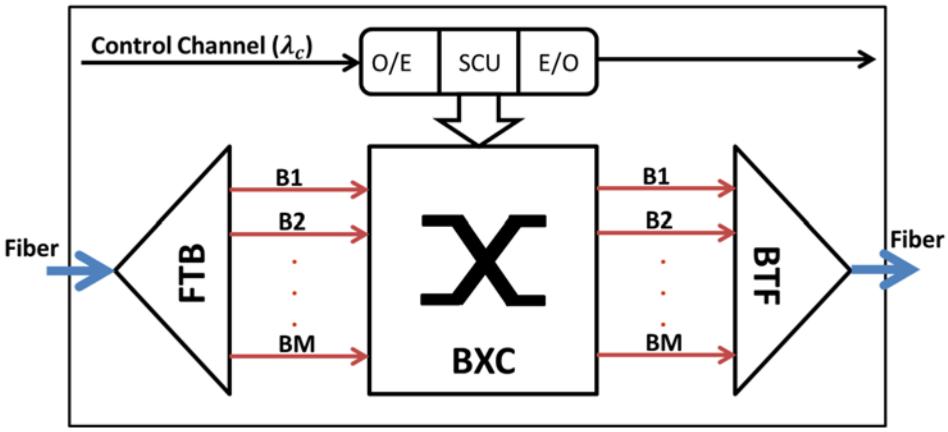

Figure 5. Architecture of a POBS core node (Zaiter, 2014)

ENERGY EFFICIENCY IN WAVELENGTH DIVISION MULTIPLEXING

To find which equipment on network infrastructures cause more energy consumption is important to manage energy consumption over internet (Hinton, 2011). It depends on changing all old tools of network operator over internet. Aim of the all researches is to get more network performance with low energy. Researchers try to get result from simulation of the new network models, network architecture and protocols that is analyzed and constructed in different network technology.

Internet that is using in resident is more than internet that is using in public access such as subway. Also power consumption on internet differs according to building structure. According to Kazovsky (2013) research, power consumption on office and resident in United States of America differs from each other. Energy in office buildings is consumed about 45% on Network Interface Card as increasing of the user number. Energy consumption in resident is changed according to connection type and Wireline LAN interface (Ethernet) is consumed the most energy as we see Figure 6. To construct optical network with high bit rate and use protocols in Passive Optical Network is specified as solutions to provide energy efficiency (Kazovsky, 2013).

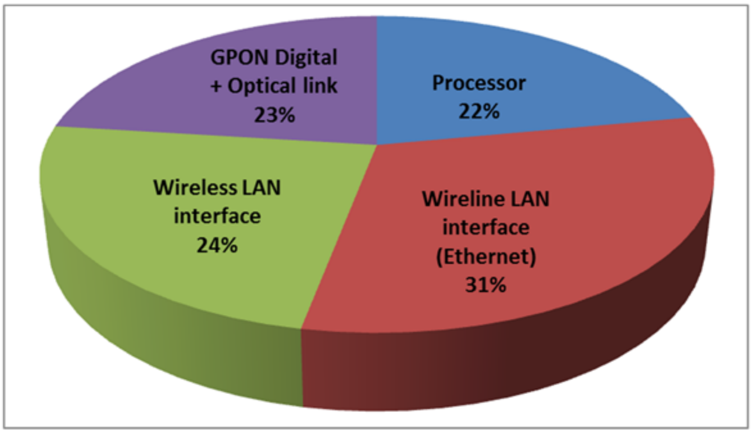

Figure 6. Power consumption distribution for current residential networks (Kazovsky, 2013)

The advantages of optical network transmission provide more efficiency (Bathula, 2009a). Energy consumption increases along with increasing transmission data so well constructed network architecture and well routing algorithm in optical network must be specified (Bathula, 2009a). Some researcher specify that optical packet switching (Yoo, 2006) and optical burst switching (Qiao,1999) network are get better solution to electronic routing. Qualified router is consumed approximately10 nj for each bit of data (Baliga, 2009). Optical packet and burst switching need to consume 1 nj for each bit (Tucker, 2006). Furthermore, size of the IP packet affect energy consumption in router. If the IP packet is transmitted with small size, energy will be consumed further. Therefore, router must optimize IP packet size when the IP packet routing schema is transmitted from router to provide energy efficiency (Zhang, 2010).

The most energy is consumed on header processing and the transmission of the header. Therefore, burst switching technique that has little header processing is the best alternative. According to Peng (2010), edge switching number must be four times than core switching number, so that burst switching will consume less energy than packet switching. Although, edge burst switches is consumed 20% more energy than edge packet switch, burst switching network is improvable with its other advantages on energy efficiency (Peng, 2010).

Energy consumption in optical network calculates summation of power consumption of signal, power consumption of main router and power consumption in amplifiers. Laser resources number that is used and the situation (active or inactive) of optical amplifiers are necessary to reduce power consumption (Bade, 2015). Moreover, to set sleepy mode part of the modem/ONU reduces power consumption significantly (Baliga, 2009).
Optical Network Unit (ONU) and Optical Line Terminal (OLT) in Passive Optical Network (PON) always must be active so there are different approaches for sleep mode. According to Turna (2015), data transmission is done over one of two OLT cards until data traffic reduces while the other is stay in deep sleep mode.

There are more routing algorithms to develop Quality of Services (QoS) while energy efficiency is improved in optical network. According to Bathula (2009a), new routing algorithm that is specified some node as sleep with threshold and is checked suitable of wavelength is developed. When this methods is compared with shortest path algorithm, this method is given good result both packet delay and energy efficiency.

A waveband consists different wavelength with POBS network to improve energy efficiency in OBS network. OBS is consume 15% more energy than parallel optical burst switching with the same scenario (Zaiter, 2014). Energy consumption can be minimized when the value of Burstification Time (BT) and waveband size (Waveband Granularity) is high. According to Zaiter's (2014) simulation, the network must be configured with high value of Burstification Time and Waveband Granularity in POBS network to reduce energy consumption and drop packet number.

ENERGY EFFICIENCY METHODS

The most energy is consumed by network switch and transmitter in network. Energy in network equipment must be minimized to provide energy efficiency. There are various energy efficiency methods that are used in recent researches.

The first energy efficiency method is to close core nodes. The best way is to use anycasting routing techniques. Among probable paths from source to destination must be select the best one to reduce power consumption. Some of nodes can be “OFF” mode so the routing must be according to “OFF” mode node (Bathula, 2009a-2009b). Generally, data is transmitted from source to destination with shortest path algorithm. But this algorithm is not suitable for energy efficiency. Therefore, path that minimizes the energy consumption must be preferred instead of shortest path.

The second energy efficiency method is to enlarge the size of data burst in OBS network (Kim, 2010, Peng, 2010, Zaiter, 2012). Packet that has same source and destination also has the same header processing. The more packets are sent with the same header, the fewer headers is processing. Optical network does not need buffering (Xiong, 2000), and also does not need conversation electrical to optical and optical to electrical (Jue, 2005, Qiao, 2000). The energy consumption that is consumed during data transmission will be decreased if more data that has same header gets together.

The last method is to get together wavelength in different waveband tunnel with Waveband Switching (Hou, 2011, Shen, 2009) instead of decrease optical transmission port number. Waveband Switching technique are grouped different wavelength in waveband so as to be one port. A fiber is consist of waveband, waveband is consist of different wavelength (see Figure 7). By means of waveband, port number and power consumption will decrease.

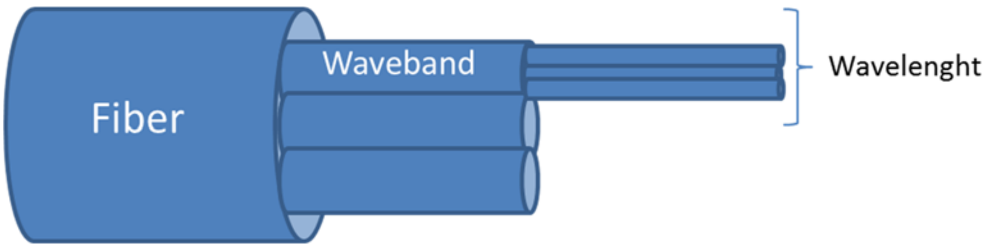

Figure 7. Fiber

HARDWARE STRATEGIES IN ENERGY EFFICIENCY

Power consumption of the hardware in network is the one of the important factor for energy efficiency. To provide more energy efficiency, architecture must support this with all equipment. Hardware strategies in recent researches

- To set existing network architecture with low energy equipment to provide more energy efficiency.
- Out of use equipment can be hold in “idle” or “sleep” mode to minimize power consumption. As long as hardware equipment does not used, this situation can be minimize energy consumption.
- To minimize device work load. Electrical circuit is consumed low energy in low speed. It will minimize energy consumption when the transmission is over low speed equipment. It can be applied all equipment in network to improve more energy efficient Ethernet protocol (IEEE, 2010).
- To maximize energy efficiency in intermediate router. This can be with improving signal processing function in router.
- To develop and generalize access network technology that is provided more energy efficiency.

Conclusion

This study gives information about switching mechanism in WDM network and is it preferable new subject energy efficiency. At the same time, it compares switching mechanism with used methods and strategies in recent researches. As we see in recent research, POBS network is provided more energy efficiency than OBS although researches deal with OBS more than POBS.

Quality of services such as loss packet, latency and usability come into question while aiming to minimize power consumption. Hybrid structure can be improved in POBS network with less packet delay, buffer memory methods and construct infrastructure to improve energy efficiency in the future.

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