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REVIEW
Doctoral Dissertation of Atyaf Al-Tameemi
„ Simultaneous Connections Routing in Wavelength-Space-Wavelength Elastic Optical Switching Fabrics"
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1. The purpose and scope of the doctoral dissertation

The doctoral dissertation concerns switching fabrics for Elastic Optical Networks (EONs). The EON is a relatively new optical technology proposed to replace the currently most popular technology Wavelength Switched Optical Networks based on the Wavelength Division Multiplexing (WDM). EON is an innovative approach for optical networks described for the first time in 2008 as a spectrum-sliced elastic optical path network (SLICE) technology. The main benefits of EON are provisioning connection with bitrate beyond 100 Gb/s and support of sub-wavelengths that improves spectrum-efficiency. The development of EON has been mainly driven by business reasons, i.e., the rapid increase of network traffic has brought the existing Wavelength Switched Optical Network systems to the capacity limit. In consequence, EONs provide cost-effective solutions to increase network capacity. Switching fabrics supporting EONs are important components necessary for deployment of EONs.

The doctoral dissertation focuses on various combinatorial aspects of switching fabrics for EONs, namely, two Wavelength-Space-Wavelength (WSW) switching fabric architectures for EONs denoted as WSW1 and WSW2 are considered. Both architectures are of special design based on the Clos switching fabrics, and thus they include three stages. Furthermore, the first and third stages contain the tunable spectrum converters (TSCs) and have wavelength conversion capabilities, while the second stage supports only switching in the space domain.

The doctoral dissertation contains both theoretical and practical results. In the field of theoretical elements, Atyaf Al-Tameemi formulated various analytical results on WSW switching fabric architectures for EONs including: development of necessary and sufficient RNB (rearrangably nonblocking) conditions for various versions of WSW1 architectures, development of algorithms for connections routing in considered WSW1 architectures, development of necessary and sufficient RNB conditions for various versions of WSW2 architectures, development of algorithms for

connections routing in considered WSW2 architectures. In turn, the practical aspect of the doctoral dissertation includes performing numerical comparisons and analysis of the proposed architectures in terms of the number of required spectrum resources (frequency slot units) and switching elements.

2. The content of the doctoral dissertation

The doctoral dissertation consists of eight chapters. The first chapter includes an introduction to the topics covered in the dissertation, motivations, goals and thesis of the dissertation. The second chapter describes basic information related to Elastic Optical Networks (EONs) and evolution of optical networks. Chapter 3 focuses on background information on switching fabrics and description of current switching techniques. Chapter 4 presents details of the switching architectures considered in the dissertation, i.e., two versions of Wavelength-Space-Wavelength (W-S-W) switching fabric architectures WSW1 and WSW2. Chapters 5-7 include the main original achievement of the dissertation. In more detail, Chapter 5 describes rearrangeable nonblocking conditions for WSW1 architecture and routing algorithms. In turn, Chapter 6 reports the rearrangeable nonblocking conditions for WSW2 architecture and routing algorithms. Chapter 7 includes numerical comparisons and analysis of the proposed architectures in terms of the number of required spectrum resources (frequency slot units) and switching elements. Finally, the last Chapter 8 concludes the research presented in the dissertation and shows directions for future work. The doctoral dissertation is well structured, written in a fluent English language with many illustrative examples showing explaining the main issues. Figures are well understandable and graphs readable.

3. Correctness and originality of the thesis

The thesis of the dissertation is formulated as follows:

The matrix decomposition algorithms, designed for simultaneous connection routing in the three-stage Clos switching fabrics, cannot be directly used to route connections in WSW1 and WSW2 switching fabrics, but they can be modified such that they can route connections successfully.

In my opinion, the thesis of the dissertation is formulated in an appropriate way. Atyaf Al-Tameemi correctly determined the scope of her work based on a literature review and her knowledge, focusing on various aspects of WSW1 and WSW2 switching fabrics for Elastic Optical Networks. The Author solved the formulated research problem using correctly selected research methods and approaches including analytical analysis of various properties of the considered WSW1 and WSW2 architectures and performing simulation studies and numerical analysis showing assessment of the proposed approaches followed by a thorough discussion. In consequence, the goals of the dissertation have been achieved.

4. Analysis of sources (including world literature and state of the art)

The doctoral dissertation of Atyaf Al-Tameemi centers on up-to-date topics related to switching fabrics for Elastic Optical Networks. The Author performed a systematic bibliographic review, the list of literature in the dissertation contains 115 items. Among them are the most important works related to:

- switching technologies,

- switching fabrics,
- Elastic Optical Networks.

I can unequivocally state that Atyaf Al-Tameemi has sufficient knowledge of contemporary literature in the field of various aspects related to telecommunication networks, with particular emphasis on switching architectures in Elastic Optical Networks.

5. The position of the dissertation in relation to the state of the art represented by world literature

The doctoral dissertation is strongly linked to up-to-date research directions in the field of telecommunication networks. The selection of the topic is appropriate, since the considered optical technology, namely Elastic Optical Network, is the most advanced and actual innovation in the field of optical networking. Furthermore, the area of switching technologies is a vital research area in the ICT sector, since the overall development of networks (i.e., increasing the overall network traffic, growing role of optical networks as the backbone networks for the Internet – especially in the COVID era) triggers the need for new solutions that allow to provision higher volumes of traffic in a cost efficient way. Moreover, I want to stress that Atyaf Al-Tameemi continues the research on switching technologies conducted for many years in the Chair of Communication and Computer Networks at the Poznan University of Technology.

6. The significance of the results obtained for a given scientific discipline

The most important and original achievements of the doctoral dissertation are as follows:

- Formulation of necessary and sufficient RNB (rearrangably nonblocking) conditions for WSW1(2, n ,k) architecture.
- Development of an algorithm for connections routing in WSW1(2, n ,k) architecture.
- Formulation of necessary and sufficient RNB conditions for WSW1(3, n ,k) architecture.
- Development of four control algorithm for connections routing in WSW1(3, n ,k) architecture.
- Development of two control algorithm for connections routing in WSW1($r > 3$, n ,k) architecture.
- Formulation of necessary and sufficient RNB conditions for WSW2(p, q, r, n, n) architecture.
- Formulation of necessary and sufficient RNB conditions for WSW2(p, q, 2, n, n) architecture.
- Development of a control algorithm for connections routing in WSW2(p, q, 2, n, n) architecture with an extended version that allows to derive the required number of center-stage switches for this algorithm.
- Numerical comparisons and analysis of the proposed architectures in terms of the number of required spectrum resources (frequency slot units) and switching elements

I want to underline that the concepts and results obtained have practical significance. In more detail, the Author defined and then solved a real and up-to-date research problem related to analysis and optimization of switching architectures for EONs. Moreover, I would like to emphasize that the dissertation is written in good language with many very illustrative examples.

7. Main disadvantages of the doctoral dissertation and critical remarks

General remarks

- Some of the obtained results are not practical in the value of k obtained for the WSW1(r, n, k) architecture to provide nonblocking. In more detail, depending on the values of other parameters (i.e., r, n) the obtained values of k are much larger than 350 or 320, while usually the number of FSUs in EONs is assumed as 350 or 320 (what follows from properties of the fiber and size of the C-band). Therefore, all results showing values of k larger of 350 have only theoretical meaning.
- The PhD candidate has several publications on topics related to the dissertation, positions [54]-[59] in the references. However, it is not clearly stated in the dissertation which elements published in these publications are included in the dissertation and in which sections.

Polemical remarks

- Usually, in EONs it is assumed that each connection (lighpath) is generated by a transceiver that serves a particular number of FSUs. For instance, in paper [C. Rottondi, M. Tornatore, A. Pattavina and G. Gavioli, "Routing, modulation level, and spectrum assignment in optical metro ring networks using elastic transceivers," in *IEEE/OSA Journal of Optical Communications and Networking*, vol. 5, no. 4, pp. 305-315, April 2013] one of analyzed transceivers serves 37.5 GHz , what means 3 FSUs. Since EONs allow using superchannels (i.e., if the capacity of a single transceiver does not support all the groomed traffic between two nodes, the aggregated traffic can still be mapped over a single optical path formed by signals generated by multiple adjacent transceivers, such optical path is referred to as a "superchannel" and is handled by the optical nodes as a single entity). Then the connections established as superchannels using transceivers serving 3 FSUs need $3k$+1 FSUs, where k denotes the number of transceivers and 1 is for the guard-band. In some cases, the guardband is not considered. However, having the above described information, we can limit the set of possible m values (number of required FSUs). It would be interesting to check if the analytical results reported in the dissertation can be modified assuming specific values of parameter m. Maybe, with such assumptions some new conditions and/or routing algorithms could be formulated.

Detailed remarks

- Some language flaws:
  - Page 8: "Chapter 2, entitled Elastic Optical Networks, **discuss** the historical view of elastic optic networks (…)."

8. Conclusions

The reviewed doctoral dissertation is an original solution of a clearly formulated scientific problem. Atyaf Al-Tameemi demonstrated the ability to conduct scientific research independently, as well as to correctly and insightfully interpret the obtained results. The critical remarks mentioned above do not have a significant impact on the overall positive evaluation of the doctoral dissertation. I believe

that the doctoral dissertation of Atyaf Al-Tameemi presented to me for review meets the requirements of the Act on Academic Degrees and Academic Title (Ustawa o stopniach naukowych i tytule naukowym z dnia 14 marca 2003 roku, Dz. U. z 2003 r., nr 65, poz. 595 z późniejszymi zmianami) and I recommend for admission to a public defense. Moreover, in my opinion the doctoral dissertation of Atyaf Al-Tameemi deserves recognition.