Research Letter

Impact of Bimodal Traffic on Latency in Optical Burst Switching Networks

Yuhua Chen[1] and Pramode K. Verma[2]

[1] Department of Electrical and Computer Engineering, University of Houston, Houston, TX 77204, USA
[2] Telecommunications Engineering Program, School of Electrical and Computer Engineering,
  The University of Oklahoma, Tulsa, OK 74135, USA

Correspondence should be addressed to Yuhua Chen, yuhua.chen@mail.uh.edu

This paper analyzes the impact of bimodal traffic composition on latency in optical burst switching networks. In particular, it studies the performance degradation to short-length packets caused by longer packets, both of which are part of a heterogeneous traffic model. The paper defines a customer satisfaction index for each of the classes of traffic, and a composite satisfaction index. The impact of higher overall utilization of the network as well as that of the ratio of the traffic mix on each of the customer satisfaction indices is specifically addressed.

1. Introduction

Optical transmission technologies have been widely adopted in the core telecommunication network today. The adoption of optical transmission technology has been far more pervasive than the switching technology. Optical burst switching [1, 2] effectively fills the gap between coarse lambda switching and the still-distant optical packet switching [3, 4], and is considered the most promising form of optical switching technology [5].

Optical burst switching relies on relatively large bursts of data assembled at the ingress node to be transported over an end-to-end optical path to the destination or egress node. Since it is economically infeasible to form a burst in response to each customer packet, the packets entering the ingress node will likely originate from different sources and thus have varying statistical characteristics. In this paper, we consider this traffic to have a bimodal distribution, each component of which is negative exponentially distributed with a separate mean. This assumption is justifiable in the instance when the ingress traffic is a mixture of short packets and relatively long packets, for example, packets containing dense payloads that allow sharing of resources of a grid network to a remote point [6].

It is generally known that heterogeneous traffic leads to poor performance, specifically, as far as the smaller-length traffic is concerned. However, it is imperative from a service provider point of view to quantify and understand the impact of the heterogeneous traffic on the network as a whole as well as on each of the constituent customer groups. In this paper, we introduce the concept of a customer satisfaction index for each of the two classes of traffic, and a composite customer satisfaction index for the network as a whole. We then derive a closed form mathematical solution for the individual and composite customer satisfaction indices as a function of the ratio of the mean lengths and further as a function of the overall traffic intensity.

2. Bimodal Traffic Model

In this paper, we are interested in evaluating the impact of the bimodal traffic on the latency of the two traffic types, as well as on the system latency as a whole. More specifically, we want to understand how the mixed traffic affects the latency experienced by individual traffic type. We define the *individual customer satisfaction index* as follows: $\eta_1 = T_1/T_c$, and $\eta_2 = T_2/T_c$, where T_1 and T_2 are the latency experienced by type 1 an type 2 traffic in systems carrying single type of

traffic, respectively, and T_c is the latency experienced by the composite traffic. We further define the *composite customer satisfaction index* as $\eta = \delta \cdot \eta_1 + (1 - \delta) \cdot \eta_2$, where δ ($0 \le \delta \le 1$) is the portion of traffic type 1 in the composite traffic load ρ_c.

In the rest of the section, we derive a mathematical model for the individual and composite customer satisfaction indices in terms of the composite load and the ratio of the mean message lengths of the two traffic types.

We assume that each component of the bimodal traffic follows a Poisson arrival process. Since the message lengths of the two streams are negative exponential distributed, we have the distribution of the composite stream as

$$f(x) = \frac{\lambda_1}{\lambda_c} \mu_1 e^{-\mu_1 x} + \frac{\lambda_2}{\lambda_c} \mu_2 e^{-\mu_2 x}. \tag{1}$$

Equation (1) follows from the fact that the probability density function of the composite stream is the sum of the density functions of the two streams weighted by the relative probabilities of their occurrence. Note that the combined stream is not negative exponentially distributed unless $\mu_1 = \mu_2$.

We derive the average latency of the composite stream as follows. For evaluating the mean delay suffered by an individual message, we have [7]

$$T = \frac{1}{\mu C} + \frac{\rho^2 + \lambda^2 \sigma_S^2}{2\lambda(1 - \rho)}, \tag{2}$$

where $1/\mu$ is the mean message length, σ_S^2 is the variance of the service time and C is the channel rate at which the messages are being emptied. Equation (2) holds for any message length distribution. Let σ_c^2 be the variance of the message length distribution.

For the combined stream, the mean length can be evaluated as

$$\frac{1}{\mu_c} = \overline{x_c} = \int_0^\infty x f(x) dx = \frac{1}{\lambda_c} \cdot \left(\frac{\lambda_1}{\mu_1} + \frac{\lambda_2}{\mu_2} \right). \tag{3}$$

Let $g_1(x) = \int_0^\infty \mu_1 e^{-\mu_1 x} dx$ and $g_2(x) = \int_0^\infty \mu_2 e^{-\mu_2 x} dx$. The Laplace transform of $g_1(x)$ is $G_1(s) = \mu_1/(\mu_1 + s)$. The second moment of $g_1(x)$ can be calculated using

$$\overline{x_{g_1}^2} = \frac{d^2 G_1^*(s)}{ds^2} \bigg|_{s=0} = \frac{d^2}{ds^2} \left(\frac{\mu_1}{\mu_1 + s} \right) \bigg|_{s=0} = \frac{2}{\mu_1^2}. \tag{4}$$

We also have $\overline{x_{g_2}^2} = 2/\mu_2^2$. The second moment of the combined stream can be calculated as

$$\begin{aligned} \overline{x_c^2} &= \int_0^\infty x^2 f(x) dx \\ &= \frac{\lambda_1}{\lambda_c} \overline{x_{g_1}^2} + \frac{\lambda_2}{\lambda_c} \overline{x_{g_2}^2} = \frac{2}{\lambda_c} \left(\frac{\lambda_1}{\mu_1^2} + \frac{\lambda_2}{\mu_2^2} \right). \end{aligned} \tag{5}$$

The variance of the combined stream can be derived as

$$\begin{aligned} \sigma_c^2 &= \overline{x_c^2} - (\overline{x_c})^2 \\ &= \frac{2}{\lambda_c} \left(\frac{\lambda_1}{\mu_1^2} + \frac{\lambda_2}{\mu_2^2} \right) - \frac{1}{\lambda_c^2} \cdot \left(\frac{\lambda_1}{\mu_1} + \frac{\lambda_2}{\mu_2} \right)^2. \end{aligned} \tag{6}$$

From (6) σ_S^2 can be calculated using $\sigma_S^2 = \sigma_c^2/C^2$. We then define the ratio of type 2 message-length to type 1 message-length as $\gamma = \mu_1/\mu_2$. Let $\chi = \delta + (1 - \delta)/\gamma$. Equation (3) becomes

$$\frac{1}{\mu_c} = \frac{1}{\mu_1} \cdot \frac{1}{\delta + (1 - \delta)/\gamma} = \frac{1}{\chi \mu_1}. \tag{7}$$

We can rewrite the variance of the service time of the combined stream as

$$\sigma_S^2 = \frac{1}{\mu_1^2 C^2} \left(\frac{2(\delta + \gamma(1 - \delta))}{\chi} - \frac{1}{\chi^2} \right). \tag{8}$$

Substituting (7) and (8) in (2), we have

$$T = \frac{1}{\chi \mu_1 C} \left(1 + \frac{\rho_c (2\chi(\delta + \gamma(1 - \delta)) - 1)}{2\chi^2 \mu_1^2 C^2 (1 - \rho_c)} \cdot (1 + \chi^2 \mu_1^2 C^2) \right). \tag{9}$$

Using the mean service times of the messages from the two streams, we have

$$T_1 = \frac{1}{\mu_1 C} + \frac{\rho_1}{\mu_1 C (1 - \rho_1)}. \tag{10}$$

T_2 can be similarly calculated. Thus, we have the individual customer satisfaction index

$$\eta_1 = \chi \left(1 + \frac{\rho_c (2\chi(\delta + \gamma(1 - \delta)) - 1)}{2\chi^2 \mu_1^2 C^2 (1 - \rho_c)} \cdot (1 + \chi^2 \mu_1^2 C^2) \right)^{-1},$$

$$\eta_2 = \gamma \cdot \chi \left(1 + \frac{\rho_c (2\chi(\delta + \gamma(1 - \delta)) - 1)}{2\chi^2 \mu_1^2 C^2 (1 - \rho_c)} \cdot (1 + \chi^2 \mu_1^2 C^2) \right)^{-1}. \tag{11}$$

The composite customer satisfaction index η can be calculated based on definition.

3. Numerical Results

Figures 1 through 3 present plots that capture the variations of the three different customer satisfaction indices as a function of the ratio of the two mean message lengths at various composite loads. The composite traffic, in each case, consists of 50% of the bits from the shorter and 50% bits from the longer messages.

As can be seen from Figure 1, with a composite load of 0.4, the satisfaction index of the customer group generating the shorter messages rapidly declines as the ratio of the mean message lengths increases. This decline can be observed to be true for all levels of the composite load. The latter observation follows from Figures 2 and 3 which address higher levels of load. This is consistent with the fact that a preponderance of longer messages increasingly affects the satisfaction index of the shorter messages.

It can be observed from all the three figures taken together that all the customer satisfaction indices decline as a function of the composite load. The intersection of the three indices when the two customer groups generate statistically identical messages verifies the fact that satisfaction indices
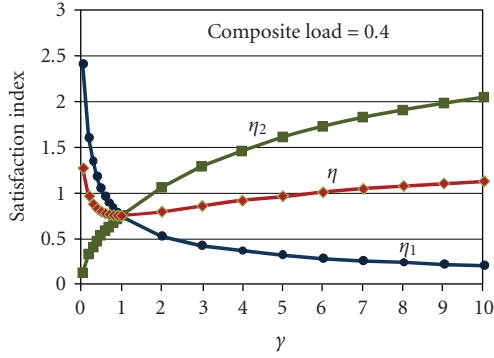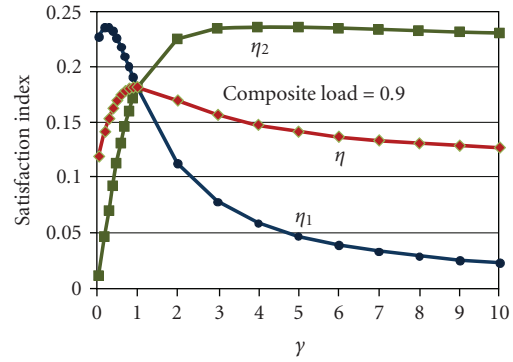
Figure 1: Customer satisfaction index at low load.

Figure 2: Customer satisfaction index at medium load.

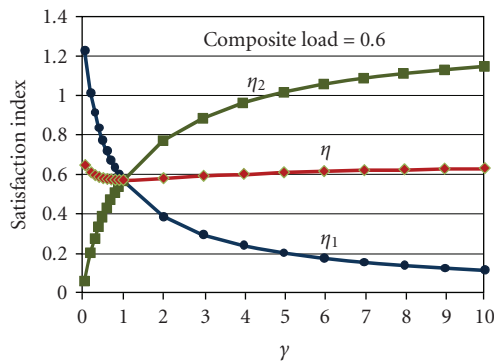Figure 3: Customer satisfaction index at heavy load.

cannot differ when the messages from the two groups are statistically identical.

Simultaneously, it can be observed that when the ratio of the mean lengths increases, the composite satisfaction index holds largely constant while the satisfaction index of the users of longer messages shows an increase. This is attributed to the fact that as the ratio of the message lengths increases, the mean latency in systems carrying only longer messages also increases, while longer messages in composite systems benefit from the existence of shorter messages, resulting in an increase in satisfaction indices.

4. Conclusion

This paper has defined parameters that reflect the satisfaction of customer groups generating bimodal traffic that constitutes the payload of the OBS burst. It has derived analytical results relating the customer satisfaction indices to variations in the ratio of the average message lengths of the two groups and to the increase in the overall utilization factor. The results clearly indicate the reducing satisfaction of all the indices as the load is increased, and especially that of the customer group generating shorter messages, as the ratio of the mean lengths of the larger to smaller messages is increased. However, surprisingly, the network as a whole, as indicated by the composite satisfaction index, is largely not affected by the ratio of the mean lengths due to the interplay between the longer and shorter messages in the composite system.

Acknowledgments

References

[1] J. S. Turner, "Terabit burst switching," *Journal of High Speed Networks*, vol. 8, no. 1, pp. 3–16, 1999.

[2] C. Qiao and M. Yoo, "Optical burst switching (OBS)—a new paradigm for an optical internet," *Journal of High Speed Networks*, vol. 8, no. 1, pp. 69–84, 1999.

[3] D. J. Blumenthal, P. R. Prucnal, and J. R. Sauer, "Photonic packet switches: architectures and experimental implementations," *Proceedings of the IEEE*, vol. 82, no. 11, pp. 1650–1667, 1994.

[4] P. Gambini, M. Renaud, C. Guillemot, et al., "Transparent optical packet switching: network architecture and demonstrators in the KEOPS project," *IEEE Journal on Selected Areas in Communications*, vol. 16, no. 7, pp. 1245–1259, 1998.

[5] M. J. O'Mahony, C. Politi, D. Klonidis, R. Nejabati, and D. Simeonidou, "Future optical networks," *Journal of Lightwave Technology*, vol. 24, no. 12, pp. 4684–4696, 2006.

[6] Y. Chen, W. Tang, and P. K. Verma, "Latency in grid over optical burst switching with heterogeneous traffic," in *Proceedings of the 3rd International Conference on High Performance Computing and Communications (HPCC '07)*, vol. 4782 of *Lecture Notes in Computer Science*, pp. 334–345, Springer, Houston, Tex, USA, September 2007.

[7] D. G. Kendall, "Some problems in the theory of queues," *Journal of the Royal Statistical Society Series B*, vol. 13, pp. 151–185, 1951.

Special Issue on
Optical Wireless Communications and Networking

Call for Papers

Optical wireless systems play an increasingly important role in our communication infrastructure, and new systems for very high-data-rate secure communications are under development. From space-based systems to terrestrial long-distance and indoor systems, they are being investigated for fixed, portable, and mobile communication applications. Current research activities in the design and performance of transceivers, pointing, acquisition, and tracking (PAT), modulation and diversity techniques, modeling and analysis of indoor wireless, and developments in hybrid systems, which use RF links together with optical links, are some examples that demonstrate current intense interests in optical wireless.

This issue aims at providing a venue for recent developments in optical wireless systems and networks. New experimental indoor and outdoor results are of particular interest. Original theoretical results, including modeling and simulation, are also welcome. Integration of optical wireless with other personal area networks is another area of interest. The contributions for this special issue should address one of the following topic areas:

- Technologies: channel modeling, modulation and coding for improved outdoor and indoor communication, statistics in reliability and availability, MIMO systems, Gbit/s technology, networking of directional wireless systems, interplay between PAT and network topology, emerging concepts and technologies, new hybrid optical/RF transceiver designs, applications of modulating retroreflectors, cross-layer issues in optical wireless sensor networks, link layer, network and transport protocols, and modeling
- Short-range systems: sensor networks, indoor systems, and IrDA personal device technologies
- Medium-range systems: special modulation and coding schemes, hybrid systems, and switchover technologies
- Long-range systems: HAPs and intersatellite communications

Before submission authors should carefully read over the journal's Author Guidelines, which are located at http://www .hindawi.com/journals/wcn/guidelines.html. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at http://mts.hindawi.com/ according to the following timetable:

Manuscript Due	December 1, 2009
First Round of Reviews	March 1, 2009
Publication Date	June 1, 2010

Lead Guest Editor

Deva K. Borah, Klipsch School of Electrical & Computer Engineering, New Mexico State University, Las Cruces, NM 88003, USA; dborah@nmsu.edu

Guest Editors

Anthony C. Boucouvalas, Telecommunication Science and Technology Department, University of Peloponnese, Terma Karaiskaki, 22100 Tripoli, Greece; acb@uop.gr

Christopher C. Davis, Department of Electrical and Computer Engineering, University of Maryland, College Park, MD 20742, USA; davis@umd.edu

Rittwik Jana, AT&T Labs Research, 180 Park Ave, Florham Park, NJ, USA; rjana@research.att.com

Steve Hranilovic, Department of Electrical and Computer Engineering, McMaster University, Hamilton, ON, Canada L8S 4K1; hranilovic@mcmaster.ca

Special Issue on Femtocell Networks

Call for Papers

Recently, there has been a growing interest in femtocell networks both in academia and industry. They offer significant advantages for next-generation broadband wireless communication systems. For example, they eliminate the deadspots in a macrocellular network. Moreover, due to short communication distances (on the order of tens of meters), they offer significantly better signal qualities compared to the current cellular networks. This makes high-quality voice communications and high data rate multimedia type of applications possible in indoor environments.

However, this new type of technology also comes with its own challenges, and there are significant technical problems that need to be addressed for successful deployment and operation of these networks. Standardization efforts related to femtocell networks in 3GPP (e.g., under TSG-RAN Working Group 4 and LTE-Advanced) and IEEE (e.g., under IEEE 802.16m) are already underway.

The goal of this special issue is to solicit high-quality unpublished research papers on design, evaluation, and performance analysis of femtocell networks. Suitable topics include but are not limited to the following:

- Downlink and uplink PHY/MAC design for femtocells in 3G systems, WiMAX systems, and LTE systems
- Interference analysis, avoidance, and mitigation
- Coexistence between a macrocellular network and femtocell network
- Resource allocation techniques
- Closed subscriber group (CSG) versus open-access femtocells
- Power control and power saving mechanisms (e.g., sleep/idle mode etc.)
- Mobility support and handover
- Time synchronization
- Multiple antenna techniques
- Tradeoffs between femtocells, picocells, relay networks, and antenna arrays
- Comparison with other fixed-mobile convergence (FMC) approaches such as UMA/GAN and dual-mode terminals

- Self-organizing networks and issues in self maintenance and self install
- Issues related to enterprise femtocells

Before submission, authors should carefully read over the journal's Author Guidelines, which are located at http://www.hindawi.com/journals/wcn/guidelines.html. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at http://mts.hindawi.com/, according to the following timetable:

Manuscript Due	September 1, 2009
First Round of Reviews	December 1, 2009
Publication Date	March 1, 2010

Lead Guest Editor

Ismail Guvenc, Wireless Access Laboratory, DOCOMO Communications Laboratories USA, Inc., Palo Alto, CA 94304, USA; iguvenc@docomolabs-usa.com

Guest Editors

Simon Saunders, Femto Forum, UK; simon@femtoforum.org

Ozgur Oyman, Corporate Technology Group, Intel Corporation, USA; ozgur.oyman@intel.com

Holger Claussen, Alcatel-Lucent Bell Labs, UK; claussen@lucent.com

Alan Gatherer, Communications Infrastructure and Voice Business Unit, Texas Instruments, USA; gatherer@ti.com

Special Issue on
Advances in Quality and Performance Assessment for Future Wireless Communication Services

Call for Papers

Wireless communication services are evolving rapidly in tandem with developments and vast growth of heterogeneous wireless access and network infrastructures and their potential. Many new, next-generation, and advanced future services are being conceived. New ideas and innovation in performance and QoS, and their assessment, are vital to the success of these developments. These should be open and transparent, with not only network-provider-driven but also service-provider-driven and especially user-driven, options on management and control to facilitate always best connected and served (ABC&S), in whatever way this is perceived by the different stake holders. To wireless communication services suppliers and users, alike the complexity and integrability of the immense, diverse, heterogeneous wireless networks' infrastructure should add real benefits and always appear as an attractive user-friendly wireless services enabler, as a wireless services performance enhancer and as a stimulant to wireless services innovation. Effecting the integration of services over a converged IP platform supported by this diverse and heterogeneous wireless infrastructure presents immense QoS and traffic engineering challenges. Within this context, a special issue is planned to address questions, advances, and innovations in quality and performance assessment in heterogeneous wireless service delivery.

Topics of interest include, but are not limited to:

- Performance evaluation and traffic modelling
- Performance assessments and techniques at system/flow level, packet level, and link level
- Multimedia and heterogeneous service integration-performance issues, tradeoffs, user-perceived QoS, and quality of experience
- Network planning; capacity; scaling; and dimensioning
- Performance assessment, management, control, and solutions: user-driven; service-provider-driven; network-provider-driven; subscriber-centric and consumer-centric business model dependency issues
- Wireless services in support of performance assessment, management, and control of multimedia service delivery

- Performance management and assessment in user-driven live-access network change and network-driven internetwork call handovers
- Subscriber-centric and consumer-centric business model dependency issues for performance management, control, and solutions
- Simulations and testbeds

Before submission, authors should carefully read over the journal's Author Guidelines, which are located at http://www.hindawi.com/journals/wcn/guidelines.html. Prospective authors should submit an electronic copy of their complete manuscript through the journal Manuscript Tracking System at http://mts.hindawi.com/, according to the following timetable:

Manuscript Due	August 1, 2009
First Round of Reviews	November 1, 2009
Publication Date	February 1, 2010

Lead Guest Editor

Máirtín O'Droma, Telecommunications Research Centre, University of Limerick, Ireland; mairtin.odroma@ul.ie

Guest Editors

Markus Rupp, Institute of Communications and Radio-Frequency Engineering, Vienna University of Technology, Gusshausstrasse 25/389, 1040 Vienna, Austria; mrupp@nt.tuwien.ac.at

Yevgeni Koucheryavy, Department of Communication Engineering, Tampere University of Technology, Korkeakoulunkatu 10, 33720 Tampere, Finland; yk@cs.tut.fi

Andreas Kassler, Computer Science Department, University of Karlstad, Universitetsgatan, 65188 Karlstad, Sweden; kassler@ieee.org