

Selected Resources on Quality of Service (QoS) Specification and Contract-Based Management for XML Web Services

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This list contains a number of resources on quality of service (QoS) specification and management for XML Web services. Since a number of peer-reviewed papers, non-refereed technical papers, documents related to industrial standardization efforts, and various other non-refereed publications were published in this area, this list does not aim at comprehensiveness. Its main purpose is to support and complement our tutorials given at ICWS/SCC 2005 and CEC/EEE 2006. Therefore, the list focuses on topics discussed in our tutorial and is organized similarly to the tutorial. For the discussed topics, we usually list one or two main references (our preference is towards peer-reviewed papers) and provide directions (e.g., links to authors' Web pages or specialized workshops) for finding additional information.

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1. Importance of QoS for Web services

The importance of QoS and management for Web services was discussed in a number of publications, such as:

- [LauT01] Lau, T.: QoS for B2B Commerce in the New Web Services Economy. Presented at the Workshop on Performance and QoS for E-Commerce Applications at ISEC 2001 (Hong Kong, China, April 2001). On-line at: <http://www.csd.uwo.ca/research/cords/ISEC2001/lautc.pdf> (2001)
- [Far02] Farrell, J. A., Kreger, H.: Web Services Management Approaches. IBM Systems Journal, Vol. 41, No. 2. IBM. (2002) 212-227. On-line at: <http://www.research.ibm.com/journal/sj/412/farrell.html>
- [vMo02] van Moorsel, A.: Ten-Step Survival Guide for the Emerging Business Web. In Proceedings of the Workshop on Web Services, e-Business, and the Semantic Web – WES 2002 at CAiSE'02 (Toronto, Canada, May 2002). Lecture Notes in Computer Science (LNCS), No. 2512. Springer-Verlag (2002) 1-11

- [Kel03] Keller, A., Ludwig, H.: The WSLA Framework: Specifying and Monitoring Service Level Agreements for Web Services. *Journal of Network and Systems Management*, Vol. 11, No 1 (March 2003). Plenum Publishing (2003) 57-81
- [Tos04b] Tasic, V.: *Service Offerings for XML Web Services and their Management Applications*. Ph.D. Dissertation, Carleton University, Ottawa, Canada, August 2004. On-line at: <http://elab.njit.edu/vladimir/TosicThesis-Final.pdf> (2004)
- [Men04] Menascé, D.A.: *Composing Web Services: A QoS View*. *IEEE Internet Computing*, Vol. 6, No. 6 (Nov.-Dec. 2004). IEEE (2004) 88-90
- [Sah05] Sahai, A., Graupner, S.: *Web Services in the Enterprise: Concepts, Standards, Solutions and Management*. Plenum US (2005)
- [Pap05] Papazoglou, M.P, van den Heuvel, W.-J.: *Web Services Management: A Survey*. *IEEE Internet Computing*, Vol. 9, No. 6 (November-December 2005), IEEE (2005) 58-64

The importance of QoS specification and management for Web services is illustrated by the fact that it is the main topic of the following specialized workshops:

- [1st Web Services Quality Workshop \(WQW 2003\)](#) held at the 4th International Conference on Web Information Systems Engineering - WISE 2003 (Rome, Italy, December 2003). The Proceedings of WISE 2003 Workshops were published by IEEE.
- [Second International Web Services Quality Workshop \(WQW 2004\)](#) held at the 5th International Conference on Web Information Systems Engineering - WISE 2004 (Brisbane, Australia, November 2004). The Proceedings of WISE 2004 Workshops were published by Springer Verlag in the series Lecture Notes in Computer Science, Vol. 3307.
- [Web Information Systems Quality \(WISQ 2005\) Workshop](#) held at the 6th International Conference on Web Information Systems Engineering - WISE 2005 (New York, USA, November 2005). The Proceedings of WISE 2005 Workshops were published by Springer Verlag in the series Lecture Notes in Computer Science, Vol. 3807. This workshop can be considered as a continuation of WQW 2003 and WQW 2004.
- [W3C Workshop on Constraints and Capabilities for Web Services](#) (Redwood Shores, USA, October 2004). While the three above workshops were oriented towards researchers and contained peer-reviewed papers, this World Wide Web Consortium (W3C) workshop was oriented mainly towards practitioners (although some researchers were present). The discussions from this workshop might become an input into future W3C standardization activities related to QoS for Web services.
- [2005 Middleware for Web Services Workshop \(MWS 2005\)](#) held at the 9th International IEEE Enterprise Distributed Object Computing Conference – EDOC 2005 (Enschede, The Netherlands, September 2005). The proceedings of EDOC 2005 workshops were published by IEEE.
- [2006 Middleware for Web Services Workshop \(MWS 2006\)](#) to be held at the 10th International IEEE Enterprise Distributed Object Computing Conference – EDOC 2006 (Hong Kong, October 2006). The proceedings of EDOC 2006 workshops will be published by IEEE.

In addition, papers on the topics related to QoS for Web services were published in many different conferences and journals, as will be evident from the remainder of this bibliography. There are also many repositories of non-refereed technical papers for Web services and some of these papers discuss QoS-related issues.

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2. Approaches to specification of QoS for Web services

The above-mentioned reference [Tos04b] discussed various approaches to comprehensive description of service and QoS for Web services. It particularly thoroughly discussed using classes of service for Web services.

The following paper suggested the “Functionality-Quality-Infrastructure” (FQI) classification of categories and types of contracts for Web services, examined and compared the achievement of the existing Web service languages, and suggested how to approach comprehensive contractual description of Web services:

- [Tos05] Tomic, V., Pagurek, B.: On Comprehensive Contractual Descriptions of Web Services. In Proceedings of the 2005 IEEE International Conference on e-Technology, e-Commerce, and e-Service – EEE-05 (Hong Kong, China, March 2005). IEEE (2005) 444-449

Contract specification and management is the topic of the [Workshop on Contract Architectures and Languages \(CoALa\)](#) held at EDOC conferences from 2004 onwards (the link points to CoALa 2006). In the previous years, improved versions of the best papers from this workshops have been published in special journal issues.

Service Level Agreements (SLAs) have been extensively used in telecommunications, so further information about them can be found in the literature from this area, such as:

- [Lew99] Lewis, L., Ray, P.: Service Level Management Definition, Architecture, and Research Challenges. In Proceedings of Global Telecommunications Conference – Globecom '99 (Rio de Janeiro, Brazil, December 1999). IEEE (1999) 1974-1978

Policy driven management was also explored in a number of papers. One of the seminal (and probably one of the most cited) papers in this area is:

- [Slo94] Sloman, M.: Policy Driven Management for Distributed Systems. Journal of Network and Systems Management, Vol. 2, No. 4 (December 1994). Plenum Press (1994) 333-360

For further information about using policies for management of computing and communication systems, see the Web site of the [Policy Research Group at Imperial College, London, UK](#) and Web sites of other research groups in this area.

The following paper suggested the classification of policy types into action, goal, and utility policies:

- [Kep04] Kephart J. O., Walsh, W.E.: An Artificial Intelligence Perspective on Autonomic Computing Policies. In Proc. of the fifth IEEE International Workshop on

Policies for Distributed Systems and Networks – Policy 2004 (Yorktown Heights, USA, June 2004). IEEE (2004) 3-12

Policy-driven management is the topic of the [IEEE International Workshop on Policies for Distributed Systems and Networks \(Policy\)](#) held from 1999 onwards (the link points to Policy 2006, see also the [list of Policy workshops](#)).

In addition, it was the topic of the [Policy Management for the Web](#) workshop held at the 14th International World Wide Web Conference – WWW 2005 (Chiba, Japan, May 2005).

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3. Languages for specification of QoS for Web services

The Web Service Level Agreement (WSLA) language and the corresponding management infrastructure were described in a number of papers. Probably the ones giving the best summary are the above-mentioned reference [Kel03] and the following two papers:

- [Kel02] Keller, A., Kar, G., Ludwig, H., Dan, A., Hellerstein, J.L.: Managing Dynamic Services: A Contract Based Approach to a Conceptual Architecture. In Proceedings of the 8th IEEE/IFIP Network Operations and Management Symposium – NOMS 2002 (Florence, Italy, April, 2002). IEEE (2002) 513-528
- [Dan04] Dan, A., Davis, D., Kearney, R., Keller, A., King, R., Kuebler, D., Ludwig, H., Polan, M., Spreitzer, M., Youssef, A.: Web Services on Demand: WSLA-Driven Automated Management. IBM Systems Journal, Vol. 43, No. 1. IBM (2004) 136-158. On-line at: <http://www.research.ibm.com/journal/sj/431/dan.pdf>

While [Kel02] presents motivation and architecture, [Dan04] also discusses how WSLA fits into the utility computing concept.

For further information on WSLA, see the [WSLA Web page at IBM Research](#), and also the Web pages of [Dr. Heiko Ludwig](#) and [Dr. Alexander Keller](#).

Information about HP's language for the formal specification of SLAs for Web Services (the Web Service Management Language – WSML) can be found in:

- [Sah02a] Sahai, A., Durante, A., Machiraju, V.: Towards Automated SLA Management for Web Services. Research Report HPL-2001-310 (R.1). Hewlett-Packard (HP) Laboratories Palo Alto. July 26, 2002. On-line at: <http://www.hpl.hp.com/techreports/2001/HPL-2001-310R1.pdf> (2002)
- [Sah02b] Sahai, A., Machiraju, V., Sayal, M., van Moorsel, A., Casati, F.: Automated SLA Monitoring for Web Services. In Proceedings of the 13th IFIP/IEEE Int. Workshop on Distributed Systems: Operations and Management – DSOM 2002 (Montreal, Canada, October, 2002). Lecture Notes in Computer Science (LNCS), No. 2506. Springer-Verlag (2002) 28-41

For further information, see the Web page of [Dr. Akhil Sahai](#) (unfortunately, the list of publications is not up to date, for the complete list search other sources or contact the author) and publications (e.g., technical reports) from [HP Labs](#).

The most important publications on SLAng are:

- [Lam03] Lamanna, D.D., Skene, J., Emmerich, W.: SLAng: A Language for Defining Service Level Agreements. In Proceedings of the 9th IEEE Workshop on Future Trends in Distributed Computing Systems – FTDCS 2003 (Puerto Rico, May 2003). IEEE-CS (2003) 100-106
- [Ske04a] Skene, J., Lamanna, D., Emmerich, W.: Precise Service Level Agreements. In Proceedings of the 26th International Conference on Software Engineering – ICSE 2004 (Edinburgh, UK, May 2004). IEEE (2004) 179-188
- [Ske04b] Skene, J., Emmerich, W.: Generating a Contract Checker for an SLA Language. In Proceedings of the Workshop on Contract Architectures and Languages (CoALa 2004) at EDOC 2004 (Monterey, California, September 2004). IEEE (2004)

[Lam03] gives an introduction to the SLAng language. [Ske04a] describes using meta-modeling to define SLAng syntax and semantics, while [Ske04] discusses using meta-modeling for creation of a corresponding conformance-checking tool.

For further information on SLAng, see the [SLAng Web page](#) and the Web page of [James Skene](#).

The most comprehensive publication on the Web Service Offerings Language (WSOL) is the above-mentioned doctoral dissertation [Tos04b]. The WSOL language was also summarized in:

- [Tos03b] Tasic, V., Patel, K., Pagurek, B.: WSOL – A Language for the Formal Specification of Classes of Service for Web Services. In Proceedings of the 2003 International Conference on Web Services – ICWS'03 (Las Vegas, USA, June 2003). CSREA Press (2003) 375-381
- [Tos03a] Tasic, V., Pagurek, B., Patel, B., Esfandiari, B., Ma, W.: Management Applications of the Web Service Offerings Language (WSOL). In Proceedings of the 15 International Conference on Advanced Systems Engineering – CAiSE'03 (Velden, Austria, June 2003). Lecture Notes in Computer Science (LNCS), No. 2681. Springer-Verlag (2003) 468-484. A significantly extended version was accepted for publication in Information Systems, Elsevier.
- [Tos06a] Tasic, V., Lutfiyya, H., Tang, Y.: Web Service Offerings Language (WSOL) Support for Context Management of Mobile/Embedded XML Web Services. In Proceedings of the the International Conference on Internet and Web Applications and Services – ICIW'06 (Guadeloupe, French Caribbean, February, 2006). IEEE-CS (2006)

While [Tos03b] gives an overview of an early version of WSOL, [Tos03a] discusses its management applications. [Tos06a] presents recent additions to WSOL for specification of context information of mobile Web services.

For further information about WSOL, see the [WSOL/WSOI Web page](#) (unfortunately, the list of publications is not up to date, for the complete list contact [Dr. Vladimir Tasic](#)).

The most important publications on Web Services Quality of Service (WS-QoS) work are:

- [Tia03] Tian, M., Gramm, A., Naumowicz, T., Ritter, H., Jchiller, J.: A Concept for QoS Integration in Web Services. In Proc. of the 1st Int. Web Services Quality

Workshop. - WQW 2003 at the 4th International Conference on Web Information Systems Engineering - WISE 2003 (Rome, Italy, December 2003) 29-36

- [Tia04b] Tian, M., Gramm, A., Naumowicz, T., Ritter, H., Jchiller, J.: Efficient Selection and Monitoring of QoS-aware Web services with the WS-QoS Framework. In Proc. of the 2004 IEEE/WIC/ACM International Conference on Web Intelligence – WI'04 (Beijing, China, September 2004). IEEE (2004) 152-158

Both papers give a high-level overview of the WS-QoS project, but [Tia04b] gives a bit broader picture and discusses a more recent version of the system.

For further information on WS-QoS, see the [WS-QoS Web page](#) and the Web page of [Min Tian](#).

The description of a recent version of the Web Ontology Language (OWL) – Services (OWL-S, previously DAML-S) is available at:

- [Mart04] Martin, D. (ed.): OWL-S: Semantic Markup for Web Services. Web resource for OWL-S version 1.1. November 2004 (last accessed: June 25, 2006). OWL-Services Coalition. On-line at: <http://www.daml.org/services/owl-s/1.1/overview/> (2004)

There have been many refereed publications related to OWL-S. The following seminal paper provides a high-level overview of a very early version of OWL-S (then called DAML-S) and is probably the most referenced peer-reviewed publication in this area:

- [Ank02] Ankolekar, A., Burstein, M., Hobbs, J.R., Lassila, O., Martin, D., McDermott, D., McIlraith, S.A., Narayanan, S., Paolucci, M., Payne, T., Sycara, K.: DAML-S: Web Service Description for the Semantic Web. In Proceedings of the First International Semantic Web Conference – ISWC 2002 (Sardinia, Italy, June 2002). Lecture Notes in Computer Science (LNCS), No. 2342. Springer-Verlag (2002) 348-363

For further information about OWL-S, see the [Semantic Web Services Web page](#). Also note that Semantic Web is the topic of the [International Semantic Web Conference \(ISWC\)](#) held from 2002 onwards (the link points to ICWS 2002) and many workshops.

The most widely accessible introductory publication on DAML-QoS at this time is:

- [Zho04b] Zhou, C., Chia, L.-T., Lee, B.-S.: DAML-QoS Ontology for Web Services. In Proceedings of the International Conference on Web Services (ICWS) 2004 (San Diego, USA, July 2004). IEEE (2004) 472-479

The follow-up of this paper was published as:

- [Zho05] Zhou, C., Chia, L.-T., Lee, B.-S.: DAML-QoS Ontology for Web Services. International Journal of Web Services Research (IJWSR), Vol. 2, No. 2. Idea Group (2005) 43-66

Further information about DAML-QoS can be found on the Web page of [Zhou Chen](#).

Probably the best reference for the Web Services Policy Framework (WS-Policy) is:

- [Sch04] Schlimmer, J. (ed.): Web Services Policy Framework (WS-Policy). Version 1.2. March 2006. Web resource (last accessed: June 25, 2006). BEA/IBM/Microsoft/SAP. On-line at: <http://download.boulder.ibm.com/ibmdl/pub/software/dw/specs/ws-polfram/ws-policy-2006-03-01.pdf> (2006)

For further information about WS-Policy, see the [WS-Policy Web page at IBM developerWorks](#).

It is also important to mention Sun's work on policies for Web services, particularly the Web Services Policy Language (WSPL) and Web Services Policy Constraint Language (WS-PolicyConstraints). Information about relevant publications on these languages can be found at [Sun's Web page on the XACML Project](#).

The following paper describes the work on WS-Agreement, and particularly on the Cremona (CREation and MONitoring of Agreements) architecture:

- [Lud04] Ludwig, H, Dan, A., Kearney, B.: Cremona: An Architecture and Library for Creation and Monitoring of WS-Agreements. In Proceedings of the 2nd International Conference on Service Oriented Computing – ICSOC 2004 (New York, USA, November 2004). ACM Press (2004) 65–74

For further information about the work on WS-Agreement, see the Web page of the [Global Grid Forum \(GGF\) Grid Resource Allocation Agreement Protocol Working Group \(GRAAP-WG\)](#) and the Web page of [Dr. Heiko Ludwig](#).

The following paper describes concisely the UDDIe (UDDI Extension) work:

- [Shai03] Shaikh Ali, A., Rana, O. F., Al-Ali, R., Walker, D. W.: UDDIe: An Extended Registry for Web Services. In Proceedings of the 2003 Symposium on Applications and the Internet (SAINT'03) Workshops, Workshop on Services Oriented Computing: Models, Architectures and Applications (Orlando, USA, January 2003). IEEE-CS (2003) 85-89

It is interesting to note that an early paper from the same research group discussed a different language for representation of SLAs for Grid services, but that this work was later integrated with UDDIe:

- [AlA02] Al-Ali R., Rana, O., Walker, D., Jha, S., Sohail, S.: G-QoS: Grid Service Discovery Using QoS Properties. Computing and Informatics Journal, Vol. 21, No. 4. Bratislava, Slovakia: Institute of Informatics, SAS (2002)

For further information about UDDIe and related projects, see the [UDDIe Web page](#) and the Web pages of [Ali Shaikh Ali](#), [Prof. Omer F. Rana](#), and [Rashid Al-Ali](#).

The following paper suggests extending BPEL4WS (Business Process Execution Language for Web Services) with specification of QoS information and using Solution Manager Service for definition, logging, and analysis of QoS for Web services:

- [McG03] McGregor, C.: A Method to Extend BPEL4WS to Enable Business Performance Measurement. In Proceedings of the 2003 International Conference on Web Services – ICWS'03 (Las Vegas, USA, June 2003). CSREA Press (2003) 46-51

The best summary of the Web Services Distributed Management (WSDM) standardization effort is the (non-refereed) paper:

- [Kre05] Kreger, H.: A Little Wisdom about WSDM. IBM developerWorks, March 11, 2005. Web resource (last accessed: June 26, 2006). IBM. On-line at: <http://www-128.ibm.com/developerworks/webservices/library/ws-wisdom/> (2005)

The survey paper [Pap05] (mentioned at the beginning of this bibliography) also provides a high-level discussion of the WSDM standardization effort. For detailed documents and

further information, see the Web page of the [OASIS Web Services Distributed Management \(WSDM\) TC](#).

Currently, the most informative summary of the Web Services Quality Model (WSQM) standardization effort is the draft:

- [Kim05] Kim, E., Lee, Y.: Quality Model for Web Services. Version 2.0, September 2005. Web resource (last accessed: June 26, 2006). OASIS. On-line at: <http://www.oasis-open.org/committees/download.php/15910/WSQM-ver-2.0.doc> (2005)

For detailed documents and further information, see the Web page of the [OASIS Web Services Quality Model TC](#).

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4. Approaches to management of QoS for Web Services

A discussion of strengths and limitations of various approaches to monitoring of QoS for Web services can be found in the above-mentioned reference [Tos04b].

The concept of a QoS certifier (a probe verifying QoS guarantees in an extended UDDI directory) was described in:

- [Ran03a] Ran, S.: A Model for Web Services Discovery with QoS. SIGecom Exchanges, Vol. 4, No. 1. ACM Press (2003) 1-10
- [Ran03b] Ran, S.: A Framework for Discovering Web Services with Desired Quality of Services Attributes. In Proceedings of the 2003 International Conference on Web Services – ICWS'03 (Las Vegas, USA, June 2003). CSREA Press (2003)

These works discuss how to extend UDDI with QoS information and how publication, certification, discovery, and verification of QoS characteristics of Web services can proceed in such a framework.

The AgFlow QoS middleware enabling selection of Web services to be composed, taking into consideration user-defined utility functions over QoS attributes, user-given constraints and required structure of the composition. It has been described in:

- [Zen04] Zeng, L., Benatallah, B., Ngu, A.H.H., Dumas, M., Kalagnanam, J., Chang, H.: QoS-Aware Middleware for Web services composition. IEEE Transactions on Software Engineering, Vol. 30, No. 5 (May 2004). IEEE (2004) 311-327

These researchers have made many other relevant publications on related topics. For further information see the Web page of the [Service Oriented Computing Research Group at the University of New South Wales, Australia](#).

The following keynote paper is probably the best summary of some research challenges related to control of the behavior of Web services:

- [Lud03] Ludwig, H.: Web Services QoS: External SLAs And Internal Policies Or: How Do We Deliver What We Promise? Keynote speech at the 1st International Web Services Quality Workshop - WQW 2003 at WISE 2003 (Rome, Italy, December

2003). In Proceedings of the Web Information Systems Engineering (WISE) 2003 Workshops. IEEE (2003) 115-120

Another reference that can provide insights on this topic is the book [Sah05] (mentioned at the beginning of this bibliography).

A discussion of strengths and limitations of various approaches to run-time adaptation of Web service compositions can be found in the above-mentioned reference [Tos04b].

The best reference for WS-Reliability at this time is:

- [Iwa04] Iwasa, K. (ed.): WS-Reliability 1.1. OASIS Standard. Web resource (last accessed: June 25, 2006). OASIS Web Services Reliable Messaging Technical Committee (TC). On-line at: http://docs.oasis-open.org/wsrn/ws-reliability/v1.1/wsrn-ws_reliability-1.1-spec-os.pdf (2004)

For further information about WS-Reliability, see the Web page of the [OASIS Web Services Reliable Messaging \(WSRM\) TC](#).

On the other hand, probably the best reference for WS-ReliableMessaging at this time is:

- [Fer05] Ferris, C., Langworthy, D.: Web Services Reliable Messaging Protocol (WS-ReliableMessaging). Version: February 2005. Web resource (last accessed: June 25, 2006). BEA/IBM/Microsoft/TIBCO. On-line at: <ftp://www6.software.ibm.com/software/developer/library/ws-reliablemessaging200502.pdf> (2005)

For further information about WS-ReliableMessaging, see the Web page of the [OASIS Web Services Reliable Exchange \(WS-RX\) TC](#) and the [WS-ReliableMessaging Web page at IBM developerWorks](#).

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5. Research and industrial tools for management of QoS for Web services

The following paper provides a critical analysis of the most important academic works in this area:

- [Tan05] Tang, Y., Lutfiyya, H., Tosic, V.: An Analysis of Web Service SLA Management Infrastructures Based on the C-MAPE Model. In Proceedings of CoALa 2005 (Workshop on Contract Architectures and Languages) held at EDOC 2005 (Enschede, The Netherlands, September 20, 2005). IEEE-CS (2005)

The following paper discusses a number of projects on QoS specification and management for Web services, including WSLA, WSOL, SLAng, UX, UDDIe, and WS-QoS:

- [Tia04a] Tian, M., Gramm, A., Naumowicz, T., Ritter, H., Jchiller, J.: A Survey of Current Approaches towards Specification and Management of Quality of Service for Web Services. Praxis der Informationsverarbeitung und Kommunikation (PIK), Fachzeitschrift für den Einsatz von Informationssystemen, Sonderthemenheft Web services, Vol. 2004, No. 3. K. G. Sauer Verlag (2004)

Note that the mentioned doctoral dissertation [Tos04b] also contains a discussion and comparison of these and other projects in the area.

UDDIe was described in [Shai03] (we mentioned it in the section on QoS specification languages for Web services). It is important to note that UDDIe is used in the G-QoS framework for QoS management of Grid services. This framework is important because it performs control of the behavior of Grid services using an SLA-based resource reservation mechanism and integrates QoS control across implementation layers. There are many publications on the G-QoS, including the reference [A1A02] (mentioned in the section on QoS specification languages for Web services) and:

- [A1A03a] Al-Ali, R., Hafid, A., Rana, O.F., Walker, D.W.: QoS Adaptation in Service-Oriented Grids. In Proceedings of International Workshop on Middleware for Grid – MGC2003 at Middleware 2003 (Rio de Janeiro, Brasil, June 2003). On-line at: http://www.wesc.ac.uk/learn/publications/pdf/MGC289_final.pdf (2003)
- [A1A03b] Al-Ali, R., Rana, O., Walker, D.: G-QoS: A Framework for Quality of Service. In Proceedings of UK e-science All Hands Meeting 2003 – AHM03 (Nottingham UK, September 2003). UK e-science (2003). On-line at: <http://www.nesc.ac.uk/events/ahm2003/AHMCD/pdf/139.pdf> (2003)

For further information about UDDIe, G-QoS, and related projects, see the Web pages of [Rashid Al-Ali](#) and [Prof. Omer F. Rana](#).

There are two publications on UX (UDDI eXtension):

- [Zho03] Zhou, C., Chia, L.-T., Silverajan, B., Lee, B.-S.: UX- An Architecture Providing QoS-Aware and Federated Support for UDDI. In Proceedings of the International Conference on Web Services (ICWS) 2003 (Las Vegas, USA, June 2003). CSREA Press (2003)

The follow-up of this paper was published as:

- [Zho04a] Zhou, C., Chia, L.-T., Lee, B.-S.: QoS-Aware and Federated Enhancement for UDDI. International Journal of Web Services Research (IJWSR), Vol. 1, No. 2. Idea Group (2004) 58-85

Further information about UX can be found on the Web page of [Zhou Chen](#).

The following paper is currently the best reference on Web Services Quality of Service Compliance (WS-QoS):

- [Shai04] Shaikh Ali, A., Rana, O., Walker, D.W.: WS-QoS: Measuring Quality of Service Compliance. Presented as a short paper at the 2nd International Conference on Service Oriented Computing – ICSOC04 (New York, USA, November 2004).

For further information about WS-QoS see the Web page of [Ali Shaikh Ali](#).

The following paper presents another work on discovery of QoS characteristics of Web services:

- [Day04] Day, J., Deters, R.: Selecting the Best Web Service. In Proceedings of CASCON 2004 (Toronto, Canada, October 2004). Available through the ACM Digital Library.

The main idea is to use historical QoS information (expressed in OWL Lite) and a new entity (QoS forum) in selection of Web services.

Another broker-based architecture for QoS-aware Web service selection was published in:

- [Ser05] Serhani, M.A., Dssouli, R., Hafid, A., Sahraoui, H.: A QoS Broker Based Architecture for Efficient Web Services Selection. In Proceedings of the International Conference on Web Services (ICWS) 2005 (Orlando, USA, July 2005), Vol. 1. IEEE (2005) 113-120

An alternative approach to Web service selection using an ontology-based QoS specification and Web Services Agent Framework (WSAF) was presented in:

- [Max04] Maximilien, E.M., Singh, M.P.: A Framework and Ontology for Dynamic Web Services Selection. IEEE Internet Computing, Vol. 8, No. 5 (September - October 2004). IEEE (2004) 84-93

The list of related publications by the same authors can be found on the Web page of [E. Michael \(Max\) Maximilien](#).

The following work compares QoS achieved by the provider with consumer expectations:

- [Deo03] Deora, V., Shao, J., Gray, W.A., Fiddian, N.J.: A Quality of Service Management Framework Based on User Expectations. In Proceedings of the 1st International Conference on Service Oriented Computing – ICSOC 2003 (Trento, Italy, December 2003). Lecture Notes in Computer Science (LNCS), Vol. 2910. Springer-Verlag (2003) 104-114

For the description of the Solution Manager Service see the reference [McG03] (mentioned in the section on QoS specification languages).

For the description of the WSLA framework see the references mentioned for the WSLA language.

While some description of the Web Service Management Network (WSMN) is given in the reference [Sah02b] (mentioned for HP's language for SLAs), a more complete description is in:

- [Mac02] Machiraju, V., Sahai, A., van Moorsel, A.: Web Services Management Network: An Overlay Network for Federated Service Management. Research Report HPL-2002-234. Hewlett-Packard (HP) Laboratories Palo Alto. August 21, 2002. On-line at: <http://www.hpl.hp.com/techreports/2001/HPL-2002-234.pdf> (2002). A shorter version in Proceedings of the Eight Int. Sym. on Integrated Network Management – IM 2003 (Colorado Springs, USA, March 2003). IEEE (2003) 351-364

For further information, see publications (e.g., technical reports) from [HP Labs](#).

The Web Service Offerings Infrastructure (WSOI) uses WSOL and the above-mentioned doctoral dissertation [Tos04b] is the most comprehensive publication on WSOI. Use of WSOI for monitoring of Web services was also illustrated in [Tos03a]. In addition, the following publications discuss high-level architecture of WSOI:

- [Tos04a] Tomic, V., Ma, W., Pagurek, B., Esfandiari, B.: Web Service Offerings Infrastructure (WSOI) – A Management Infrastructure for XML Web Services. In Proceedings of the 2004 IEEE/IFIP Network Operations and Management Symposium – NOMS 2004 (Seoul, South Korea, April 2004). IEEE (2004) 817-830
- [Tos06b] Tomic, V., Lutfiyya, H., Tang, Y.: Extending Web Service Offerings Infrastructure (WSOI) for Management of Mobile/Embedded XML Web Services. In Proceedings of the Joint 2nd International Workshop on Business Service Networks and 2nd International Workshop on Service-oriented Solutions for Cooperative Organizations (BSN '06 – SoS4CO '06) at CEC/EEE 2006 (San Francisco, USA, June 2006). IEEE (2006) 571-578

For further information about WSOI, see the [WSOL/WSOI Web page](#) (unfortunately, the list of publications is not up to date, for the complete list contact [Dr. Vladimir Tomic](#)).

For the description of the WS-QoS architecture, see the references mentioned for the WS-QoS language.

For the description of the Cremona architecture, see the references mentioned for WS-Agreement.

There were two papers on the Smartware architecture for differentiated scheduling of requests based on context properties:

- [Sid03] Siddhartha, P., Ganesan, R., Sengupta, S.: Smartware - A Management Infrastructure for Web Services. In Proceedings of the 1st Workshop on Web Services: Modeling, Architecture and Infrastructure (WSMAI-2003) at ICEIS 2003 (Angers, France, April 2003). ICEIS Press (2003) 42-49
- [Shar03] Sharma, A., Adarkar, H., Sengupta, S.: Managing QoS through Prioritization in Web Services. In Proc. of the 1st International Web Services Quality Workshop – WQW 2003 at the 4th International Conference on Web Information Systems Engineering – WISE 2003 (Rome, Italy, December 2003) 20-28

[Sid03] introduces the concept of service differentiation for different contexts determined by different user categories, application priorities, and client devices. [Shar03] builds upon the previous paper and presents detailed implementation and experimental results.

The following paper describes an architecture that uses WSLA to specify Computational Quality Attributes (CQA) for BPEL4WS workflows:

- [Fun05] Fung, C.K., Hung, C.K.P., Linger, R.C., Walton, G.H.: Extending Business Process Execution Language for Web Services with Service Level Agreements Expressed in Computational Quality Attributes. In Proceedings of the IEEE 38th Hawaii International Conference on System Sciences – HICSS-38, (Hawaii, USA, January 2005). IEEE (2005) 166b

The following paper presents an intermediary-based Web services middleware that provides message prioritization, reliability, fault tolerance, load balancing, and security:

- [Err05] Erradi, A., Maheshwari, P.: wsBus: QoS-Aware Middleware for Reliable Web Services Interactions. In Proceedings of the 2005 IEEE International

Conference on e-Technology, e-Commerce, and e-Service – EEE-05 (Hong Kong, China, March 2005). IEEE (2005) 634-639

The following paper describes a QoS broker for QoS-enabled discovery of Web service and implements dynamic re-composition of Web services to adapt to changes:

- [YuT05] Yu, T., Lin, K.-J.: A Broker-Based Framework for QoS-Aware Web Service Composition. In Proceedings of the 2005 IEEE International Conference on e-Technology, e-Commerce, and e-Service – EEE-05 (Hong Kong, China, March 2005). IEEE (2005) 22-29

This research group has made several other publications on QoS for Web services. For further information, see the Web page of [Kwei-Jay Lin](#).

The following paper presents a solution for run-time monitoring of WS-BPEL processes:

- [Bar05] Baresi, L., Guinea, S.: Towards Dynamic Monitoring of WS-BPEL Processes. In Proceedings of the 3rd International Conference of Service-oriented Computing – ICSOC'05 (Amsterdam, The Netherlands, December 2005). Lecture Notes in Computer Science (LNCS), No. 3826. Springer-Verlag (2005) 269-282

This research group has made several other publications on QoS for Web services. For further information, see the Web page of [Luciano Baresi](#).

The following paper outlines how to calculate overall QoS of a Web service composition from known QoS of individual Web services:

- [Jae05] Jaeger, M.C., Rojec-Goldmann, G., Muhl, G.: QoS Aggregation in Web Service Compositions. In Proceedings of the 2005 IEEE International Conference on e-Technology, e-Commerce and e-Service – EEE-05 (Hong Kong, China, March 2005). IEEE (2005) 181-185

This research group has made several other publications on QoS for Web services. For further information, see the Web page of [Michael C. Jaeger](#).

The paper that best summarizes the Process Execution Monitoring (PEM) framework is:

- [Buc05] Buco, M.J., Chang, R.N., Luan, L.Z., So, E., Chunqiang T., Ward, C.: PEM: A Framework Enabling Continual Optimization of Workflow Process Executions based upon Business Value Metrics. In Proceedings of the 2005 IEEE International Conference on Services Computing – SCC 2005 (Orlando, USA, July 2005), Vol. 2. IEEE (2005) 33- 40

The following are two representative publications about the Multichannel Adaptive Information Systems (MAIS) project:

- [Marc03] Marchetti, C., Pernici, B., Plebani, P.: A Quality Model for e-Service based Multi-Channel Adaptive Information Systems. In Proceedings of the 1st International Web Services Quality Workshop – WQW 2003 at WISE 2003 (Rome, Italy, December 2003) 47-54
- [Marc04] Marchetti, C., Pernici, B., Plebani, P.: A Quality Model for Multichannel Adaptive Information Systems. In Proceedings of the 13th International World Wide Web Conference – WWW 2004 (New York, USA, May 2004). ACM Press (2004) 48-54

[Marc04] builds upon [Marc03]. For further information, see the [MAIS Web page](#) and the Web pages of participating researchers (the most up-to-date is the Web page of [Pierluigi Plebani](#)).

The following paper is probably the best introduction into the work on the Web Services Management Layer (WSML) that uses aspect-oriented programming to code WS monitoring:

- [Ver04] Verheecke B., Cibran M.A., and Jonckers V.: Aspect-Oriented Programming for Dynamic Web Service Monitoring and Selection. In Proceedings of the European Conference on Web Services 2004 – ECOWS'04 (Erfurt, Germany, September 2004). Lecture Notes in Computer Science (LNCS), Vol. 3250. Springer-Verlag (2004) 15-29

For further information about the Web Services Management Layer and other publications, see the [Web Services Management Layer \(WSML\) Web page](#), as well as the Web pages of [Bart Verheecke](#) and [Maria Agustina Cibran](#).

The following paper discusses how to measure compliance to QoS guarantees:

- [Kal03] Kalepu, S., Krishnaswamy, S., and Loke, S, W.: Verity: A QoS Metric for Selecting Web Services and Providers. In Proceedings of the 1st Web Services Quality Workshop (WQW 2003), held at WISE 2003 (Rome, Italy, December 2003). IEEE (2003)

This research group has made several other publications on QoS for Web services. For further information, see the Web page of [Shonali Krishnaswamy](#).

The following paper discusses another approach to monitoring of SLAs for Web services:

- [Mor05] Morgan, G., Parkin, S., Molina-Jimenez, C., Skene, J.: Monitoring Middleware for Service Level Agreements in Heterogeneous Environments. In Proceedings of the 5th IFIP Conference on e-Commerce, e-Business, and e-Government – I3E 2005 (Poznan, Poland, October 2005). IFIP, Vol. 189. Springer (2005) 79-93

This research group has made several other publications on monitoring of various contracts related to Web services. For further information, see the Web page of [Carlos Molina-Jimenez](#).

While the discussion of QoS specification and management for Grid services (and more generally, for utility computing) is outside the scope of this bibliography, it must be noted that a number of papers build upon the results for QoS specification and management for XML Web services. Apart from the publications related to WS-Agreement, additional examples are the reference [Dan04] (mentioned for the WSLA language), [AIA02], [AIA03a], [AIA03b] (the latter 3 were mentioned related to UDDIe and the G-QoSM framework) and:

- [Sah03] Sahai, A., Graupner, S., Machiraju, V., van Moorsel, A.: Specifying And Monitoring Guarantees in Commercial Grids through SLA. In Proceedings of the 3rd IEEE/ACM International Symposium on Cluster Computing and the Grid – CCGrid 2003 (Tokyo, Japan, May 2003). IEEE (2003) 292-299

The following is the list of some (not all!) specialized companies that sell one or more commercial products for QoS management (if a company has more than one management product, only one representative listed):

- Actional [SOA Management](#)
- AmberPoint [Service Level Manager](#)
- Blue Titan [Network Director](#)
- SOA Software [Service Manager](#)
- Infravio [X-Registry](#)
- WestGlobal [mScape](#)

These are the major systems management suites and some specific products on QoS management for Web services:

- [HP OpenView](#) contains [SOA Manager](#)
- [IBM Tivoli](#) (for example, [Business Systems Manager](#) can be related to Web services)
- [Computer Associates \(CA\) Unicenter](#) contains [Web Services Distributed Management \(WSDM\)](#)
- [BMC Patrol](#) (for example, [MAINVIEW](#) can be related to Web services)
- [Microsoft management products and solutions](#) include [Application Center](#)

(Note that these management suites have multiple or even large number of diverse products for management of computer applications, systems, networks, and business processes. Oftentimes, many of the products from such as suite can be used to contribute to QoS management of Web services. However, we listed only the most closely related products.)

The following is the list of some (not all!) specialized companies that sell Web services infrastructures that perform some QoS management.

- IONA [Artix](#)
- webMethods [Enterprise Services Platform](#)

The following is the list of some (not all!) specialized companies that sell one or more commercial products for application performance management, which can be used for QoS management of Web services:

- Mercury [Service Level Management](#)
- OPNET [Commander](#)
- Quest Software [Foglight](#)

(Note that in the above lists, if a company has more than one management product, only one representative was listed.)

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6. Past results and open issues

The keynote paper [Lud03] (mentioned for approaches to management of QoS) is probably the best summary of some research topics in the area. Also, see the book

[Sah05] (mentioned at the beginning of this bibliography) for a thorough discussion of many past results and open issues in this area.

We hope that our tutorial and this bibliography will stimulate you to conduct research and development in this area, the results of which you will publish at prestigious venues, such as:

- the [IEEE Internet Computing](#),
- the [ACM Transactions on Internet Technology](#),
- the [International Journal of Business Process Integration and Management](#) (published by Inderscience),
- the [IEEE International Conference on Web Services](#) (the link points to ICWS 2006),
- the [IEEE International Conference on Services Computing](#) (the link points to SCC 2006),
- the [International Conference on Service Oriented Computing](#) (the link points to ICSOC 2006),
- the [IEEE International Conference on e-Commerce Technology](#) (the link points to CEC 2006 / EEE 2006),
- the [IEEE International Conference on e-Technology, e-Commerce, and e-Service](#) (the link points to CEC 2006 / EEE 2006), and
- the [IEEE International Enterprise Distributed Computing Conference](#). (the link points to EDOC 2006).