8 Conclusion and future work

This dissertation addresses key issues to integrate QoS into Web services. We proposed the WS-QoS framework that ensures QoS-awareness during a whole Web services communication process, namely, the QoS-aware specification of Web services requirements and offers, the lookup and selection of Web services based on the specified QoS issues, and finally the QoS-aware Web service invocation at runtime.

We designed the WS-QoS XML schema, which is core of the WS-QoS framework. All components such as clients, servers, routers, access points that participate in Web service communication, apply the WS-QoS XML schema in order to support QoS-awareness. The proposed schema is easy to use, standard conform, and fully extensible. We demonstrated these properties in our prototypic implementations and performance measurements.

We augmented the standard Web service interaction model with a Web service Broker (WSB) that is responsible for looking and selecting the most suitable Web service offer based on clients' requirements, which is defined by applying the WS-QoS XML schema. We demonstrated the feasibility and performance of the WSB with our prototypic implementation and in various scenarios of the performance measurements.

We proposed that only an overall QoS support can ensure the fulfillment of clients' requirements due to QoS. It is not sufficient to consider QoS in each layer in terms of the Internet model separately. The different layers should communicate and cooperate with each other. Traditionally, only network metrics such as jitter and bandwidth are considered as QoS. In the realm of Web services, more QoS aspects should be taken into consideration to improve the total performance of Web service communication. Therefore, our WS-QoS XML schema

encompasses not only the traditional network QoS aspect, but also (application and Web) server, security, transaction, SLA, and pricing related aspects and parameters. One can augment the schema with custom aspects and parameters easily.

We introduced an Adaptation Layer between the Web services and the communication network. The Adaptation Layer understands the QoS requirements for the underlying communication network and maps the high level requirements onto the concrete network technology at runtime. The Adaptation Layer is realized by the QoS proxies and ensures that the high-level definition of the network metrics can be specified in a technology independent way.

In the conducted performance measurements, we have demonstrated that both the client and the server can benefit from applying the WS-QoS framework and that the total performance of Web service communication can be improved significantly when the WS-QoS framework is applied.

8.1 Comparison of WS-QoS with existing approaches

In Chapter 3, we introduced five different frameworks dealing with QoS and Web services. The result of the assessment was summarized in Table 1. One can easily identify that only the WS-QoS framework addresses QoS-awareness during the whole Web service communication process, ranging from the definition of QoS requirements and offers to QoS-aware lookup, selection, and invocation. Table 7 extends Table 1 with our WS-QoS framework.

Requirement specification: The flexible and extensible WS-QoS XML schema allows the specification of QoS requirements and aspects. The schema is extensible with custom metrics and aspects.

Class of service: Class of service is supported by the WS-QoS framework. QoS definitions can be grouped to classes such bronze, silver, and gold. They can be than assigned to either a whole Web service or each methods of the Web service. Most of the introduced approaches do not support class of service.

QoS aspects: WS-QoS supports various QoS aspects ranging from traditional networks metrics to more high level metrics such as security, server performance. Each aspect encompasses of different QoS parameters. Both QoS aspects and parameters can be extended in a flexible way. Most of the other approaches just defined two or three simple QoS metrics without any extensibility.

Another important contribution of the WS-QoS framework is the dynamic mapping of high level QoS definitions onto different components such as communication network, and server hosting Web services. None of the other approaches supports QoS mapping.

As demonstrated in the performance measurements, the WS-QoS framework is fully and easily extensible. WS-QoS is conforming to the standardized Web service protocols.

Table 7. Comparison of WS-QoS with other approaches

	Requirements specification	Class of service	QoS aspects	QoS mapping	Flexibility
WSLA	++	O	+	-	++
WSOL	++	++	+	-	+
SLang	+	-	+	-	+
UX	O	-	O	-	O
UDDIe	O	-	O	-	O
WS-QoS	++	+	++	++	+

8.2 Future research

There are several extensions to the WS-QoS framework. One of them is the signature of dynamic offers. Service offers consisting of various QoS parameters and aspects are provided with a signature identifying offers for the valid time period. That results in that all actors such as WSB, clients and service providers need not send and process the various metrics, since the signature of an offer identifies the metrics belonging to an offer is unique.

Another interesting project would be the integration of the WS-QoS framework in a project dealing with a Web service execution plan. We think that our framework can be applied to Web service orchestration, when a chain of different services is to be found and selected among competing services at runtime.

In this thesis, we have demonstrated the advantages of our WS-QoS framework of mobile and wireless devices such as smart phones and personal digital assistants. Future research, along the philosophy of this dissertation, focuses on supporting QoS for small sensor nodes. The ultimate goal is to provide such small, wireless, and even invisible devices with a flexible and adaptive platform for offering services. Adaptive techniques need to be designed to compensate the resource-constrained devices such as limited CPU power, memory, power supply, low data rate etc.