Applying Formal Methods for QoS Provisioning in Mobile Architectures

This project focuses on the application of formal methods to model and manage QoS for Network Mobility. The field of network mobility is gaining ground in telecommunications because of the evolution of broadband technologies and the increasing applications that demand broadband access, e.g. connectivity in public transportation and IMS. Network Mobility is the field that considers sets of mobile devices moving together as one entity with one or more access points which are called mobile routers. These networks are standardized under the IETF-RFC3963 specification also known as NEMO Basic Support, while QoS challenges are described in IETF-RFC4980. NEMO BS is an extension to MIPv6 described under IETF-RFC3775. Mobile routers can possess multiple Radio Access Technologies (RATs) and have to perform real-time operations, e.g. handover, managing binding updates, merging/splitting mobile networks and managing QoS. The intelligent management of mobility, data streams of different QoS requirements and the available RATs makes the formalization of this problem a necessity due to its complexity. The importance of this study comes from the industry focus on network operator’s IP services, especially IMS. NEMO BS provides a solution for this system and at the same time requires investment in research to improve QoS.

Work Plan

This work consists of two main parts; building the formal model and simulating the NEMO protocol. These parts are to be run in parallel to achieve interdependability between each other. This means that simulation measurements will be used to support theoretic hypothesis made by the formalized description of the QoS problem. On the other hand, formal tools have to be implemented in order to be able to incorporate extensions which in turn will allow making predictions of the behavior of the modeled system in a similar way to simulations. This means that these tools will be designed to be able to generate quantitative as well as qualitative conclusions.

The Formal Model

π Calculus

Π-Calculus is a modeling formality that focuses on communicating processes. It offers firm representation of connectivity and messaging using math-like expressions. Π-Calculus had initially a monadic syntax where single arguments are passed through channels. Later on, polyadic π-Calculus was introduced to allow pushing sets of arguments at once over the communication channels. Process replication was also introduced. In the higher order π-Calculus, process names can be exchanged through the channels too. Some research uses available syntax to express problems like QoS while others ground their own flavor of it by introducing modifications to the syntax like spi-Calculus which is specifically suitable for cryptology. One more example is Ambient-Calculus which concerns itself with defining computation domains or ambiences where communication between local processes happens within its boundary, ambiences can move and communication crossing the border is analogous to crossing firewalls. The extensibility, expressiveness, flexibility and firm formality of π-Calculus make it the most suitable tool for modeling communication protocols and prototypes of enhancements. This work aims to make further contributions to π-Calculus in order to achieve the following:

- Π-Calculus is founded on the principle of state automata. Consequently, processes in π-Calculus interact and switch their states upon reception of messages over communication channels, which means that message reception among processes triggers the interaction and causes the system to evolve. However, modeling real-world systems needs more than that. The notion of time is currently unavailable in the syntax of π-Calculus, which makes it unsuitable for performing simulations in which particular events take place at certain points of time, e.g. time-out events. In this work we aim to introduce a new component in the syntax of π-Calculus to enable it to model timed events.
- Π-Calculus is suitable for deducing qualitative conclusions about processes' interaction and states. However, more meaningful verification results can be made when quantitative conclusions are made from the π-Calculus model such as bandwidth utilization and power consumption. This can be done if the notion of time was present in the model. Available tools for π-Calculus have limitations to be covered, e.g. polyadic π-Calculus has to be supported in order to be able to model process replication. Otherwise, polyadic systems have to be downgraded to monadic syntax which is unrealistic for complex systems.
- There have been models suggested about using π-Calculus to model QoS supervision in telecommunication networks. As our work touches the foundations of π-Calculus, we would like to see how these changes will affect the suggested models and how we can improve them.
- A π-Calculus model for NEMO BS has to be built as described in RFC3963. Software development of the protocol under the simulation tool and QoS enhancements should be based on this model. This is important to ensure strong analogy interrelationships between simulation measurements and the qualitative deductions made from the formal model.
- Depending on the interdependency between simulation and formal model verification results further studies can evolve to explain observed phenomena and try to set rules to make this relation deterministic.

The ability to make realistic assessments of modeled systems before the implementation phase using formal model checking techniques has several advantages:

- It will be possible on basis of the qualitative attributes of the suggested model to judge whether it answers the requirements it is meant to satisfy.
- It allows quantitatively comparing formal models and making early choices about modifications and improvements.
- It shortens the software development cycle by limiting the need to go back to the model and make modifications for issues discovered after implementation.

Our simulator tool SimPiCal can be found here.

Simulating the Protocol

For this purpose OPNET Modeler® is being used under university licensing. This simulator contains a huge library of standardized protocols and devices as well as commercial ones, e.g. MIPv6 and mobile routers. The hierarchical structure of components and their modular design shortens the time required to develop own devices and extend particular protocols. <more info>

References

1. 3GPP-23.401 General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access.
2. 3GPP-23.402 Architecture enhancements for non-3GPP accesses.
3. 3GPP-22.259 Service requirements for Personal Network Management (PNM).
4. M. Abadi and A.D. Gordon. A calculus for cryptographic protocols: The spi calculus. In Fourth ACM Conference on Computer and Communications Security, pages 36-47. ACM, 1997.
5. L. Cardelli and A. D. Gordon. Mobile ambients. In Foundations of Software Science and Computation Structures, Lisbon, 1998.
6. IETF-RFC3963 Network Mobility (NEMO) Basic Support Protocol.
7. IETF-RFC4980 Analysis of Multihoming in Network Mobility Support.
8. IETF-RFC3775 Mobility Support in IPv6.
9. R. Milner. Communicating and Mobile Systems: The pi-Calculus. Cambridge University Press, 1999.

10. R. Milner. The Polyadic π-calculus: a tutorial. ECS-LFCS-89-85 91-180, University of Edinburgh, 1991.
11. Claus Pahl, A PiCalculus based Framework for the Composition and Replacement of Components. In Workshop on Specification and Verification of Component-Based Systems (OOPSLA 2001), 2001.

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