Preface

A simulation is something nobody believes, except the person who made it.
An experiment is something everybody believes, except the person who made it.
Freely modified after Albert Einstein

The Vienna LTE Simulators started as a project in 2009. Our first concept included two simulators, a link and a system level simulator for Downlink (DL). With one postdoc, five Ph.D., and some five Master level students we started this endeavor and soon realized that it would take longer than expected. After one year, we had basic functionality working and were continuously puzzled by inconsistent results. The more we tested, the more we found inconsistencies. Once we were satisfied with overcoming most of those hurdles, we decided to make the first release freely available on the Internet. Although we included from the very beginning an acknowledgment that the simulator is only to use for academic research, not all of the downloading parties took their promise seriously. At this point we did not care much about it but were mostly happy about the feedback we obtained. We started a web forum on which everybody could freely post troubles that were encountered and to our utmost surprise even people outside of our group showed up as experts and helped us in solving our 'mysteries'. After some two years we counted ten thousands of downloads, by far much more than serious users and it was time to become more professional about it. Both simulators had evolved into a product and after spending several hundred thousand Euros to pay all the students' salaries, we needed to see something in return. Also, the continuation of the project was in serious financial jeopardy at some time periods. Our download handling thus changed into a business part that allowed only downloads for obvious academic usage, confirmed by deans or department heads of existing universities, while all others had to pay a fee. The fees have been kept moderately low in comparison to commercial products on the market. We basically traded responsibility against price. Some companies decided not to use our 'cheap' tools as we were not willing to guarantee compensatory payment in case of faults, some companies required 24 h switching boards to have someone answering their

questions; all of such desires we could not possibly satisfy. Nevertheless, word had passed around that our simulators were quite useful and that we behaved as trustworthy partners, taking requests seriously and repairing reported bugs in the next revisions. Finally, many 3rd Generation Partnership Project (3GPP) companies had decided to use the tools as platform for exchanging ideas. Our simulators serve as reference to compare against their own ideas.

While there were sporadic requests for Uplink (UL) simulators as well, for a long time we could not respond positively as we were not having sufficient personnel as well as money to pay extra students. Finally, in 2012 we decided to devote also effort into a link level UL simulator. All three simulators together now have experienced more than 50,000 downloads and have become reliable tools for companies as well as academia worldwide. As we still continue working out our own research tasks, the simulators are permanently improved and enhanced by more and more capabilities. This book is intended to provide an overview of our own research activities related to these three simulators. We are aware of hundreds of serious efforts of other research groups that are covering fields we could not and will not. Listing all of those would certainly blast this book. From the very beginning, quality issues were important for us and even if it hampered down the publication rate, we devoted ourselves to some requirements. These are as follows:

Reproducibility has become an increasingly important issue in the past years. As systems become more and more complex and thus complicated, it becomes more and more difficult to repeat results of others and even reproducing our own results is often difficult after some time has passed. To facilitate reproducibility we have therefore launched open access 'Vienna LTE Simulators' to provide a common platform for researchers and engineers. Furthermore, most of our research papers are associated with code that can be downloaded and easily repeated on other researchers' personal computers.

Our Web Forum represents a focal point for information exchange and provides us with permanent requests by third-party users. Through this measure many bugs are found and, as we take these seriously, we permanently repair them and provide new improved releases. By this means we have been tested by several hundreds of experts. Not many software providers can say that about their products.

Quality insurance is important to us. How do you know your Monte Carlo (MC) runs are sufficient? We always include confidence intervals with every averaging point to measure how reliable our simulation is. This often leads to significant speed improvements as there is no need to average more data once the confidence intervals have become very small. Standard bootstrapping techniques are being applied to compute such intervals.

Speed of simulation is a relevant factor. As multi-core machines are becoming cheaper and cheaper, it makes sense to parallelize the software and speedup simulation significantly. Some time-consuming decoders have also been ported to the graphical boards featuring hundreds of cores, which are now available in every personal computer as standard equipment; this allows to boost performance even more.

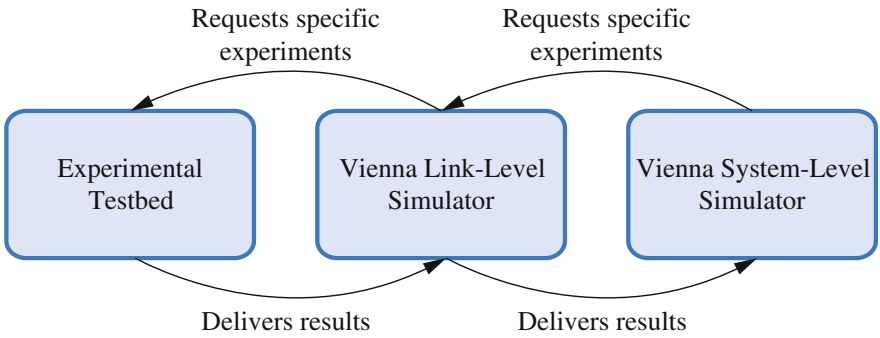

Fig. 1 Applied evaluation chain, cross-validating amongst experimental results from testbed measurements and simulation outcomes from the Vienna Link Level and System Level Simulators

Evaluation is particularly important when modeling is very abstract. We thus conduct experimental research for which the link level simulators in up- and downlink provide key functionality. In the same way the link level simulator provides the reference for the system level simulator, Fig. 1 describes the scenarios. While many more ensemble values can be generated by the link level simulator, only a few are selected to be evaluated by the testbed. Similarly, the system level simulator selects small setups with a few base stations and/or a few users that can still be computed at link level precision in reasonable time.

How to Read This Book

Part I of this book is about long-term evolution (LTE) and long-term evolution-advanced (LTEA) link level techniques. As the downlink direction has experienced high demand and interest from our partners and collaborators, a lot of research work has been conducted by the DL simulator and most chapters thus focus on the downlink. This first part of the book reports some highlights including single-user (SU) and multi-user (MU) as well as single-input single-output (SISO) and multiple-input multiple-output (MIMO) transmissions, and also reports on optimal pilot pattern for high-speed communications as well as synchronization issues. One chapter is devoted to experiments showing how the link level simulator can provide input to the measurement testbed. Also basic results on orthogonal frequency division multiplexing (OFDM) transmissions, not only valid for LTE, are reported and validated by measurements. Furthermore, one chapter deals with our newest tool, the UL link level simulator, and explains some interesting novel results obtained by it.

The second part of this book is on system level simulations. From early on system level simulations have been in high demand in industry and academia, since people wanted to find answers for situations when many base stations and hundreds

of users were involved. How the mathematical abstraction of such large cellular networks can be accomplished to speedup simulations by a factor of several hundred without sacrificing precision is explained in this part of the book. We explain some new theories of how to abstract large cities equipped with small cells, that is, heterogeneous networks, and demonstrate the capabilities of our system level simulator on applications such as train and car transmissions.

Both parts are in general a rather independent read; if the reader is interested in comparing link and system level results, he is recommended to study both.

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