multitude of eNodeBs that cover a specific area in which many mobile terminals are located and/or moving around. While simulations of individual physical layer links allow for the investigation of MIMO gains, AMC feedback, modeling of the channel code, and retransmissions [16, 47, 48, 54, 60], it is not possible to reflect the effects of cell planning, scheduling, or interference in a large scale with dozens of eNodeBs and hundreds of users. Simply performing physical layer simulations of the radio links between all terminals and base-stations is unfeasible for system level investigations due to the vast amount of computational power required. Thus, the physical layer has to be abstracted by simplified models capturing its essential dynamics with high accuracy at low complexity.

Following the standard approach in literature [55, 61], our simulator consists of two parts: (i) a link measurement model and (ii) a link performance model. The link measurement model reflects the link quality, given by the UE measurement reports, and is required to carry out link adaptation and resource allocation. The chosen link quality measure is evaluated per subcarrier. Based on the Signal to Interference and Noise Ratio (SINR), the UE computes the feedback (PMI, RI, and CQI), which is employed for link adaptation at the eNodeB as described in Section II-A. The scheduling algorithm assigns resources to users to optimize the performance of the system (e.g., in terms of throughput) based on this feedback [24]. Following the link measurement model, the link performance model predicts the BLER of the link, based on the receiver SINR and the transmission parameters (e.g., modulation and coding). Figure 5 illustrates the interaction between the two models and the several physical layer parameters.

Implementation-wise, the simulator follows the structure shown in Figure 6. Each network element is represented by a suitable class object, whose interactions are described below.

In order to generate the network topology, transmission sites are generated, to which three eNodeBs are appended, i.e., sectors, each containing a scheduler (see Figure 6). In the simulator, traffic modeling assumes full buffers in the downlink. A scheduler assigns PHY resources, precoding matrices, and a suitable MCS to each UE attached to an eNodeB. The actual assignment depends on the scheduling algorithm and the received UE feedback.

At the UE side, the received subcarrier post-equalization symbol SINR is calculated in the link measurement model. The SINR is determined by the signal, interference, and noise power levels, which are dependent on the cell layout (defined by the eNodeB positions, large-scale (macroscopic, macro-scale) pathloss, shadow fading [62]) and the time-variant small-scale (microscopic, micro-scale) fading [63].

The CQI feedback report is calculated based on the subcarrier SINRs and the target transport BLER. The CQI reports are generated by an SNR-to-CQI mapping [38] and made available to the eNodeB implementation via a feedback channel with adjustable delay. At the transmitter, the appropriate MCS is selected by the CQI to achieve the target BLER during the transmission. Especially in high mobility scenarios, the feedback delay caused by computation and signaling timing can lead to a performance degradation if the channel state changes significantly during the delay. In the link performance model, an AWGN-equivalent SINR ($\gamma_{\text{AWGN}}$) is obtained via Mutual Information Effective Signal to Interference and Noise Ratio Mapping (MIESM) [64–66]. In a second step, $\gamma_{\text{AWGN}}$ is mapped to BLER via AWGN link performance curves [37, 38]. The BLER value acts as a probability for computing ACK/NACKs, which are combined with the Transport Block (TB) size to compute the link throughput. The simulation output consists of traces, containing link throughput and error ratios for each user, as well as a cell aggregates, from which statistical distributions of throughputs and errors can be extracted.

B. Complexity

One desirable functionality of a system level simulator is the ability to precalculate as many of the simulation parameters as possible. This not only reduces the computational load while carrying out a simulation, but also offers repeatability by loading an already partly precalculated scenario.

The precalculations involved in the LTE system level simulator are the generation of (i) eNodeB-dependent large-scale pathloss maps, (ii) site-dependent shadow fading maps,