Postprint: Air Interface Technology Simulation Platform for Fourth-Generation Mobile Communication Systems

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Abstract

This paper first analyzes the simulation methods commonly used in wireless communication technology research and the current mainstream simulation software, then briefly introduces the fourth-generation mobile communication standards, and subsequently elaborates on the air interface simulation platform for fourth-generation mobile communication systems developed by the Wireless Communication Technology Research Center of the Institute of Computing Technology, Chinese Academy of Sciences, particularly the system' s overall architecture, design features, and key technologies, including multi-scenario support, link abstraction methods, and enhanced multi-antenna technologies.

Full Text

Preamble

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Abstract

This paper first analyzes the commonly used simulation methods and mainstream simulation software in wireless communication technology research, then provides a brief introduction to fourth-generation mobile communication standards, and finally focuses on the air interface simulation platform for 4G systems developed by the Wireless Communication Technology Research Center of the

Institute of Computing Technology, Chinese Academy of Sciences. The discussion particularly emphasizes the system' s overall architecture, design characteristics, and key technologies, including multi-scenario support, link abstraction methodology, and enhanced multi-antenna technology.

Keywords: simulation platform; fourth-generation mobile communication; air interface; link abstraction

1 Introduction

The air interface technology constitutes the core component of wireless communication systems. The air interface refers to the wireless transmission link between communication entities, encompassing the physical and link layers of the OSI model. Only when a wireless link is established through air interface technology can upper-layer protocols and services operate correctly, making air interface technology the foundation of the entire wireless communication system.

Currently, air interface technology research primarily focuses on two aspects: baseband signal processing at the physical layer and wireless resource management at the link layer. Both areas require verification and analysis of new algorithms and technical solutions. Research methods for air interface technology mainly include three approaches: analytical methods, experimental methods, and simulation methods. Analytical methods verify systems theoretically, but when systems become complex, detailed description becomes impossible and effectiveness cannot be guaranteed. Experimental methods require building testbeds that approximate real environments, which are limited by cost constraints, resulting in limited experimental scale and poor flexibility. Simulation methods can compensate for the deficiencies of the first two approaches by enabling large-scale experiments on technologies with relatively less time and cost through simulation platforms and reasonable models. Therefore, comprehensive and in-depth research on air interface technology and key technological innovation inevitably require simulation verification of theoretical results and algorithms.

Mobile communication systems have begun evolving from third-generation (3G) to fourth-generation (4G). International standardization organizations such as 3GPP are formulating 4G standards, and scholars worldwide are conducting research on new technologies for 4G systems. An air interface technology simulation platform for 4G systems can provide verification means for technical solutions and theoretical results through accurate simulation of wireless channels, links, and systems, serving as a fundamental platform for 4G system research. Although most enterprises and research institutions perform simulation verification of individual algorithms, few truly possess system-level simulation platforms. This paper elaborates in detail on the system architecture and simulation mechanisms of the 4G-oriented air interface technology simulation platform developed by the Institute of Computing Technology, Chinese Academy of

Sciences.

2 Simulation Methods and Software Tools

2.1 Simulation Methods

In air interface technology research, wireless communication system simulations are typically divided into two categories based on research focus: link-level simulation and system-level simulation.

Link-level simulation aims to examine the performance of different wireless transmission technology schemes without drawing any conclusive evaluations of typical system behavior [1]. The focus is on performance differences resulting from different air interface technologies employed on a single wireless connection. The output of link-level simulation is the relationship between error probability (such as BER3, BLER4, or FER5) and SINR6.

System-level simulation aims to determine system capacity and spectral efficiency under certain quality-of-service conditions based on fundamental performance data obtained from link-level simulations, reflecting capacity/efficiency metrics of communication systems composed of the studied wireless transmission technologies. Therefore, system-level simulation typically requires establishing a simulation network containing multiple base stations and multiple terminals to examine various performance statistical indicators exhibited by the entire system.

System-level simulation has the following characteristics: it represents a combination of random processes that simulate user random behavior; it involves substantial computational load and high time costs, making implementation complexity an important metric; and due to complexity limitations, parameters and processes must be prioritized and 取舍, with system-level simulation typically making certain conditional settings (such as link-level simulation results, specified values in protocols, or empirically set values) and reasonable assumptions, meaning simulation results are obtained under these prerequisite conditions.

System-level simulation methods can be further divided into two categories: static simulation and dynamic simulation, each with distinct characteristics that determine their applicable scenarios.

2.1.1 Static Simulation Method Static system simulation treats the entire system' s operational behavior as the statistical average of behavioral samples exhibited within multiple time fragments, with each fragment called a snapshot. In each snapshot, user locations are statically and randomly determined, independent of positions and velocities in previous snapshots. Each user' s ability to connect to the network is calculated through an iterative process until convergence conditions are met. Monte Carlo methods are then used to analyze snapshots, ultimately obtaining approximate actual performance of the simulated system. This approach reflects relatively stable system behavior in the short term and offers high simulation efficiency. However, due to employing more assumptions than dynamic simulation algorithms to reduce computational load, its simulation accuracy is relatively low.

2.1.2 Dynamic Simulation Method Dynamic system simulation simulates user mobility and other characteristics in the network through continuous time steps, integrating all possible factors to constitute a time-driven simulator. As simulation time progresses, user locations are continuously updated dynamically, and users may initiate calls or disconnect at any time. Related parameters such as transmission and reception power, interference levels, and path loss also require dynamic calculation. Consequently, dynamic system simulation demands substantial computational and time costs.

2.2 Mainstream Simulation Software

2.2.1 OPNET Modeler OPNET Modeler is a network simulation software product from OPNET Technology, primarily targeting network design professionals to assist in designing, constructing, analyzing, and managing network structures, devices, and applications. It can satisfy simulation needs for large and complex networks.

OPNET Modeler offers relatively complete functionality, enabling detailed configuration of packet arrival time distributions, packet length distributions, network node types, and link types. Users can design their own simulation environments through network equipment and application scenarios provided by different manufacturers and can conveniently select existing network topology structures from the library.

However, OPNET is expensive and has a high entry barrier. Simulation efficiency decreases when network simulation scale and traffic are large, and its model library is relatively limited.

2.2.2 NS2 NS2 is an object-oriented network simulator developed by the University of California, Berkeley, essentially a discrete-event simulator. It has its own virtual clock, with all simulations driven by discrete events. NS2 uses C++ and Otcl as development languages. For efficiency reasons, NS2 separates the implementation of data channels and control channels. To reduce packet and event processing time, the event scheduler and basic network component objects on data channels are written in C++ and compiled, with these objects made visible to the Otcl interpreter through mapping.

NS2 was designed for network simulation and integrates multiple network protocols, traffic types, routing queue management mechanisms, routing algorithms, multicast services, and some MAC8 layer protocols applied to LAN simulation.

NS2' s disadvantages include requiring installation and use under Linux systems, being most suitable for simulation above the TCP9 layer, and having poor interface usability.

2.2.3 MATLAB MATLAB is a scientific computing system environment for numerical computation and graphics processing launched by Mathworks. It integrates program design, numerical computation, graphics drawing, input/output, file management, and other functions. MATLAB provides a human-computer interactive mathematical system environment where the basic data structure is the matrix, with no explicit dimension declaration required when creating matrix objects.

MATLAB has a rich and powerful mathematical function library that can save substantial programming time. It also has strong functional expansion capabilities and can be equipped with various toolboxes alongside its main system to complete specific tasks. MATLAB' s disadvantage is relatively slow execution speed, inability to implement port operations and real-time control, but combined with C++ Builder, it can achieve complementary advantages.

2.2.4 CASSAP CASSAP, developed by Synopsys, is primarily applied in digital signal processing and network communication fields. It can achieve simulation at three levels: concept, architecture, and algorithm. Its design philosophy follows a top-down design approach: first performing system performance analysis and algorithm analysis, then hardware/software partitioning and design, and finally merging software and hardware for simulation, debugging, verification, and ultimately completing system design.

2.2.5 SPW SPW simulation software is a product of Cadence Design Systems. It provides a modular design, simulation, and implementation environment for electronic systems, serving as an ideal environment for algorithm development, filter design, C code generation, hardware/software co-design, and hardware synthesis.

A notable feature of SPW is its provision of HDS11 and Matlab interfaces. Many models from Matlab can be directly imported into SPW, which then uses HDS to generate C language simulation code or HDL12 language simulation code. SPW is typically applied in wireless and wired carrier communications, multimedia, and network design and analysis.

In summary, CASSAP and SPW software are typically used for link-level simulation and environments requiring hardware-software interaction. Among mainstream system-level simulation tools, OPNET is mainly used for enterprise or professional-level simulation; NS2 can simulate various IP network protocols and routing algorithms; Matlab has rich library functions, is easy to use, and receives support from multiple companies' software, hardware, and instruments, making it widely applied. Researchers can select appropriate simulation tools based on different simulation requirements.

3 4G Standards and Technical Features

In the first half of 2008, ITU13 completed specific system technical requirements [2] based on 4G vision planning and officially issued a "circular letter" soliciting 4G candidate technology proposals worldwide, thus initiating the international standardization process for 4G technology. The 4G system requirements specify achieving peak rates above 1Gbps under conditions of 4×4 MIMO14 and transmission bandwidth greater than 70MHz. In terms of peak spectral efficiency, the downlink requires 15bps/Hz and the uplink 7.5bps/Hz. A more accurate description of 4G peak rates is 100Mbps in high-speed mobile scenarios and 1Gbps in low-speed mobile scenarios.

Currently, 3GPP' s LTE-Advanced (LTE-A) and IEEE 802.16m are the two main 4G candidate standards submitted to ITU. The 3GPP LTE-A standard evolved from WCDMA and TD-SCDMA. China will fully support the LTE-A standard, which is the 4G standard targeted by the simulation platform in this paper. The technical features of this standard are briefly introduced below.

To meet the performance metrics proposed by ITU for 4G systems, LTE-A primarily introduces four categories of enhancement technologies: Carrier Aggregation, Enhanced MIMO, CoMP15, and Relay [3].

Carrier Aggregation: ITU requires the maximum bandwidth of 4G systems to be no less than 40MHz. Based on conclusions from the WRC07 conference, potential deployment frequency bands for LTE-A include: 450MHz-470MHz, 698MHz-862MHz, 790MHz-862MHz, 2.3GHz-2.4GHz, 3.4GHz-4.2GHz, and 4.4GHz-4.99GHz. Except for 2.3GHz-2.4GHz located in traditional cellular system bands, new frequency bands show a trend of differentiation toward high and low frequencies. Considering that existing spectrum allocation methods and planning can hardly find contiguous bands sufficient to carry 4G system bandwidth, 3GPP determined to adopt carrier aggregation technology to aggregate two or more basic carriers, thereby addressing 4G system requirements for spectrum resources. The basic frequency block of carrier aggregation is called a component carrier, which supports both contiguous and non-contiguous spectrum aggregation.

Enhanced MIMO Technology: To satisfy 4G requirements for peak and average spectral efficiency, multi-antenna enhancement is one of the key technologies adopted by LTE-A. LTE-A' s predecessor, LTE, supports 1, 2, or 4 antenna transmissions in the downlink and 2 or 4 antenna receptions at the terminal side, supporting maximum 4-layer transmission in the downlink. The uplink only supports single-antenna transmission at the terminal side, with base stations receiving with up to 4 antennas. LTE' s multi-antenna transmission modes include open-loop MIMO, closed-loop MIMO, beamforming, and transmit diversity, all implemented through precoding. Building upon LTE, LTE-A expands the maximum number of transmit/receive antennas in both uplink and downlink, allowing up to 4-antenna 4-layer transmission in the uplink and up to 8-antenna 8-layer transmission in the downlink. Therefore, LTE-A needs to consider multi-antenna transmission schemes under more antenna configurations.

Coordinated Multipoint Transmission and Reception (CoMP): CoMP serves as an important means in LTE-A to improve cell throughput, especially for cell-edge users. A CoMP cooperation cluster includes multiple base stations at different geographical locations that share channel and scheduling information with each other. Through cooperation among base stations within the cluster, a multi-cell virtual MIMO network is established, using existing MIMO detection algorithms for interference cancellation. CoMP technology is divided into two categories: CoMP-CS16 and CoMP-JP17. In the coordinated scheduling mode, base stations share channel and scheduling information for joint scheduling. In the joint processing mode, base stations use shared information to treat inter-cell interference as useful signals for joint processing. Both methods can improve service quality and throughput for cell-edge users, making the network user experience rate more uniform.

Relay: LTE-A introduces Relay to increase coverage and improve cell-edge throughput. Relay is mainly divided into three categories: L1 relay, L2 relay, and L3 relay. L1 relay is an enhanced repeater implementing amplify-and-forward functionality at the physical layer. L2 relay implements decode-and-forward functionality, forwarding PDCP PDU, RLC PDU, MAC PDU, and transport blocks. It lies between L1 and L3, being simpler and cheaper than wireless backhaul base stations but more complex than repeaters. In terms of protocol functions, L2 relay nodes have certain resource allocation functions but lack complete Layer 3 resource management functions. L3 relay is a wireless backhaul base station containing complete Layer 3 protocols, forwarding IP packets. Currently, 3GPP has defined Type1 Relay (L3 Relay) and Type2 Relay (L2 Relay).

3.2 Architecture Design

The simulation platform in this paper is developed based on Matlab software, using scenarios as the thread to implement simulations in single-link, single-base-station, and multi-base-station environments. In implementation, it references existing LTE standards in terms of traffic flow characteristics and link characteristics, while incorporating LTE-A technologies such as CoMP and enhanced MIMO. For system simulation, the link abstraction method is adopted, achieving a good compromise between accuracy and efficiency.

shows the schematic diagram of the simulation platform architecture, which mainly includes user interface, flow control, result statistics, application layer, transport layer, link layer, link abstraction, physical layer, and physical channel components. The user interface provides user operation interfaces, obtains user input, and displays simulation result information in user-defined ways (as shown in

and

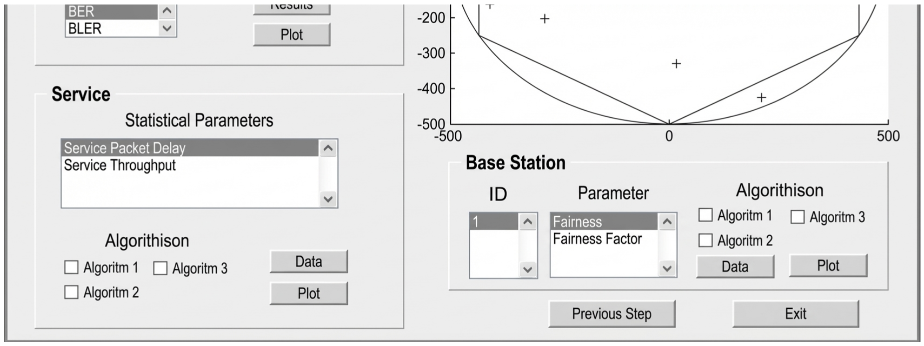

Figure 1: Figure 1

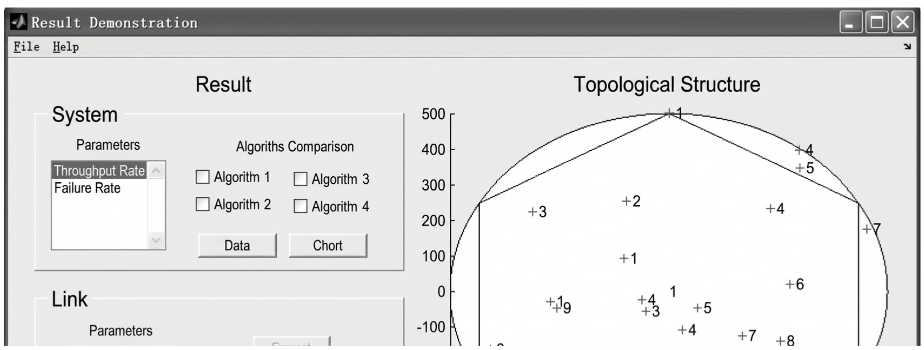

Figure 2: Figure 2

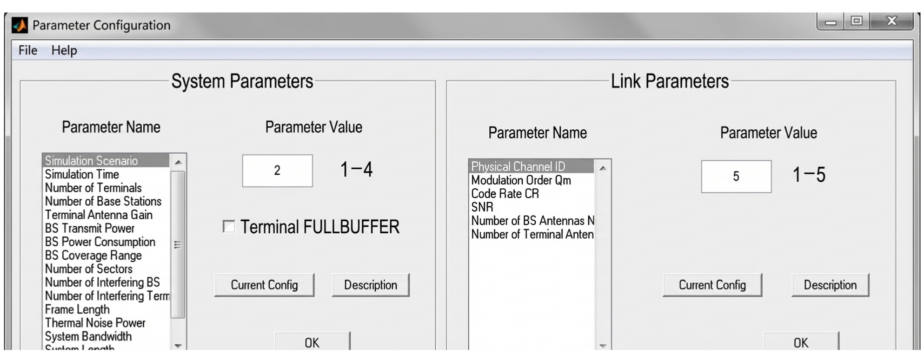

Figure 3: Figure 3

). The flow control module controls the simulation mode (link-level or system-level simulation) and selects operating components and processes according to different modes. The application layer generates application-layer data streams including HTTP, FTP, VOIP and other protocols, managing traffic flow communication transactions. The link layer supports LTE-standard-defined network entry management, data scheduling, handover control, HARQ18 functions, and provides replaceable interfaces for wireless resource management algorithms. The link abstraction module provides effective SINR functional mapping and SINR-to-BLER lookup, supporting modulation schemes of QPSK19/16QAM20/64QAM/256QAM with code rates of 1/3, 1/2, 2/3, 3/4, and 4/5. The physical layer, based on MIMO and OFDM21 technology, implements sub-modules for channel coding, interleaving, rate matching, constellation mapping, layer mapping, precoding, serial-to-parallel conversion, pilot insertion, channel estimation, and their corresponding inverse processes. The physical channel module, based on 3GPP-recommended SCM22 channels, also provides support interfaces for Rayleigh, Rician, Typical Urban (TU23), and other channels.

The simulation platform in this paper has the following main characteristics:

1) **Low-coupling component-based design:** The air interface functional components in this simulation platform are combinable with clear interfaces, facilitating core algorithm replacement. For example, the simulation platform defines link-layer core functions according to requirements, unlike standard functional module divisions in typical standards. Simultaneously, considering support for comparing different algorithms during system simulation, each core function allows flexible and replaceable algorithms and defines relatively universal, well-extensible interfaces.

2) **Support for multiple simulation modes:** Through the flow control module, the platform flexibly supports multiple simulation modes. In link-level simulation, for single algorithm simulation without considering system impact, only the algorithm' s belonging module and necessary supporting components are selected to run during node generation. For single algorithm simulation considering system impact, the complete functional framework is selected and the algorithm' s belonging module is modified. In system-level simulation, the actual physical layer is not run; instead, physical layer performance is simulated through the link abstraction module.

3) **Rich algorithm statistical analysis functions:** The platform' s result statistics module abstracts commonly used performance parameters in wireless mobile communication technology research, including throughput, bit error rate, frame error rate, packet delay, packet loss rate, fairness factor, user drop rate, etc., and provides statistical analysis functions for these parameters. This avoids repetitive work in testing different algorithms and improves simulation efficiency.

4.1 Multi-Scenario Support

Multi-base-station multi-user simulation scenarios are crucial in air interface technology system-level simulation, enabling us to simulate inter-user interference and coordination, inter-base-station interference and coordination, and large-scale channel fading effects in real-world scenarios by constructing environments with multiple base stations and users, thereby supporting simulations of system-level wireless resource scheduling, inter-base-station handover, and base station coordination.

Traditional multi-base-station multi-user simulation scenario construction often targets specific simulation needs. For example, the 802.11 protocol module provided in NS2 targets fixed wireless LANs, while the UMTS module provided by OPNET targets mobile communication networks. Neither can satisfy the configuration and support of simulation environments for multiple protocol characteristics, reflecting specific scenarios of certain protocols and losing the generality and extensibility of simulation scenario construction.

Multi-base-station multi-user simulation scenarios simulate the emergence of various specific scenarios through changes in the number of base stations and users, changes in service relationships between them over time, and changes in transmission conditions. Typically, specific simulations are conducted under particular base station and user constraints and cannot be reused for other simulation scenarios, resulting in low overall simulation efficiency and poor generality. However, in air interface technology simulation, most scenarios share some essential data entities, such as base stations, users, and physical channels, and also share some relatively universal simulation workflows, such as initialization of data entity relationships and updating entity relationships over time. This provides the possibility for implementing a simulation method with good generality and extensibility.

Therefore, this simulation platform extracts objects and typical functions in the construction process of multi-base-station multi-user scenarios to achieve good generality and extensibility. The extracted objects and functional entities include base station maintenance module, user maintenance module, scenario initialization module, scenario update module, link sampling module, and physical channel module, specifically described as follows:

- **Base station maintenance module:** Maintains base station entities in the simulation environment. A base station entity refers to the record entity of base station information in the simulation scenario, including physical and functional information. Physical information includes sector information, coverage information, and base station location information. Functional information includes base station frequency resource information, load information, and base station antenna configuration information.
- **User maintenance module:** Maintains user entities in the simulation

environment. A user entity refers to the record entity of user information in the simulation scenario, including serving base station information, user location information, user mobility trajectory information, user load information, and user antenna configuration information.

- **Scenario initialization module:** Performs initialization operations on the simulation scenario, including configuring the entire simulation scenario settings into base station entities and user entities, while randomly initializing unconfigured content in the simulation scenario (such as user mobility trajectories including speed and direction, user locations, etc.).
- **Scenario update module:** Updates information in base station entities and user entities, including updating user locations according to user mobility trajectories, subsequently updating user serving base stations and monitoring base stations, as well as base station load and serving user indexes.
- **Link sampling module:** Samples link information for links monitored by users in the current moment, obtaining link distance, angle, and other information from user entities and base station entities and inputting them to the physical channel module to obtain instantaneous channel responses of links.
- **Physical channel module:** Provides multiple types of physical channel responses according to configuration information, including additive white Gaussian noise channels, Rayleigh, Rician, typical urban channels, spatial channel models, and custom physical channels.

This platform separates data and dynamic functions that change over time, providing a relatively universal multi-scenario support process: first, set up base station entities and user entities according to simulation scenario definitions; then use the initialization module to initialize service relationships for the entire scenario; subsequently, alternately apply scenario update and sampling modules to drive the operation of the entire simulation scenario.

The above multi-base-station multi-user simulation construction method provides a scenario construction architecture with strong generality and extensibility, defining the functions and workflows of each module and the cooperative workflows between modules. Through this method, required multi-base-station multi-user simulation scenarios can be quickly and flexibly constructed for research, providing multi-scenario support and improving work efficiency.

4.2 Link Abstraction Method

System simulation mostly focuses on the multi-link or multi-base-station level. Such simulations involve multiple communication links simultaneously, with primary attention on overall system performance such as fairness, communication capacity, and resource utilization. If actual communication links from link simulation are used in system simulation, simulation time becomes unacceptable.

High resolution and long time duration cannot be simultaneously accommodated in system simulation. Therefore, link simulation must be separated from system simulation in time to reduce system simulation time complexity. In this case, data exchange interfaces between link simulation and system simulation must be defined. For system simulation, this interface is the Link-to-System (L2S) interface produced by link abstraction, and the method adopted by the L2S interface is the link abstraction method. The introduction of link abstraction methods separates the system part and link part in system simulation in time, replacing Monte Carlo methods with data computation, which greatly reduces system simulation time complexity while sacrificing only a small amount of accuracy.

In traditional system-level simulation, link abstraction can use average values or real values. However, the average value method has significant errors in application, resulting in insufficient accuracy of interface data. The real value interface method, while highly accurate, requires simultaneous operation of link-level and system-level simulations, with system-level simulation controlling topology structure and link-level simulation determining whether transmitted data is correct. Such interface methods, though precise, make the system extremely complex and greatly limit its application.

In 4G wireless communication technology research, new technologies such as MIMO and OFDM are introduced in the physical layer. These technologies inevitably pose new demands on existing simulation methods, and original link abstraction methods can no longer well satisfy current requirements for simulation accuracy and efficiency.

During 4G standard research, proposals have put forward a series of methods centered on ESM24 [4], such as EESM25, MIESM26, and newly emerged MMIBESM27 and BEESM28 algorithms. The basic idea of ESM algorithms is to implement link abstraction in two steps: the first step maps multi-state channels—where multi-state can be multi-frequency, multi-time, multi-space, or any combination of frequency, time, and space—into a single-state channel, simplifying the complexity of channel conditions caused by complex physical layer technologies; the second step performs link abstraction on the single-state channel. The core of this method is the transformation in the first step, which adopts the principle of equivalent Chernoff bound based on binary transmission and maximum likelihood decoding. Verification for OFDM links has proven the effectiveness and efficiency of ESM methods. However, the establishment of this principle requires equivalent analysis of binary coding and maximum likelihood decoding for physical layer links, meaning this method requires different equivalent analyses for different physical layer technologies during application.

For different physical layers, our simulation platform adopts different ESM methods:

- **Pure OFDM links:** The EESM method is adopted, with literature having proven the effectiveness of EESM in OFDM links [5-6].

- **MIMO links:** Divided into two cases. First, when MIMO decoding adopts linear decoding algorithms, since linear decoding can be well equivalent to binary transmission through arithmetic linear expressions, using the EESM method can achieve good link abstraction accuracy. Second, when MIMO decoding adopts non-linear decoding algorithms, a modified EESM algorithm is used. Considering that non-linear decoding algorithms lack linear expressions for decoding output, a linear Monte Carlo approach is adopted, adding linear optimization factors to the EESM algorithm to achieve a compromise between efficiency and accuracy.
- **Hybrid Automatic Repeat Request (HARQ) links:** Due to the particularity of retransmission, link abstraction involves multiple link transmissions separated in time, requiring consideration of the superposition of current retransmission and previous transmission information. We developed a link abstraction method for HARQ links. The core idea is to map different modulation schemes to the same basic modulation scheme and transform different data coding rates to the same basic data coding rate, ensuring that information from retransmission and previous transmission can be normalized and superimposed in terms of modulation scheme and coding rate, directly equivalent to a link conforming to ESM principles, thus directly adopting ESM algorithms.

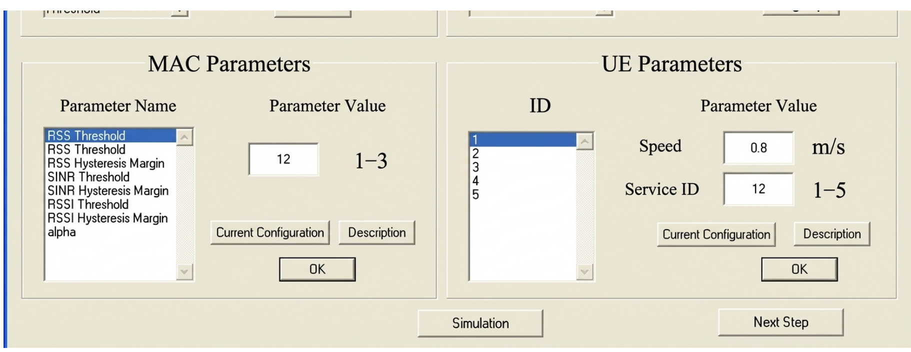

Figure 4: Figure 4

shows a schematic diagram of the HARQ link abstraction method.

The main parameters in

are: {hk}n represents the channel response on resource element k in the nth HARQ transmission; {SINRk}n represents the signal-to-interference-plus-noise ratio on resource element k in the nth HARQ transmission; {SINRb,k}n represents the SINR of the b-th bit on resource element k in the nth HARQ transmission; {SINR' b,k}n represents the SINR of the b-th bit on resource element k in the nth HARQ transmission, corresponding to a code rate of 1/3; {SINR' b,k}n-1 represents the SINR of the b-th bit on resource element k in the (n-1)th HARQ transmission; {SINR' b,k}n|n-1 represents the SINR after combining

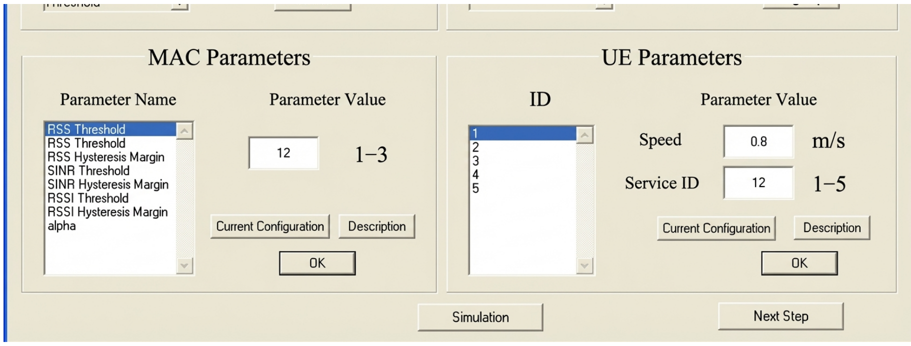

Figure 5: Figure 4

the b-th bit on resource element k in the nth HARQ transmission with the previous transmission; BLERn represents the block error rate of the nth HARQ transmission.

After adopting the above link abstraction scheme, the platform well covers core 4G physical layer technologies, providing efficient and high-precision support for system simulation and greatly enhancing the platform' s applicability.

4.3 Enhanced Multi-Antenna Technology

4.3.1 Uplink Multi-Antenna Enhancement

In LTE-A uplink, besides considering more antenna configurations, requirements for low peak-to-average power ratio and single-carrier transmission on each component carrier must also be considered.

For uplink traffic channels, capacity improvement is the primary requirement, and multi-antenna technology needs to consider the introduction of spatial multiplexing. Meanwhile, since transmit diversity has no performance advantage over simpler open-loop rank-1 precoding, the LTE-A standard ultimately determined not to adopt transmit diversity for uplink traffic channels. For cell-edge users, open-loop rank-1 precoding can be directly applied. Currently, codebook design for 2-transmit-antenna and 4-transmit-antenna precoding has been completed.

Like LTE, LTE-A uplink reference signals include reference signals for channel measurement and reference signals for signal detection. Due to the adoption of uplink spatial multiplexing and multi-carrier, the resource overhead of demodulation reference signals for a single user needs to be expanded. The most direct approach is to have demodulation reference signals for different data transmission layers use different cyclic shifts based on the constant-amplitude zero-autocorrelation code cyclic shift used in LTE uplink reference signals. Another possibility is to superimpose orthogonal codes on multiple reference signal symbols in the time domain to expand code multiplexing space. The standard ultimately adopted a combination of both approaches [3].

For sounding reference signals, to support uplink multi-antenna channel measurement and multi-carrier measurement, resource overhead also needs to expand relative to LTE signals. Besides continuing LTE' s periodic sounding reference signal transmission mode, LTE-A also added an aperiodic sounding reference signal transmission mode, triggered by base stations to enable user transmission, achieving expansion of sounding reference signal resources.

4.3.2 Downlink Multi-Antenna Enhancement

Due to the increased number of supported transmission layers in the downlink, codebook design size needs to be enlarged. In closed-loop MIMO scenarios, to reduce feedback overhead, codebook-based principal index feedback should be adopted. Currently, 8-antenna codebook design is underway, with a preliminary trend toward adopting a dual precoding matrix codebook structure, representing the codebook matrix as the product of two matrices. Typically, one matrix is the base codebook, and the other is a correction based on channel variation characteristics on the base codebook. To further reduce feedback overhead, separate long-period feedback and short-period feedback can be considered based on different statistical characteristics of channel variation speed [7].

LTE-A adopts user-specific reference signal methods for traffic channel transmission, with reference signals used by different layers of the same user' s traffic channel being mutually orthogonal through code division plus frequency division.

This simulation platform supports LTE MIMO and LTE-A MIMO enhancements. [FIGURE:5] shows a transmission scheme compatible with uplink/downlink MIMO and its enhancements. When using layer mapping, precoding, and reference signals matched with MIMO, the transmission signal for the current MIMO scheme can be obtained.

[FIGURE:6] shows a reception scheme compatible with uplink/downlink MIMO and its enhancements. Similarly, when using demodulation reference signal methods and layer demapping matched with transmission MIMO, the corresponding signals can be demodulated.

As described above, a compatible transmission and reception scheme not only supports MIMO enhancement simulation on LTE MIMO simulation links but also ensures backward compatibility with previous standards in subsequent standard research.

5 Conclusion

The 4G air interface simulation platform developed by the Wireless Communication Technology Research Center of the Institute of Computing Technology, Chinese Academy of Sciences, as introduced in this paper, includes link-level and system-level simulation for LTE/LTE-A, supporting multi-cell, multi-user, multi-service, multi-channel, and multiple mobility models. This platform will lay a solid foundation for future wireless communication new technology research and standardization work.

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