Author reference

Summary of monographic work
“New 5G Mobile Cellular Systems. Investigating the interaction between 4G-LTE and 5G systems: architecture, network functions, interfaces and protocols",
ISBN: 978-619-233-282-2

With author: Assoc. prof. Rosen Ivanov Pasarelski

(According to a competition for the occupation of the academic position of "professor" in professional direction 5.3 "Communication and computer technology", provided for the needs of the "Telecommunications" department, FDENO of the New Bulgarian University, announced in SG No. 85 / 08.10.2024)

Monographic work with author Rosen Ivanov Pasarelski on the topic "New 5G mobile cellular systems. Study of the interaction between 4G-LTE and 5G systems: architecture, network functions, interfaces and protocols", with ISBN: 978-619-233-282-2, NBU publishing house, is a comprehensive and detailed study of one of the most current and dynamic topics in the field of telecommunications - mobile networks of the fifth generation (5G) and their interaction with the systems of the fourth generation (4G LTE).

The monograph thoroughly explores and analyzes the architecture, network functions, interfaces and protocols of the fifth generation 5G mobile cellular networks and their interaction with 4G LTE systems. An approach of consistent analysis and assessment of network architecture status in 4G-LTE mobile systems, backbone network and radio access network, interfaces and protocols in 4G networks, radio resource management and services, security, channels and multiple access methods in LTE networks is presented. The monograph covers a survey and analytical review of the network architecture in 5G mobile systems, looking at the backbone network, the radio access network and the new radio in 5G systems. The monograph analyzes in detail the network functions and objects in 5G systems, management and quality of services, control, auditing and authentication, network protocols and methods for multiple access in the network architecture. Interaction approaches between 4G LTE and 5G systems are investigated, emphasizing the connection between the core 4G-EPC and the backbone 5G network, as well as the connection in the radio access networks E-UTRAN and 5G RAN. The monograph provides a thorough analysis of the exposure of services between different types of networks.

At the end of each Section of the monographic work, extended mathematical analyzes and models with numerical results of the multiple access methods used in 4G and in 5G systems are presented, as well as mathematical models with specific examples and calculations for optimizing radio signaling capabilities in 5G systems .

Summary of the content of the monographic work

The monograph has a total volume of 220 pages, including 1 table and 23 figures. It is structured in two main sections, with a preface and an introduction. The monographic work ends with a conclusion, with which the author summarizes his studies, analyzes, and systematizes his contributions to the work. A list of a total of 85 cited sources, a list of used abbreviations, as well as lists of figures and tables are attached at the end of the text.

The monograph presents a study and analysis of the architecture, network functions, interfaces and protocols of the fifth generation mobile cellular networks, as well as the interaction between 4G LTE and 5G systems. The main functionalities and interconnections in the network architecture of the two mobile systems are examined in detail.

The content of the monograph is divided into two main Sections as follows:

Section 1 - Network Architecture Survey of 4G LTE Mobile Systems;

Section 2 - Exploring the Network Architecture of 5G Mobile Systems.

The paper begins with a preface and an introduction to the field of mobile cellular systems and their evolutionary development.

Section 1 covers a survey of the network architecture of 4G LTE mobile systems. At the beginning of the Section, the reference model of the 4G LTE architecture is analyzed, which provides a standardized basis for the deployment of LTE networks. This model provides efficient communication between different LTE network elements and facilitates interoperability between equipment from different vendors. The core network components in 4G LTE systems are examined in sequence and detail, with special attention paid to - the extended packet core, the mobility management entity, the service gateway, the packet data network gateway and the home subscriber server. The structure and operation of these components, their importance in the LTE architecture, and their importance to the smooth operation of the network are highlighted.

In this Section of the monograph, connection interfaces in 4G LTE networks are investigated. A wide range of basic interfaces used to connect and communicate between different network components are surveyed. These interfaces are organized as follows: Uu interface, S1 interface, X2 interface, SGi interface, S5/S8 interface, S11 interface, S2a/S2b interface, S6a/S6d interface, S9 interface, Rx interface, Gx interface, and Gxc interface. The investigated interfaces play an important role in operating and ensuring the efficient and reliable operation of the 4G-LTE network, ensuring seamless communication between different network components and ensuring reliable and fast data transmission for mobile devices.

Detailed attention has been paid to the control and user planes in the 4G network. The control plane is analyzed in the context of the LTE network architecture, which plays a key role in the management of the radio access carriers and the connection between the user equipment and the extended core (EPC). This plane provides signaling between the Universal Terrestrial Radio Access Network E-UTRAN and the EPC, enabling the network to manage the data flow between the end user (UE) and the network infrastructure. On the other hand, the user plane is considered with a focus on the transfer of user data, such as voice, video and others, between the user equipment, E-UTRAN and packet core (EPC). User plane functions related to the management of quality of service (QoS) parameters regarding data transmission are also discussed, including prioritizing certain data types over others and ensuring reliable delivery of information with low latency.

Section 1 continues with a survey of radio resource management (RRM), emphasizing functions related to the allocation, scheduling, and reuse of radio resources among different user devices. The goal is to optimize network capacity and performance. Security-related authentication and authorization features in LTE, which ensure that only authorized users and devices can access the network and its services, are also discussed.

Separate points in Section 1 methodically explore the network security architecture, with an emphasis on the protection of user data exchanged between mobile devices and the network, the

mechanisms for ensuring network security, including encryption and data integrity protection, which prevent eavesdropping and unauthorized access. The LTE radio access network is studied by analyzing the radio layer components and the functions related to mobility management, including handover and cell reselection. Channels in LTE networks are discussed in detail, emphasizing that LTE uses different channels for efficient and reliable communication between base stations and user devices. Channels are divided into two main categories: control channels and data channels.

At the end of Section 1, substantial attention is given to multiple access methods in LTE networks, with a focus on two main technologies: frequency division multiple access (FDMA) and orthogonal frequency division multiple access (OFDMA). A mathematical analysis of OFDM is provided, including models and calculations for subcarrier orthogonality, spectral efficiency, bandwidth, and modulation and demodulation. Mathematical analysis of OFDMA includes system studies, subcarrier orthogonality and capacity, and spectral efficiency.

Section 1 of the monograph concludes with general conclusions summarizing the work in this section of the monograph.

Section 2 of the monograph presents an in-depth study of the network architecture of 5G mobile systems. The architectural reference model of 5G networks, the backbone network, the hardware components and the software used in 5G systems are examined in sequence.

In this part of the monograph, the network functions and objects in 5G systems are analyzed extensively and in detail, namely: the access and mobility management function, the user plane function, the session management function, the network segment selection function, the server function for authentication, network exposure function, policy control function, billing function, unstructured data storage function, unified data management function, application function, network storage function, unified data storage function, for network segment specific authentication and authorization, UE radio capability management function, network data analysis function, 5g equipment identification registry, service communication proxy, network edge security protection proxy, non-3GPP interaction function, non-3GPP Trusted Gateway function, Wired Access Gateway function, WLAN Trusted Interconnection function, UE Radio Access Capability Management function, UE Parameter Management function, Capability Exposure function for service, network automation function, communication service continuity application function, network data processing function for analysis, charging policy and rule function, network segment subnet management function, network selection support information function segment, UE reference point function, security assurance function.

The monograph continues with a study of the protocols in the 5G network architecture, in particular the user plane protocol stack and the control plane protocol stack. The reference model of 5G architecture without roaming is also explored. It examines the structure and components required to maintain communication between different networks and service providers within a country or region. At the foundation of the architecture is the backbone 5GC network, which encompasses a set of network functions interoperating to provide end-to-end communication and services.

In Section 2 of the monograph, the reference points in 5G architecture are analyzed very thoroughly and in detail. A large number of reference points are affected in the architecture of 5G networks, which serve as interfaces between different network functions and entities.

At a separate point in Section 2, the reference 5G roaming architecture is explored, which is designed to support users traveling outside their home network and needing to access 5G mobile services from another network. The architecture provides guidance and best practices for the design and implementation of network infrastructure, protocols and procedures required to support seamless delivery of 5G services across multiple networks. It also enables mobile network operators to connect and exchange information to facilitate the provision of 5G services to their subscribers when traveling abroad.

In Section 2 of the monograph, significant attention is paid to the data storage architecture in 5G. Emphasis is placed on three types of data storage architectures used in 5G networks - centralized

storage architecture, distributed storage architecture, and network edge storage architecture. Data storage architectures in 5G systems are designed to efficiently manage and store large amounts of data generated by 5G networks, devices and applications.

The monograph continues with an in-depth study of the access radio network in 5G systems. A comprehensive study of 5G - NG RAN architecture has been done. The next generation NG-RAN identifiers, the application protocol identifier, the transport addresses and the provision of radio access to user devices over the next generation NG-RAN radio network are affected. The main functions of NG-RAN responsible for providing wireless access to the basic network services of user equipment are surveyed. It is explained that these functions are distributed across multiple nodes in the NG-RAN architecture and are designed to work seamlessly in interaction.

Special emphasis in the second Section of the monograph is placed on the new radio in 5G systems, which defines a new air interface. It is the radio interface standard for 5G mobile communication systems that is designed to offer higher data rates, lower latency and better coverage than previous generations of wireless technology. The key features and specifications of the new radio - NR in 5G systems are analyzed.

This part of the monograph also explores in detail the problem of optimizing radio signaling capabilities in 5G systems, which is key to confirming that the network operates at optimal efficiency while providing the high-quality services and capabilities expected of a 5G network. This includes optimizing signaling between the network and end-user devices to ensure that the right radio capabilities are used at the right time and that overhead signals are minimized. Mathematical models of the optimization of radio signaling capabilities in 5G systems are provided. Various modeling techniques are systematized, namely: channel modeling, signal processing, optimization algorithms, linear programming, queuing theory, machine learning, information theory, radio resource management, interference management, and network topology and routing. Numerical results from mathematical models and analyzes are presented.

At a separate point in Section 2, the interaction between 4G-LTE and 5G networks is explored in detail, touching upon the EPC core and 5G RAN. It is emphasized that the Radio Access Network - 5G RAN is being built to work seamlessly with the existing 4G EPC network infrastructure. This enables a smooth transition from fourth 4G to fifth generation 5G mobile systems, both for operators and end users. The radio access network - 5G RAN uses a new core network architecture - 5GC, which is designed to be more flexible and scalable than the previous EPC architecture. However, the 5GC can still interface with the EPC through a set of standardized interfaces and protocols.

The interaction between 5GS with non-3GPP access and EPC/E-UTRAN is successively considered. It gives a clear idea that the interaction between the 5G core network and the E-UTRAN connected to the EPC is possible to be achieved through non-3GPP access. Non-3GPP access refers to networks that are not based on 3GPP radio access technologies, such as Wi-Fi, Ethernet, or DSL. In this scenario, user equipment can connect to the 5GC via non-3GPP access and still access the services provided by E-UTRAN. Interaction between the two networks is achieved through a 5G Service Gateway - SGW in System Architecture Evolution (SAE) and a 4G EPC Service Gateway - SGW.

Also discussed is the interaction between an evolved packet data gateway (ePDG) connected to an EPC and a 5G system. This interaction includes supporting non-3GPP access to the core 5G network, which is necessary to enable 5G connectivity for devices that do not have native 5G capabilities. and rely on other access technologies such as Wi-Fi or wired connections.

In Section 2, the process of exposure of services between different networks is analyzed. It explains that exposing services in interoperability scenarios is a key feature of 5G that enables seamless connectivity and use of network services across different networks. The SBA architecture in 5G provides a standardized service exposure interface, enabling different networks to interoperate and deliver reliable and highly resilient subscriber consumption.

The study continues as a separate point of this Section emphasizes the architecture of 5G systems for time-sensitive communications and industrial automation. The main features of the 5G architecture to support time-sensitive communications and industrial automation are reviewed.
It is particularly important to note that Section 2 of the monograph provides a thorough analysis of multiple access methods in 5G systems. Non-orthogonal multiple access (NOMA) in 5G systems and the principles of transmission with no-orthogonal multiple access are discussed in detail. A mathematical analysis of direct channel transmission of 5G systems with non-orthogonal multiple access is presented. The complexity of the mathematical analysis of direct channel (DL) transmission of 5G systems with nonorthogonal multiple access - NOMA is described, touching on key mathematical concepts and presenting numerical results.
At the end of Section 2 of the monograph, a comparative analysis between the NOMA and OFDMA multiple access methods is prepared, with the aim of a clearer picture in the study of the two methods.
The monograph ends with a conclusion summarizing the research and analysis and presenting the author's main contributions to the work.

Summary of scientific contributions and scientific applied results of the author in the monographic work.

The following scientific contributions and scientific applied results can be summarized in the monographic work:

- Extensive studies and analyzes have been made of the main interfaces for connection and communication between different network components in a 4G - LTE network, of the functions and protocols of the control and user planes in a 4G - LTE network, of the channels for effective and reliable communication between the base station and the user equipment in LTE networks, the radio resource management, the security architecture, the radio access network and the core network in LTE.
- Mathematical analysis and numerical results of Orthogonal Frequency Division Multiplexing - OFDM in LTE networks, Mathematical analysis and modeling for OFDM system in LTE, Mathematical analysis and modeling for OFDMA system in LTE are provided.
- The network functions and objects in 5G systems, non-3GPP 5G interaction functions, the protocol stack in the control and user planes, the reference points in the 5G network architecture, the radio access network and the core network in 5G, the architecture of next generation - NG RAN, the interaction between 4G and 5G networks - between core EPC and 5G RAN, between 5GS with non-3GPP access and EPC/E-UTRAN and between evolved packet data gateway connected to EPC and 5G system.
- The architecture of 5G systems for time-sensitive communications and industrial automation is explored.
- Non-orthogonal multiple access - NOMA and transmission principles in 5G systems with non-orthogonal multiple access are comprehensively researched and analyzed.
- Mathematical analyzes supported by numerical results and models for the optimization of radio signaling capabilities in 5G systems, mathematical analysis of forward and reverse channel transmission of 5G systems with non-orthogonal multiple access and comparative analysis between NOMA and OFDMA multiple access methods have been made. in order to have a clearer picture in the study of the two methods.

The work is also characterized by scientific application value, as the results presented in it can be used in the telecommunications sector in the design, implementation and management of 5G networks. Specific technical issues and opportunities for integration of 4G and 5G networks are explored and described, which has practical implications for existing operators.

The monograph is suitable for a wide range of readers, including students, researchers and telecommunications professionals. It can serve as a comprehensive resource on topics related to mobile cellular networks and wireless communications.

October, 2024 Rosen Pasarelski