BULGARIAN ACADEMY OF SCIENCES
INSTITUTE OF INFORMATION AND COMMUNICATION TECHNOLOGIES

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MODELING AND OPTIMIZATION OF COMMUNICATION STRATEGIES IN INFORMATION PROCESS MANAGEMENT

ABSTRACT OF DOCTORAL DISSERTATION

for awarding the educational and scientific degree "Doctor"
Professional field: 4.6. “Informatics and Computer Science”
Doctoral Program “Informatics”

Supervisor:

Prof. Dr. Tatyana Atanasova

Sofia, 2025

Institute of Information and Communication Technologies

The dissertation was discussed and admitted to defense at an extended meeting of the section " Modelling and Optimization" at the Institute of Information and Communication Technologies-BAS, which took place on 01/09/2025.

The dissertation is structured in an introduction, 3 chapters, conclusion, contributions, directions for future research, list of publications, list of noted citations, declaration of originality of the results and bibliography. The dissertation has a total volume of 135 pages, 48 figures, 9 tables and 130 literary sources.

The dissertation defense will take place on ……...2025 from …………… hours in hall ………… of block 2 of IICT-BAS at an open meeting of a scientific jury composed of:

Scientific jury

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The reviews and opinions of the members of the scientific jury and the abstract are published on the website of IICT-BAS.

The materials for the defense are available to those interested in room 315 of IICT-BAS, ul. "Akad. G. Bonchev", bl. 2.

Author: Gergana Petkova Mateeva

Title: Modeling and optimization of communication strategies in information process management

Introduction

This doctoral dissertation analyzes existing models and proposes novel approaches for the utilization of Information and Communication Technologies (ICT) in information provision and management of information processes. Furthermore, it addresses the integration of ICT with heuristic optimization techniques and artificial intelligence-based methods to optimize strategies for managing information processes. The research proposes a new hybrid framework for optimizing communication strategies in distributed digital environments with limited resources.

Aim and Objectives

The main aim of this dissertation is to develop models and methods for optimizing communication strategies in information process management. To achieve this aim, the following objectives have been defined:

- To develop heuristic methods for optimizing communication strategies in information process management in a digital environment.
- To propose a modification of genetic algorithms for optimizing communication strategies in information process management.
- To propose a method for improving the efficiency of genetic algorithms for the purposes of information process management.
- To develop models that allow effective implementation and application of the developed heuristic methods on heterogeneous mobile and IoT devices in distributed digital environments with limited resources.
- To propose an approach for assessing the effect of the application of the developed models and methods for optimizing communication strategies for managing information flows in distributed digital environments.

Structure of the Dissertation

The dissertation is structured into three main chapters:

- Chapter 1 presents an analytical overview of contemporary trends in the development of communication strategies and technologies for managing information processes.

- Chapter 2 describes the developed heuristic methods, focusing on the DNA-inspired modification of genetic algorithms and adaptive approximation of fitness functions for optimizing communication strategies in information process management.
- Chapter 3 covers models enabling efficient application of heuristic methods on heterogeneous mobile and IoT devices in distributed digital environments with limited resources, including technical and architectural aspects of information flow management with detailed implementation.

Chapter 1: Contemporary Trends in the Development of Communication Strategies for Information Process Management

Chapter 1 provides an analytical overview of current trends in the development of communication strategies and technologies for managing information processes.

1.1 Information Processes in the Digital Environment

The advancement of ICT has led to the modern information era, where ICT serve as transformative factors across various industries. The information process includes collection, processing, acquisition, recording, organization, retrieval, display, and dissemination of data, ultimately enabling information analysis [Galbraith, 1977]. The digital environment encompasses diverse digital devices, platforms, media, data, and technologies supporting the achievement of digital goals. Figure 1.1 illustrates this environment. A profound understanding of communication as the fundamental mechanism for management and information exchange is key to effective organizational functioning.

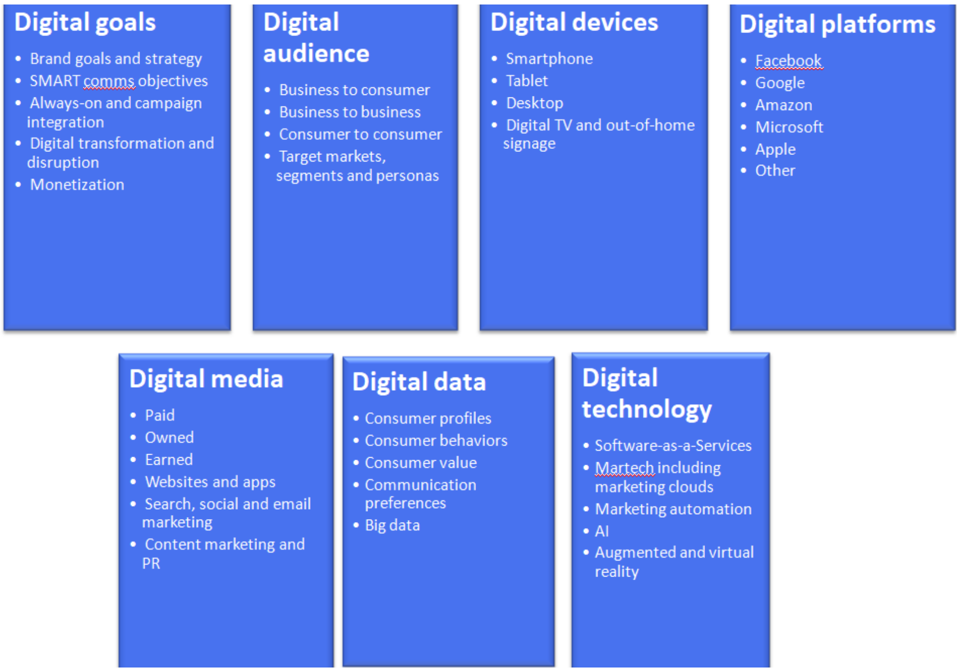

Figure 1.1. Digital Environment (Adapted from:https://www.sciencedirect.com/science/article/pii/S1029313222000719)

1.2 Communication Models

The term "communication" originates from Latin, meaning "sharing," "messaging," "dividing," or "transmitting," emphasizing community creation, connection, and interaction among people. Effective communication requires messages to be clear, concise, specific, credible, and context- and audience-appropriate.

- Linear communication model: Represents communication as a one-way process from sender to receiver, similar to Aristotle's and later Shannon-Weaver models. This model includes elements such as information source, transmitter, channel, noise (any disturbances), receiver, and final destination. Visualized in Figures 1.2 and Figures 1.3.

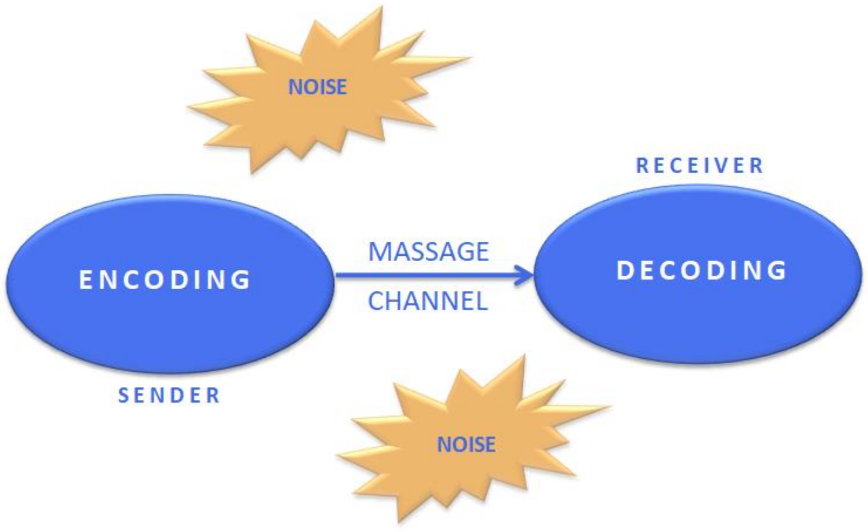

Figure 1.2. Linear Model of Communication (Adapted from:https://pressbooks.bccampus.ca/professionalcomms/chapter/3-2-the-communication-process-communication-in-the-real-world-an-introduction-to-communication-studies/)

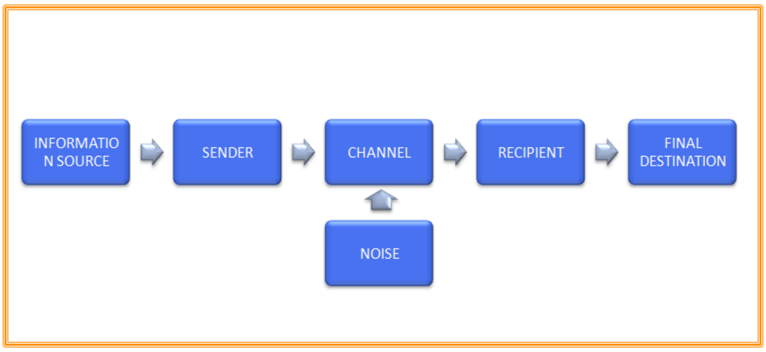

Figure 1.3. Shannon and Weaver's Linear Communication Model (Adapted from:https://www.novavizia.com/model-za-linejna-komunikatsiya-na-shenyn-i-uivyr/.)

- Interactive communication model: Views communication as a two-way process with feedback, where participants alternate roles of sender and receiver. Emphasizes the ongoing process and feedback significance rather than just successful transmission [Elkins et al., 2012]. Illustrated in Figure 1.4.

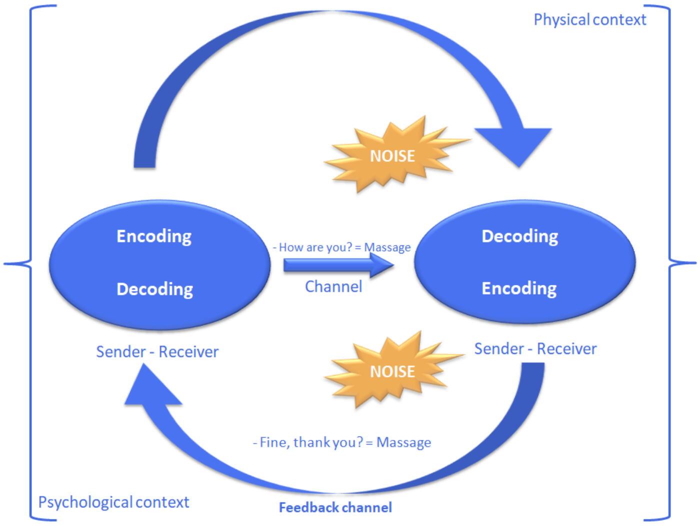

Figure 1.4. Interactive communication model

- Transactional communication model: Describes communication as a continual process where participants simultaneously send and receive messages, jointly creating social reality within a given context. Participants are seen as "communicators." Presented in Figure 1.5.

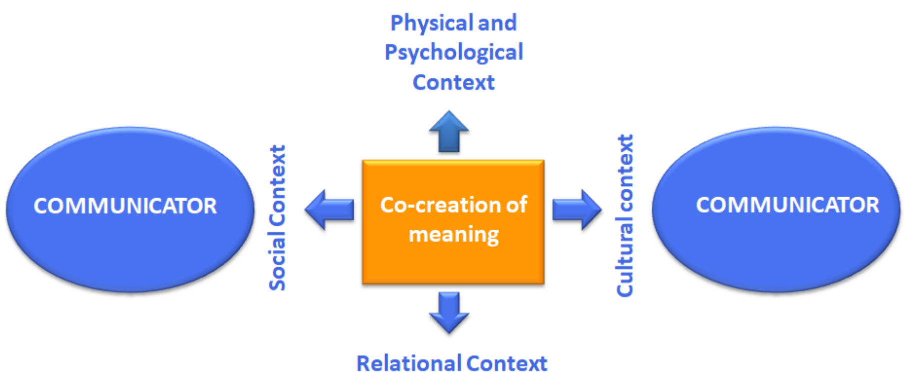

Figure 1.5. Transactional model of communication

1.3 Theoretical Foundations and Contemporary Communication Models

This section explores both classical and modern approaches, based on intelligent agents and complex organizational structures.

- Shannon-Weaver communication model: A linear, one-way message transmission model with six main elements. Widely applied in technical and network communication systems for optimizing data flow. Key elements shown in Figure 1.6, and noise influence illustrated in Figure 1.7.

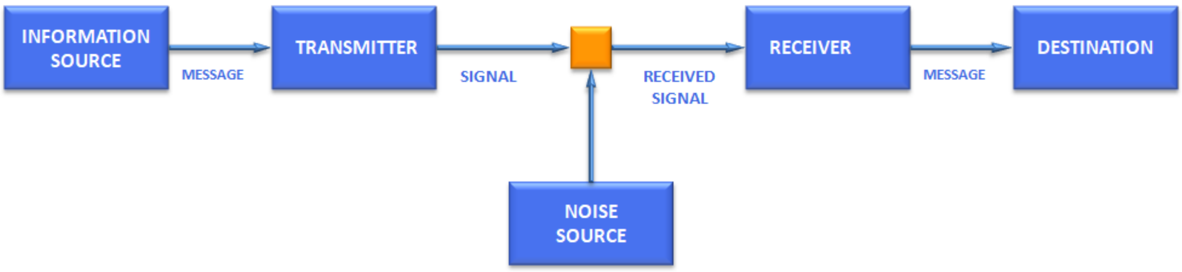

Figure 1.6. Key elements of the Shannon-Weaver model

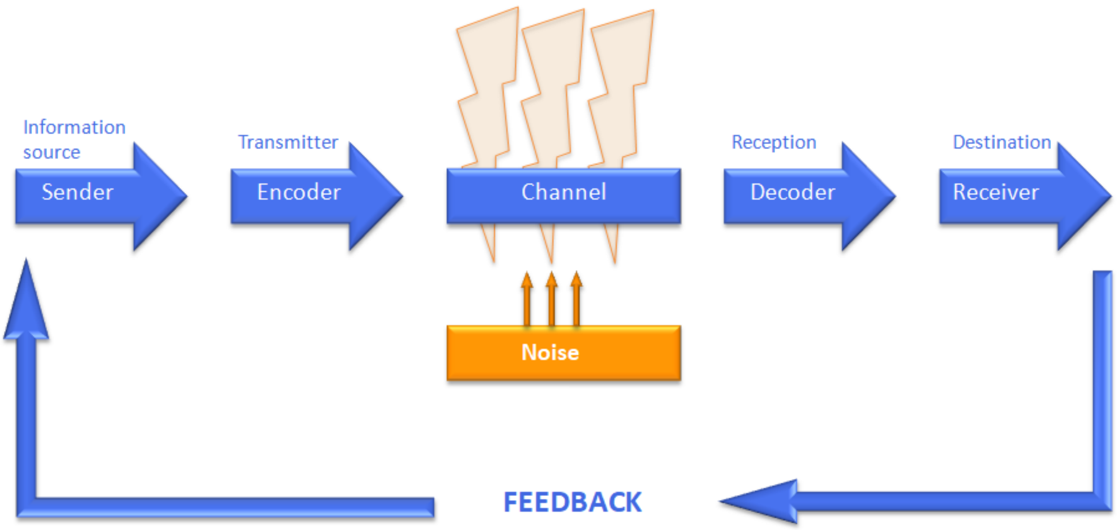

Figure 1.7. Impact of noise on the communication process

- Agent-based communication model: Uses autonomous software agents governed by Artificial Intelligence (AI) to interact and optimize data exchange in multi-agent systems (MAS), supporting automated decision-making. Typical characteristics of autonomous agents shown in Figure 1.8; taxonomy of interaction models in Figure 1.9.

Figure 1.8. Typical characteristics of an autonomous agent (Adapted from: Martin Ivanov, Modern application of multi-agent simulation models in research and practice, New Bulgarian University, Department of Informatics)

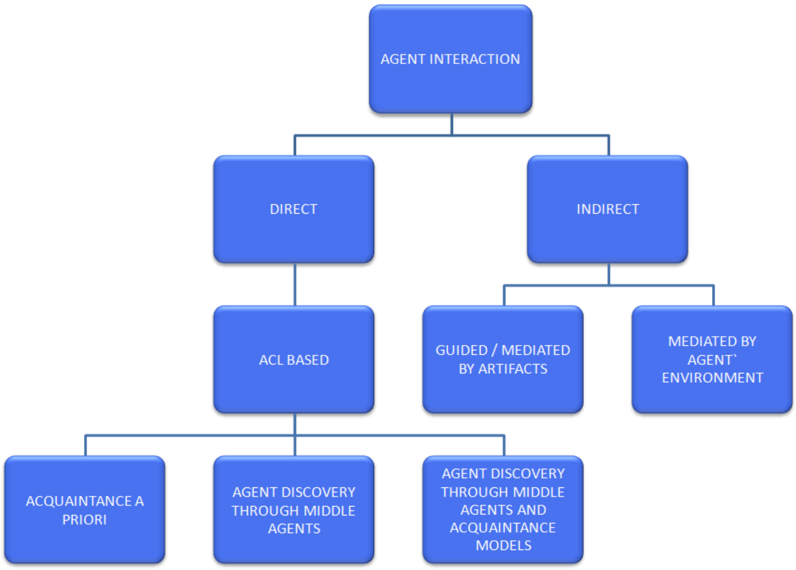

Figure 1.9. Taxonomy of Agent Interaction Models (Adapted from: Bandini Stefania, Sara Manzoni and Giuseppe Vizzari, Agent Based Modeling and Simulation: AnInformatics Perspective, Journal of Artificial Societies and Social Simulation 12 (4) 4, 2009, http://jasss.soc.surrey.ac.uk/12/4/4.html)

- Hierarchical and decentralized communication models: Hierarchical models feature structured top-down communication typical for corporate environments, while decentralized models provide secure and distributed communication (e.g., peer-to-peer or blockchain-based systems). Hybrid structures combine advantages of both. Theoretical model illustrated in Figure 1.10. Table 1.1 summarizes key differences in decision-making, communication, responsibility, and system scale.

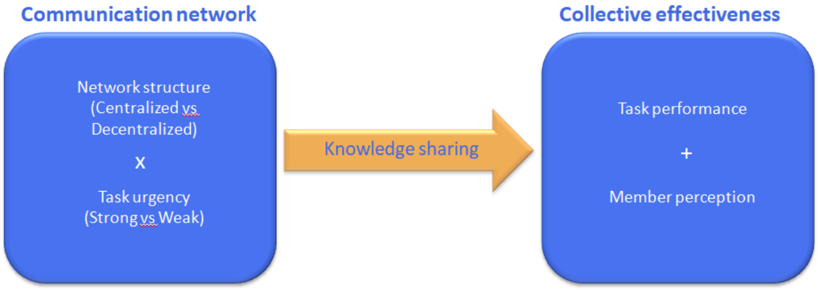

Figure 1.10. Theoretical model of centralized/decentralized communication structure (Adapted from: Ding, X., Shen, W., &Wang, S. (2024). Centralizedor Decentralized? Communication Network and Collective Effectiveness of PBOs — A Task Urgency Perspective. Buildings, 14(2), 448. https://doi.org/10.3390/buildings14020448)

Differences	CENTRALIZED	DECENTRALIZED
Decision-making	One main controlling element defines the processes and strategies.	Different components in the system make independent decisions related to their areas.
Communication	The flow of information is mostly one-way, from the control center to the executive elements that implement the tasks.	System components exchange information more flexibly and directly with each other, allowing for a freer exchange of information flows.
Responsibility	The main responsibility is concentrated in the central management element, which directs the execution of information processes with minimal external intervention.	Responsibility is distributed among the interacting components in the communication system, which provides the opportunity for feedback and adaptation in the management of information processes.
Size of system	This model is often more suitable for systems with a smaller scale or a smaller number of interacting elements and information flows.	It is usually effective for large-scale systems with multiple distributed components, where flexible management of information processes is required.

Table 1.1. Comparison between centralized and decentralized models

- Game-theoretic communication model: Optimizes strategic interactions between agents in competitive or cooperative settings, with applications in cybersecurity and business negotiations [Marchao et al., 2020].

- Modeling and simulation in communication: Integrates communication between design, production, marketing, and management to optimize the entire product and process development chain [Balasko et al., 2008].
- Data quality management in information processes: Involves defining standards, control, and continuous improvement of information flows to ensure accuracy, completeness, timeliness, and relevance.

Figure 1.11 structurally presents main directions and interrelations in communication strategies [Glowalla et al., 2014; Demirdöğen et al., 2020].

Figure 1.11. Communication strategies (Scopus)

1.4 Communication Strategies in the Digital Environment

Communication strategies in the digital environment focus on achieving objectives through online platforms and tools. Strategic communication is a deliberate and systematic approach to delivering messages aligned with organizational values and goals. Information management is conceptually divided into phases: collection, storage, analysis, and transmission [Hinton, 2006]. The development of a digital communication strategy involves sequential steps, visualized in Figure 1.12, encompassing data collection and analysis, channel and target audience identification, selection of communication levers, data analysis and interpretation, key message formulation, as well as monitoring, feedback, and adaptation.

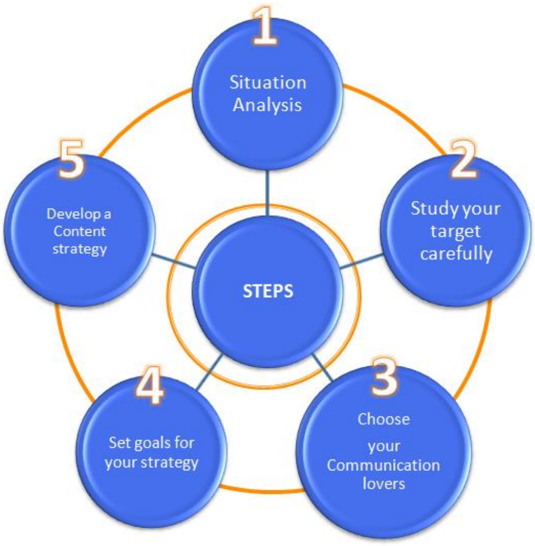

Figure 1.12. Steps in creating a digital communication strategy (Adapted from:https://dottopia.com/what-is-digital-communication-strategy/)

Table 1.2 covers interrelations among social, technical, and management elements; communication; organizational culture; information dissemination; information management; ICT alignment; stakeholder engagement; and continuous improvement. A successful strategy informs, prepares for change, and convinces stakeholders of decision optimality.

Characteristics	Description
Interconnection of social, technical and management components	Integrating social, technical, and management elements ensures that communication is comprehensive and covers all aspects of the organization.
Top-down and bottom-up communication	Information needs to flow both ways, ensuring that all levels of the organization are engaged and informed.
Alignment with organizational culture and strategy	This alignment helps achieve organizational goals and increases the effectiveness of the organization.
Information distribution channels	Identifying and using key channels for information dissemination is crucial. This includes both formal and informal channels to ensure that information reaches all relevant stakeholders effectively.
Information management phases	A communication strategy should cover key phases of information management: collecting, storing, analyzing, and communicating information. This structured approach ensures that information is

	managed efficiently and effectively..
Strategic alignment with ICT	Communication strategies need to be aligned with ICT. This alignment helps to optimize the use of ICT for better information management and decision-making processes.
Stakeholder engagement and feedback	This ensures that the communication strategy is well accepted and understood by all parties involved, facilitating smoother implementation of the strategies.
Constant improvement and adaptation	Communication strategies must be dynamic and adaptable to change. Maintaining effective communication requires continuous improvement based on feedback and changing organizational needs.

Table 1.2. Main requirements for communication strategies

1.5 Components of Modern Communication Strategies

Modern communication strategies include several fundamental components:

- ICT integration: A foundational element providing infrastructure, tools, and platforms for effective information collection, processing, storage, and dissemination, supporting automation and interaction.
- Strategic planning and communication management: A systematic process of planning, crafting, and disseminating messages aligned with organizational goals. Key stages are shown in Figure 1.13.

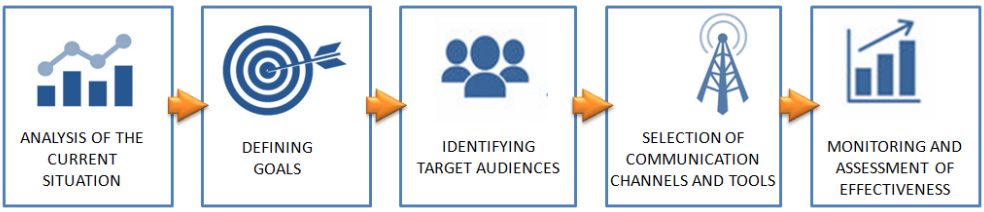

Figure 1.13. Key stages in the communication strategy

- Integration of organizational processes and communication flows: Ensures synchronization and coordination among various units (design, production, marketing, management) to optimize product and service chains.
- Human factors and cultural context: Considers motivation, attitudes, cultural characteristics, and participant expectations to build trust and collaboration.
- Monitoring, evaluation, and adaptation: Mechanisms for timely problem identification, approach adjustment, and continuous strategy improvement.

1.6 Role and Impact of ICT in Communication Strategies for Information Process Management

ICT plays a crucial role in several aspects:

- Importance for decision-making and management: Provides reliable methods for information collection, access, storage, processing, dissemination, and evaluation, which are essential for effective management and competitiveness enhancement [Escobar-Toledo & Martínez-Berumen, 2011, 2013]. Illustrated in Figure 1.14.

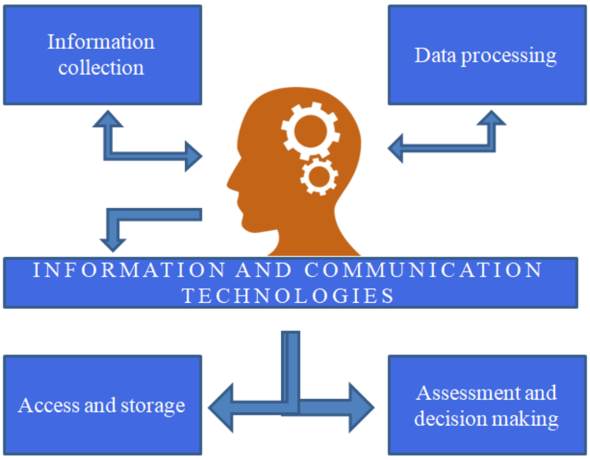

Figure 1.14. Importance of ICT for decision-making and management

- Role in knowledge management and innovation: Supports acquisition, dissemination, and use of knowledge vital for employee-driven innovation and overall organizational efficiency.
- Integration and digitalization of management systems: ICT streamlines operational, tactical, and strategic processes, strengthens communication links, and forms the basis for the Fourth Industrial Revolution technologies [Caffrey & McDonagh, 2015].
- Need for dynamic adaptation of communication strategies: Changing environmental demands require dynamic communication strategies to maintain competitiveness, including comprehensive risk management processes [de Freitas et al., 2018].

1.7 Challenges in Implementing Communication Strategies in Organizational Information Process Management

Implementing communication strategies entails several challenges:

- Complex organizational structures: Matrix structures present unique communication challenges due to their complexity [Gillard, 2005].
- Decentralized data sharing: Effective query evaluation and information integration are difficult due to overlapping data and the need for inter-source processing [Chen et al., 2008].
- Effective communication and management control: Lack of effective communication mechanisms may hinder management control and organizational effectiveness [Chtioui & Dubuisson, 2020].
- Dynamic and evolving requirements: Changing environmental demands require dynamic strategies, while mismatches in information system abstractions lead to inefficiencies [Bendoly et al., 2008].
- Technological integration and adaptation: The complexity of integrating diverse data sources and maintaining up-to-date information is significant, especially during transitions to electronic document management [Pobegaylov et al., 2016].

1.8 Optimization and Improvement of Communication Strategies

Optimization is a key factor for organizational success, involving systematic approaches for analysis, improvement, and adaptation.

- Analysis and evaluation of communication processes: Starts with detailed analysis of existing processes, data collection, communication model usage, and feedback. Table 1.3 outlines steps such as data gathering, communication model application, visual analysis, feedback analysis, channel effectiveness evaluation, and root cause identification.

1. Data Collection
• **Surveys and Interviews:** Conducted with participants in the communication process to gather feedback on the frequency, channels, quality, and results of communication.
• **Observation:** Analysis of real communication situations to identify difficulties or inefficiencies.
2. Use of Communication Models
• Linear, Interactive, Transactional, and Agent-Based Models: Examine the various aspects of communication – who is the source, how is the information transmitted, who is the recipient, and what feedback is received.
3. Visual Analysis through Graphs and Charts

• **Graphs like the one attached:** Visualize key stages and possible problem areas, making it easier to identify weak points.
4. Feedback Analysis
• **Qualitative and Quantitative Analysis:** Evaluate the content of the feedback to identify common difficulties, ambiguities, or lack of information.
5. Channel Performance Assessment
• **Comparison between different channels:** It is determined which communication channels are the most effective and where difficulties or delays are observed.
6. Determining the causes of problems
• **Root cause analysis:** Analysis of cause-and-effect relationships to find the root causes of communication difficulties.

Table 1.3. Identification and analysis of problem areas in communication processes

- Implementation of modern ICT: Integrating innovative ICT is essential for optimization, enabling automation, personalization, and audience segmentation. The role of ICT is depicted in Figure 1.15.

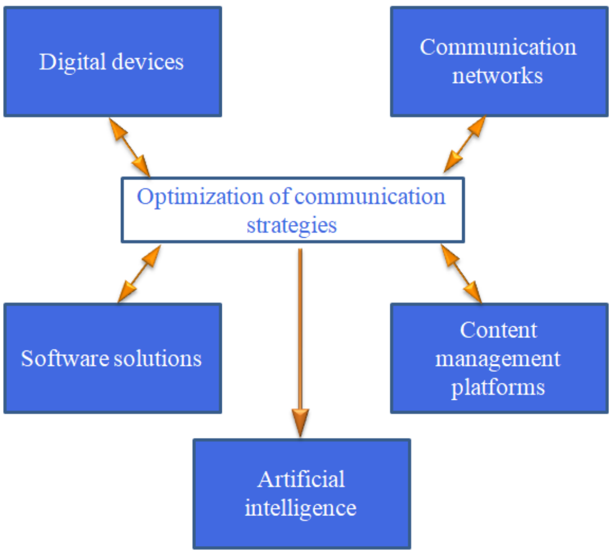

Figure 1.15. Integration of ICT in communication strategies

- Contemporary industry developments in communication: Use of analytical tools for continuous monitoring of key performance indicators (KPI), providing visual reports and recommendations. Table 1.4 lists tools such as Trello, Asana, Slack, Microsoft Teams, Lightico, Google Analytics, and Hootsuite with their functions and applications.

Tool	Features	Applications
Trello	Task and Process Management	Campaign Planning and Tracking
Asana	Team Task Coordination	Internal Communication Optimization
Slack	Real-Time Communication	Improving Internal Communication
Microsoft Teams	Video Conferencing and Chat	Remote Team Management
Lightico	Conversation Analytics and KPI	Customer Interaction Optimization
Google Analytics	Traffic and Conversion Measurement	Digital Campaign Evaluation
Hootsuite	Social Media Management and Analysis	Strategy Monitoring and Adaptation

Table 1.4. Basic analytical tools for optimizing communication strategies

- Information overload management: A critical aspect involving ensuring information quality and strategies to prevent overload [Eppler, 2015]. The efficiency curve in Figure 1.16 illustrates how increased information volume can improve but beyond a certain point reduce decision-making effectiveness.

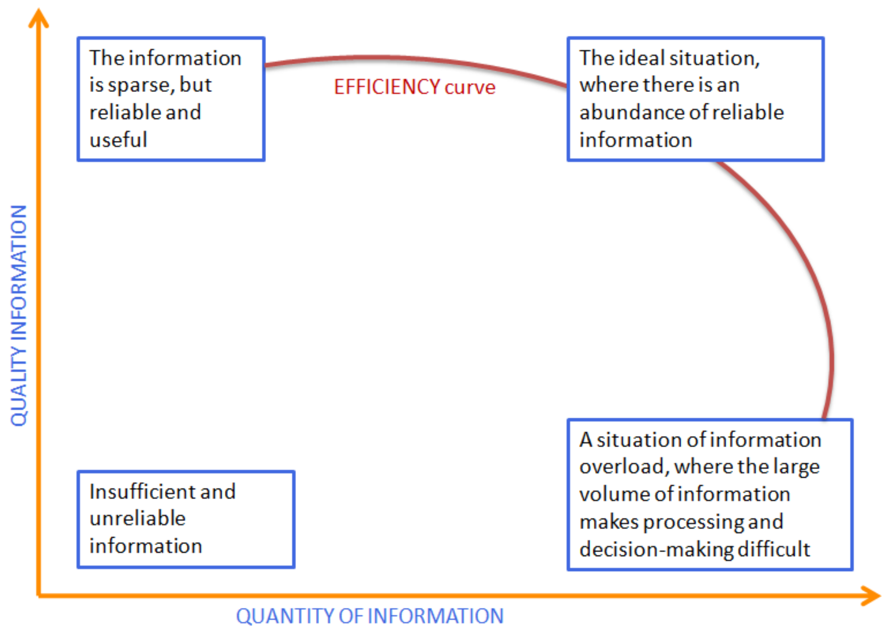

Figure 1.16. Efficiency curve

- Integration of organizational processes and communication flows: Optimization requires process integration for better coordination and information exchange.
- Impact assessment and continuous improvement: Periodic reviews and feedback analysis for adaptation to dynamic changes and sustainable development.

1.9 Methods for Optimizing Communication Strategies

Heuristic and AI-driven techniques are applied to improve communication strategies, enhancing efficiency and effectiveness in complex systems, including hyperheuristics and meta-heuristic techniques. Figure 1.17 visualizes these approaches.

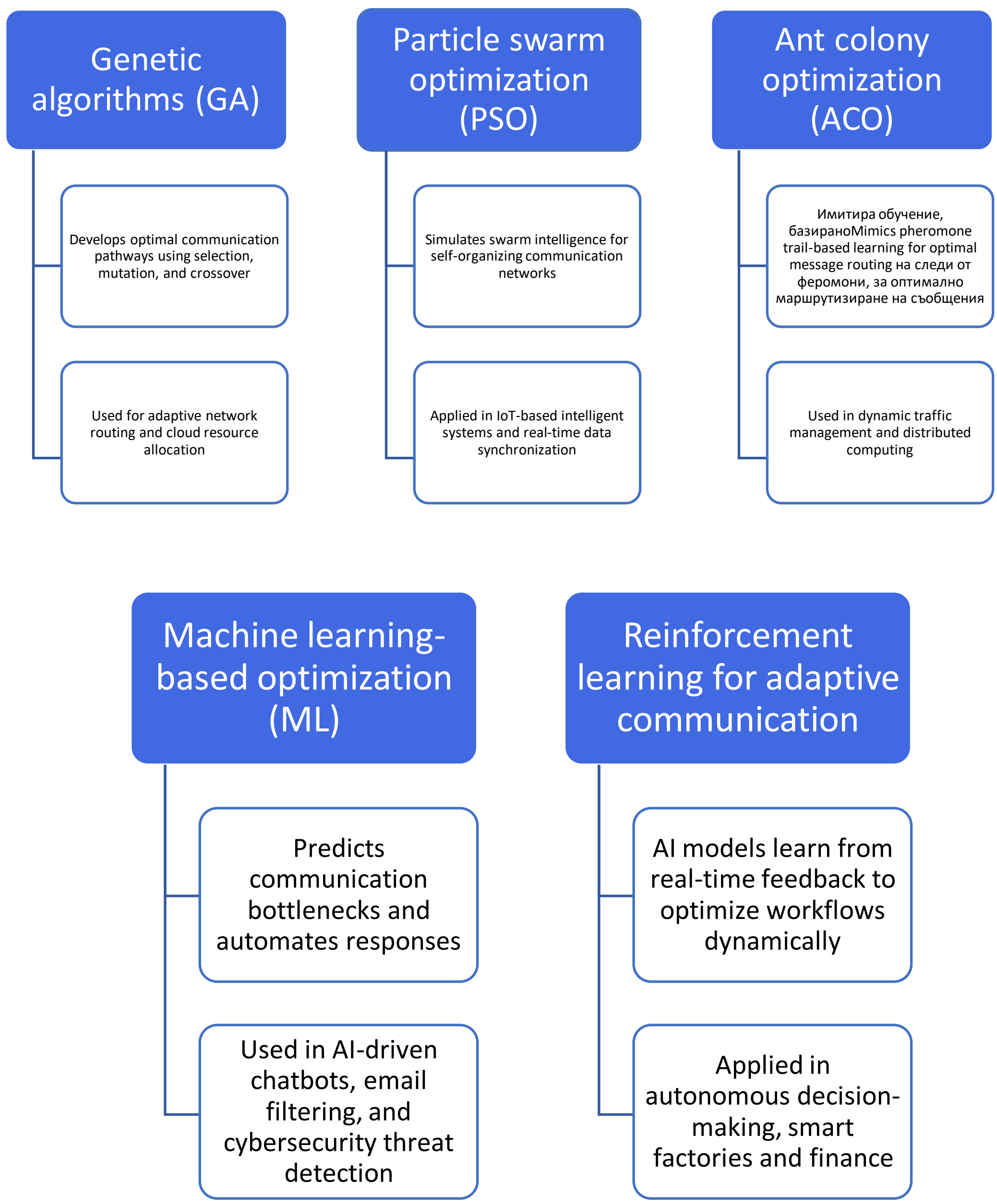

Figure 1.17. Optimization methods

- Optimization techniques and methods include:
  - Genetic Algorithms (GA): Stochastic optimization methods inspired by natural selection, using selection, mutation, and crossover for optimal solutions in adaptive network routing and cloud resource allocation [Cormen et al., 2022].
  - Particle Swarm Optimization (PSO): Algorithm based on collective swarm behavior, applied in self-organizing communication networks and IoT systems [Heaton, 2014; Iba, 2020].
  - Ant Colony Optimization (ACO): Algorithms mimicking ant food-searching behavior, used for dynamic message routing [Heaton, 2014; Iba, 2020].
  - Machine Learning (ML): Predicts bottlenecks, automates responses, integrates into AI systems for enhanced efficiency and security [Petrov et al., 2022].
  - Reinforcement Learning: Enables AI models to learn from real-time feedback for dynamic optimization of communication and work processes [Petrov et al., 2022].
- Practical applications of optimized communication strategies include corporate communication and collaboration, cloud and distributed computing, cybersecurity and secure information exchange, IoT and intelligent systems with self-optimizing networks and AI-assisted predictive maintenance.

1.10 Contemporary Trends in the Development of Communication Strategies for Information Process Management

These trends focus on enhancing efficiency, automation, and decision-making, summarized in Figure 1.18.

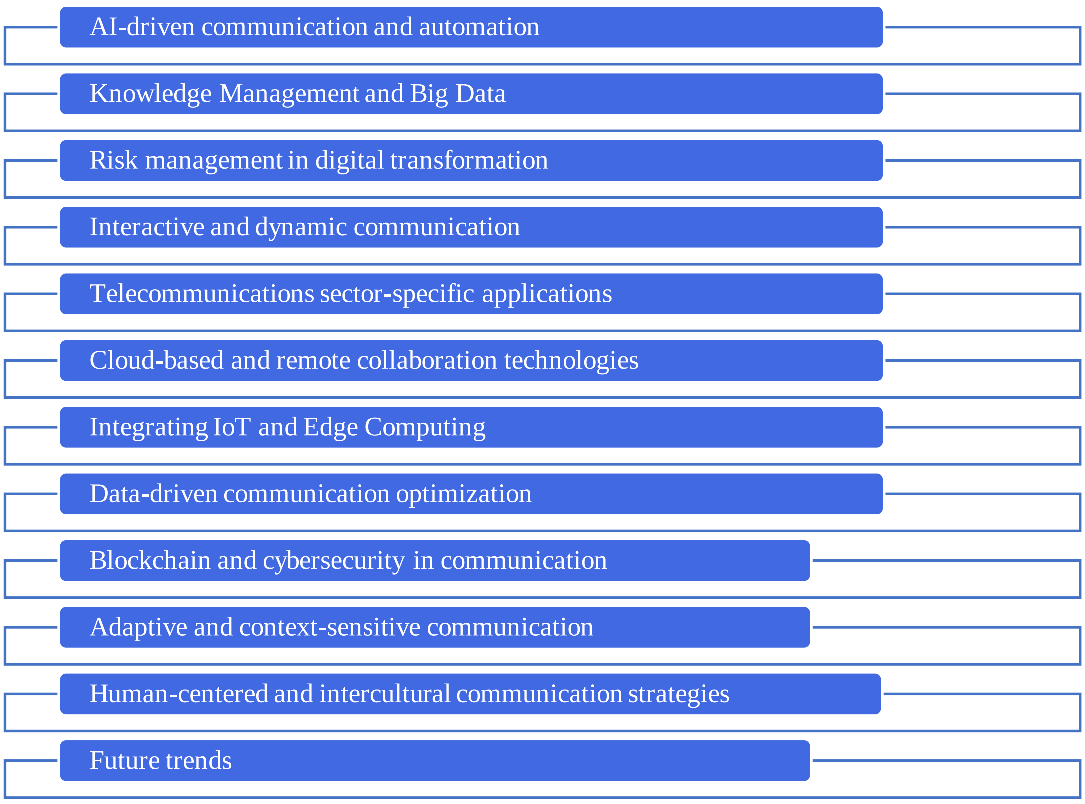

Figure 1.18. Main contemporary trends in the development of communication strategies for information process management

- AI-driven communication and automation: AI chatbots and virtual assistants with NLP improve real-time communication, reduce human intervention, and support decision-making via predictive analytics.
- Knowledge and big data management: Development of Big Data and quantum computing transforms data analysis, requiring effective knowledge management and new approaches [Van De Bogart, 2015].
- Risk management in digital transformation: Effective communication strategies must include mechanisms for managing risks related to new digital transformation challenges [Salutina et al., 2023].
- Interactive and dynamic communication: Uses new technologies to enhance engagement and efficiency with dynamic search strategies [Tešić, 2016].
- Sector-specific telecommunications applications: Development of digital strategies is vital for competitive advantage through innovative solutions and new business models [Polyanin et al., 2017; Martyakova et al., 2019; Folch & Tamayo, 2008; Prokofiev et al., 2021].

- Cloud-based and remote collaboration technologies: Platforms like UCaaS unify communication channels, while cloud and blockchain technologies improve transparency and security for hybrid and remote work.
- IoT and Edge Computing integration: Smart IoT devices automate information exchange, and Edge Computing reduces latency in time-sensitive applications.
- Data-driven communication optimization: Dynamic workflow automation and Digital Twin technology regulate information flow and simulate optimization strategies.
- Blockchain and cybersecurity in communication: Decentralized blockchain networks provide transparency and immutability; zero-trust security models and end-to-end encryption enhance protection.
- Adaptive and context-aware communication: AI personalizes information flow, and gamification increases effectiveness.
- Human-centered and intercultural communication strategies: Emotional AI and multilingual AI translation improve human interactions and global information processes, aligned with digital ethics.
- Future trends in optimizing communication strategies: Include quantum communication (QKD) for exceptional security, 5G/6G networks for high-speed connectivity, AI collaboration, and holographic interfaces for more secure, fast, and intelligent communication strategies.

1.11 Conclusions

Modeling and optimizing communication strategies in information process management significantly enhances their efficiency, security, and adaptability. Utilizing AI, heuristic algorithms, and decentralized architectural models enables organizations to achieve effective data-driven decision-making. Future trends emphasize greater adaptability, personalization, and real-time decision-making. Technology integration in communication strategies optimizes decision-making, internal communication, business processes, flexibility, risk management, and collaboration.

Chapter 2: Methods for Heuristic Optimization of Communication Strategies in Information Process Management

This chapter focuses on the use of heuristic and metaheuristic methods for optimizing communication strategies in managing information processes, emphasizing efficiency and handling system complexity.

2.1 Heuristic Optimization Methods for Communication Strategies

To improve the efficiency and effectiveness of communication in complex systems, the dissertation proposes the use of hyperheuristics and metaheuristic techniques.

2.1.1 Hyperheuristics

Hyperheuristics are high-level strategies that select, combine, or generate heuristics to solve problems. They use information gained during the search process, often involving probabilistic selection and reward-punishment mechanisms for optimization [Navarro et al., 2023].

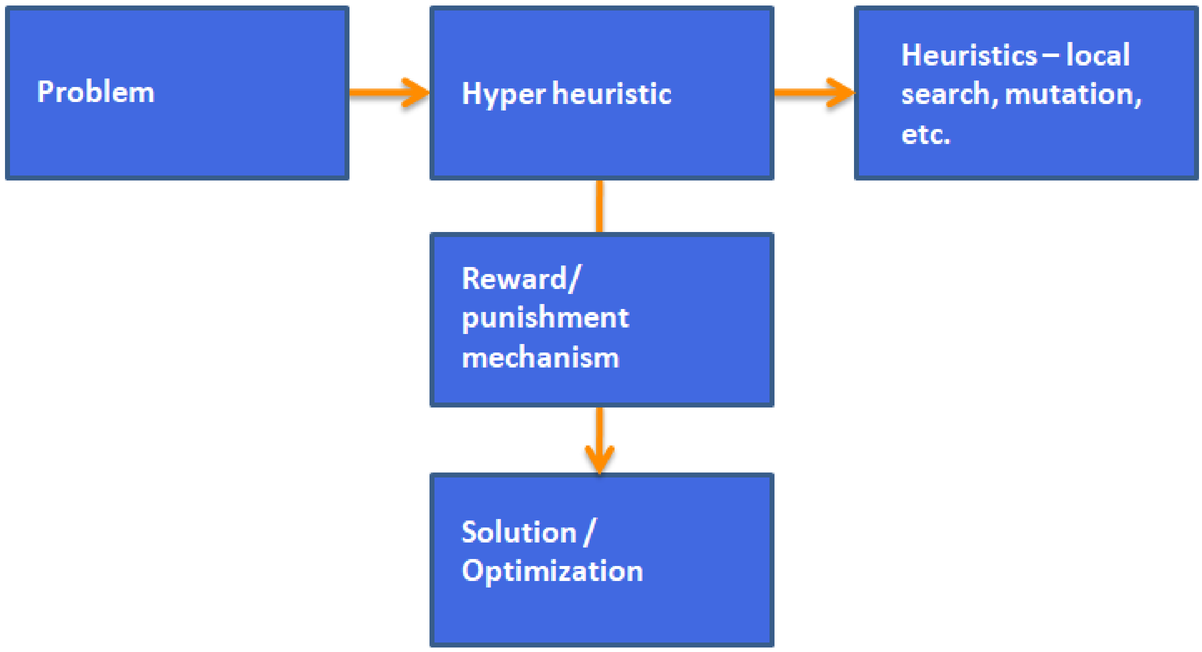

Figure 2.1. Information on the search process

2.1.2 Metaheuristic Techniques

Metaheuristic techniques (MHT) are used for effective information management in complex systems such as logistics and distribution. They focus on collaboration, communication, and knowledge exchange along the supply chain and are critical for organizations requiring advanced decision support systems [Yang, 2022].

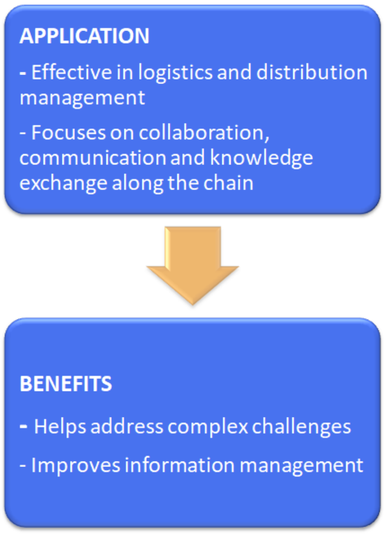

Figure 2.2. Applications and benefits

2.2 Genetic Algorithms: Theoretical Foundations and Modifications

Genetic algorithms (GA) are heuristic global optimization methods inspired by natural selection and genetics, used to solve complex optimization problems by mimicking natural selection and reproduction processes.

2.2.1 Basic Principles of GA

The process starts with a random population of candidate solutions. Key stages include:

- Selection: Better-performing solutions have a higher chance to be chosen for reproduction.
- Crossover: Combining two or more solutions to create new ones.
- Mutation: Random changes to solutions to introduce diversity.

The fitness value of each individual is calculated by a fitness function assigning a numerical quality score to the solution. This function may represent error or cost. The population evolves towards better solutions through repeated application of these operators [Mateeva et al., 2023].

2.2.2 DNA-Inspired Modification of Genetic Algorithms

A DNA-inspired GA modification is proposed, using chromosomes as binary twins with inverted bits (bit-string twin optimization). Each chromosome has a complementary pair, allowing more efficient search space exploration, better constraint handling, and maintaining population diversity [Mateeva et al., 2023]. Despite potentially higher computational costs, twin chromosomes share the same fitness value, possibly avoiding premature convergence. The implementation uses the open GA C/C++ library.

2.2.3 Experiments and Results

Experiments validating the DNA-inspired GA modification were conducted using well-known benchmark optimization functions [Balabanov, 2020]. Figure 2.3 depicts a two-dimensional benchmark function surface with many flat areas and local optima, making global optimum discovery challenging.

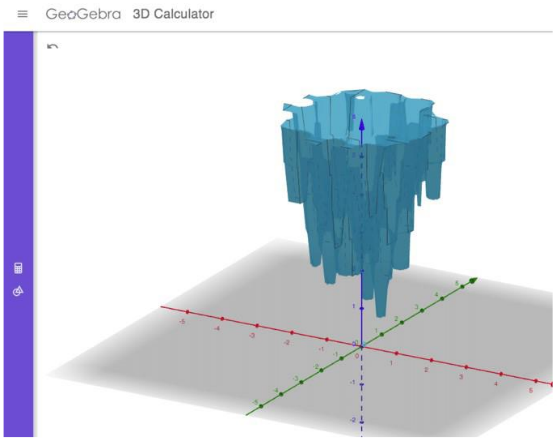

Figure 2.3. A two-dimensional version

The C/C++ source code was executed on a mobile device with the Linux Postmarket OS distribution.

2.3 Application of GA in Information Flow Management in Distributed Computing

2.3.1 Managing Information Flows in Distributed Computing with GA

The dissertation proposes a strategy for managing information flows in distributed computing systems using GA:

- Data flow from server to mobile devices: Financial time series data is provided by a web server to mobile devices for computation [Mateeva et al., 2022].
- Management of global and local populations: The application maintains a global population on the server and local populations on devices, controlled by different evolutionary algorithms.

- Distributed computing without frequent synchronization: The architecture allows local solution evolution over extended periods without frequent synchronization, reducing node interdependence.
- Modular architecture: The mobile application features a modular architecture for maximum configurability.

Figures 2.4 to 2.8 illustrate data flow, algorithm convergence, performance, and computational cost evaluations related to MOEA Framework and Jenetics implementations.

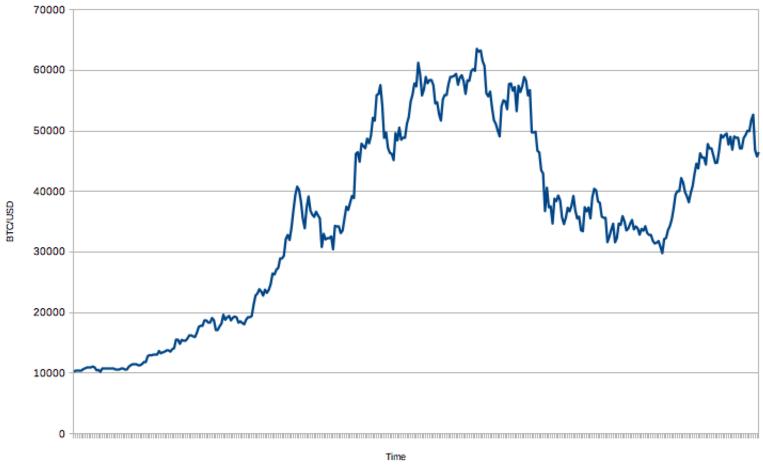

Figure 2.4. Bitcoin price

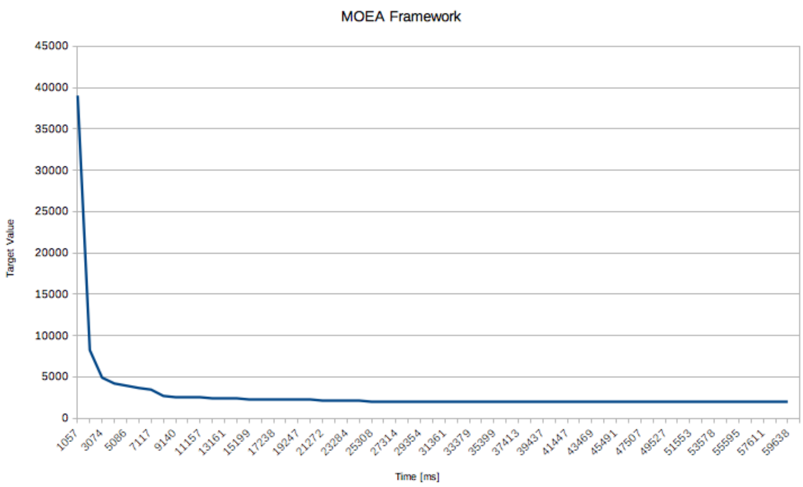

Figure 2.5. MOEA Framework convergence

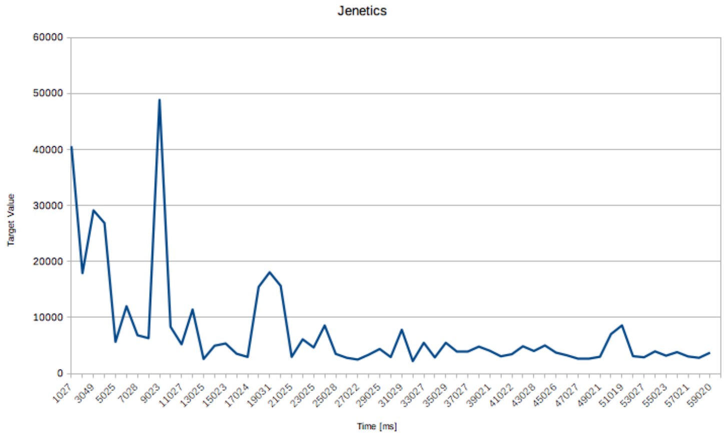

Figure 2.6. Jenetics convergence.

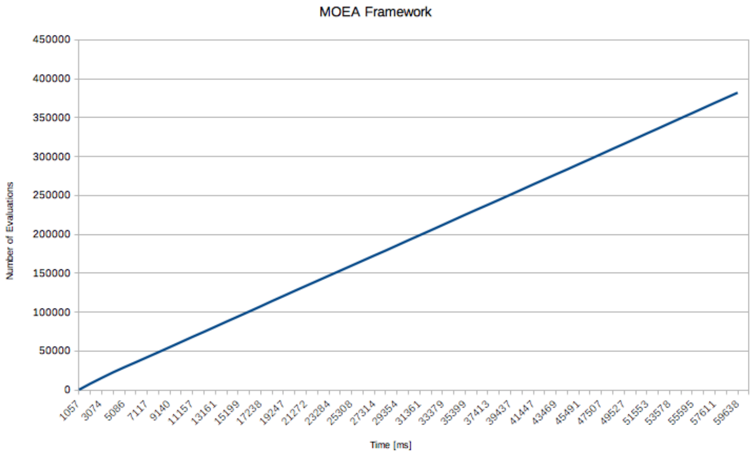

Figure 2.7. MOEA Framework number of target function calculations

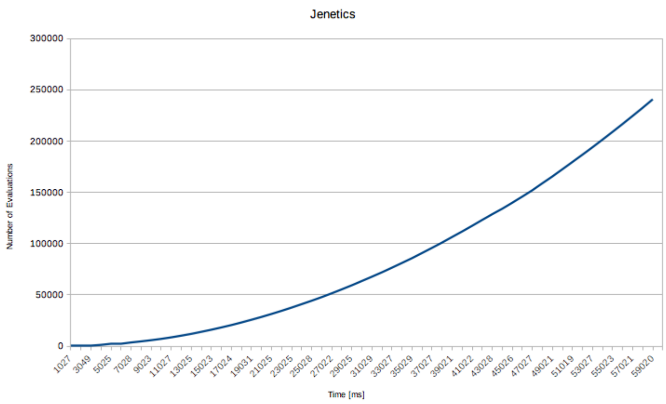

Figure 2.8. Jenetics number of target function calculations

2.3.2 Financial Time Series Forecasting Using GA

GA are applied for forecasting financial time series in distributed computing, utilizing gradient methods for training Artificial Neural Networks (ANN). Android OS services support background computations, and Live Wallpaper is used for intermediate result visualization.

Figures 2.9 to 2.11 illustrate sample time series, training data formation, and data feeding into ANN.

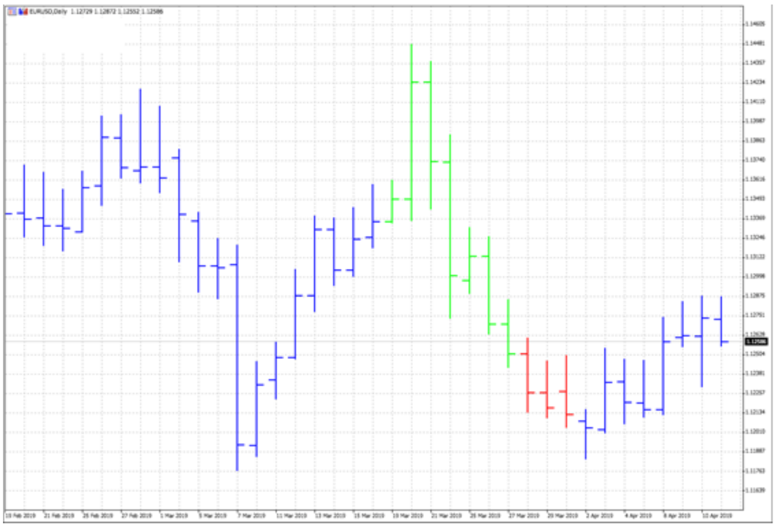

Figure 2.9. Time series

Figure 2.10. Training set formation

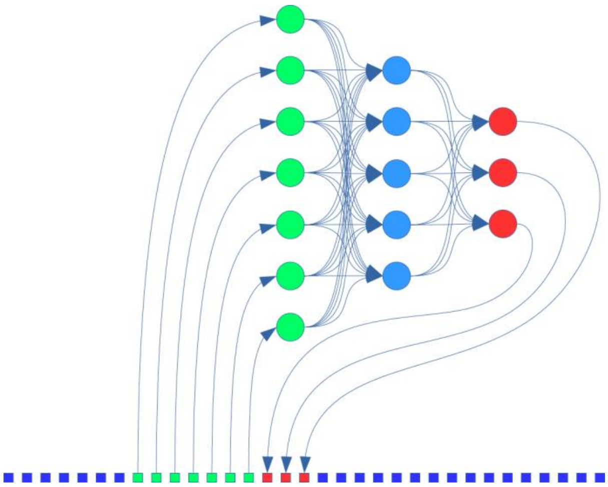

Figure 2.11. Artificial neural network data feeding

Quantitative evaluation uses metrics such as Mean Absolute Error (MAE) and Root Mean Square Error (RMSE). The system employs a client-server architecture with mobile devices connecting via RESTful HTTP/JSON communication. An alternative forecasting approach uses curve approximation via sinusoidal series and linear regression, with GA optimizing coefficients [Xujie Tan et al., 2023].

2.3.3 Internal Information Management Strategies in GA in Digital Environment via Fitness Function Approximation

The fitness function is a key information process in GA guiding their evolution. When fitness functions are time-consuming, GA efficiency drastically decreases. Approximation using Lagrange polynomials is proposed to speed up optimization and reduce costly interactions. This enhancement enables metaheuristics to be applied in previously inaccessible domains [Mateeva et al., 2022].

2.3.4 Experiments and Results

Three experiments compared standard GA with GA using approximated fitness functions in an optimization gaming environment (RTP). The first experiment showed the advantage of the approximated fitness function near the optimization process end (Figures 2.12 to 2.14).

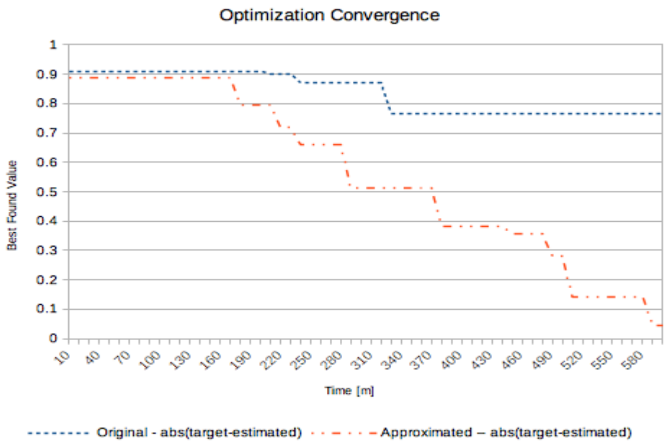

Figure 2.12. First experiment

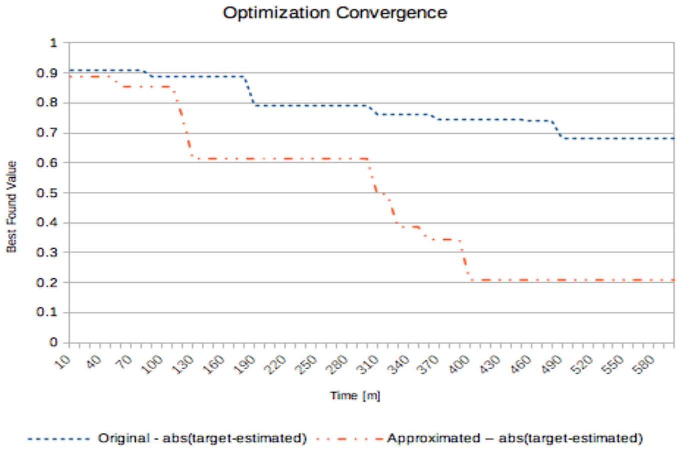

Figure 2.13. Second experiment

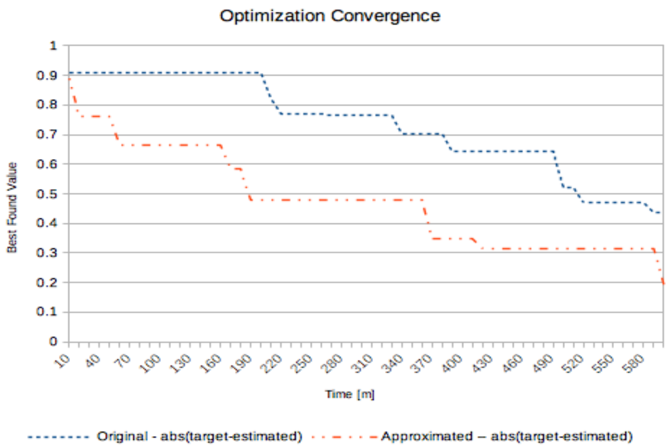

Figure 2.14. Third experiment

2.4 Study of Statistical Properties in Optimization: Data Quality and Random Number Scaling

Data quality is crucial. The generation and scaling of random numbers are critical for GA.

2.4.1 Generation and Scaling of Random Numbers

Random numbers can be generated by:

- Pseudorandom Number Generators (PRNG): Use deterministic algorithms such as Mersenne Twister.
- True Random Number Generators (TRNG): Use physical processes such as TrueRNG v3.

2.4.2 Random Number Scaling Techniques

Scaling transforms generated numbers into desired ranges using linear, nonlinear, or specific scaling without introducing bias.

2.4.3 Statistical Tools and Experiments

The "ent" tool evaluates entropy of files and byte sequences, measuring:

- Entropy: Degree of randomness and unpredictability.
- Chi-square test: Assesses uniformity of byte value distribution.
- Arithmetic mean value: Average byte value.
- Monte Carlo estimation of Pi: Approximate value of Pi via sampling.
- Serial correlation coefficient: Measures dependence between consecutive values.

2.4.4 Experiments and Results

Experiments with Mersenne Twister and TrueRNG v3 data scaled from 0–1 to 0–32 show scaling does not significantly affect statistical properties of pseudorandom numbers.

Figures 2.15 to 2.26 present entropy, chi-square values, mean values, and serial correlations for different ranges.

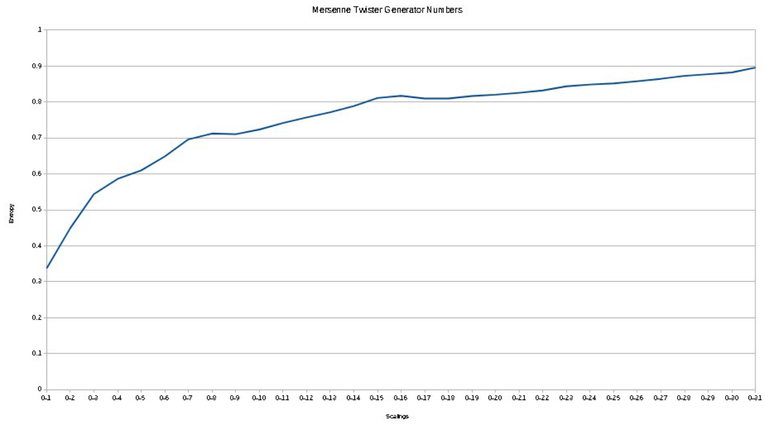

Figure 2.15. Mersenne Twister entropy

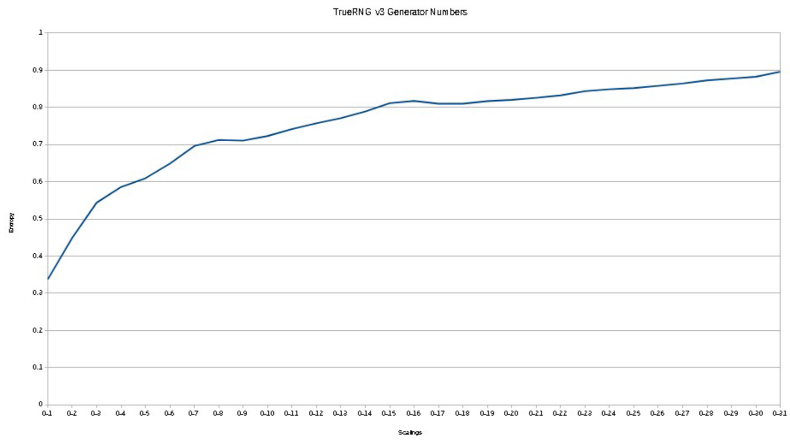

Figure 2.16. TrueRNG v3 entropy

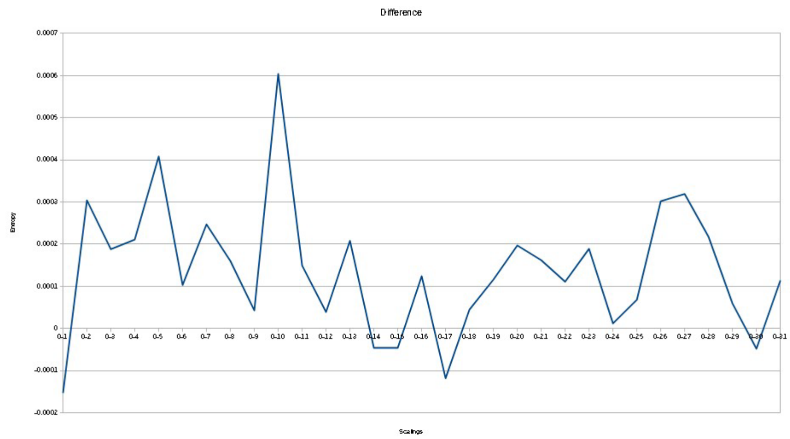

Figure 2.17. Entropy difference

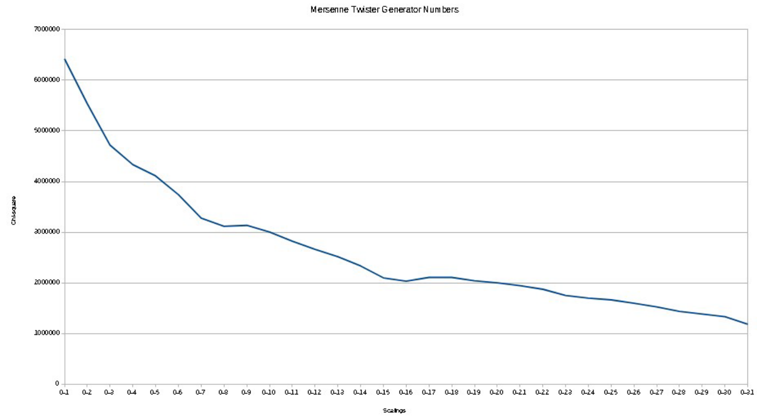

Figure 2.18. Mersenne Twister chi-square

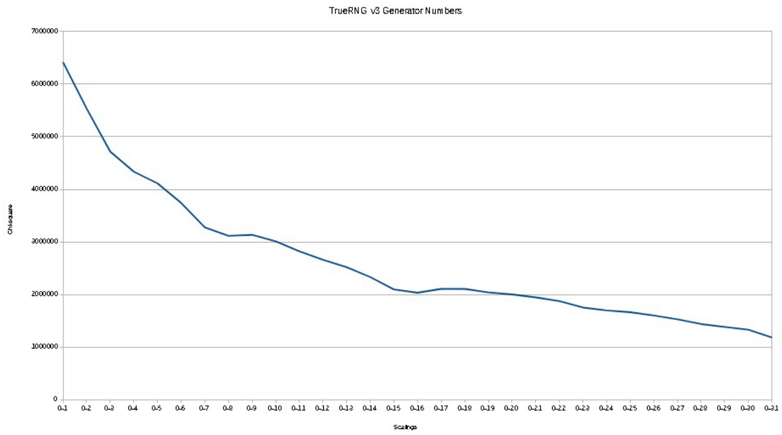

Figure 2.19. TrueRNG v3 chi-square

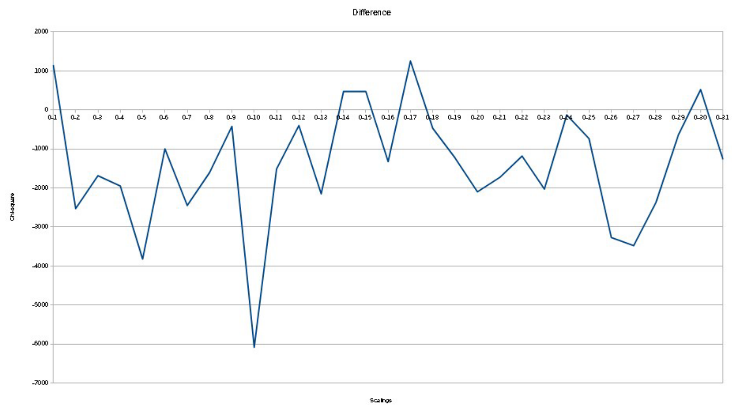

Figure 2.20. Chi-square difference

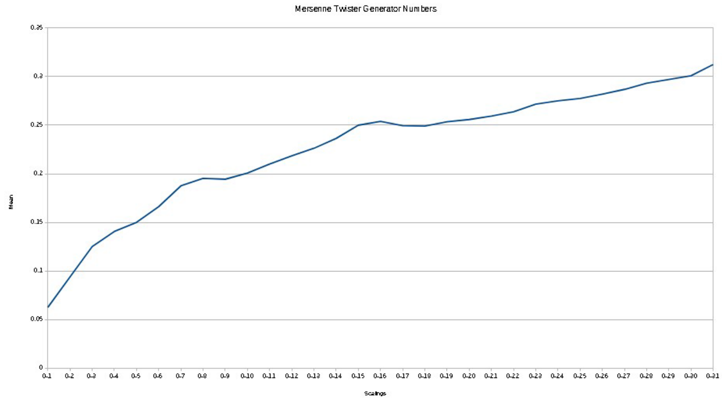

Figure 2.21. Mersenne Twister mean

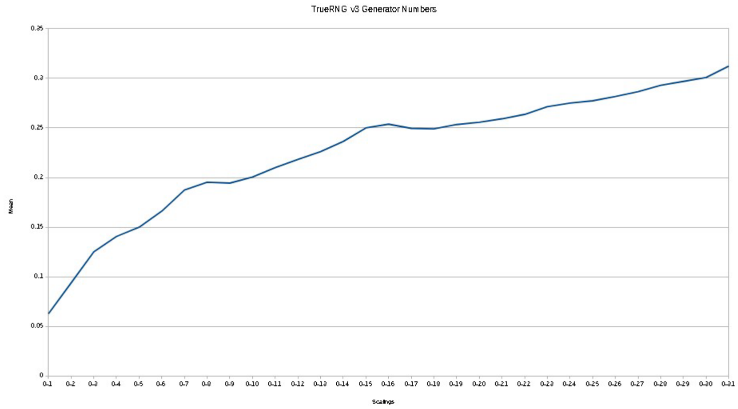

Figure 2.22. TrueRNG v3 mean

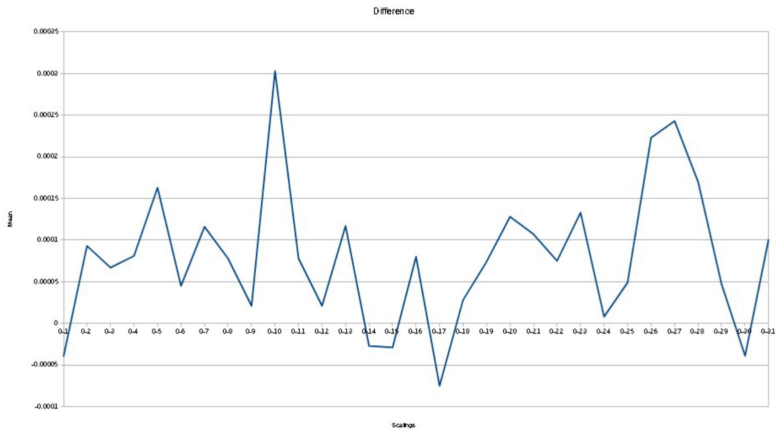

Figure 2.23. Mean difference

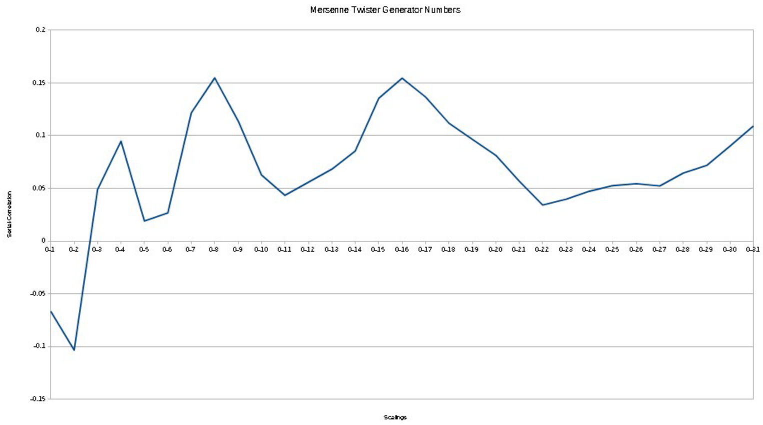

Figure 2.24. Mersenne Twister serial correlation

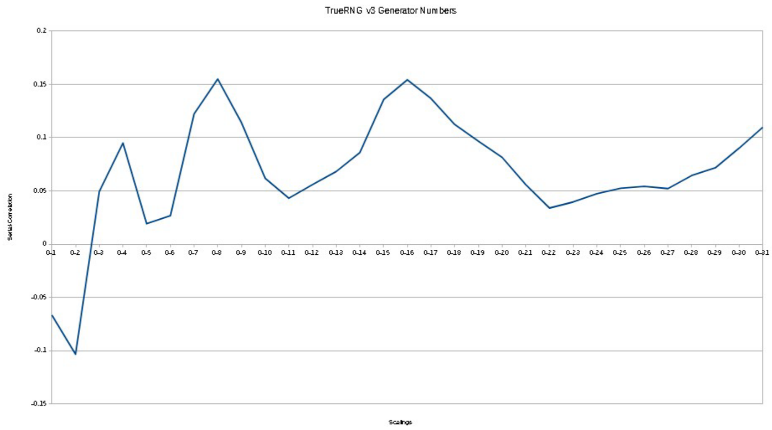

Figure 2.25. TrueRNG v3 serial correlation

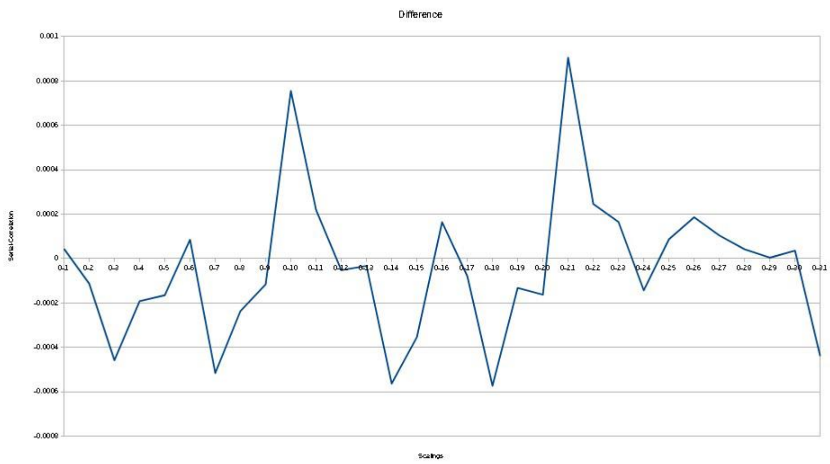

Figure 2.26. Serial correlation difference

2.5 Conclusions

Heuristic and metaheuristic methods, especially GA, provide robust frameworks for improving communication strategies and information process management in complex systems. The DNA-inspired GA modification and adaptive approximation of time-consuming fitness functions significantly reduce computational and communication traffic, enabling GA applicability on resource-constrained devices. Modular software organization and use of open libraries contribute to flexibility and quality of distributed systems. The holistic optimization approach considers both algorithmic results and the efficiency of underlying communication processes. Scientific publications reflecting the content of this chapter are listed at the end.

Chapter 3: Models for Communication Strategies in Information Process Management in Digital Environments: Technical and Architectural Aspects

Chapter 3 addresses the modeling of communication strategies in digital environments from technical and architectural viewpoints, focusing on optimizing information flows and communication processes. It discusses opportunities and challenges posed by digital environments, as well as interfaces and algorithms structuring online communication [Kevin Lewis, 2021].

A key aspect is digital literacy, encompassing technical, cognitive, and socio-emotional skills necessary for effective digital environment utilization. Higher technical digital literacy correlates with increased use of collaborative technologies [Andree-Anne Deschênes, 2023].

The diversity of digital channels and tools is presented in Table 3.1 [Anthony Cherbonnier et al., 2024], comparing immersive environments (e.g., video games and scenario-based simulations requiring group activity for collaborative skills training) with non-immersive environments (e.g., sharing platforms and online courses that provide shared workspaces for synchronous and asynchronous discussion).

IMMERSIVE ENVIRONMENTS *Can be used to teach collaborative skills and require group activity to achieve common goals*	**NON-IMMERSIVE ENVIRONMENTS** *Provide shared workspaces and channels for synchronous and asynchronous discussion*
Video Games	Sharing Platforms
Scenario Simulations	Online Courses
PC-Based Simulators and Augmented Reality Tools	Collaborative Problem Solving Tools

Table 3.1. Types of digital environments and their characteristics

Use of Android Content Providers and Architectural Aspects

For effective data management in mobile distributed environments, the dissertation proposes the use of Android Content Providers. They serve as a mechanism for modular data management and access, improving modularity and application robustness.

The client-server architecture is a fundamental model for digital information processes, where the server provides information or services to mobile devices (clients) via HTTP/JSON protocol.

Figures 3.1 to 3.3 illustrate client-server architecture, HTTP communication, and modular system components.

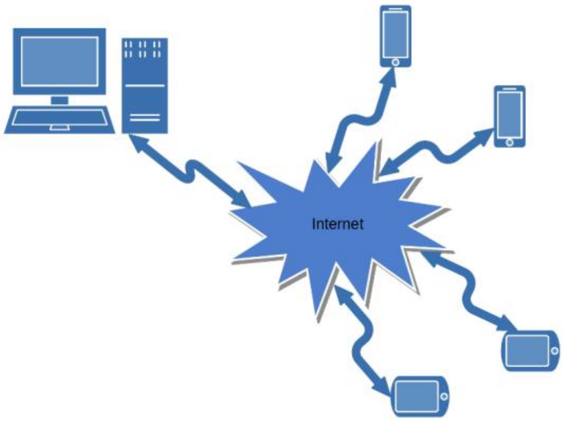

Figure 3.1. Client-server architecture

Figure 3.2. HTTP communication

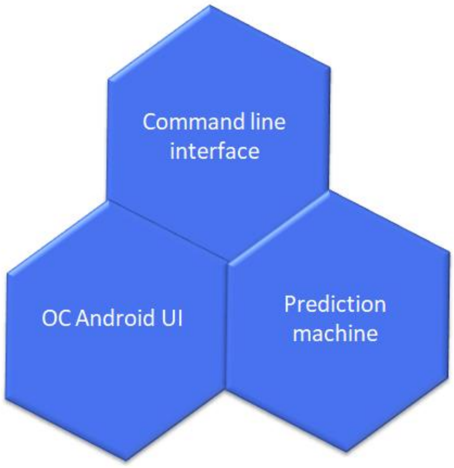

Figure 3.3. Modular architecture

Application of Content Providers in distributed computing includes data flow from server to mobile devices, management of global and local populations, and asynchronous communication models without frequent synchronization. This approach is particularly crucial for time-consuming fitness functions, where approximation reduces the need for frequent communication [Mateeva et al., 2022].

Technical and Architectural Analyses and Solutions

Mobile Cyber-Physical Systems (CPS) and the Internet of Things (IoT) underpin intensive digital transformation, creating new opportunities and challenges. CPS integrates physical process dynamics with software and networks for integrated modeling, design, and analysis [Sanfelice et al., 2016; Chen et al., 2020].

IoT data is often noisy, highly variable, and "rough," necessitating preprocessing to extract business value [Dineva et al., 2019]. The increasing number of IoT devices reaches the limits of existing architectural scalability. Cloud-Based IoT (CB-IoT) provides computational capabilities and storage via virtualization [Dineva et al., 2020]. Developed architecture is based on AWS cloud, enabling automated scaling and data analysis. Figure 3.4 visualizes these platforms.

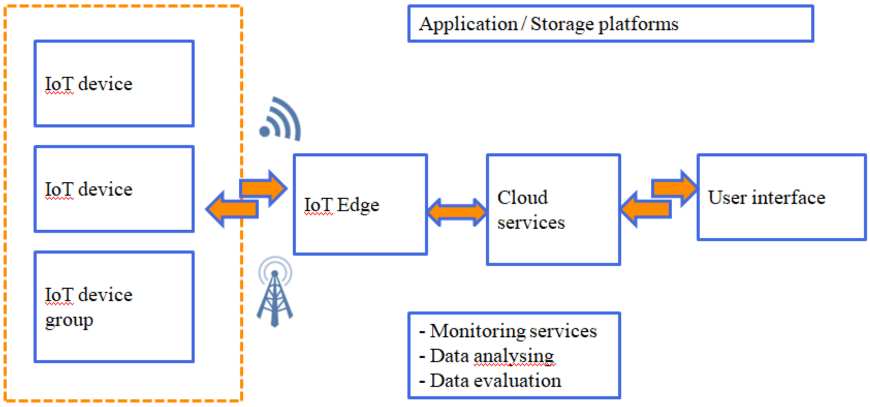

Figure 3.4. Cloud-based CPS/IoT architecture for monitoring livestock

Key means for distributed computing implementation include Android OS APIs (such as Android Services for background operations, Live Wallpaper for intermediate visualization, and Android Widgets for flexible visualization and user input) [Mateeva et al., 2021]. Systems use client-server architecture with HTTP/JSON RESTful communication, background execution, and local data storage in SQLite, alongside external Java-based libraries for machine learning, optimization, and communication. Modular design ensures flexibility.

Challenges and SWOT Analysis

Main challenges in interaction system design include operational interoperability (systems working seamlessly together) and resource constraints (limited memory, no display, weak processors) [Sadeghi & Mersedeh, 2023].

Table 3.2 summarizes problems, causes, and proposes principles such as minimalism and adaptability to address them [Margaria et al., 2011].

Category	Description	Impact / Consequences	Principles and Recommendations
Resource constraints	Limitations such as limited memory, lack of display, weak processors	Makes implementation and management difficult	Optimal use of resources through simplification
Reasons for restrictions	Economies of scale and constraints imposed by the host environment (weight, size, energy)	Affect system costs and capabilities	Taking into account at an early stage
Design	Working on not yet fully	The process is	Using iterative and

challenges	designed systems with critical unknown factors	complex and uncertain	adaptive approaches
A perspective on simplification	An approach to more efficient use of resources and creating stable, easy-to-maintain systems	Improves stability and performance	Applying the principle of "less is more"
Empirical observations	Collected findings and examples from experts, supporting the identification of good practices	Facilitate the practical application of the principles	Applying recommended methods in system design

Table 3.2. Challenges and principles in the design of resource-constrained systems

SWOT analysis of CPS/IoT and distributed computing resources identifies:

- Strengths: New product/service opportunities, integrated modeling approach, data value creation, cloud computing advantages (AWS), use of Android OS APIs, client-server architecture, background execution, local storage, and modular design.
- Weaknesses: Lack of data sharing standards, noisy and variable IoT data, need for preprocessing, architectural capacity limits, interoperability and resource constraint challenges.
- Opportunities: Development of data transformation methods, CB-IoT, enhanced data processing, distributed knowledge, AWS scaling and analysis, flexible standardized processes, and design simplification.
- Threats: Noise and data errors, data inconsistency, computational limits, lack of interoperability, and compromises due to resource constraints.

Architectural Models and Communication Optimization Techniques

Several architectural models for distributed systems are examined [Washizaki et al., 2020]:

- Client-server architecture: Centralized management, implemented in the dissertation, but susceptible to single point of failure.
- Peer-to-Peer (P2P) architecture: Decentralized with high fault tolerance, reducing dependence on a central server.
- Event-based (Publish-Subscribe) architecture: Suitable for IoT systems with asynchronous data generation (e.g., Smart Farming).

- Layered architecture: Models in the dissertation can be framed within layered architecture (Sensor, Network, Services, Application layers) [Triantafyllou et al., 2019].

Table 3.3 compares these models by principle, scalability, fault tolerance, latency, suitability for resource-constrained IoT, and relation to the dissertation model. A future hybrid architecture combining client-server, event-based, and P2P advantages is proposed to address SWOT-identified challenges.

Architectural Model	Key Principle	Scalability	Resilience	Latency Characteristics	Suitability for IoT with Limited Resources	Relationship to the Dissertation Model
Client-server	Centralized control	Limited by the server	Low (single point of failure)	Depends on proximity and server load	High (thin clients)	**Implementation model:** Central server for managing the population in GA; mobile clients for computation.
Peer-to-Peer (P2P)	Decentralized control	High	High (no single point of failure)	Variable; can be low for local participants	Medium (participants also act as servers)	**Alternative/Hybrid model:** Can be used for direct data exchange between mobile nodes without the intermediary of a server.
Event-driven (Pub/Sub)	Asynchronous messaging	High	High (weak connectivity)	Low for event distribution	High (lightweight publishers)	**Conceptual suitability:** Fits the nature of data generation from IoT sensors in smart agriculture.
Multilayer	Segregation of Responsibilities	Varies	Varies	Varies	High	**Overall Framework:** The system in the dissertation can be described by a multi-layer model (Sensory, Network, Services, Applied).

Table 3.3. Comparison table of basic architectural models

Specific communication optimization techniques in CPS/IoT include adaptive communication models (data transmission adaptation based on conditions), energy-efficient routing and data aggregation (traffic reduction via local processing), and low-energy technologies (e.g., backscatter communication) [Taha et al., 2020; Wei et al., 2018; Ding et al., 2024; Chen et al., 2021]. Optimization is a holistic, multi-layered problem linking algorithmic optimization with network and energy efficiency [Taha et al., 2020; Wei et al., 2018; Ding et al., 2024].

Heuristic optimization architectural design in distributed systems employs an "island model" for GA (each mobile device is an "island" with a local population). Information exchange among nodes and central server includes initial population distribution, individual migration, and broadcasting the global best solution, balancing quality and communication traffic [Mohamed et al., 2012].

Integration of "DNA-inspired GA modification" and "time-consuming fitness function approximation" changes architectural requirements, allowing GA execution on resource-constrained devices by reducing communication traffic. This algorithm-architecture synergy represents a holistic algorithmic-architectural framework [Krupitzer et al., 2020].

Prospective Architectural Vision and Conclusions

Future directions include integration with federated learning (training local device models, sending only parameters for aggregation), multi-agent systems (decentralized negotiations, devices as autonomous agents), and the impact of 5G/6G networks and quantum communication for lower latency and higher security [Marfo et al., 2025; Dritsas et al., 2025; Yang et al., 2012; Saad et al., 2009; Zreikat et al., 2025]. The dissertation framework is a fundamental step toward fully autonomous and decentralized intelligent systems.

Mobile, cyber-physical systems (CPS), and IoT form the basis of digital transformation but require innovative design strategies to address interoperability and resource constraints. The developed models enable efficient application of heuristic methods on heterogeneous mobile and IoT devices in resource-constrained distributed digital environments, including their technical and architectural aspects of information flow management.

Main Scientific and Applied Contributions

This dissertation presents a holistic hybrid framework for optimizing communication strategies in distributed digital environments with limited resources, integrating flexible architectural models, advanced heuristic methods, and a holistic approach to information flow management.

Contributions are grouped into three categories:

1. Methodological contribution: Two new approaches for improving genetic algorithm efficiency in networked environments are developed:

- DNA-inspired genetic algorithm modification: A new representation using paired chromosomes with inverted bits is proposed and validated. This method enhances search space exploration and maintains population diversity, providing more stable solutions for complex optimization problems compared to standard GA.
- Adaptive method for approximating computationally expensive fitness functions: A new technique using Lagrange polynomials to approximate time-consuming fitness functions is developed. This approach significantly reduces computational and communication traffic, making GA applicable on resource-constrained devices. The adaptive nature of the approximation set represents a self-optimizing mechanism within the algorithm itself.

2. Architectural contribution: A new architectural model for practical deployment of computationally intensive optimization algorithms (such as GA) on heterogeneous mobile and IoT devices with limited resources is created. The novelty lies in the synergistic combination of:

- Asynchronous communication protocols: The model minimizes the need for frequent synchronization between central server and clients, mitigating the "slowest client" problem common in distributed systems.
- Modular and buffered data management: Specific use of mechanisms like Android Content Providers serves as a generalized model separating user interaction from background computation, ensuring system responsiveness and efficient local data processing. This joint algorithm-architecture design is a significant contribution to Edge AI and distributed intelligence.

3. Applied contribution: A comprehensive applied model for intelligent monitoring and data processing in smart agriculture is developed, validated through the "Smart Livestock" project. Validation is multidisciplinary, using:

- Quantitative performance metrics: Rigorous evaluation using standard metrics such as Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) to demonstrate forecasting accuracy and optimization algorithm effectiveness.

- Qualitative strategic analysis: SWOT analysis contextualizes system strengths and weaknesses and validates design decisions against domain key challenges like data quality, interoperability, and resource constraints.

Directions for Future Research

Key future research directions include:

- Further development and application of advanced heuristic methods, particularly genetic algorithms, in distributed digital environments with limited resources.
- Expansion of studies on adaptive and decentralized architectural models for effective management of information flows and resources.
- In-depth exploration of integration and application of emerging communication technologies and AI approaches for improving optimization strategies (e.g., quantum communication, 5G/6G, holographic interfaces).

Publications Related to the Dissertation Topic

1. Mateeva, G., Parvanov, D., Balabanov, T. Study on Random Numbers Scaling. The 37th European Simulation and Modelling Conference, ESM 2023, EUROSIS-ETI, 2023, ISBN:978-9-492-859-28-0, pp. 21-25 (Scopus)
2. Mateeva, G., Parvanov, D., Balabanov, T. DNA-INSPIRED GENETIC ALGORITHM MODIFICATION. Proceedings of 21st INTERNATIONAL INDUSTRIAL SIMULATION CONFERENCE ISC'2023, EUROSIS-ETI, 2023, ISBN:978-9-492-859-26-6, pp. 27-31 (Scopus)
3. Mateeva, G., Parvanov, D., Dimitrov, I., Iliev, I., Balabanov, T. An Efficiency of Third Party Genetic Algorithms Software Libraries in Mobile Distributed Computing for Financial Time Series Forecasting. Proceedings of 2022 International Conference Automatics and Informatics (ICAI), IEEE, 2022, ISBN:978-1-6654-7626-3, DOI: 10.1109/ICAI55857.2022.9960128, pp. 351-354 (Scopus)
4. Mateeva, G., Parvanov, D., Dimitrov, I., Iliev, I., Balabanov, T. Android Content Providers in Mobile Distributed Computing. Proceedings of 2022 13th National Conference with International Participation (ELECTRONICA), IEEE, 2022, ISBN:978-1-6654-8101-4, DOI: 10.1109/ELECTRONICA55578.2022.9874360 (Scopus)

5. Dineva, K., Atanasova, T., Petrov, P., Parvanov, D., Mateeva, G., Kostadinov, G. Towards CPS/IoT System for Livestock Smart Farm Monitoring. 2021 International Conference Automatics and Informatics (ICAI), IEEE, 2021, ISSN:978-1-6654-2661-9, DOI: 10.1109/ICAI52893.2021.9639460, pp. 252-255 (Scopus)
6. Mateeva, G., Tomov, P., Parvanov, D., Petrov, P., Kostadinov, G., Balabanov, T. Some Capabilities of Android OS for Distributed Computing. Proceedings of Big Data, Knowledge and Control Systems Engineering (BdKCSE), 2021, ISBN:978-1-6654-1043-4, DOI: 10.1109/BdKCSE53180.2021.9627286, pp. 1-6 (Scopus)
7. Mateeva, G., Parvanov, D., Dimitrov, I., Iliev, I., Balabanov, T. Time-Consuming Fitness Functions Approximation for Genetic Algorithms Performance Improvement. Proceedings of 9th SWS International Scientific Conference on Social Sciences - ISCSS 2022, 9(1), SGEM WORLD SCIENCE (SWS) Scholarly Society, 2022, ISBN:978-3-903438-04-0, ISSN:2682-9959, DOI: 10.35603/sws.iscss.2022/s04.053

Participation in Projects

- National Scientific Program "Smart Livestock" (Inte-Zhivo), RP 5 and RP 11.
- Research on Methods and Technologies for Digitalization of Education, KP-06-M75/3.

Bibliography

1. Mateeva, G., Parvanov, D., Balabanov, T. Study on Random Numbers Scaling. The 37th European Simulation and Modelling Conference, ESM 2023, EUROSIS-ETI, 2023, ISBN:978-9-492-859-28-0, 21-25
2. Mateeva, G., Parvanov, D., Balabanov, T. DNA-INSPIRED GENETIC ALGORITHM MODIFICATION. Proceedings of 21st INTERNATIONAL INDUSTRIAL SIMULATION CONFERENCE ISC'2023, EUROSIS-ETI, 2023, ISBN:978-9-492859-26-6, 27-31
3. Mateeva, G., Parvanov, D., Dimitrov, I., Iliev, I., Balabanov, T. An Efficiency of Third Party Genetic Algorithms Software Libraries in Mobile Distributed Computing for Financial Time Series Forecasting. Proceedings of 2022 International Conference Automatics and Informatics (ICAI), IEEE, 2022, ISBN:978-1-6654-7626-3, DOI:10.1109/ICAI55857.2022.9960128, 351-354
4. Mateeva, G., Parvanov, D., Dimitrov, I., Iliev, I., Balabanov, T. Android Content Providers in Mobile Distributed Computing. Proceedings of 2022 13th National Conference with International Participation (ELECTRONICA), IEEE, 2022, ISBN:978-1-6654-8101-4, DOI:10.1109/ELECTRONICA55578.2022.9874360
5. Dineva K., Atanasova T., Petrov P., Parvanov D., Mateeva G., Kostadinov G. Towards CPS/IoT System for Livestock Smart Farm Monitoring. 2021 International Conference Automatics and Informatics (ICAI), IEEE, 2021, ISSN:978-1-6654-2661-9, DOI:10.1109/ICAI52893.2021.9639460, 252-255
6. Mateeva, G., Tomov, P., Parvanov, D., Petrov, P., Kostadinov, G., Balabanov, T. Some Capabilities of Android OS for Distributed Computing. Proceedings of Big Data,

Knowledge and Control Systems Engineering (BdKCSE), 2021, ISBN:978-1-6654-1043-4, DOI:10.1109/BdKCSE53180.2021.9627286, 1-6

7. Mateeva, G., Parvanov, D., Dimitrov, I., Iliev, I., Balabanov, T. Time-Consuming Fitness Functions Approximation for Genetic Algorithms Performance Improvement. Proceedings of 9th SWS International Scientific Conference on Social Sciences - ISCSS 2022, 9, 1, SGEM WORLD SCIENCE (SWS) Scholarly Society, 2022, ISBN:978-3-903438-04-0, ISSN:2682-9959, DOI:10.35603/sws.iscss.2022/s04.053
8. A. C. Elkins, D. C. Derrick, J. K. Burgoonand J. F. Nunamaker Jr., "Predicting Users' Perceived Trust in Embodied Conversational Agents Using Vocal Dynamics," 2012 45th Hawaii International Conference on System Sciences, Maui, HI, USA, 2012, pp. 579-588, doi: 10.1109/HICSS.2012.483
9. A. Triantafyllou, D. C. Tsouros, P. Sarigiannidisand S. Bibi, "An Architecture model for Smart Farming," 2019 15th International Conferenceon DistributedComputingin Sensor Systems (DCOSS), Santorini, Greece, 2019, pp. 385-392, doi: 10.1109/DCOSS.2019.00081.
10. Balasko B., Nemeth S., Nagy G., Abonyi J. Integrated process and control system model for product quality control-application to a polypropylene plant (2008) Chemical Product and Process Modeling, 3 (1), art. no. 50, DOI: 10.2202/1934-2659.1213
11. Balabanov, T. 2020. “Global optimization benchmark function?”. ResearchGate. https://www.researchgate.net/ post/Global_optimization_benchmark_function , last visited 24 Mar 2023
12. Bendoly E., Bachrach D.G., Powell B. The role of operational interdependence and supervisory experience on management assessments of resource planning systems (2008) Production and Operations Management, 17 (1), pp. 93 - 106, DOI: 10.3401/poms.1070.0001
13. Caffrey E., Mc Donagh J. Aligning strategy and information and communication technology in public organizations: A critical management challenge (2015) Information and Communication Technologies in Public Administration: Innovations from Developed Countries, pp. 141 - 164, DOI: 10.1201/b18321
14. Chen D., Chirkova R., Kormilitsin M., Sadri F., Salo T.J. Query optimization in XML-based information integration (2008) International Conference on Information and Knowledge Management, Proceedings, pp. 1405 - 1406, DOI: 10.1145/1458082.1458303
15. Chen Y., Li Y., Li C., Electronic agriculture, blockchain and digital agricultural democratization: Origin, theory and application, Journal ofCleaner Production, 268, 122071, 2020
16. Chtioui T., Dubuisson S.T. Towards a communication-based typology of management control modes: Showing the relevance of communicative action for entrepreneurial settings (2020) International Journal of Entrepreneurship and Small Business, 39 (1-2), pp. 163 - 191, DOI: 10.1504/ijesb.2020.104249
17. Cormen, T. H., Leiserson, C. E., Rivest, R. L., Stein, C. (2022). Introduction to algorithms, MIT Press, ISBN9780262046305
18. C. Krupitzer, T. Temizer, T. Prantl and C. Raibulet, "An Overview of Design Patterns for Self-Adaptive Systems in the Context of the Internet of Things," in IEEE Access, vol. 8, pp. 187384-187399, 2020, doi: 10.1109/ACCESS.2020.3031189.
19. de Freitas S.A.A., Canedo E.D., Felisdório R.C.S., Leão H.A.T. Analysis of the risk management process on the development of the public sector information technology master plan (2018) Information (Switzerland), 9 (10), art. no. 248, DOI: 10.3390/INFO9100248
20. Demirdöğen G., Işik Z., Arayici Y. Lean management framework for healthcare facilities integrating BIM, BEPS and big data analytics (2020) Sustainability (Switzerland), 12 (17), art. no. 7061, DOI: 10.3390/su12177061
21. Dejun Yang, Xi Fang, Guoliang Xue. Game theory in cooperative communications, IEEE Wireless Communications, Article2012, DOI: 10.1109/MWC.2012.6189412

22. Ding, X., Shen, W., & Wang, S. (2024). Centralized or Decentralized? Communication Network and Collective Effectiveness of PBOs—A Task Urgency Perspective. Buildings, 14(2), 448. https://doi.org/10.3390/buildings14020448
23. Dritsas, E., &Trigka, M. (2025). Federated Learning for IoT: A Survey of Techniques, Challenges, and Applications. Journal of Sensor and Actuator Networks, 14(1), 9. https://doi.org/10.3390/jsan14010009
24. Escobar-Toledo C.E., Martínez-Berumen H.A. Strategic development of a decision making support system in a public R & D center (2013) Engineering Effective Decision Support Technologies: New Models and Applications, pp. 181 - 193, DOI: 10.4018/978-1-4666-4002-3.ch011
25. Escobar-Toledo C.E., Martínez-Berumen H.A. Strategic Development of a Decision Making Support System in a Public R&D Center (2011) International Journal of Decision Support System Technology, 3 (2), pp. 32 - 43, DOI: 10.4018/jdsst.2011040103
26. Folch M.T., Tamayo P.S. Technologies of information and communication: A key element of communication among university faculty [Las tecnologías de información y comunicacióncomo un elemento clave de la comunicación entre elprofesoradouniversitario] (2008) Education Policy Analysis Archives, 16
27. Gillard S. Managing IT projects: Communication pitfalls and bridges (2005) Journal of Information Science, 31 (1), pp. 37 - 43, DOI: 10.1177/0165551505049257
28. Glowalla P., Balazy P., Basten D., Sunyaev A. Process-driven data quality management - An application of the combined conceptual life cycle model (2014) Proceedings of the Annual Hawaii International Conference on System Sciences, art. no. 6759178, pp. 4700 - 4709, DOI: 10.1109/HICSS.2014.575
29. Hinton M. The process of information management (2006) Introducing Information Management: The Business Approach, pp. 56 - 62, DOI: 10.4324/9780080458397-11
30. H. Washizaki, S. Ogata, A. Hazeyama, T. Okubo, E. B. Fernandezand N. Yoshioka, "Landscape of Architecture and Design Patterns for IoT Systems," in IEEE Internet ofThingsJournal, vol. 7, no. 10, pp. 10091-10101, Oct. 2020, doi: 10.1109/JIOT.2020.3003528.
31. Margaria T., Floid B. D., Srefen B, 2011
32. Marchao J., Reis L., Martins P.V. Business Areas and Processes Alignment in ICT Framework [Framework de Alinhamento de Áreas e Processos de Negócio das TIC] (2020) Iberian Conference on Information Systems and Technologies, CISTI, 2020-June, art. no. 9141067, DOI: 10.23919/CISTI49556.2020.9141067
33. Martyakova E.V., Nagornaya O.A., Bondarenko I.G. Current Trends in Using Information and Communication Technologies at Universities (2019) Proceedings of the 2019 IEEE International Conference Quality Management, Transport and Information Security, Information Technologies IT and QM and IS 2019, art. no. 8928372, pp. 535 - 538, DOI: 10.1109/ITQMIS.2019.8928372
34. M.Mohamed Surputheen, G. Ravi, R. Srinivasan, Optimizing Routesusing Genetic Algorithms based on Throughput or Delay Sensitivity of Applications using SNMP for Automatic Discovery of Network Topology. International Journal of Computer Applications (0975 – 888) Volume 47– No.12, June 2012
35. Navarro M.A., Morales-Castaneda B., Ramos-Michel A., Oliva D., Valdivia A., Casas-Ordaz A., Rodriguez-Esparza E. An Hyper-Heuristic Based Population Management Through Statistical Analysis and Phases Optimization (2023) 2023 IEEE Congress on Evolutionary Computation, CEC 2023, DOI: 10.1109/CEC53210.2023.10254032
36. Pobegaylov O.A., Myasishchev G.I., Gaybarian O.E. Organization and Management Efficiency Assessment in the Aspect of Linguistic Communication and Professional Text (2016) Procedia Engineering, 150, pp. 2173 - 2177, DOI: 10.1016/j.proeng.2016.07.260
37. PolyaninA., Golovina T., Avdeeva I., Dokukina I., Vertakova Y. Digital strategy of telecommunications development: Concept and implementation phases (2017) Proceedings

of the 30th International Business Information Management Association Conference, IBIMA 2017 - Vision 2020: Sustainable Economic development, Innovation Management, and Global Growth, 2017-January, pp. 1792 – 1803

38. Prokofiev S.E., Kadyrova G.M., Artyukhin R.E., Yeremin S.G., Savelyev A.A. Present-day information technologies in public administration in Russia (2021) IOP Conference Series: Earth and Environmental Science, 650 (1), art. no. 012016, Cited 3 times. DOI: 10.1088/1755-1315/650/1/012016
39. Sadeghi M., Carenini A., Corcho O., Rossi M., Santoro R., Vogelsang A. Interoperability of Heterogeneous Systems of Systems: Review of Challenges, Emerging Requirements and Options (2023) Proceedings of the ACM Symposium on Applied Computing, pp. 741 - 750, DOI: 10.1145/3555776.3577692
40. SanfeliceR., Analysis and Design of Cyber-Physical Systems. A Hybrid Control SystemsApproach, In: Cyber-PhysicalSystems: FromTheorytoPractice, D. Rawat, J. Rodrigues, I. Stojmenovic, 2016.]
41. Salutina T.Y., Platunina G.P., Frank I.A. Features of Risk Management of Digital and Infocommunication Development to Ensure a Unified Information Space of Companies in Modern Conditions (2023) 2023 Intelligent Technologies and Electronic Devices in Vehicle and Road Transport Complex, TIRVED 2023 - Conference Proceedings, DOI: 10.1109/TIRVED58506.2023.10332796
42. Tan X., Wang Y., Liu C., Yuan X., Wang K. Unlocking operational excellence: A deep dive into a communication-driven multi-strategy state transition algorithm for industrial process optimization (2023) Chemometrics and Intelligent Laboratory Systems, 240, art. no. 104934, DOI: 10.1016/j.chemolab.2023.104934
43. Taha, A.-E. M., Rashwan, A. M., &Hassanein, H. S. (2020). Secure Communications for Resource-Constrained IoT Devices. Sensors, 20(13), 3637. https://doi.org/10.3390/s20133637]
44. Tešić M. More Efficient Operations of the Company with the Help of Communication Technologies (2016) ECONOMICS - Innovative and Economics Research Journal, 4 (2), pp. 143 - 152, DOI: 10.1515/eoik-2017-0005
45. Van De Bogart W. Information entanglement: Developments in cognitive based knowledge acquisition strategies based on big data (2015) Proceedings of the International Conference on Intellectual Capital, Knowledge Management and Organisational Learning, ICICKM, 2015-January, pp. 299 – 307
46. Wei, Y., Chen, J., &Hwang, S.-H. (2018). AdjacentVehicleNumber-TriggeredAdaptiveTransmissionfor V2V Communications. Sensors, 18(3), 755. https://doi.org/10.3390/s18030755
47. William Marfo, Deepak K. Tosh, Shirley V. Moore, Joshua Suetterlein, Joseph Manzano. Reducing Communication Overhead in Federated Learning for Network Anomaly Detection with Adaptive Client Selection. arXiv:2503.15448v1 [cs.DC] 19 Mar 2025
48. W. Saad, Z. Han, M. Debbah, A. Hjorungnesand T. Basar, "Coalitional game theory for communication networks," in IEEE Signal Processing Magazine, vol. 26, no. 5, pp. 77-97, September 2009, doi: 10.1109/MSP.2009.000000
49. Yang P. Information Management in the Logistics and Distribution Sector Using Metaheuristic Techniques (2022) International Journal of Information Systems and Supply Chain Management, 15 (4), DOI: 10.4018/IJISSCM.305850
50. Z. Chenand B. Ji, "Resource all ocation algorithm for IoT communication based on ambient backscatter," 2021 IEEE 93rd Vehicular Technology Conference (VTC2021-Spring), Helsinki, Finland, 2021, pp. 1-5, doi: 10.1109/VTC2021-Spring51267.2021.9448677
51. Zreikat, A. I., Al Arnaout, Z., Abadleh, A., Elbasi, E., & Mostafa, N. (2025). The Integration of the Internet of Things (IoT) Applications into 5G Networks: A Reviewand Analysis. Computers, 14(7), 250. https://doi.org/10.3390/computers14070250
52. Galbraith, 1977

53. Heaton, J. (2014). Artificial Intelligence for Humans, Volume 2: Nature-Inspired Algorithms, ISBN 978-1499720570. IbaHitoshi. (2020).
54. Approximated Sequences Reconstruction with Genetic Algorithms P. Petrov, G. Kostadinov, P. Zhivkov, V. Velichkova, T. Balabanov, АВТОМАТИКА И ИНФОРМАТИКА 3-4, 2021 г.
55. Xujie Tan, Yalin Wang, Chenliang Liu *, Xiaofeng Yuan, Kai Wang, Unlocking operational excellence: A deep dive into a communication-driven multi-strategy state transition algorithm for industrial process optimization, Chemometrics and Intelligent Laboratory Systems, 2023
56. Collaborative Skills Training Using Digital Tools: A Systematic Literature Review, Anthony Cherbonnier, BrivaelHémon, NicolasMichinov, Eric Jamet & Estelle Michinov, 2024]
57. Digitalliteracy, the use of collaborative technologies, and perceived social proximity in a hybrid work environment: Technology as a socialbinder, Andree-AnneDeschˆ enes, 2023
58. Digital networks: Elementsof a theoretical framework, Kevin Lewis, 2021
59. Sanfelice R., Analysis and Design of Cyber-Physical Systems. A Hybrid Control Systems Approach, In: Cyber-Physical Systems: From Theory to Practice, D. Rawat, J. Rodrigues, I. Stojmenovic, 2016.
60. Chen Y., Li Y., Li C., Electronic agriculture, blockchain and digital agricultural democratization: Origin, theoryand application, Journal of Cleaner Production, 268, 122071, 2020.
61. Atanasova, T.: Methods for processing of Heterogeneous Data in IoT based Systems. DCCN 2019, CCIS 1141, Springer, 42, 2019.
62. Dineva, K., Atanasova, T., Methodology for Data Processing in Modular IoT System. DCCN 2019, In: V. M. Vishnevskiyetal. (Eds.):DCCN 2019, LNCS 11965, pp. 457–468. Springer, 2019.
63. Dineva K., Atanasova T. Architectural ML Framework for IoT Services Delivery Based on Microservices. In: Vishnevskiy V.M., etal(eds) DCCN 2020. LNCS, 12563. Springer, 2020.