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A New Methodology for Designing of Tactical Integrated Telecommunications and Computer Networks for OPNET Simulation

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This paper present a novel methodological approach in the design of integrated tactical telecommunications and computer networks for command information system and defining the elements for the OPNET simulation model. The elements proposed for design of network information architecture. For that purpose, the way established to set up relationships between elements that uses for network topologies design, building of network elements and network traffic. They are integrated with its parameters in the preliminary model defined by an OPNET simulation model. We propose the measure of efficiency for accomplishment of tactical command requirements to use the design model network. This measure of efficiency is mean time delay that described with mathematical relations, involving the communication parameters speed of generating traffic, packet size, link capacity and adequately reflects the projected network. Furthermore, the applications of the proposed approach and given instructions allow to designers full examination of the network architecture, and provide translation into preliminary model and design OPNET simulation model.

Key words: **tactical communications, command requirements, telecommunications, computer, network design, integrated networks, OPNET, simulation model, communication information system.**

Introduction

COMMANDI System (CIS) in a broader sense can be defined as a set of hardware and software solutions by which achieves real-time integration of organizational structure, doctrine, technological systems and equipment, information flows and process for the effective and rational decision-making and operation. Distribution time and quality of information generated directly affect on the implementation of the decision making process. Also, they are important criteria for assessing the effectiveness of system whose most important role is achieving Integrated Telecommunication and Computer Networks (ITCN) dimensioned. With this the spatial distribution of tactical combat units on the battlefield connect all its elements in a communications unit attach. Basic design concept of battlefield information architecture needs to support tactical command requirements. They determine the hierarchical structure of command and established information flows. Information architecture that should support the communication is defined by organization, system, software, technical, information and communications [1]. Further development of the tactical communication network is conditioned by the application of new communication technologies for network information exchange. Its design requires the identification of critical user requirements. The proper analysis enables the use of technologies in the design of a network communication environment.

Motivation

All approaches in related works are part of the same and of specific elements to be analyzed in the design of tactical communications network without description of the steps and necessary relations order of input elements to get to the output elements necessary for the implementation of the OPNET network simulation model. The main problem in the ITRM design process is the approach to which the analysis is performed and the selection of elements for analysis. It should provide the use of tactical CIS. The question is how to perform element analysis to determine the parameters required for network modeling and OPNET simulation model design? At the same time it is necessary to achieve the set command and tactical requirements, applicable standards and available telecommunication and information technology for network integration. Following the ideas described in [2-14], motivation for this work was to propose an approach to ITCN modeling methodology and design for OPNET simulation which defines the phases and steps the network designer needs to implement and thereby establish the necessary relationships between command requirements and ITCN design elements and communications network parameters.

The methodology and ITCN design phases

Methodology approach in this work defines all relations between input elements, network design elements and

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simulation model with the order of their definition. Application of this approach allows the designer network clear perception to ITCN design based on request for tactical CIS, mapping solutions in OPNET simulation model, implement testing and appropriate optimization. In this work we have applied this methodology to design ITCN for the model of tactical unit with 100 active network elements. Starting from the basic relations of the DoDAF [1] viewpoints for design C4ISR system, this paper defines an approach to the ITCN design methodology of tactical CIS as a way of indicating how to proceed with the analysis and extract all the elements necessary for its design simulation model.

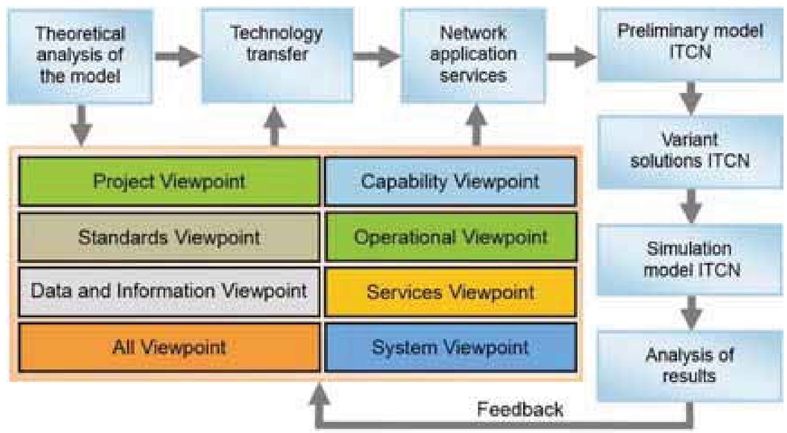

Figure 1. Phases and the elements in the methodology of designing ITCN

The methodology of designing model ITCN tactical CIS combat units we propose implementation of a series of analytical phases within which there is a necessary elements for the design. Functional block diagram (Fig.1) shows relations between design phases. ITCN design flow model of the initial request to the creation and verification of the simulation model is divided into design phases in which the envisaged steps carried out analysis with various DoDAF viewpoints. The methodology is applied throughout the design phases and elements on the model of a tactical unit. The organizational structure of tactical unit is analyzed theoreticaly, defined the functional interrelationships, and information flow process of command between the established groups of organizational structure elements which are classified according to a network-centric concept [15,16].

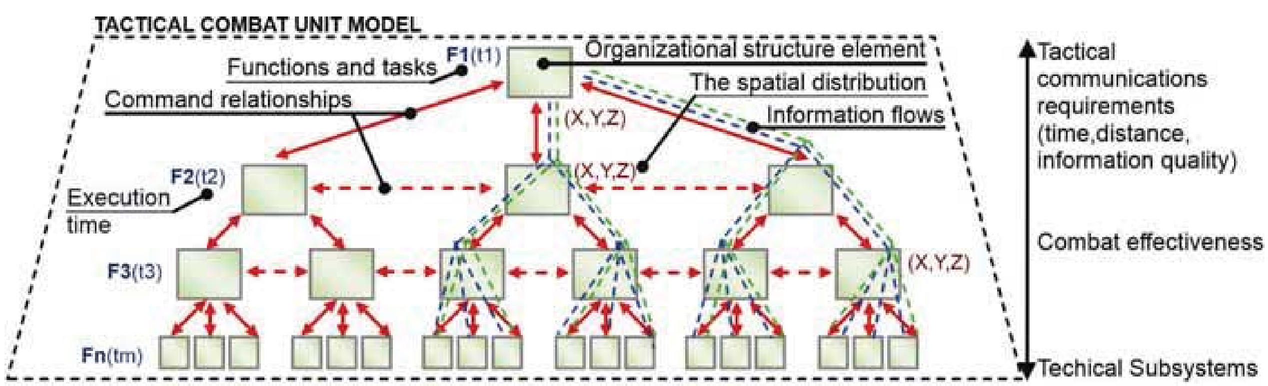

Figure 2. Elements of theoretical analysis model of tactical combat unit

The next phase defines a relation model ITCN with available technology transfer, and then follows phase of network application services and applications design for operational procedures implementation and distribution data in the command process. Projected elements of the network are mapped in the preliminary model followed by carrying solutions of the ITCN model and its optimization. Each variant of the simulation model is realized using OPNET. Phase analysis of simulation results and draw conclusions about the designed network model according to the tactical and communication requirements for achieving the required combat effectiveness. Feedback loop with the initial viewpoints is established based on analysis of simulation results.

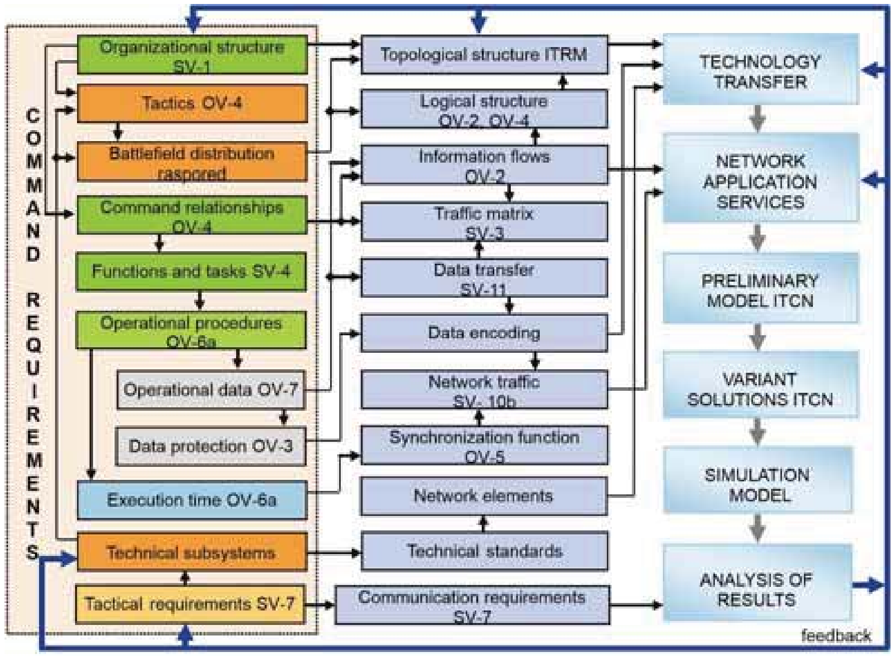

Figure 3. DoDAF elements analysis aspects and relationship of design ements ITCN

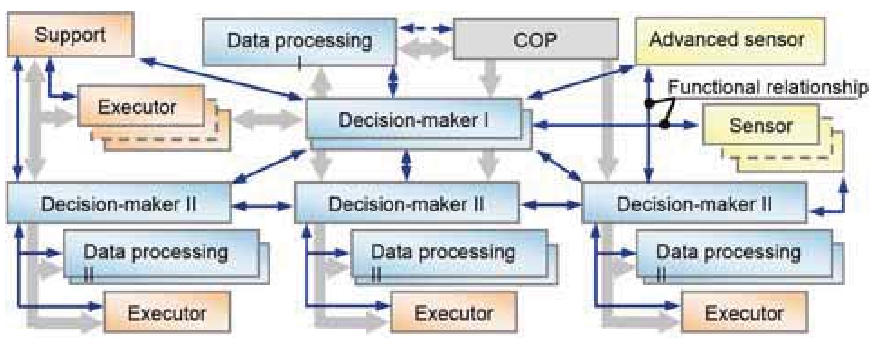

Figure 4. Example of tactical unit organizational network-centric functional scheme

Theoretical analysis of the model

The first phase in the process of designing model ITCN is a theoretical analysis of documentation that defines the organizational structure of the Army and functionality of a tactical unit. A theoretical analysis is performed in accordance DoDAF viewpoints and for the ITCN design appropriated necessary input elements which structural position in the description of tactical units are shown in Figure 2. Theoretical analysis of the DoDAF elements that stand out with their descriptive parameters of the basic input information called ***command requirements*** needed for the design of ITCN.

The analysis found that between elements of command requirements there are interconnections and shows their interdependence and the order in which elements take one of the following (Fig.3.)

Organizational structure

The goal of the organizational structure analysis is to determine the basic functional relations and structure elements which realize the function and tasks assigned. It is necessary to decompose the organizational structure applying the principles of network-centric warfare concept, according to which elements of the organizational structure should be defined by their roles, responsibilities, tasks, decisions made by, mutual functional connections and the information to exchanged. Selected structure elements should be grouped as network elements (nodes) in three basic modes in which they as elements of the battlefield can be found: sensing, decision making, execution [15,16].

Level of representation modes in single-element depends on his role in the military operation. Applying this procedure to organizational structure model tactical unit of used for this study, was performed and Figure 4. shows the basic network-centric functional diagram of the unit.

Functional relationship between the grouping of network elements is derived from a hierarchy of command defined by the command relationships for tactical unit. The above division plays a key role in the systematization of network elements in the design of network structure, defining workstations, network subnets and application services.

Functions and tasks

In further analysis should be carried out the processes decomposed to specific functional activities in the organizational structure and defined with the command relationships. Each element of the organizational structure in which the modeling of ITCN gets the role of a network element performs a specific function Fn(tm), n=[1,j] m=[0,i] as a specific activity, where is necessary to achieve their mutual synchronization time of duration, repetition and completion. Synchronization function is defined with command rules, instants of their mutual time of initialization ($t_1,t_2,t_3,..,t_i$), Δt - time interval of duration ($\Delta t_1, \Delta t_2, \Delta t_3, ..\Delta t_i$) defined in Operational procedures. Besides analyzing the operational rules of procedure it comes to the *operational data type*, *size* and *quantity of information* which is distributed in the command process for various time-critical tactical unit operations.

Functional and temporal relations are essential in design of simulation network model ITCN for description and implementation of real network traffic. Functional and temporal relations are essential in design of simulation network model ITCN for description and implementation of real network traffic.

Execution time

The result of the network elements ITCN functions execution is the generation of data and information and their distribution to the planned destination at a certain time. The variability of the sources in terms of quantity, speed, time moments and intervals of data generation, indicates that the process time of the command process function is fundamentally important element for implementation of network traffic in a simulation model. Properly defining the source of data and more realistic description of the network traffic information flow is necessary for each group of network elements and perform scenario analysis in terms of the time and sequence of command functions activation, duration and repetition. Analysis of the function and tasks synchronization should be implemented for the corresponding time critical operational situations. The result of this time synchronization analysis is a time scenario of simulation network model. Scenario is defined as the temporal pattern of activation and repetition of functions Fn(tm) in the corresponding operational situation. Method of preparation and presentation of this temporal pattern with network application services (Sn) for groups of network elements illustrate the principle shown in Figure 5. *Temporal pattern* is a form for defining the transport network application services Sn.

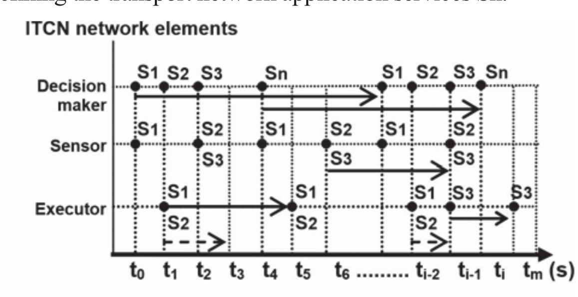

Figure 5. Temporal pattern of activation and repetition of network elements functions Fn (services Sn)

where is t_0 - activation time function (services) S_1 on the network elements Decision maker and Sensor, t_1 - activation time function (services) S_1 and S_2 on the network elements Executor and S_2 on the Decision maker, t_i - the time by which activated required functions Fn (services Sn). Time variability t_m=[0,i] and duration intervals $\Delta t = t_i - t_{i-1}$ of functions $F_n(t_m)$ that is services Sn shows the statistical nature of events function time in a temporal pattern scenario. Mathematical probability distribution function and autocorrelation is relevant way to describe the variability of time moments, duration intervals and network traffic parameters, which could be discrete and continuous and to be implemented in the simulation model of network traffic as statistical processes. In this research particular distribution function and the interpretation of them is given [17,18,19,20,21]. Medium discrete values of time, scope changes and interval repetition of deterministic process preparation for a tactical unit combat is necessary to determine with the operational procedures analysis. Analysis of the stochastic process during combat operations should be implemented on generating assumptions variable network traffic.

Information flows

The realization of functions $F_n(t_m)$ of network elements with network application services Sn essentially represents the distribution of data and information from the source to the destination where their meaning will be used in the command process. Information flows are communications paths by which in the organizational structure realized distribution of information between their source and destination. Flows are determined by the command process which includes a set of functional relations based on rules of functioning of the tactical unit.

Data transfer

Amount of useful data information flows should be transmitted from source to destination is one of the parameters required for the selection of telecommunication network access techniques, media and transfer technology for the implementation in simulation model. It is necessary to calculate the minimum and maximum amount of information distributed in each network element depending on the function of command process. Variability in amount of data generated also describes by mathematical distribution function. In the process of determining the quantity of data to be transferred is necessary to take into account the increase in the amount of code necessary for their protection (reconstruction, encryption, error detection) that can be applied to layers of the OSI network model.

Code and user required level data encryption protection is an essential factor affecting the transmission rate and required transmission range of communication channels is determined by the applied coding techniques, length, type and distribution of cipher keys [22]. It is necessary to the existing technique of the protective coding considered in relation to effectiveness of protection, an additional amount of entered data, required transmission capacity, required BER and the time achieved tactical efficiency.

Traffic matrix

Matrix of the network traffic between nodes in the ITCN reflects relationships and is necessary and indispensable element required for the design of network links and traffic implementation in simulation model. Based on the information flow is defined matrix of network traffic is. Distribution of data and information from source to destination is defined by the relations of command process which are mapped to the matrix network traffic. Network node relationships is defined by matrix position (Mij) which is defined by organizational structure of network-centric elements, subnetworks, information flows and network application services presented in the ITCN network node for data distribution.

Tactical communication requirements

Efficiency in terms of tactical units CIS presence determines that the request must meet ITCN in terms of required *communication quality*, *quantity* and *time distribution of information*. Tactical communications requirements apply the time needed to takes information from the moment of its generation at the source, complete arrives through the entire ITCN to a specific destination, entirely accurate, authentic and available to organizational elements to perform a task. Communication parameter which can be used to define time of arrival and use of information in the command process we proposed the ***mean delay time*** of packets as one of the criteria for evaluation of packet switching network based on.

The mathematical model that brings into the relationship mean delay time T and the communication parameters speed traffic generation (λ_i), the mean size of the package (b), link capacity (C_i) indicates the state of the network designed with N points. Packet delay includes total retention time of packets in the network from the moment of generation source until arrival at the destination, which is a random value and evaluation should be done based on its mean value T formula:

$$T = \sum_{j=1}^{N}\sum_{k=1}^{N} Z_{jk}\gamma_{jk}/\gamma \qquad (1)$$

Z_{jk} – mean latency time of all packets of information flow the path between the network points j-k, γ – the total amount of network traffic, γ_{jk} – inbound network traffic, γ_{jk}/γ – amount of packet traffic on the network whose delay Z_{jk}. Each i-th link in the path of the package π_{jk} between the j-source and k-destination point in the network has a certain transmission capacity C_i within which transports packages information that belongs to a particular information flow and that path leads to its delay. If the λ_i - the intensity of the arrival of the package at the i-th link and belong to this information flow then the mean amount of its traffic is:

$$\lambda_i = \sum_{j=1}^{N}\sum_{k=1}^{N} \gamma_{jk} ; j,k : C_i \in \pi_{jk} \qquad (2)$$

Z_{jk} was obtained as the sum of the average packet delay passing through the various links on the path π_{jk} where the individual components in the sum of individual packages waiting time in order to handle the network devices (switch, router), time for a packet to the i-th branch and time for acceptance of the package in temporary memory (buffer) based on what is done:

$$Z_{jk} = \sum_{i=1}^{N} T_i ; i: C_i \in \pi_{jk} \qquad (3)$$

$$Z_{jk} = \sum_{j=1}^{N}\sum_{k=1}^{N} Z_{jk}\lambda_{jk}/\gamma = \sum_{j=1}^{N}\sum_{k=1}^{N}(\gamma_{jk}/\gamma)\sum_{i=1}^{N} T_i \qquad (4)$$

$$T = \sum_{j=1}^{N}(T_i\lambda_i)\sum_{j=1}^{N}\sum_{k=1}^{N}\gamma_{jk} ; j,k: C_i \in \pi_{jk} \qquad (5)$$

Further analysis of individual time delays T_i shows the relationship with the mean packet length value (b) expressed in bits and is given by:

$$T_i = \frac{1}{\mu C_i - \lambda_i};\ \ \mu = \frac{1}{b};\ \ T = \sum_{i=1}^{N}\frac{\lambda_i}{\gamma(\mu_i C_i - \lambda_i)} \qquad (6)$$

The processing time in the network nodes and propagation of the signal is zero and that it can be concluded that the mathematical relations (6) mean time delay reflects the network designed through communication parameters speed of generating traffic (λ_i), the size of the package (b), link capacity (C_i) and that is the basic tactical communication criterion for evaluating variants of the models ICTN.

Technology transfer of ITCN

Analysis of telecommunications and computer networks in terms of multiple access techniques standardization and integration of different technology transmission in ITCN is a necessary step needed to determine the possibility to implement the required functions. The choice of technology access and technology transfer is factors that determine whether and to what extent, be achieved efficiency of ITCN. It has to be carried out in relation to achieve compatibility for interconnecting various telecommunications networks and network equipment [22]. The relationship of technology transfer of ITCN and network application services (Figure 6.) shown the telecommunication network is integral segment ITCN and a physical layer to which relies computer network as layer through which to implement the CIS application services.

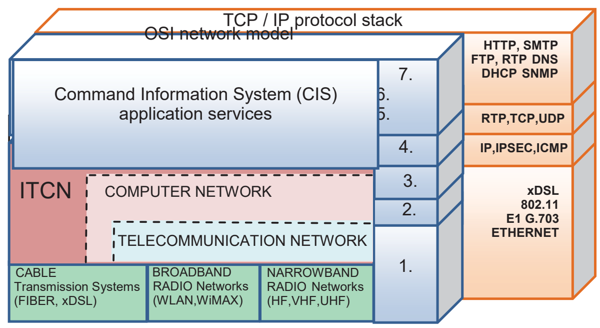

Figure 6. Technology transfer of ITCN

Preliminary model

Implementation of approach described in this work through steps and stages (Figures 1 and 3), the requests potential and possible additional constraints, we obtained results define and systematize the elements ITCN and their relationships as a ***preliminary model***. Defining the elements of the preliminary model through their network parameters allows defines the elements for OPNET simulation model realization. Structure of preliminary model based on projected ITCN topology of tactical unit in OPNET simulation model are shown in Fig.7. Methodological approach proposed in these paper more clearly define the relationship between the required design elements then the methodological approach described in [2-14].

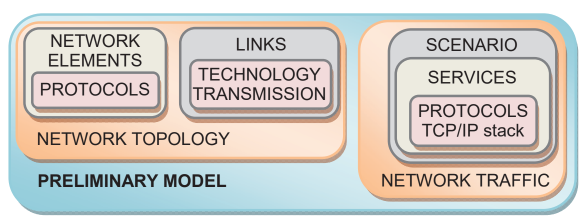

Figure 7. The structure of the preliminary model ITCN

Using the OPNET [18] performs the mapping model in the simulation model ITCN, perform simulations and obtain graphical results. Starting from preliminary model is derived variant ITCN models as follows: changing topology by introducing links, using SHDSL, fiber and VVF band radio technology, Layer-3 switches, modes of TCP protocol, OSPF, QoS and different MTU. Variation of structural elements of a preliminary model and their parameters optimization is realized and perform various variants of the model solutions in order to achieve a set of communication requirements.

Results

Using OPNET simulation model is obtained graphical results for analyze the timing requirements in scenario of combat operations. Figure 8.(a),(b) shows one of the number results of Email service time delays.

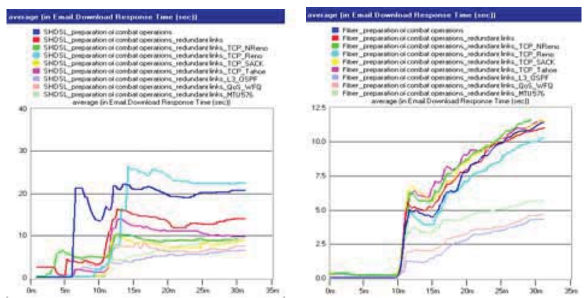

Figure 8. Email service time delays in ITCN of tactical unit (a) SHDSL, (b) Fiber

Analysis of the results shows that using SHDSL transfer technology for the realization of the main links partially meets the criterion time but space limits the effectiveness of tactical maneuver compared to the far more efficient use of fiber results shown, where the spatial range and greater usability. Expected results show the validity of applying the methodology.

Conclusion

Application of the described methodological approach of designing models ITCN has practical contribution as a way to include all factors that affect the description of the real model and realize its optimization. Analysis of the parameters given in a mathematical model justifies the use of simulation in the design process of complex tactical units ITCN. Using simulation in OPNET enables obtain results that are adequate basis for drawing conclusions about quality and timely distribution of information in the ITCN and the communication effectiveness of tactical combat units. Designing a simulation model ITCN realized the advantage in planning and proper implementation of transfer technology in the realization of communication structures. Following proposed methodological approach define all the elements needed for the design of OPNET simulation model and analysis of efficiency measures for ITCN.

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Nova metodologija projektovanja taktičkih integrisanih telekomunikacionih i računarskih mreža za OPNET simulaciju

Rad predstavlja jedan nov metodološki pristup u projektovanju integrisane taktičke telekomunikacione i računarske mreže komandno informacionog sistema i definisanja elemenata za OPNET simulacioni model.
Predstavljeni su elementi za projekotovanje mrežne informacione arhitekture
U navedenu svrhu se uspostavljaju relacije između elemenata sa kojima se projektuje mrežna topologija, definišu mrežni elementi i mrežni saobraćaj. Oni se sa svojim parametrima integrišu u preliminarni model kojim se definiše OPNET simulacionimodel. Za projektovanje modela mreže predlažemo meru efikasnosti postizanjem taktičkih komandnih zahteva Mera efikasnosti je srednje vreme kašnjenja, opisano matematičkim relacijama koje uključuju komunikacione parametre: brzinu generisanja mrežnog saobraćaja, veličinu paketa, kapacitet linka i koji imaju uticaj na projektovanu mrežu. Primena predloženog pristupa i date instrukcije omogućava projektantu potpuno ispitivanje mrežne arhitekture i prevođenje u preliminarni model i projektovanje OPNET simulacionog modela.

Ključne reči: **taktičke komunikacije, komandni zahtevi, računar, telekomunikacije, projektovanje mreže, integrisane mreže, OPNET, simulacioni model, komunikacioni informacioni sistem.**