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IMPLEMENTATION OF WIRELESS HETEROGENEOUS NETWORK BASED ON LTE CORE VIRTUALIZATION FOR MILITARY COMMUNICATION SYSTEMS

Telecommunication systems have always been the cornerstone of military forces. Modern systems like LTE provide high speed channels in pair with high mobility. Intelligent devices with advanced capabilities of information processing require from communication system to be able to transfer high speed flows of data between any two mobile terminals or stationary base. In this paper the concept of wireless heterogeneous network is proposed for utilization by military units. This concept implies use of network function virtualization for creating mobile core of LTE system that is paired with base station. For extension of the coverage area, the concept of mesh network that is based on self-organizing architecture of quad copters is proposed. The mathematical model of functioning of mesh network is proposed.

Key words: *LTE, NFV, MESH network, heterogeneous network.*

Introduction

Today military forces are evolving with introduction of new information and telecommunication technologies. Military actions are conducted in the way that ensures minimal losses among both military and civilians. Modern army units use various electronic devices that help them to fulfill their tasks and to achieve the set goals. For coordination of units by commanders a reliable communication must be ensured the whole time the military operation is conducted. Very often the specific unit operates within a small area or location but soldiers don't see each other, thus, they also require facilities for instant communication in order to coordinate their actions. Soldiers now can use smart mobile terminals like laptops, cell-phones, tablets. These devices can be used not only for communication between each other but also for control of remote machines.

Very often some units, e.g., reconnaissance combat units use special remote controlled devices (e.g., quad copters, terrain machines, unmanned flying devices). These devices can collect information using various sensors. The most exhaustive information from reconnaissance can be obtained using graphical data that is captured by photo or video camera. Depending on the specifics of the reconnaissance task, such devices can follow pre-defined set of rules without communication with base or use real-time instructions. This also determines the way of collected information processing. The video data can be transferred in a stream to the base of can be stored on a hard drive of reconnaissance device. For establishing real-time wireless channel between these devices and base a technology that ensures high quality of stream (e.g., minimal delay, jitter, packet losses) and reliability must be used.

Many military machines became smarter due to more intelligent computing techniques and facilities. Thus, they can themselves perform complicated tasks more efficiently. Still, there are situations when these machines need to be controlled by people in situations that require taking of human-related specific decisions.

To enable such real-time information exchange, it is necessary to use a telecommunication systems must ensures the next performance indexes:

- Security – all information that is transferred between mobile devices must be encrypted. Communication channel must be robust to attacks be based on algorithms of dynamic encryption including use of various techniques that can be chosen dynamically depending on situation.
- Reliability – communication system must be stable to failures that can be caused due to software errors or physical damage.
- High performance – communication systems core must possess highly powerful computing resources in order to establish connections between two or more devices and process high-speed traffic flows in a real-time.

As far as communication system can also be mobile, that is the base stations and their controllers can be installed on a special driving platform, the management system must include specialized algorithms for control of mobile elements. This management system is a part of communication systems core. Nowadays, a concept of NFV (Network Function Virtualization) is being more often used in telecommunication systems. NFV allows creating the systems core of arbitrary performance and dynamically scale it depending on requirements at the particular moment of time. To enable mobility of the core, the specialized compact cloud implementations are used. Such implementations have already been introduced by many telecommunication companies, among which is Alcatel-Lucent.

1. Mobile network core virtualization

The strategies and solutions explored in the 4G Americas report on NFV aim to address these issues and others by leveraging IT virtualization technology to consolidate many network equipment types onto industry standard high volume servers, networking and storage. NFV is about separating network functions from proprietary hardware and then consolidating and running those functions as virtualized applications on a commodity server. Broadly speaking, NFV will enable carriers to virtualize network functions and run them as software applications within their networks. NFV focuses on virtualizing network functions such as firewalls, Wide-Area Network (WAN) acceleration, network routers, border controllers (used in Voice over IP (VoIP) networks), Content Delivery Networks (CDNs) and other specialized network applications. NFV is applicable to a wide variety of networking functions in both fixed and mobile networks.

"NFV is making great progress throughout the world as operators work with their vendor partners to address the opportunities of increasing efficiency within their network infrastructure elements," stated Chris Pearson, President of 4G Americas. "There is a great deal of collaborative innovation and cooperation between wireless carriers, IT vendors, networking companies and wireless infrastructure vendors making NFV for LTE possible."

Global communication service providers, along with many leading vendors, are participating in the European Telecommunications Standards Institute's (ETSI) Industry Specification Group for Network Functions Virtualization (NFV ISG) to address challenges such as:

- An increasing variety of proprietary hardware appliances like routers, firewalls and switches.
- Space and power to accommodate these appliances.
- Capital investment challenges.
- Short lifespan.
- A long procure-design-integrate-deploy lifecycle.
- Increasing complexity and diversity of network traffic.
- Network capacity limitations.

Three main benefits of NFV outlined in the 4G America's paper include:

Improved capital efficiency: Provisioning capacity for all functions versus each individual function, providing more granular capacity, exploiting the larger economies of scale associated with Commercial Off-the-Shelf (COTS) hardware, centralizing Virtual Network Functions (VNFs) in data centers where latency requirements allow, and separately and dynamically scaling VNFs residing in the user (or data or forwarding) plane designed for execution in the cloud, control and user-plane functions as needed.

Operational efficiencies: Deploying VNFs as software using cloud management techniques which enables scalable automation at the click of an user's mouse or in response to stimulus from network analytics. The ability to automate onboarding, provisioning and in-service activation of new virtualized network functions can yield significant savings.

Service agility, innovation and differentiation: In deploying these new VNFs, development time of new network services can be significantly reduced, increasing the owner's ability to capture market share and develop market-differentiating services.

In particular, military can take advantage of NFV. Evolved Packet Core (EPC), Voice over LTE (VoLTE), Real-time video streaming and enhanced messaging services, among others, are examples of opportunities to use virtualized solutions. Some vendors started deploying elements of NFV in 2013 with an expectation that many service areas could be mostly virtualized in the next decade.

2. The concept of military communication system

In order to ensure full mobility of military units and support communication among all members of the unit, the centralized mobile system based on LTE standard is proposed [1].

LTE, commonly called 4G LTE, is the wireless communications standard and enabling technology behind high-speed data and communications networks and handheld communications devices such as smartphones, tablet and laptop computers, and other mobile electronics.

The latest LTE networks not only offer increased bandwidth (as seen in Table 1), but also the added advantage of lower latency, making real-time, two-way mobile video communications a reality.

Table 1

LTE Overview Performance

Metric	Requirement
Peak Data Rates	DL: 100Mbps UP:50Mbps (for 20MHz spectrum)
Mobility Support	Up to 500kmph but optimized for low speeds: 0 to 15 mph
Control Plane Latency	<100mx(for idle o active)
User Plane Latency	<5ms
Control Plane Capacity	>200 users per cell (for 5MHz spectrum)
Coverage (cell sizes)	5-100km with slight degradation after 30km
Spectrum Flexibility	1.25,2.5,5,10,15,20MHz

LTE delivers higher speeds and lower latency than competing technologies (as seen in Fig. 1), such as the recently terminated Joint Tactical Radio System (JTRS), as well as provides numerous other advantages for battlespace communications.

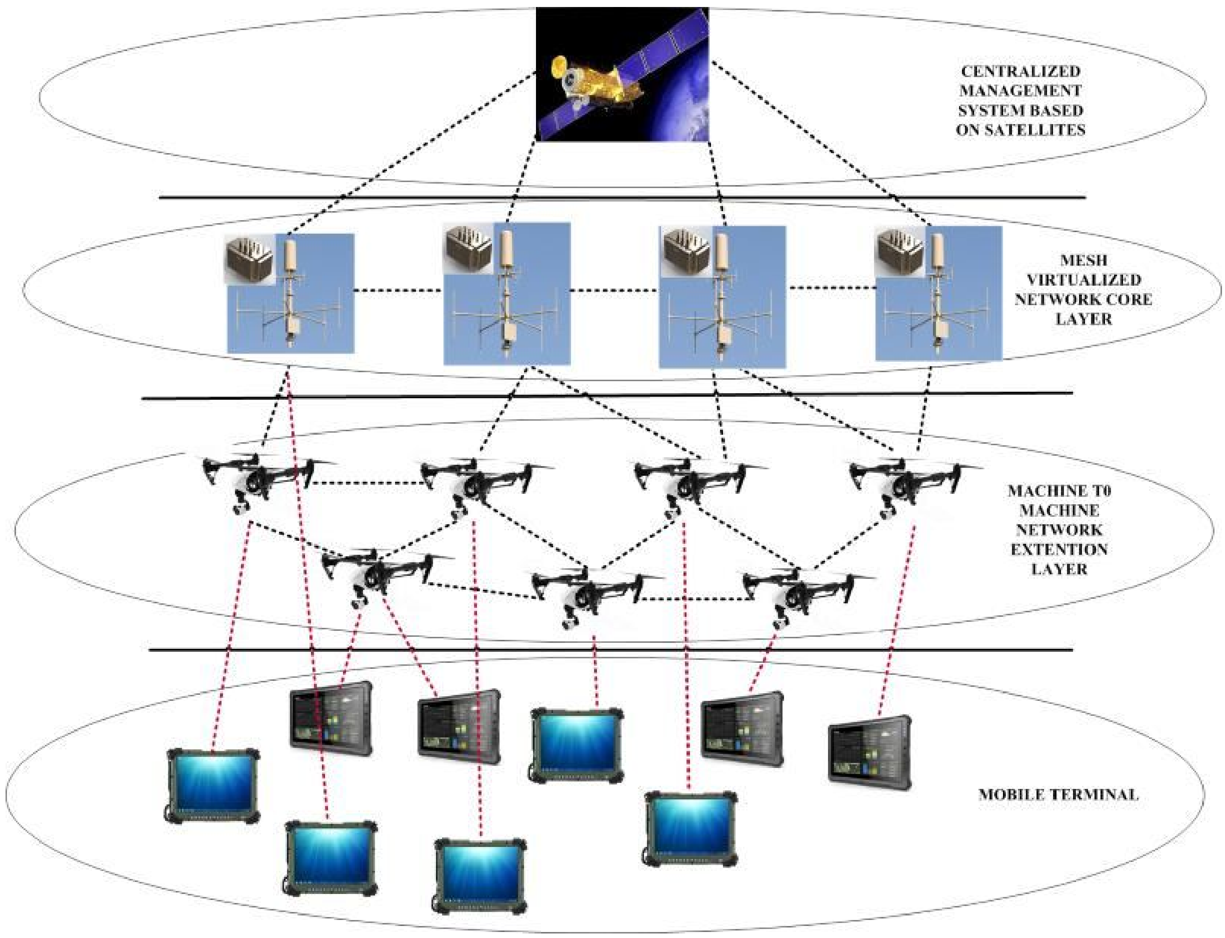

Fig. 1. The concept of military wireless communication system

By implementing an LTE network, which is all-IP and standards-based, militaries gain access to a large pool of technology vendors translating to greater parts availability, competitive pricing, and interoperability.

LTE is fault tolerant, enabling the network to continue operating properly in the event of a failure. With LTE deployed in the field, the loss of a node on the network-centric battlefield will not shut down the entire network. LTE technologies support failover, automatically switching to a redundant or standby hardware component upon the failure of one or more components. Further, users can swap out failed system components with readily available and inexpensive COTS hardware in the field. Similarly, militaries can quickly and easily scale the LTE communications infrastructure, adding COTS system building blocks and expanding capacity on demand and as needed.

Today's military has ever-improving communication technologies and standards. Modern commercial mobile networking technologies deliver superior mobile bandwidth, when compared to the once promising JTRS military communications initiative.

Building an LTE network suitable for battlespace communications is relatively easy, especially given the broad spectrum of capabilities currently available in today's marketplace. In this paper it is proposed a battlespace-ready LTE network that consists of three main layers: machine to machine network extension layer, mesh access layer based on mobile eNodeB, virtualized network core [2].

Virtualized EPC (Evolved Packet Core). In the proposed architecture the core of the communication system is implemented as a virtualized network functions (VNF). In case of LTE it is P-GW, S-GW and MME. This functions are implemented as a specialized hardware gateway. One of the current most well-known implementations is created by Alcatel-Lucent. The 7750 SR Mobile Gateway provides combined LTE PGW, Gateway General Packet [3].

Radio Service (GPRS) Support Node (GGSN), and SGW network functions. The 7750 SR Mobile Gateway is based on the industry-leading 7750 SR and the feature-rich Alcatel-Lucent Service Router Operating System (SR OS).

The PGW/GGSN represents the IP anchor point of the subscriber's connection. It provides the entry and exit points of traffic from the mobile provider's network to the UE (the user's mobile device). The PGW/GGSN also represents the service edge of the mobile provider's network, where much of the packet processing is performed.

PGW/GGSN functions for each UE and each service include:

• Creation and termination of bearer channels.

• Packet inspection and filtering (determination of the appropriate bearer channel based on the type of service/application).

• Policy enforcement (QoS and charging support assigned to each bearer as defined by the user's individual package) [4].

• Accounting and reporting.

The SGW is critical to the user's mobility. Like the PGW, it routes and forwards user data packets through the bearer channels. The SGW also represents the mobility anchor, ensuring that packets are continuously delivered even if the user changes location.

Fig. 2. 7750 SR Mobile Gateway

Such model can be used for creation of fully mobile military unit. For that purpose it should be put in a container with high protection form physical damage, radio influence. Such container must provide backup power battery and must provide interfaces for quick battery swap. Such node can be installed on a moving platform and thus can follow the unit. This way each mobile station can establish communication with another mobile station in the unit within few milliseconds.

In pair with each gateway, the eNodeB base station is installed. This allows minimizing of signaling and data latency of connections. These gateways can communicate with each other using radio interface technology, thus creating a wireless backbone network. If the distance between two gateways is small enough that a LTE radio interface can work then this interface is used. With the growth of distance another wireless technologies may be used. For centralized management of such wireless backbone network a satellite system is used. Using satellites, network can be configured dynamically. Such management requires strong security. One of the main advantages of such control is that the gateway can be shut down remotely with erasing of all restricted information. Another advantage is that for higher security of communication between gateways, the satellite can dynamically transfer security keys.

The base station can cover only a limited area. During military actions it is usually not possible that all mobile terminals will be in the area of BS. That is why in this paper is proposed to use quad copters as a highly mobile base station. Each quad copter can communicate with the core base station (the one that is paired to gateway) using sucired LTE channel [6]. Moreover, quad copters can communicate between each other, thus organizing themselves into a mesh network. Due to this even when the mobile terminal is located pretty far from the core station, it can still establish connection with the core through the chain of quad copters. Such quad copters can also be used for other purposes, e.g., reconnaissance. Thus, they extend the basic LTE network by forming additional layer of architecture that is represented by a mesh self-organized network.

Specialized quad copters come with a 4K camera in a 3 axis gimbal and it can be "transformed" in mid-air to get an unobstructed 360° view.

The aircraft has a completely new patented mechanism which lifts the entire booms including landing gear and motors above the main frame, so that the camera forms the lowest part [5].

The definition of mesh network implies the networks construction principle. Its peculiarity is self-organizing architecture that realizes the next capabilities:

- Creation of information zones that cover large areas.
- Networks scalability (increase of coverage area and information distribution density) in the self-organizing mode.
- Use of wireless transport channels for connection of access point in “all-to-all” mode.
- Robustness of the network against elements failures.

In a mesh network nodes are connected with each other. Organization of networks according to cell structure allows routing of data, voice and signaling between its nodes. The network takes into account continuous connection establishments and network configuration changes in case problems occur (e.g., the node is broken of the network path is blocked) selecting optimal path (going hop-by-hop until the destination address is reached).

3. Self-organizing military communication system based on MESH networks

This chapter is devoted to realization of mesh network model architecture that is used for integration of mobile systems of fourth generation. In this paper this model is used for describing functioning of mesh network that is constructed of quad copters for extension of coverage area of military communication systems. The example of such network is shown on fig. 3, where small quad copters form a mesh network by communicating with each other using radio interface.

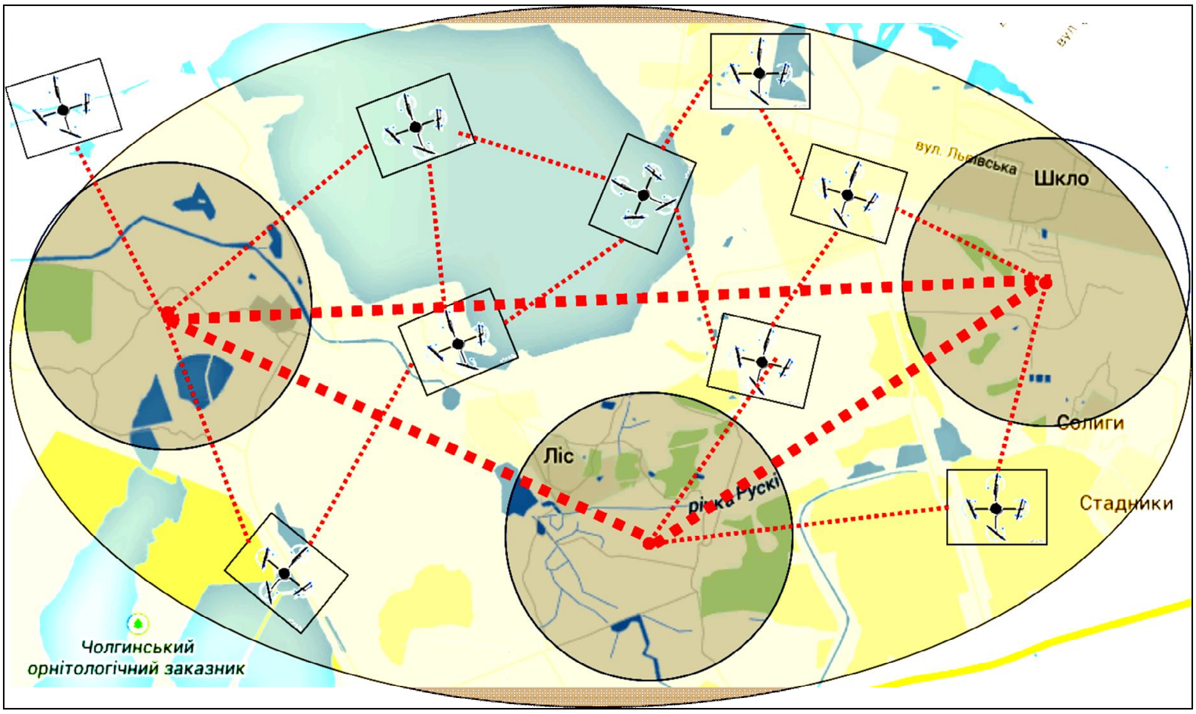

Fig. 3. Representation of the proposed communication system architecture on the map

According to system requirements the mathematical model of structural self-orgnization is proposed in this paper. Within this model the next input data is selected: $\left\{R_{i, i=\overline{1,N}}\right\}$ – set of mesh-nodes, where N – general number of mesh-nodes in the network; m_i – number of radio interfaces per node R_i; K – number of channels that are used in the network and don’t interfere. Moreover, let $\left\{G_{i, z=\overline{1,Z}}\right\}$ – number of zones with stable receiving – clusters (Transmission Range, TR), that are created with location distributed mesh-nodes, where Z – general number of these zones in the network. In this paper it is assumed that zone of stable receiving can be created with a big number of mesh-nodes with maximal power, within which nodes can transfer information between each other, i.e., they can exchange data using selected wireless technology in the mesh-network.

To achieve the goal of accounting distribution of mesh-network nodes, it is introced the definition of stable reception zones or TR matrices. Matrix consists of the number of rows that correspond to number of stable zones of reception Z and of the number of columns that correspond to general number of mesh-nodes N in the network, i.e.:

$$D = \left\| d_{i,j} \right\|, i = \overline{1,Z}, j = \overline{1,N}, \tag{1}$$

where $d_{i,j} = 1$, if j node is located in i TR, in other case $d_{i,j} = 0$.

Within the proposed model, according to the methodology of solving the task of channel distribution over the radio interfaces of mesh-nodes of the network, it is necessary to ensure the calculation of bool variable:

$$x_{i,j} \in= \{0,1\}, \left(i = \overline{1,Z}, j = \overline{1,N}\right), \tag{2}$$

where $d^k_{i,j} = 1$, if j radio interface works in k – frequency channel , in other case $d^k_{i,j} = 0$.

The total number of variables (2) that define the order of channel distribution depends on the number of nodes in the network, number of radio interfaces that use channels i, respectively, can be calculated as $N \times m \times K$. The result of the calculation of variables (2) is a division of the mesh-network as a whole and each zone of stable reception separately on the interconnected between each other collision domains, where mesh-nodes operate using the same channel. Because of this, finding variables $x^k_{i,j}$ in each separately taken G_z, it is necessary to fulfill a set of very important conditions-constraints (8), (9).

The condition of the node for connecting the network is [7]:

$$\sum_{k=1}^{K} x^k_{i,j} \sum_{j=1}^{m_i} x^k_{i,j} \ge m^* \left(i = \overline{1,N}\right), \tag{3}$$

where $1 \le m* \le m_i$ is a parameter that characterizes minimal number of radio interfaces on the arbitrary selected mesh-node; $\sum_{k=1}^{K} x^k_{i,j} \sum_{j=1}^{m_i} x^k_{i,j} x^D_{i,j}$, is a number of active radio interfaces on one mesh-node. As a rule, the number of radio interfaces on a mesh-node equals 2÷3 (10), (11).

The condition of allocating of a single channel to the j radio interface of i mesh-node is:

$$\sum_{k=1}^{K_i} x^k_{i,j} \le 1\left(i = \overline{1,N}, j = \overline{1,m_i}\right). \tag{4}$$

The condition of attaching k channel to i node to not more than one radio interface:

$$\sum_{j=1}^{m_i} x^k_{i,j} \le 1\left(i = \overline{1,N}, j = \overline{1,K}\right). \tag{5}$$

The condition of operating of two mesh-nodes on one the same channel (for one zone of stable reception):

$$\sum_{k=1}^{K} \left[\sum\nolimits_{j=1}^{m_i} x^k_{i,j} * \sum\nolimits_{j=1}^{m_i} x^k_{s,j} \right] \le 1, \tag{6}$$

(for (i,s) – node pairs, i,s = (1,N); i ≠ s), which is introduced for elimination of unwanted structural redundancy and fits the square character.

The condition of interconnection level of the network (interconnection of mesh nodes bewteen collision domains):

$$p = \sum_{i=1}^{N} \sum_{i=1}^{N} \sum_{i=1}^{N} x^k_{i,j} \ge N + K - 1 \tag{7}$$

the performance of which is common with (7) under the conditions of lack of channels $K \le N - 1$ guarantees, that the number of active radio interfaces (p) and number of mesh-nodes and supported by the wireless technology channels will ensure high level of interconnection of multichannel mesh-network.

Two domains of the network are interconnected if there is a mesh-node that at the same time operates on the channels of these two domains, i.e., the first radio interface operates on one channel and the second radio interface operates on another channel.

Two mesh-networks are interconnected if they are located in one collision domain, i.e., they operate on the same channel.

It is recommended that in the process of structural self-organization of mesh-network, the nodes should be distributed over the collision domains equally, since the performance of the domain depends on the number of nodes the conclude it.

With this goal, lets introduce the condition of balancing of mesh-nodes over the collision domains of wireless telecommunication system.

The condition of load balancing of the number of mesh-nodes depending on the location distribution, nodes activity and number of zones of stable reception will have several interpretations.

If all nodes are located in one TR, the condition of balancing of mesh-nodes over the collision domains will have the next form:

$$p = \sum_{i=1}^{N} \sum_{i=1}^{m_j} x^k_{i,j} \le \beta(k = \overline{1,k}), \tag{8}$$

where $\sum_{i=1}^{N} \sum_{i=1}^{N} x^k_{i,j}$ is a number of mesh-nodes in the network that operate on k channel; β is a top dynamically controlled threshold of the number of mesh-nodes in the arbitrary selected collision domain in the multichannel network.

When assessing the location distribution of the nodes, i.e., when nodes are located in different zones of stable reception, the condition of balancing will have the next form:

$$\sum_{i=1}^{N} d_{z,i} \sum_{i=1}^{m_j} x_{i,j}^{k} \le \beta \qquad (9)$$

(for each (z,k) – pair, $\left(i=\overline{1,N}, k=\overline{1,K}, j=\overline{1,m_i}\right)$ where in the left part of the inequality the number of nodes in *z* TR is represented.

The important factor of balancing the number of stations over the collision domains is their level of activity. Here, activity denoted a coefficient that depends on the frequency of the node being active over the radio, duration of sessions and intensity of traffic that is transmitted.

According to this, the condition of balancing mech-nodes over the collision domains will have the next form:

$$\sum_{i=1}^{N} d_{z,i} * \beta_i \sum_{i=1}^{m_j} x_{i,j}^{k} \le \beta \qquad (10)$$

(for each (z,k) – pair, $\left(z=\overline{1,Z}, k=\overline{1,K}\right)$,

where β_i is a coefficient of activity of i node that depends on the number of connected terminals, intensities of incoming and outgoing traffic, type of traffic.

According to unequal load of radio interface of the node and considering their operating in different directions, for obtaining precise condition (8) it is recommended to use normalized coefficient of activity of mesh-nodes

$$\beta_i \Big/ \sum_{k=1}^{K}\sum_{j=1}^{m_j} x_{i,j}^{k}\,.$$

Then, the balancing condition will have a form of:

$$\sum_{i=1}^{N} \times \frac{\beta_i}{\sum_{k=1}^{K}\sum_{j=1}^{m_j} x_{i,j}^{k}} \times \sum_{j=1}^{m_j} x_{i,j}^{k} \le \beta / \qquad (11)$$

The calculation of unknown variables (2) and β parameter according to conditions that are formalized by inequalities (3) – (11), it is recommended to perform optimization task, ensuring minimum or maximum of selected criteria of decision quality of structural self-organization. The main requirements to the optimal criteria on the one hand should be physics of the task, i.e., task of channel distribution in the mesh-network and on the other hand should be the abilities to obtain solutions that can be practically realized. This way, the input conditions and the task itself must not be too complicated. For its solution the effective method must be developed.

Due to the fact that the number of nodes in the mesh-network overwhelms the number of channels that do not interfere, thus there is a necessity of solving such problems as interference and hidden node exist, as a optimization criteria the minimal number of working mesh-nodes in created collision domains is selected, as it is well known that it helps to increase total performance of the multichannel mesh network.

Then, within the proposed mathematical model, the task of structural self-organization form the point of view of distribution of channels in the mesh-network obtains the form of optimization task. When solving this task, the next criteria should be taken into account:

$$\min_{x,\beta} \beta\,, \qquad (12)$$

when following conditions-constraints (2) – (11).

The formulated task from the point of view of physics of the processes that are held in multichannel mesh-network is related to the class of network resources balancing tasks – weighted number of mesh-nodes in collision domains regarding to location distribution and activity. From mathematical point of view it is a task of mixed integer non-linear programming – MINLP (Mixed – Integer Non Linear Programming). In the model, the searched variables $x_{i,j}^{k}$ (2) are of the bool type; variable β, that is minimized is of an integer type (under the conditions (8) – (11)) or real (under the conditions (11), (12)) and constrains on the searched variables can be both of linear and non-linear character.

For solving the tasks of this class it is used a set of effective methods such as: rounding – off, branch – and – bound, serial linearization (SLP), penalty function, lagrangian relaxation, simulated annealing and also genetic algorithm and different mixed hybrid methods.

Thus, the concept of incremental increase of network coverage is realized. Starting the development of the network in one point, it is possible to extend its coverage area without bounds by simply adding new nodes.

Conclusions

In this paper the concept of wireless heterogeneous network for military purposes is proposed. The concept is built on using NFV and LTE technologies. By virtualizing the core of LTE and locking it into the highly protected container, the core of LTE can follow the military units and provide coverage area where it is necessary.

While the core is virtualized, it can be scaled up or down on demand. The core can server several base stations that can be paired to it or distributed over the area using radio interface or communication.

In the proposed concept cores can communicate with each other, thus creating a network that can connect many military units and coordinate their actions. To control such distributed wireless network, a centralized management system based on satellites is proposed. Satellites can manage the whole network from one control point. This approach allows increasing security. In this paper is proposed to dynamically update security keys on each virtual core that creates additional features for security guarantees.

For extension of coverage area of the network in this paper the concept of mesh network that is constructed of mobile quad copters is proposed. Such mesh network allows transferring information from very distant locations through the chain of quad copters. These quad copters can be used not only for extending coverage area but also for collecting information in a real time what can be important during the actual military operations. Formalization of such mesh network is proposed achieve using mathematical model that is proposed in chapter 3.

This model describes the principles of mesh-network self-organization and constraint of its effective and reliable functioning.

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ВПРОВАДЖЕННЯ БЕЗПРОВІДНОЇ ГЕТЕРОГЕННОЇ МЕРЕЖІ ДЛЯ ВІЙСЬКОВОГО ЗАСТОСУВАННЯ НА ОСНОВІ ВІРТУАЛІЗАЦІЇ ЯДРА LTE

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У цій роботі запропоновано концепцію безпровідної гетерогенної мережі військового призначення. Ця концепція передбачає використання технології віртуалізації мережевих функцій для створення мобільного ядра системи LTE, яке може бути конструктивно поєднане з базовою станцією в одному мобільному модулі з високим рівнем захисту від відмов та уражень. Для розширення зони покриття запропонована концепція використовує безпілотні літаючі пристрої, які оснащені модулем передачі. Ці пристрої можуть самоорганізовуватися у безпровідну мережу та виступати у ролі проміжних вузлів при передачі інформації з кінця у кінець. У цій роботі також представлена математична модель функціонування та самоорганізації такої мережі.

Ключові слова: *NFV, LTE, MESH мережа, гетерогенна мережа.*

ВНЕДРЕНИЕ БЕСПРОВОДНОЙ ГЕТЕРОГЕННОЙ СЕТИ ДЛЯ ВОЕННОГО ПРИМЕНЕНИЯ НА ОСНОВЕ ВИРТУАЛИЗАЦИИ ЯДРА LTE

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В этой работе предложена концепция беспроводной гетерогенной сети военного назначения. Эта концепция предусматривает использование технологии виртуализации сетевых функций для создания мобильного ядра системы LTE, которое может быть конструктивно сопряжено с базовой станцией в одном мобильном модуле с высоким уровнем защиты от отказов и поражений. Для расширения зоны покрытия предложенная концепция использует беспилотные летающие устройств, оснащенные модулем передачи. Эти устройства могут самоорганизовываться в беспроводную сеть и выступать в роли промежуточных узлов при передаче информации с конца в конец. В этой работе также представлена математическая модель функционирования и самоорганизации такой сети.

Ключевые слова: *NFV, LTE, MESH сеть, гетерогенная сеть.*