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QUANTUM FIELD MODEL OF DATA TRANSFER IN TELECOMMUNICATION NETWORK

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КВАНТОВО-ПОЛЬОВА МОДЕЛЬ ПЕРЕДАВАННЯ ДАНИХ В ТЕЛЕКОМУНІКАЦІЙНІЙ МЕРЕЖІ

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КВАНТОВО-ПОЛЕВАЯ МОДЕЛЬ ПЕРЕДАЧИ ДАННЫХ В ТЕЛЕКОММУНИКАЦИОННОЙ СЕТИ

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Abstract. This paper focuses researches on telecommunications traffic engineering. A data-transfer math model introduced for the open transport network based on quantum field fundamentals. The four types of data transaction quanta are distinguished upon their properties: client/server and datagram/connection transfer. The data-transfer model is composed of two interleaving items: structural part (quasi stationary trend of digital flow) and functional part (dynamically changed component of digital flow). The structural part of the model is shaped in multi dimensional hyper sphere to map the space of data transfer functional states. The functional part of the model presented by two forms of quantum field (scalar and vector fields) determined on the set of hyper sphere dots. The proposed model aims to benefit methods of quantum field theory for data flow simulation and analysis in traffic engineering tasks.

Key words: telecommunications, data transfer, quantum field model.

Анотація. У даній статті розглядаються питання інженерії трафіка в телекомунікаціях. Для відкритої транспортної мережі запропонована математична модель передавання даних у каналі зв'язку на основі понять квантової теорії поля. За властивостями транзакцій визначено чотири типи квантів: клієнт/серверні та датаграмні. Модель передавання даних об'єднує структурну частину (квазістаціонарний тренд цифрового потоку) і функціональну частину (динамічно змінювана компонента цифрового потоку). Структурна частина моделі задає простір функціональних станів процесу передавання даних у вигляді багатовимірної гіперсфери. Функціональна частина моделі надана двома формами квантового поля (скалярним і векторним), заданими на множині точок багатовимірної гіперсфери. Запропонована модель дозволяє застосувати методи теорії поля для опису та аналізу потоків даних у задачах інжинірингу трафіка.

Ключові слова: телекомунікації, передавання даних, квантово-польова модель.

Аннотация. В данной статье рассматриваются вопросы инженерии трафика в телекоммуникациях. Для открытой транспортной сети предложена математическая модель передачи данных в канале связи на основе понятий квантовой теории поля. По свойствам транзакций выделены четыре типа квантов: клиент/серверные и датаграмные. Модель передачи данных объединяет структурную часть (квазистационарный тренд цифрового потока) и функциональную часть (динамически изменяющаяся компонента цифрового потока). Структурная часть модели задает пространство функциональных состояний процесса передачи данных в виде многомерной гиперсферы. Функциональная часть модели представлена двумя формами квантового поля (скалярным и векторным), заданными на множестве точек многомерной гиперсферы. Предложенная модель позволяет применить методы теории поля для описания и анализа потоков данных в задачах инжиниринга трафика.

Ключевые слова: телекоммуникации, передача данных, квантово-полевая модель.

New perspectives in telecom market stimulate emerging of enhanced mathematical approaches to meet the challenges of network traffic engineering and satisfy increased quality of service (QoS) requirements for real time network applications [1], [2]. Among the others, the math methods of differential geometry, tensor analysis and field theory consider being versatile tools in study various physical phenomena and objects [3]–[4]. Many processes (gas or liquid flow, elastic deformation et al) are effectively modeled by vector fields [4]. Classical field concepts have been further developed in quantum field theory [5]–[6]. Recently tensor analysis and field theory found experience in telecommunication theory and applications; however, the modeling of real objects and processes of discrete nature (e.g. data transfer over an open network) faces some issues in appliance of field theory basics [7]–[8]. This work aims to substantiate an enhanced discrete model of network data transfer in terms of field theory.

Quantum model of network interoperability. Consider a transport telecommunications network to be an open object O that interacts with its network environment W via one or more gateways due to transfer of data link layer frames (denoted as quanta q) of two different types: either d-type (transmitted in connectionless datagram mode) or r-type (transmitted in virtual connection mode), Fig.1.

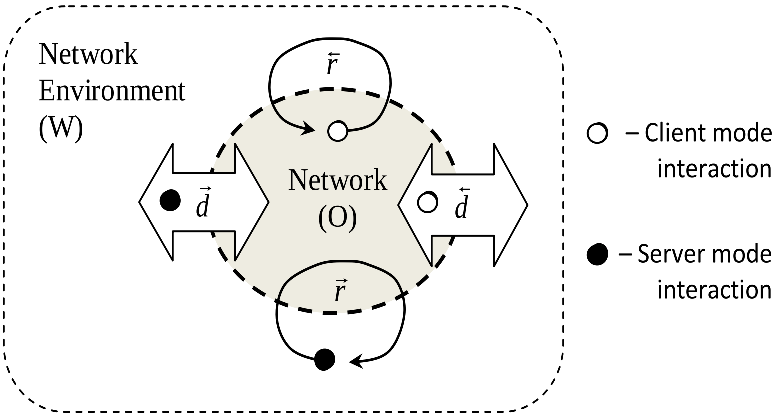

Figure 1– Type of network O interactions with its environment W

Additionally, we will split all the quanta $q = d \cup r$ in two clusters: server-cluster $\vec{q} = \vec{d} \cup \vec{r}$ (“black-color” interaction in Fig.1) and client-cluster $\overleftarrow{q} = \overleftarrow{d} \cup \overleftarrow{r}$ (“white-color” interaction in Fig.1). Quantum $\vec{q}$ means that a data frame q transaction has been triggered by environment W and afterwards data quantum occurred between network O and its environment W (either in datagram mode as $\vec{d}$-quantum or via connection transfer as $\vec{r}$-quantum), regardless of transfer direction (either “in” or “out” of network O).

Quantum $\overleftarrow{q}$ means that a data frame q transaction has been triggered by network O. Suppose that for a certain period of time $(t \pm \tau) \in T$ (e.g. $\tau \le 5\text{min}$, $T = 24$ hours) when monitoring external network data transfer there has been retrieved the following set of integer numbers: $2 \cdot D^{+}_{\tau t}$ quanta of type $\vec{d}$; $2 \cdot D^{-}_{\tau t}$ quanta of type $\overleftarrow{d}$; $2 \cdot R^{+}_{\tau t}$ quanta of type $\vec{r}$; $2 \cdot R^{-}_{\tau t}$ quanta of type $\overleftarrow{r}$. We will present this set of numbers as a vector sum, where quanta $\vec{d}$, $\overleftarrow{d}$, $\vec{r}$, $\overleftarrow{r}$ will play the role of unitary vectors of 4-dimensional Euclidean space with basis $\overleftrightarrow{q} = \{\vec{d}, \overleftarrow{d}, \vec{r}, \overleftarrow{r}\}$:

$$\overleftrightarrow{Q}_{\tau}(t) = (2 \cdot D^{+}_{\tau t} \cdot \vec{d} + 2 \cdot D^{-}_{\tau t} \cdot \overleftarrow{d} + 2 \cdot R^{+}_{\tau t} \cdot \vec{r} + 2 \cdot R^{-}_{\tau t} \cdot \overleftarrow{r}). \tag{1}$$

Based on (1) we determine average network power as

$$p_{\tau}(t) = \frac{1}{2 \cdot \tau}(2 \cdot D^{+}_{\tau t} + 2 \cdot D^{-}_{\tau t} + 2 \cdot R^{+}_{\tau t} + 2 \cdot R^{-}_{\tau t}). \tag{2}$$

Using (2) we will define the following functions:

$D_\tau^+(t) = \dfrac{D_{\tau t}^+}{\tau} \ge 0$ – proactive server power;

$D_\tau^-(t) = \dfrac{D_{\tau t}^-}{\tau} \ge 0$ – proactive client power;

$R_\tau^+(t) = \dfrac{R_{\tau t}^+}{\tau} \ge 0$ – reactive server power;

$R_\tau^-(t) = \dfrac{R_{\tau t}^-}{\tau} \ge 0$ – reactive client power;

$D_\tau(t) = D_\tau^+(t) + D_\tau^-(t) \ge 0$ – proactive server/client power;

$R_\tau(t) = R_\tau^+(t) + R_\tau^-(t) \ge 0$ – reactive server/client power;

$\mathrm{Div}_\tau(t) = D_\tau^+(t) - D_\tau^-(t) \ge\le 0$ – proactive power skew (divergence);

$Rot_\tau(t) = R_\tau^+(t) - R_\tau^-(t) \ge\le 0$ – reactive power skew (rotor);

$\vec{p}_\tau(t) = D_\tau^+(t) + R_\tau^+(t) \ge 0$ – server power of network;

$\bar{p}_\tau(t) = D_\tau^-(t) + R_\tau^-(t) \ge 0$ – client power of network.

The set of proactive functional properties $D_\tau^+(t)$, $D_\tau^-(t)$, $D_\tau(t)$, $\mathrm{Div}_\tau(t)$ displays the datagram mode traffic components between the network O and its environment W as real functions of current time t and parameter τ of estimation time interval $t \pm \tau$. Likewise the set of reactive functional properties $R_\tau^+(t)$, $R_\tau^-(t)$, $R_\tau(t)$, $Rot_\tau(t)$ reflects connection oriented traffic components. The two functions $\mathrm{Div}_\tau(t)$ and $Rot_\tau(t)$ indicate the current misbalance in network traffic billing with respect to all the external network parties differentiated in two types of traffic – datagram mode and connection oriented mode. The set of two functions $\vec{p}_\tau(t)$ and $\bar{p}_\tau(t)$ summarizes the instant state of network performance consider the server and client traffic clusters; based on these two functions we define the instant performance efficiency $p_\tau^E(t)$ of the network O, Fig.1:

$$p_\tau^E(t) = \vec{p}_\tau(t) - \bar{p}_\tau(t) = \left[\mathrm{Div}_\tau(t) + \mathrm{Rot}_\tau(t)\right] \ge\le 0\,. \qquad (3)$$

In case $p_\tau^E(t) = 0$ the network O is instantly balanced in relation to all of its partnerships in network environment. The more positive function $p_\tau^E(t) > 0$ is retrieved, the better network performance considered. The four basic functional properties of network performance can be presented as vector

$$\vec{f}(t,\tau) = \pm\left[D_\tau^+(t)\right]^{0.5} \cdot \vec{d} \pm \left[D_\tau^-(t)\right]^{0.5} \cdot \overleftarrow{d} \pm \left[R_\tau^+(t)\right]^{0.5} \cdot \vec{r} \pm \left[R_\tau^-(t)\right]^{0.5} \cdot \bar{r}\,. \qquad (4)$$

The square vector $\vec{f}(t,\tau)$ module in (4) we will define as

$$p_\tau(t) = \left|\vec{f}(t,\tau)\right|^2. \qquad (5)$$

Now we will define differential operator ∇ to calculate contra variant projection for vector $\vec{f}(t,\tau)$ in (4):

$$\nabla \cdot \vec{f}(t,\tau) = \left(\frac{\partial}{\partial \vec{d}}, \frac{\partial}{\partial \overleftarrow{d}}, \frac{\partial}{\partial \vec{r}}, \frac{\partial}{\partial \bar{r}}\right) \cdot \vec{f}(t,\tau)\,. \qquad (6)$$

After (4) and (6) the following set of functions determined:

$$\begin{cases} f_d^+(t,\tau) = \dfrac{\partial \overleftrightarrow{f}(t,\tau)}{\partial \vec{d}} = \pm\left[D_\tau^+(t)\right]^{0.5}, \\ f_d^-(t,\tau) = \dfrac{\partial \overleftrightarrow{f}(t,\tau)}{\partial \overleftarrow{d}} = \pm\left[D_\tau^-(t)\right]^{0.5}, \\ f_r^+(t,\tau) = \dfrac{\partial \overleftrightarrow{f}(t,\tau)}{\partial \vec{r}} = \pm\left[R_\tau^+(t)\right]^{0.5}, \\ f_r^-(t,\tau) = \dfrac{\partial \overleftrightarrow{f}(t,\tau)}{\partial \overleftarrow{r}} = \pm\left[R_\tau^-(t)\right]^{0.5}. \end{cases} \qquad (7)$$

The set of functions in (7) can be mapped in function $\underline{f}(t,\tau)$ that depends on time t and parameter τ:

$$\underline{f}(t,\tau) = \nabla \cdot \overleftrightarrow{f}(t,\tau) = \left[f_d^+(t,\tau), f_d^-(t,\tau), f_r^+(t,\tau), f_r^-(t,\tau)\right]. \qquad (8)$$

Let's denote an instant value of function $\underline{f}(t,\tau)$ in (8) as contra variant (on $\vec{q}$) vector $\underline{f}^q$ in real 4-dimensional Euclidian space $\mathbb{R}^4$ with basis $\vec{q} = \{\vec{d}, \overleftarrow{d}, \vec{r}, \overleftarrow{r}\}$ and metrics $\underline{\underline{q}} = \langle \vec{q} \cdot \vec{q} \rangle = \underline{\underline{I}}$, where $\langle \vec{q} \cdot \vec{q} \rangle$ is scalar product, $\underline{\underline{I}}$ is unitary matrix, [9]:

$$\underline{f}^q = \left[f_d^+, f_d^-, f_r^+, f_r^-\right]. \qquad (9)$$

As a main local invariant of tensor $\underline{f}^q$ within the current time interval $t \pm \tau$ we will take the instant network flow power $p_\tau(t)$ in (5); denote it as double covariant metric tensor $\underline{\underline{f}}$ calculated as following, [9]:

$$\underline{\underline{f}} = \underline{f}^q \cdot \underline{\underline{q}} \cdot (\underline{f}^q)^* = (f_d^+)^2 + (f_d^-)^2 + (f_r^+)^2 + (f_r^-)^2, \qquad (10)$$

where $(\underline{f}^q)^*$ is conjugate vector $\underline{f}^q$ (in case of real $\underline{f}^q$ figure $(\underline{f}^q)^*$ is transposed vector $\underline{f}^q$). Thus, an instant state of network data flow within the time interval $t \pm \tau$ is mapped into related network status dot (denote s) on the 4-dimensional hyper sphere (denote S) with radius $\rho = \left|\underline{f}^q\right| = \sqrt{\underline{\underline{f}}}$; four Euclidian coordinates of the status dot $s \in S$ are predetermined by tensor $\underline{f}^q$ in (9). If t in progress, the radius ρ turns into the real function $\rho(t,\tau) = \left|\underline{f}^q(t,\tau)\right|$; meanwhile the status dot $s \in S$ moves on the hyper sphere evolving into network state evolution track $s(t,\tau)$. Therefore, dynamic properties of the network interoperability are reflected by the composition $\Psi(t,\tau)$ of two components: $\Psi(t,\tau) = \{\rho(t,\tau), s(t,\tau)\}$. The component $\rho(t,\tau)$ we will define as inherent structural framework of the network interoperability (i.e. the space of possible data transfer functional states), whereas the $s(t,\tau)$ component we determine as the instant functional state of the network data transfer.

The given methodological approach, i.e. distinction of two mutual components within an integral collection of network data flow state properties – structure $\rho(t,\tau)$ and functional $s(t,\tau)$ – we consider a principal axiomatic assumption in proposed quantum model of telecom network.

Scalar quantum field model of data transfer. The spoken above axiomatic statement concerning the structure/function dualism in network interoperability model relies on the fundamental theoretical concept of “space-structure” originated in the nonstandard tensor analysis [13], as well as on recent empirical researches of telecom network traffic, [14] … [16]. The spectral characteristics of network traffic experienced in [14], [15], [17] testify that under certain conditions, the average intensity of network data flow behaves quit modestly in contrast to significant fluctuations of inner components of the traffic. Therefore, the separate study of dynamic network functionality beyond its slow evolving inherent framework aids to reduce the overall network model complexity. The experiments on network traffic monitoring demonstrate a rigorous impact of the estimation parameter τ on both structural and functional components of the entire network data flow model. Mostly, in commercial network monitoring systems and scientific investigations, the network traffic intensity is estimated within the local time interval of about $2\cdot\tau = 5\,\text{min}$, [14], [15].

The gradual decrease of local estimation time interval τ results in severe oscillation of network traffic. Therefore, a proper individual compromise needed towards the τ to T ratio for any given class of network modeling task. Henceforth, we assume that local functional component $s(t,\tau)$ within a common structure/function composition $\Psi(t,\tau)$ of the network flow model is a stationary stochastic process; we denote this process in simplified manner as function $s(t)$ omitting the estimation time symbol τ. According to taken assumption, any k-indexed sample of stochastic process $s_k(t)$ generates an induced network status track $s_k(t)\in S$ on the sphere S of radius $\rho = \left|\underline{f}(t)\right| \approx \text{const}$.

The overall set $\{s_k(t)\}$ of track samples $s_k(t)$ consider to be an exhaustive representation of stochastic process $s(t)$ defined on the sphere S of radius ρ. However, due to complexity of such presentation, it rather seems to be more ideal category than effective instrument to experience. To tailor this ideal category of network flow model for practical appliance two derivative forms of it are given below.

We will introduce the *first derivative form* of stochastic process $s(t)$ in terms of *scalar quantum field* $\psi(\theta)$ that is defined on the dots $\theta\in S$ of sphere S. Suppose a comprehensive finite set $\{s_k(t)\}$, $k\in[1,K]$ of track samples $s_k(t)$ covers the sphere S which is completely coated by the finite set of small dots θ_m, $m\in[1,M]$, where K, M are integer numbers. Any track $s_k(t)$ hereafter denote as $s(k)$ omitting the argument t. For any dot θ_m calculate the number n of tracks $s(k)$ crossing the dot θ_m due to the integer function $n(\theta_m)$.

Definition 1: the real function

$$\psi(\theta_m) = \left(\frac{n(\theta_m)}{\sum_{m=1}^{M} n(\theta_m)}\right)^{0.5}, \quad \theta_m \in S, \quad m\in[1,M], \tag{11}$$

we define as *scalar quantum field model* of network data transfer status determined on the sphere S of radius $\rho = \left|\underline{f}^q\right|$, where $\underline{f}^q = \left[f_d^+, f_d^-, f_r^+, f_r^-\right]$; $\rho^2 = \left|\underline{f}^q\right|^2$ is the average instant network flow power estimated within the current time interval $t\pm\tau$; the sphere S we call “quantum phase space of network data transfer states”. It is obvious from (11)

$$\sum_m \psi^2(\theta_m) = 1. \tag{12}$$

Formula (12) means that scalar function $\psi(\theta_m)$ approaches the probability of network data transfer states in the phase space. If the number of tracks s_k and number of dots θ_m on the sphere S increase indefinitely then the scalar function $\psi(\theta_m)$ in (11) evolves into the near continuous function of probability density distribution denote $\psi(\theta)$: $\psi(\theta_m)\to\psi(\theta)$. Based on the $\psi(\theta)$ distribution we calculate the probability of vector $\underline{f}^q$ to appear in dot location $L(\theta)\subset S$:

$$p(\underline{f}^q \in L(\theta)) = \oint_L \psi^2(\theta). \tag{13}$$

The scalar quantum field model (11) eventually comprises two mutual parts: the first part of this model is sphere S of radius $\rho = \left|\underline{f}^q\right|$ called “quantum phase space of network data transfer states”; the second part of this model is probability distribution $\psi(\theta)$, $\theta\in S$ of phase state that describes the instant network flow intensity estimated within the current time interval $t\pm\tau$. Consider radius ρ be approximately constant within a monitoring interval $t \pm t_0$ where $\tau << t_0 << T$ (e.g. $2 \cdot \tau = 5\min$, $2 \cdot t_0 = 60\min$, $T = 24$ hours).

However, within an extended time interval $t \in T$ we consider the radius ρ may slowly evolve, i.e. results in function $\rho(t)$. This part of the scalar quantum field model forms quasi stationary phase space $S(t)$ of network flow states $\theta \in S(t)$ in geometric figure like 4-dimensional hyper sphere $S(t)$ of radius $\rho(t)$; the sphere phase space $S(t)$ tends to slowly evolve in time t according to function $\rho(t)$.

The second part of the scalar quantum field model (11) is probability density distribution $\psi(\theta)$, $\theta \in S$ estimated within the current time interval $t \pm \tau$ and consider being approximately constant within a monitoring interval $t \pm t_0$, where $\tau << t_0$. This part of the model reflects relationships between various quantum elements of the entire network traffic (e.g. between connectionless datagram data and connection oriented data transfer).

The scalar quantum field (11) is rather simple prior model of network behavior. It facilitates foreseeing the critical periods of network operation to enhance its performance. Based on this model, virtual channels for real time data transfer can be provided in connection oriented mode.

Vector quantum field model of data transfer. The scalar quantum field model introduced in the previous section does not reflect dynamic properties of the data flow state within a local time interval $t \pm t_0$. To retrieve dynamic features of data flow we introduce the *second derivative form* of stochastic process $s(t)$ in terms of *vector field* $\vec{v}(\theta)$ that is defined on the set of dots $\theta \in S$ covering the sphere S.

Consider a subset of 6 tracks $s_k(t)$ has been experienced in a local environment of the selected dot $\theta_m = \theta_1$, Fig.2. The first five tracks $s_k(t)$ with numbers $k = 1, 2, ..., 5$ cross the dot θ_1; the track $s_k(t)$ with $k = 6$ does not cross the track θ_1. Two tracks in first five (numbers 1 and 3) direct from θ_1 to θ_2; the other three ones move to the dots θ_3, θ_4, θ_6 one time each. Among the six neighbors of θ_1 the dot θ_2 is crossed by tracks $s_k(t)$ the most intensively (two times).

The set of data related to Fig.2 is mapped into the Tab.1 of $s_k(t_j)$ where six rows $(k = 1, 2, ..., 6)$ correspond to six experienced tracks $s_k(t)$. The index j in Tab.1 refers to sequential moments $t_{kj} = t_{k1}, t_{k2}, ..., t_{k5}$ for given track $s_k(t)$. Each entry (k, j) of Tab.1 reflects the number m_{kj} of dot θ_m crossed by the track $s_k(t)$, along with the time moment t_{kj} when track $s_k(t)$ passes the dot θ_m (e.g. track $s_1(t)$ passes the focused local area of the sphere S in Fig.2 through the following rout: $... \to \theta_{16} \to \theta_5 \to \theta_1 \to \theta_2 \to \theta_9 \to ...$ in correspondent time moments …, 12.01, 12.03, 12.07, 12.10, 12.14,…).

Based on Tab.1 we find the most expected pass from any given dot θ_m to adjacent dot $\theta_n(m)$. In our case, $\theta_n(1) = \theta_2$. The phase state vector $\theta_m \to \theta_n(m)$ direction on the sphere S we will take as collinear to vector $\vec{v}(\theta)$ of expected progress direction for the current data flow state $\theta = \theta_m$. Let $\underline{f}^q(m)$, $\underline{f}^q(n)$ be vectors of phase coordinates for dots θ_m and θ_n according to (9); define the phase distance $|\Delta\theta_{mn}|$ between θ_m and θ_n:

$$\begin{cases} \Delta\theta_{mn} = \underline{f}^q(m) - \underline{f}^q(n) \\ |\Delta\theta_{mn}| = \left[\Delta\theta_{mn} \times (\Delta\theta_{mn})^*\right]^{1/2} \end{cases} . \qquad (14)$$

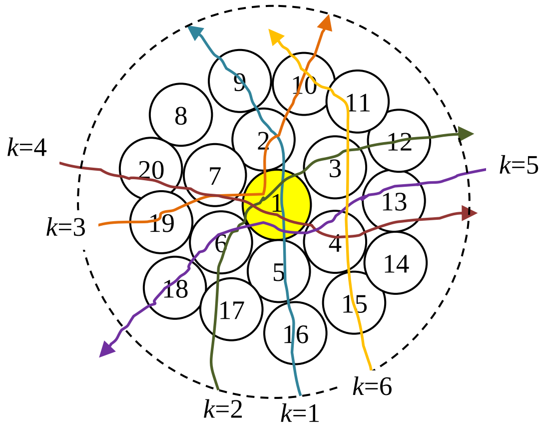

Figure 2 – The subset of tracks in a local environment of selectyed dot

Let $|\Delta\theta_m| = |\Delta\theta_{mn}|$, where $\theta_n = \theta_n(m)$. Define velocity estimation $\frac{\partial}{\partial t}(\theta_m)$ for a dot θ_m:

$$\frac{\partial}{\partial t}(\theta_m) \approx \frac{|\Delta\theta_m|}{\Delta t_m}\,, \tag{15}$$

where Δt_m is the mean value of time intervals t_{kj} in Tab.1 related to the most expected crossover from the current dot θ_m to its next step neighbor $\theta_n(m)$. In our case we have $m=1$(colon 3 in Tab.1), $n=2$ (colon 4 in Tab.1), tracks $s_1(t)$ and $s_3(t)$ (rows $k=1$ and $k=3$ in Tab.1); therefore, $\Delta t_1 = \frac{1}{2}\cdot(12{,}07-12{,}03)+(10{,}33-10{,}31) = 3\min$. Let take velocity estimation in (15) as module of vector $\vec{v}(\theta)$:

$$|\vec{v}(\theta)| = \frac{\partial}{\partial t}(\theta(m))\,. \tag{16}$$

Table 1 – Network flow phase state tracks

Dot m number, *j*	*j*=1		*j*=2		*j*=3		*j*=4		*j*=5	
Dot *m* Track, *k*	m_{kj}	t_{kj}	m_{kj}	t_{kj}	m_{kj}	t_{kj}	m_{kj}	t_{kj}	m_{kj}	t_{kj}
k=1	**16**	12,01	**5**	12,03	**1**	12,07	**2**	12,10	**9**	12,14
k=2	**17**	08,55	**6**	08,59	**1**	09,02	**3**	09,05	**12**	09,07
k=3	**19**	10,15	**7**	10,20	**1**	10,31	**2**	10,33	**10**	10,35
k=4	**20**	07,01	**7**	07,05	**1**	07,08	**4**	07,10	**13**	07,12
k=5	**13**	21,14	**4**	21,17	**1**	21,22	**6**	21,25	**18**	21,27
k=6	**15**	19,08	**4**	19,11	**3**	19,15	**11**	19,18	**10**	19,22

Definition 2: the real vector function $\vec{v}(\theta)$ determined on the set of dots $\theta \in S$ of the sphere S with radius $\rho = |\underline{f}^q|$, where $\underline{f}^q = \left[f_d^+, f_d^-, f_r^+, f_r^-\right]$, $\rho^2 = |\underline{f}^q|^2$ is the average instant network flow power estimated within the current time interval $t \pm \tau$, module $|\vec{v}(\theta)|$ is average velocity of the phase state passage from the current phase state $\theta_m \in S$ into the most expected phase state

$\theta_n(m) \in S$, we define as *quantum vector field model* of network data transfer state determined on the sphere S that reflects the phase space of the network data transfer states.

The introduced vector quantum field $\vec{v}(\theta),\ \ \theta \in S$ is more adequate dynamic model of telecommunication network data transfer in comparison to the scalar field model $\psi(\theta),\ \ \theta \in S$ defined above in (11). This model facilitates a near term posterior prediction of network data flow behavior based on the current phase state $\theta(t)$. Due to this prediction, a cognitive forehanded operation of network topology and metrics ensured (e.g. edge routers and channel productivity reorganization for QoS aware real time application provision).

Conclusions.Math methods of differential geometry, tensor analysis and field theory are effective tools in study various physical phenomena. Though simulation real objects of discrete nature like network data transfer faces issues in appliance of field theory basics. In this work an enhanced discrete model has been substantiated for network data transfer in terms of quantum field theory. Towards a transport telecommunications network as open object a quantum model of network interoperability introduced. The four types of data transaction quanta are distinguished upon their properties: client/server and datagram/connection transfer. The set of network functional characteristics was specified. Through the four functional network characteristics a stochastic presentation of network data flows proposed in terms of phase track records on the 4-dimensional hyper sphere determining the space of network flow states. Scalar and vector forms of quantum field model have been introduced for network information processes monitoring. The scalar quantum field aims simple prior simulation of network behavior to enhance its performance in static mode. The vector quantum field is more comprehensive dynamic model for real time operation of telecommunication network topology and metrics in traffic engineering task.

REFERENCES:

1. H. Abrahamson, A. Gunnar, “Traffic engineering in ambient networks: challenges and approaches”, https://www.sics.se/~henrik/ante-sncnw-final.pdf.
2. V.I. Tikhonov, P.P. Vorobiyenko, “Integrated telecommunication technology for the next generation networks”, in proc. of the 2013 ITU. Kaleidoscope academic conference “Building sustainable communities”, Kyoto, Japan, April 2013, pp. 187-193.
3. B. Schutz , “Geometrical methods of mathematical physics”, Cambridge University Press, UK, 1980, 264 p.
4. J.J. Binney, “Classical fields, Part I: Relativistic covariance”, Oxford Univ., Michaelmas Term 206 & Hilary Term 2007, 94 p.
5. E. Zeidler, “Quantum field theory I: Basics in mathematics and physics: a bridge between mathematics and physics”, Springer, 2006, 1051 p.
6. V. Tikhonov, “Renormalization the quantum field model of particle interaction”, in “Problems of atomic sience and technology”, 2012, № 1, Series: “Nuclear physics unvestigations (57) ”, pp. 55-58.
7. O. Yevsyeyeva, “Diakoptical approach in telecommunication engineering”, TCSET'2010, 2010, Lviv-Slavske, Ukraine, p. 29.
8. V.I. Tikhonov, “Digital flow control method for the coherent optical communication”, Proc. of the 23-rd International Crimea conference “Microwave equipment and telecommunication technologies”. – Sevastopol, September, 2013, pp. 521–522.
9. G.A. Korn, T.M. Korn, “Mathematical handbook for scientists and engineers”, General publishing company, 2000, 1151 p.
10. G. Kron, “Tensor analysis of networks”, N.Y., J. Wiley&S., Inc., London, Chapman&Hall, Ltd, 1965, 379 p.
11. V.V. Petrov, “Teletraffic structure and algorithm of quality of service provision on self-similiraty impact”, Moscow, 2004, 199 p., http://pi.314159.ru/petroff3.pdf.
12. V.I. Tikhonov, “Quantum field model of the digital telecommunication channel”, “Tsyfrovi technologiy”, № 9, 2011, pp.7–19, http://digitech.onat.edu.ua/metod/download/975/ua.

ЛІТЕРАТУРА:

1. Абрахамсон Г. Інжиніринг трафика в оточуючих мережах: проблеми та підходи / Г. Абрахамсон, А. Гуннар. – Режим доступу: https://www.sics.se/~henrik/ante-sncnw-final.pdf.
2. Тіхонов В.І. Інтегрована технологія телекомунікацій в мережах майбутніх поколінь / В.І. Тіхонов, П.П. Воробієнко // Матеріали наукової конференції МСЕ, 22–24 квітня 2013 р. – Японія, 2013. – С. 187–193.
3. Шутц Б. Геометричні методи математичної фізики / Шутц Б. – UK: Cambridge University Press, 1980. – 264 с.
4. Біні Дж.Дж. Класичні поля, частина 1: Релятивістська коваріантність / Біні Дж.Дж. – Oxford Univy. Michaelmas Term 206 & Hilary Term, 2007. – 94 с.
5. Зедлер Е. Квантова теорія поля. 1: основи математики і фізики – міст між математикою і фізикою / Зедлер Е. – Springer, 2006. – 1051 с.
6. Тіхонов В.І. Ренормалізація квантово-польової моделі взаємодії часток / В.І. Тіхонов // Проблеми атомної науки і технології. – 2012. – №1. – С. 55–58.
7. Євсеєва О. Діакоптичний підхід інжинірингу телекомунікацій / Матеріали міжнародної конференції TCSET'2010. – Львів-Славське, 2010. – С.29.
8. Тіхонов В.І. Метод управління цифровими потоками в когерентних оптичних комунікаціях / В.І. Тіхонов // Матеріали 23 міжнародної конференції ["Мікрохвильова техніка та телекомунікаційні технології"], (8–13 вересня 2013 р.). – Севастополь, 2013. – С. 521–522.
9. Корн. Г. Довідник з математики для науковців та інженерів / Г.Корн, Т.Корн. – General publishing company, 2000. – 1151 с.
10. Крон Г. Тензорний аналіз мереж / Крон Г. – М.: Рад. радіо, 1978. – 720 с.
11. Петров В.В. Структура телетрафіка та алгоритми забезпечення якості послуг щодо впливу самоподібності / Петров В.В. – М., 2004. – 199 с. – Режим доступу: http://pi.314159.ru/petroff3.pdf.
12. Тіхонов В.І. Квантово-польова модель цифрового телекомунікаційного канала / В.І.Тіхонов // Цифрові технології. – 2011. – № 9. – С. 7-19.