Informational-entropic routing in wireless network

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***Abstract*— Methods usually used for estimation of signal-to-noise ratio are based on using a given noise level or conditional criteria. In the present work we have obtained formulas for bandwidth and noise immunity of communication channels via conditional information and informational entropy that doesn’t contain empirical data. These formulas have been approved by computer modeling, and our goal is to use this new method for routing in wireless networks.**

Keywords*— *Routing, probabilistic measures, signal-to-noise ratio, bandwidth, noise immunity.

I. Introduction

Multichannel telecommunication systems (MTS) contain telecommunication networks with communication lines and necessary hardware-software nodes for transmitting and receiving of signals [1-3]. Telecommunication network systems can have complex topology, and each network can operate on many communication channels different in frequency, time, code, and package separation. Interconnection between channels at a network level is supplied by routers which are the most complex nodes in digital multichannel telecommunication systems.

There are many routing protocols, especially in wireless technology (more than 50, [4]). Every router is provided with a status map which is a set of characteristics of location, bandwidth, noisy immunity, cost of traffic, etc. We use metric as a generalized characteristic. Routers software determines trajectory (sequence of passing nodes) with an extreme (maximum, minimum) total characteristic for a given set of metrics. There are standard routing protocols for many MTS, for example, Cisco's hierarchical MTS uses OSPF protocol based on the Dijkstra algorithm. The essence of this algorithm is the sequential finding of neighboring nodes with minimal difference in metrics between the given nodes. Search of all possible variants leads to a big amount of calculations. Difficulties of existing routing algorithms also include search of a universal type, normalization of metrics with different meanings (for example, cost of traffic and delay time), adaptation of metrics to changes in time and space. Evidently, these factors lead to development of new protocols taking into account different conditions in local networks.

II. The problem and aims of the work

We pay attention that another approach to choose the metrics is possible. This approach is probabilistic, and in case of using this algorithm we must use the corresponding routing algorithms. Probabilistic measures are normalized values. Typical probability density distribution functions are considered as known functions. Such routing algorithms are discussed in the following papers. In [5], a probabilistic emergent routing algorithm (PERA) based on the swarm intelligence paradigm [6] for Mobile Ad Hoc Networks (MANET) is considered. Combined Ant Hoc Net (Ant Agents for Hybrid Multipath Routing in Mobile Ad Hoc Networks) [7] also contains elements of the probabilistic approach for detection of "pheromone" (signal element). In continuation of such studies, we want to use in the routing algorithms some types of quantitative probabilistic metrics which are information and informational entropy.

We suggest a new method which has an obvious advantage over existing protocols. It’s enough to note that number of possible combinations of 15 nodes is about 15!, and statistical regularities can be established in a set containing 15 or more elements and in calculations of probability measures of the same order of repetitions.

The concept of informational entropy introduced into the theory of telecommunications by C. Shannon is now widely uses in physics of non-equilibrium, chaotic processes. The reason of using of informational entropy is that Clausius's classical thermodynamic entropy, Boltzmann's physical entropy is applicable for the description of equilibrium states. Information is a quantitative measure of certainty and order in non-equilibrium systems. Average value of information for an ensemble determines informational entropy which is a quantitative measure of uncertainty, disorder for a mix of deterministic and noisy signals.

On the other hand, mutual information is defined as difference between one-dimensional (transmitted signal) and

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conditional (at known received signal) entropy. Maximal value of mutual information determines capacity of communicational channel. Assuming received signal as a Gaussian noise with a predetermined variance, it's possible to obtain Shannon's formula for capacity of communicational channel. This formula contains signal variance as well as noise variance. In practice, the widely used signal-to-noise ratio (SNR) is also determined via relation of signal and noise variances. In this case the noise variance should be known. After these necessary explanations we'll discuss the essence of scientific novelty of our work.

We suggest a new algorithm for quantitative estimation of SNR which is an important characteristic of MTS. Increasing accuracy of SNR estimation is discussed in many recent studies [8-11] in which a known noise level is defined from an experiment or by a conditional criterion for various types of noise. We propose to estimate SNR as a ratio of information to entropy (IER). These criteria are similar each other in their physical meaning: information is the measure of certainty (signal), entropy is the measure of uncertainty (noise). The main advantage of using the new IER criterion is that in this case it isn't necessary to determine value of noise level empirically or conditionally. Both informational entropy and information are described as difference of values of unconditional (full or one-dimensional) and conditional entropy, and these values can be calculated via signal representing as corresponding time series or image. In case of time series (one-dimensional signal) processing, we can choose second variable as a derivative of initial signal, i.e. use a phase portrait of the dynamic system. After determining mutual or conditional information, we can find ratio of this value to full or conditional entropy, i.e. the desired value of IER. Here, all values must be normalized to full entropy of the ensemble. This new method was tested on typical telecommunication signals. For this aim we have added stochastic noise with given variance to signals of various types (harmonic, modulated, chaotic). Then we have defined SNR (with given noise variance) and IER (without using noise level). Dependences of these characteristics for signal-noise mixture on signal intensity are the same. Unlike SNR, the new IER characteristic also can be used to distinguish shape of signals. We believe that this result is very important [12]. Real signals (technical, radiophysical, astrophysical, etc.) are always signals containing noise. Knowledge of quantitative characteristics of signal quality without additional empirical, conditional criteria is extremely important for all technical, telecommunication measurements.

Bandwidth of communication channels is determined as multiplication of maximal value of mutual information on bandwidth. Standard formula for capacity contains difference between entropy of message from a transmitter and conditional entropy determined at known received message. This formula is applicable only for dummy communication channels. According to the described above ideas, for real we can use derivative of the time series as a condition in form of the signal from transmitter. Appropriateness of this idea is obvious, because IER is an analytical analog of SNR proportional to required bandwidth of communication channel, measured in bits/s. Application of this conclusion to specific types of digital communication is an important technical problem.

The next important standard characteristic of MTSs is the bit error rate (BER). To estimate signal transmission quality at appearance of errors we can use criteria describing percentage of time intervals in which errors exceed the threshold (block with errors EB (Error Block), second with errors ES (Error Second), second struck by errors SES (Severlely Errored Second) one-second interval containing 15% of blocks with errors, etc.). There are norms for errors in national and international communication areas measured in seconds of multiplexing, in time duration for testing of signal propagation, etc. [13].

It's clear that such practically important parameters as BER should be determined as accurately as possible and it's necessary to develop scientific basis for corresponding algorithm. This problem can also be solved using the suggested criterion IER (analytical analogue of SNR) [12]. The fact is that error function is found by integrating probability density in the range from SNR to infinity. Using of IER instead of SNR let us on scientific basis significantly improve the whole technology of testing for noise immunity of MTS nodes.

Aim of the present work is to develop a new algorithm for routing based on informational-entropic analysis of telecommunication nodes' characteristics and verification of basic statements of this algorithm on different types of signals and on the ensemble of routers.

III. Results of Informational – Entropic Analysis

Let us consider a possibility of constructing an algorithm for routing based on probabilistic criteria that we suggest in the present work. Computing and communication nodes are supplied with a map describing probability of realizing of some characteristic in all MTS nodes. Problem of routing is to determine an optimal sequence for passing of nodes for transmission of information packets. We choose mutual information, or, information entropy of any possible sequence of nodes (trajectory) as a criterion function. It's necessary to select an extreme trajectory from the stochastic set of possible trajectories. This extreme trajectory must be characterized by minimal entropy or maximal value of conditional entropy at maximum of argument variance. Condition of minimum of entropy and maximum of information for each trajectory indicates to presence of order, regularities, and maximum of variance of set of their local values corresponds to stability, reliability of the result. In contrast to usual metrics, for each node, the used in our method measures (conditional information and entropy) are additive summaries.

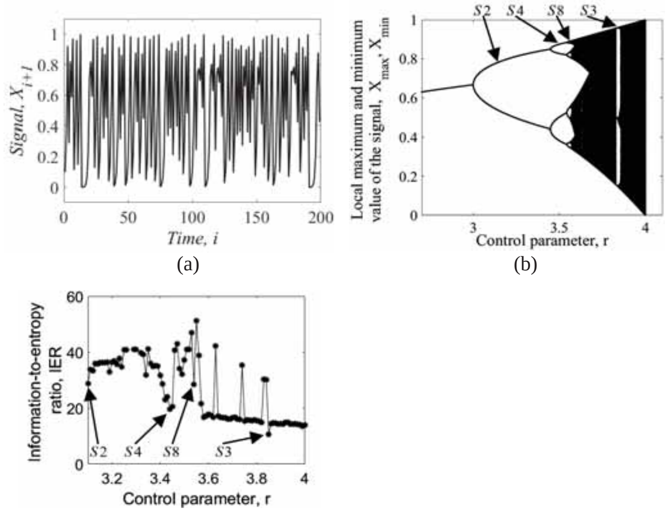
We have analyzed computer implementations of the proposed routing algorithm for distribution of the metric at nodes in accordance with Gaussian and harmonic probability density laws. Even for these two distributions, which are opposite in form (maximum and minimum at zero of the argument), we can detect general regularities in spread and asymptotic behavior of the desired measure. So, we can conclude that it's necessary to lead model and technically test studies of the proposed probabilistic routing algorithm.

Values of SNR and channel traffic in the MTS nodes can be directly measured or calculated by use of time series describing electric field strength. From this time series, IER and channel traffic (mutual information) can be calculated.

Let us show an example of definition IER which is the necessary characteristic for probabilistic routing. We consider a dynamic system described by the logistic map

$$x_{i+1} = rx_i(1 - x_i) \quad (1)$$

as a source of chaotic signal (Fig. 1). Here r is a control parameter.



(a) (b)

(c)

Fig. 1. (a) -Time series at r = 4, (b) - bifurcation diagram of the logistic map (1) at iteration step δ = 10^{-2}, number of counts N= 10^3 and (c) - dependence of IER on control parameter r.

By the definition given in [14], value of mutual information of a signal $X = X(t)$ transmitted over a communication channel is defined as difference between one-dimensional and conditional Shannon entropy as

$$I(X,Y) = H(X) - H(X/Y), \quad (2)$$

where $Y(t)$ is characteristic of a receiver. Unconditional Shannon entropy is defined as

$$H(X) = -\sum_{i}^{N} p(x_i)\ln(p(x_i)), \quad (3)$$

where $p(x_i)$ is probability of detecting of a value X in the i[th] cell with size δ, $H(X/Y)$ is conditional entropy given as

$$H(X/Y) = -\sum_{i}^{N}\sum_{j}^{M} p(x_i, y_j)\ln(p(x_i / y_j)). \quad (4)$$

Here $p(x_i,y_j)$ is total probability, $p(x_i/y_j)$ is conditional probability. Mutual information $I(X,Y)$ is different from zero only in case of non-zero correlations between $X(t)$ and $Y(t)$. For the description of dynamical systems we can accept $Y(t) = X'(t)$, so, we consider the time derivative $X(t)$ as a second variable.

Instead of one-dimensional Shannon entropy $H(X)$ we use two-dimensional full entropy of the ensemble $H(X,Y)$. So, we rewrite (2) as

$$\begin{cases} I(X/Y) = H(X,Y) - H(X/Y) = H(Y) > 0, \\ H(X,Y) = -\sum_{i}^{N}\sum_{j}^{M} p(x_i, y_j)\ln(p(x_i, y_j)), \end{cases} \quad (5)$$

where $p(x_i,y_j)$ is probability of detection of points in cells of phase space with equal sizes δ. We have introduced the notation for conditional information $I(X/Y)$ to emphasize the role of conditions for definition of information but not correlations, as in (2). Using of $H(X,Y)$ instead of $H(X)$ better provides a condition for positivity of conditional information $I(X/Y)>0$. Formula (5) is more noise-immune in this meaning than (2). Taking into account conditional probability $p(x_i/y_j)$ we can notice that conditional entropy $H(X/Y)$ is different from $H(X,Y)$.

Two-dimensional information and entropy can be normalized to full entropy as

$$\tilde{I}(X/Y) + \tilde{H}(X/Y) = 1 \quad (6)$$

$$\tilde{I}(X/Y) = I(X/Y)/H(X,Y),$$

$$\tilde{H}(X/Y) = H(X/Y)/H(X,Y). \quad (7)$$

This is the convenient relation for the analysis of probabilistic processes in a peculiar form of the law of conservation of conditional information and entropy.

We determine value of IER as ratio of normalized values of conditional information and entropy as

$$IER = \tilde{I}(X/Y)/\tilde{H}(X/Y) = 1/\tilde{H}(X/Y) - 1. \quad (8)$$

Equation (8) can be used for determination the important characteristic of signals similar to SNR. Its advantage is in the following fact. By use of this value we can define value of IER in case of unknown noise level. So, it's necessary to describe only time series $X(t)$.

To construct a metric matrix of each router we have randomly set probabilities $P(x_n)$ depending on characteristic x_n as $P(x_n)$ = {0.952, 0.448, … 0.993}, $1 \le n \le 25$.

So, we have as example 10 possible stochastic trajectories. Some of these trajectories are shown in Fig. 2.

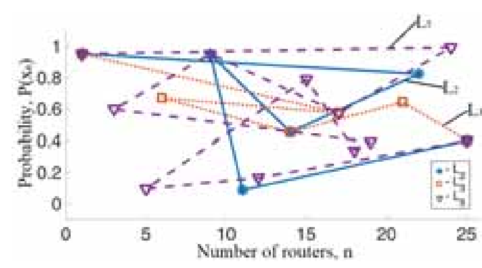


Fig. 2. Example of stochastic trajectories for routers. Number of trajectories L_i: L_2 - *, L_3 - □, L_5 - ▼.

We find normalized conditional information $\tilde{I}(X/Y)$ for every trajectory with equations (7). These values are shown in Fig. 3.

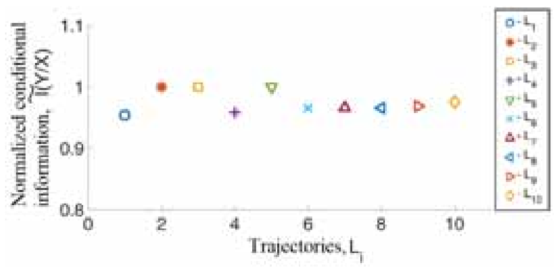


Fig. 3. Conditional information of stochastic trajectories.

We define dependence of $\tilde{I}(X/Y)$ on variance $\sigma^2(P(X))$ for each trajectory which are shown on Fig.4.

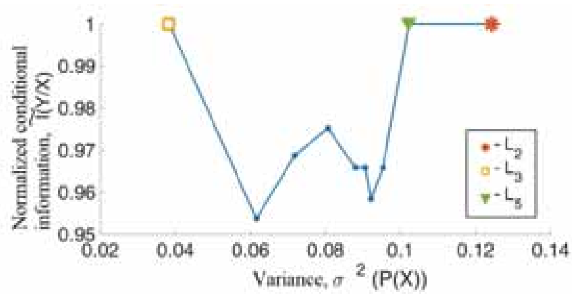


Fig. 4. Optimal telecommunication routes for maximum $\tilde{I}(X/Y)$ and variance $\sigma^2(P(X))$ for every trajectories L_i ($1 \le i \le 10$) at condition (6). Because of stochastic character of variables X and Y here we have used Y instead of X, i.e. $\tilde{I}(Y/X) = \tilde{H}(X)$.

Condition for maximum (minimum) of information (entropy) is fulfilled for trajectory L_2 with the nodes $L_2 = \{1, 22, 14, 9, 11, 25\}$.

Conclusions

Principal difference between ideas of the present work and existing analogues is using of characteristics of telecommunications system in the form of conditional information and informational entropy, which significantly improves quantitative description of digital signals. This idea is based on results of our numerous theoretical and experimental studies of nonlinear maps, signal synchronization, statistical characteristics of dynamic chaos and neural networks. Possibility of application of the new approach to routing in wireless communications is demonstrated by model experiments.

We consider it's possible to realize the proposed informational-entropic routing in specialized mobile wireless sensor networks UWB (Ultra-Wide Band) with MANET protocol (Mobile Ad hoc Network). Several tens of UWB transceivers can be used as transponders considered as the MTS nodes. These mobile devices perform functions of both routers and hosts. We can use the routing algorithms based on distance vector (DV - Distance Vector) on state of communication channels (LS - Link State). In this case, it's necessary to use metrics in form of information and i average value of entropy over the ensemble. One of applied problems will be to search for possibilities of using simple standard MANET algorithms (with active routing) by converting of input signals to probabilistic measures.

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References

[1] WuyiYue, Yutaka Matsumoto. Performance Analysis of Multi-Channel and Multi-Traffic on Wireless Communication Networks, Springer Science & Business Media, 2007, p. 324.

[2] Roger L. Freeman. Telecommunication System Engineering, John Wiley & Sons, 2015, p. 1024.

[3] Roger L. Freeman. Fundamentals of Telecommunications, John Wiley & Sons, 2005, p.720.

[4] Huseyin Arslan, Zhi Ning Chen, Maria-Gabriella Di Benedetto. Ultra Wideband Wireless Communication, John Wiley & Sons, 2006, p.474.

[5] J. S. Baras, H. Mehta. A probabilistic emergent routing algorithm for mobile ad hoc networks, Proceedings at WIOPT03: Modeling and Optimization in mobile, ad hoc and Wireless Networks, 2003.

[6] E. Bonabeau, M. Dorigo and G. Theraulaz, Swarm Intelligence: From Natural to Artificial Systems, Oxford University Press, 1999.

[7] F. Ducatelle, Gianni Di Caro, Luca M. G. Ant Agents for Hybrid Multipath Routing in Mobile Ad Hoc Networks, Proceedings of the Second Annual Conference on Wireless On-demand Network Systems and Services, IEEE, New York, 2005.

[8] Arun Narayanan, DeLiang Wang. A CASA-Based System for Long-Term SNR Estimation, IEEE Trans. Audio, Speech, Lang. Process, vol. 20, No. 9, 2012, pp. 2518-2527.

[9] Shao H., Wu D., Li Y., Liu W., Chu X., Improved signal-to-noise ratio estimation algorithm for asymmetric pulse-shaped signals, IET Communications, vol. 9, No 14, 2015, pp. 1788-1792.

[10] Soojeong Lee, Chungsoo Lim, Joon-Hyuk Chang, A new a priori SNR estimator based on multiple linear regression technique for speech enhancement, Digital Signal Processing, vol. 30, 2014, pp. 154–164.

[11] FeiQin, Xuewu Dai, John E. Mitchell. Effective-SNR estimation for wireless sensor network using Kalman filter, Ad Hoc Networks, vol. 11, Issue 3, 2013, pp. 944–958.

[12] Z. Zh. Zhanabaev, S.N. Akhtanov, et al., arXiv:1609.09212.

[13] Andrea Goldsmith. Wireless Communications, Cambridge University Press, 2005, p. 644.

[14] Ali Grami. Introduction to Digital Communications, Academic Press, 2015, p. 604.