# STUDY OF VIVALDI ALGORITHM IN ENERGY CONSTRAINT NETWORKS

*Patrik MORAVEK*[1], *Dan KOMOSNY*[1], *Pavel VAJSAR*[1], *Jaroslav SVEDA*[1], *Tomas HANDL*[1]

[1]Department of Telecommunication, Faculty of Electrical Engineering and Communication, Brno University of Technology, Purkynova 118, 612 00 Brno, Czech Republic

moravek@phd.feec.vutbr.cz, komosny@feec.vutbr.cz, xvajsa01@stud.feec.vutbr.cz

***Abstract.*** *The presented paper discusses a viability of Vivaldi localization algorithm and synthetic coordinate system in general to be used for localization purposes in energy constraint networks. Synthetic coordinate systems achieve good results in IP based networks and thus, it could be a perspective way of node localization in other types of networks. However, transfer of Vivaldi algorithm into a different kind of network is a difficult task because the different basic characteristic of the network and network nodes. In this paper we focus on different aspects of IP based networks and networks of wireless sensors which suffer from strict energy limitation. During our work we proposed a modified version of two-dimensional Vivaldi localization algorithm with height system and developed a simulator tool for initial investigation of its function in ad-hoc energy constraint networks.*

## Keywords

***Energy, localization, simulations, synthetic coordinates, Vivaldi, wireless sensor networks.***

## 1. Introduction

Wireless Sensor Networks (WSN) are an emerging network technology with promising perspective in the future. The networks consist of small low-cost, low-powered devices capable of sensing surrounding quantities and monitoring the environment. The devices called sensor nodes are equipped with radio interface for wireless communication. Standard that describes physical and link layer of such communication is IEEE 802.15.4 [1], for addressing, routing and other functions on higher levels Zigbee standard is often used [2].

WSN cover broad band of applications ranging from military projects (the historical origin of this technology) to medical surveillance including habitat monitoring, storehouse management or building automation.

In a lot of applications self-localization of network nodes is a high desirable feature. Sensed data without location information are meaningless. Moreover, other processes run in WSN can advantageously exploit the position knowledge for better and more efficient function. Geographical routing, hierarchical aggregation, multicast and data gathering can be mentioned as examples of such processes [3].

Because of a high variety of application in different fields and with different features, there are also a lot of different requirements on localization process. Some of the applications need a precise localization with an error less than 10 % but a coarse grained localization is sufficient for others. However, in general, WSN nodes are equipped with limited energy sources, and thus, each process in WSN should be energy aware.

One of the approaches increasing accuracy of localization in IP based network contains synthetic coordinate system Vivaldi algorithm. Our work discusses the viability of such approach in source limited networks such WSN.

The rest of the paper is organized as follows. Section 2 gives a brief overview of localization techniques and approaches, section 3 introduces synthetic coordinate systems and their representatives. The discussion of viability of synthetic coordinates and necessary modification of Vivaldi algorithm for use in WSN follow in section 4. New simulator designed for simulation of Vivaldi algorithm and its modification is described in section 5, which precedes the last summarizing section 6.

## 2. Localization

The term "localization" relates to finding a position of an object in a defined area, generally. In IP based networks, the localization mainly means locating a station within a network. However, since a lot of applications provide surveillance, localization in WSN can also include a localization of an object, which is not a component of the network topology. This is called tracking and we do not consider it in this paper.

Localization protocols incorporate a localization algorithm to estimate the location of a sensor node without previous knowledge of its coordinates. The localization can be relative to the other nodes in a network or absolute in a determined coordinate system. If the network contains a certain percentage of nodes with a known position (called anchors), the unknown nodes (nodes having no knowledge of their position) use a certain measurement technique to estimate distances to these nodes and calculate their own position using determined localization algorithm. Anchor nodes can obtain their coordinates from GPS or by manual assignment. However, both approaches have their shortcomings either in higher energy cost or demanding initial process. The coordinate system of anchors is then applied to other nodes as well. The brief taxonomy of WSN localization is given in [4].

Localization algorithms require certain input information for the position determination. They work with information including mainly distances or angles. To obtain this information, specific measurement techniques are used. These techniques can be categorized into three main classes: RSS (received signal strength), TOA (time of arrival) and AOA (angle of arrival) based techniques [5]. Direct measurement is another technique, which is however impossible to use in the majority of applications.

RSS based method of distance estimation infers the distance from signal strength measured in a receiver. There are several signal propagation models that approximate the real radio channel and allow relating received signal strength to the distance between transmitter and receiver. It is an inexpensive and easy method of estimation in WSN since no extra hardware is required. However, several negative influences affect the measurement and cause estimation errors [6], [7].

Next category of measurements is based on measurement of signal propagation time. One-way measurement infers the distance between two nodes from the time of transmission and reception of packets. It requires precise a clock at each node and a complex time synchronization of all the nodes. To overcome this inconveniences, round-trip delay (RTT) can be calculated. The difference between the time of transmission and reception is measured at the same node, and thus, the synchronization is not necessary. However, a processing delay (to handle a packet) of the other node is included in the measured value. TDOA (time difference of arrival) is another method, which computes the position of a transmitter from the delay measured at several different nodes with a known position.

The last class of measurement techniques employs a system of angle measurements. If the unknown node knows at least the coordinates of two transmitting nodes and their directions, it is able to calculate its own position. For more detailed information about localization techniques and algorithms please refer to [5].

## 3. Synthetic Coordinate Systems

To improve localization accuracy in IP based networks, the problem of the distance estimation between stations was transferred into an artificial multidimensional coordinate system. Generally, RTT measurement was performed to estimate the distance between two stations. There is no need to measure the RTT between each pair of stations in localization algorithm based on a synthetic coordination system. Instead, the RTT value between two stations is estimated from their known coordinates in a predefined synthetic coordinate system. The RTT value refers to a distance between the stations in the coordinate system. Provided that data networks work ideally (there are no delays), a geographical coordinate system with longitude and latitude would be the appropriate choice as a coordinate system for localization purposes. Unfortunately, this condition is not accomplished in any current data network – packets are transmitted via more direct links, delayed at intermediate nodes, etc. Therefore, it is not possible to use a simple 2D coordinate system for RTT value prediction of network nodes. As a result, new artificial coordinate systems were proposed to meet conditions in IP based networks. There is no limitation in the number of dimensions or the type of coordinate system. Besides the standard Euclidian system, other coordinate systems (spherical, toroid, hyperbolic) were investigated (for more details see [8]). However, the Euclidian coordinate system is used the most because it offers the most suitable possibilities for this purpose.

There are proposed several algorithms using synthetic coordinate system (GNP, Lighthouse system, Vivaldi etc.). GNP [9] is a centralized algorithm with reference stations, which form a matrix of distances between themselves in the first phase and the rest of nodes is localized in the following step.

Lighthouse system presented in [10] uses reference station as well (called lighthouses). Contrary to GNP, it uses simpler mathematical operations and features more scalability thanks to employing recently localized nodes into a reference nodes infrastructure in each iteration step.

### 3.1. Vivaldi Algorithm

The Vivaldi algorithm proposed by Dabek et al. in [11] is a favorite localization algorithm used to obtain the position of stations in a network using the synthetic coordinate system. The algorithm uses synthetic coordinates with Euclidian distances; two standard dimensions and one extra dimension called height are defined in the new coordinate system. Communication delay in an access network is covered by the third dimension (as the main purpose of this dimension) while delay in a distribution network is expressed by coordinates.

The new coordinate system, 2D Euclidian system with height, is described by the following equations:

$$x - y = (x_1 - y_1, x_2 - y_2, x_h + y_h), \tag{1}$$

$$\|x\| = \sqrt{x_1^{\,2} + x_2^{\,2}} + x_h, \tag{2}$$

$$ax = (ax_1, ax_2, ax_h). \tag{3}$$

Coordinates of nodes are taken as vectors in the whole following text. The difference between standard 3D, 2D system and 2D coordinate system with height is depicted in Fig. 1.

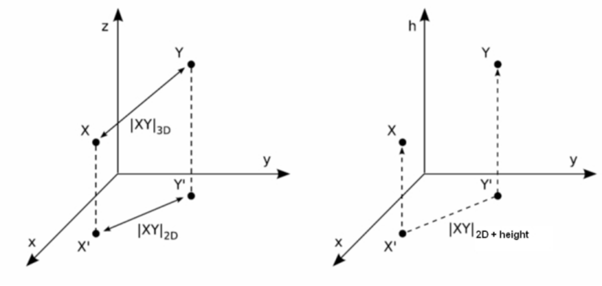


**Fig. 1:** Distance in 2D, 3D and 2D with height coordinate system.

The Vivaldi algorithm is a distributed and decentralized algorithm working without any infrastructure (such as reference stations). All nodes are equivalent in the system.

Finding node coordinates that minimize the error in predicted round-trip latency between arbitrary two nodes in a network is the basic principle of the Vivaldi algorithm. The idea of the algorithm comes from the analogy to a physical mass-spring system described in [12].

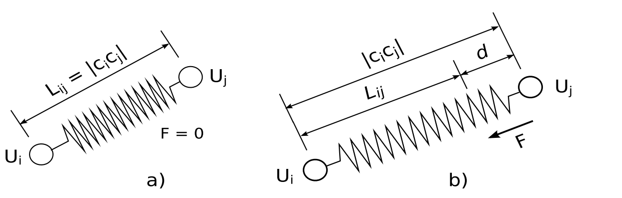


**Fig. 2:** Spring analogy to predicted latency; a) errorless prediction b) prediction with error.

As a spring tends to maintain its length with minimum energy, distances between nodes in a network are set such that minimum predicted latency error is achieved. Findings the energy minimum in the system of springs corresponds to finding the minimum error in the position estimation. Searching for node position is simulated as a movement of nodes connected with springs, see Fig. 2.

Nodes in a network are moved in a way in order to minimize the error function $E$:

$$E = \sum_i \sum_j \left( L_{ij} - \left\| \vec{c}_i - \vec{c}_j \right\| \right), \tag{4}$$

where $L_{ij}$ is the real latency between nodes $i$ and $j$ and $\vec{c}_i$ and $\vec{c}_j$ are their coordinates in the synthetic coordinate space. This equation corresponds to a spring between $i$ and $j$ nodes with a length of $L_{ij}$.

The principle of minimizing the error function is derived from the impact of a spring placed between two nodes. According to the Hook law

$$\vec{F} = -k\vec{d}, \tag{5}$$

the stretched or compressed spring affects the surrounding nodes, which are linked by the spring, by the force $\vec{F}$ in the opposite direction to this stretch or compression. This force is proportional to the length of the stretch (compression) described by the vector $\vec{d}$ and the spring constant k. In the Vivaldi algorithm, the force $\vec{F}_{ij}$ affecting the nodes $i$ and $j$ is

$$\vec{F}_{ij} = \left( L_{ij} - \left\| \vec{c}_i - \vec{c}_j \right\| \right) \vec{u}\left( \vec{c}_i - \vec{c}_j \right), \tag{6}$$

Where $\vec{u}\left( \vec{c}_i - \vec{c}_j \right)$ is the unit vector with the same direction as the vector $\vec{c}_i - \vec{c}_j$.

The resultant vector $\vec{F}_i$ of a node $i$ is the summation of partial vectors $\vec{F}_{ij}$ affecting the node $i$ (from all springs connected to the node $i$). In the one iteration step of the computational process the time interval δ of the affecting force $\vec{F}_i$ is considered. The node $i$ is subsequently moved to a new position $\vec{c}_i$ in the direction of force $\vec{F}_i$ according to the equation

$$\vec{c}_i = \vec{c}_i + \delta \vec{F}_{ij}, \tag{7}$$

Since the Vivaldi algorithm is a decentralized localization algorithm, the presented idea is performed at all nodes in a network. Each node then individually simulates its movement. The direction and the length of movement are computed from the latency values $L_{ij}$ and coordinates $\vec{c}_j$ received from nodes *j*.

The decentralized character of the algorithm means also that the coordinates received do not have to be reliable. The node with the coordinate $\vec{c}_j$ can be, for example, a new node at the beginning of the localization process or a node that cannot determine its position for whatever reason, and its coordinate oscillates.

The negative impact of the situations described is reduced in the Vivaldi algorithm with an adaptive timestep by assigning a specific error $e_j$ to each node. This error is sent by node with its coordinate.

The complete process of algorithm for node *I* is described in five steps below.

1. the weight *w* is computed from the estimated errors in coordinate calculation at the local node *i* and a distant node *j*

$$w = \frac{e_i}{e_i + e_j}. \tag{8}$$

2. the relative error $e_s$ of latency measurement calculation

$$e_s = \frac{L_{ij} - \left\| \vec{c}_i - \vec{c}_j \right\|}{L_{ij}}. \tag{9}$$

3. the weighted moving average of local error $e_i$ is updated

$$e_i = e_s c_e w + e_i (1 - c_e w). \tag{10}$$

4. timestep δ calculation

$$\delta = c_c w. \tag{11}$$

5. the node coordinate is updated

$$\vec{c}_i = \vec{c}_i + \delta (L_{ij} - \left\| \vec{c}_i - \vec{c}_j \right\|) \vec{u}(\vec{c}_i - \vec{c}_j). \tag{12}$$

One modification of the Vivaldi algorithm implements also the timestep δ adapted by multiplication by the constant $c_c$ and the weight *w* (step 4). The weight *w* depends on both local error $e_i$ and distant error $e_j$. If the error $e_j$ is greater related to local error $e_i$ the weight *w* is smaller and the node *j* has small relevance in position calculation. On the contrary, if the error $e_j$ is small, the weight *w* is close to one and the node *j* impacts on position calculation significantly.

The error $e_i$ in coordinate estimation is calculated in step 3 as a weighted moving average of relative latency error $e_s$. The value of this average can be changed by a tune constant $c_e$. If the constant $c_e$ is close to one, the error $e_i$ is affected the most by the current error $e_s$. With decreasing value of $c_e$ the previous value of $e_i$ plays a more significant role in the calculation.

Besides the above described algorithm, two simpler variants exist [11]. The main difference is that the timestep δ is a constant or a slowly decreasing value instead of dynamically adapting in these modifications.

## 4. Synthetic Coordinates in WSN

Since synthetic coordinate systems were proposed for IP based networks, there are several inconveniences rising from their usage in WSN. Algorithms described in the previous section are very demanding; especially from the energy point of view. We have to be always aware of strict energy constraints relating with WSN technology. Sensor nodes are relatively simple devices with weak microcontroller and very limited energy source. And provided that we use synthetic coordinate system, we affect both. There is higher computation cost and because of the frequent communication, the energy consumed by a radio part also increases. Moreover, system management and control require certain amount of energy too. On the other hand, the synthetic coordinate system offers indisputable advantages. Decentralized feature of a localization algorithm means that the system is less vulnerable to system collapse because of node dysfunction or local error. There is an option to start localization without anchor nodes and form a completely relative map. But mainly, it provides more accurate position estimation based on the cooperation of all nodes. The synthetic coordinate algorithms are able to eliminate or minimize error caused by measurement methods, which is a serious problem in the range based localization. The optimization of accuracy is based on iterative approximation. However, this means an undesirable increase of energy cost, since each iteration requires updated information about the position of other nodes and a new measurement of the distance.

All the mentioned facts infer that we have to accept a certain trade-off considering the use of synthetic coordinate systems in WSN. Also, application requirements set the important conditions and limitations. Therefore, we proposed following modification of Vivaldi algorithm to adapt it for wireless sensor networks. The modification is called EAVA (Energy Aware Vivaldi Algorithm) and we will refer to it in the following text.

First, we decided to use two dimensional system with height (2D+h) with possible extension to 4D+h system, which can have better results (as stated in [13]). In IP based networks *h* is a positive value since it represents delay between two stations. In WSN, *h* can be related to general error caused by measurement method. Thus, it can be either positive or negative.

The distances are derived from RTT measurements in IP based networks. However, this is hardly possible in WSN. Time measurement requires precise time synchronization, which means a precise clock embedded in each device. Moreover, time synchronization process and its control is a difficult task and additional energy costs. In low-cost applications, mostly RSS based distance estimation is used. So, we recommend using the RSS measurement for the distance estimation instead of time based measurements. In proposed simulations with EAVA we consider RSS measurement as well.

The initial setting of a network depends on the presence of anchor nodes. If there are some, they can be either equipped with GPS receiver to set the coordinates or set manually. Then, the third coordinate *h* states for the error of GPS estimation. The other two coordinates relate to the standard 2D geographical system. With this initial setting of anchor nodes, triangulation or maximum likelihood method is performed to obtain a rough position estimation of all the nodes.

Provided that there are no anchor nodes in the network, all the nodes are set with certain determined initial coordinates (such as $x_i=0$, $y_i=0$, $h_i=0$, for example). The localization process then starts from the very beginning and there is naturally slower convergence requiring more iteration steps, which consumes subsequently more energy.

To save energy during the communication before each iteration step, only the RSS measurement and the communication with neighbours is performed. In case of high node degree (number of neighbours), only a subset of neighbours can be involved.

The energy consumption is the most crucial parameter of the localization, highly dependent on the number of iterations and the speed of convergence. Therefore, the setting of a shift constant$\Delta$ analogical to the timestep $\delta$ is highly important. However, there are other conditions and parameters, which considerably influence the convergence, and thus, the energy depletion and they have to be investigated. For parameters adjustment purposes certain simulations were proposed.

## 5. Simulations

The adjustment of protocols developed for a certain kind of networks and their transfer to an environment with totally different main features is always a challenging process. It is difficult to predict functionality and reliability of a protocol under different conditions. Although, a certain protocol works well in IP networks, it can totally fail in WSN. The energy depletion is the most problematic in this case, which is not considered in networks of mains-operated stations. Therefore, it is necessary to run certain simulations to verify the viability of a transferred protocol in new environment. Simulations can answer the question if it is reasonable to use the protocol without changes, with changes or if the protocol is totally inapplicable and a new one should be proposed.

For the purposes of the simulation of synthetic coordinate algorithms Vivaldi and EAVA, we proposed and developed a new simulation tool [14], [15]. The simulator is a JAVA based application implementing Vivaldi algorithm and its modified versions. The base coordinate system is 2D with height but can be easily upgraded to 4D with height system. The main simulator window can be seen in Fig. 3.

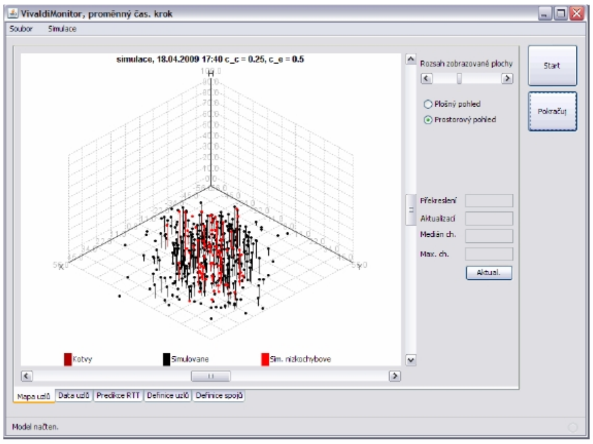

**Fig. 3:** Graphic user interface of developed simulation tool.

The simulator displays the convergence process of localization by updating the main window. There are three types of network nodes distinguished in the figure; anchors, unknown nodes with position error under threshold (0,15 by default) and nodes with higher position error.

The other modules of the simulator offer the graphical representation of position and error evolution. The example of a position convergence simulation is depicted in Fig. 4.

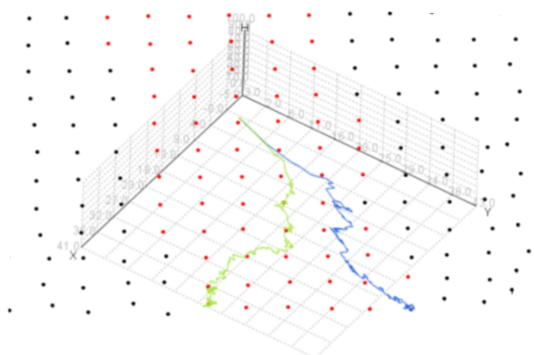

**Fig. 4:** Convergence of position of two nodes.

Another example of a simulator output can be seen in Fig. 5, Fig. 6 and Fig. 7. They show the two dimensional area of deployed nodes after simulation.

First, the real node deployment is defined (or imported) in the simulator. Then, the distance metrics are given to the nodes (defined or imported). When the simulator runs the Vivaldi or EAVA algorithm it successively updates the picture of node deployment. The figures present the result picture after 50, 700 and 1500 iteration steps respectively. The black marks in the figures represent the nodes, which are still far away from their real location, it means, they have a large position error. On the other hand, the red mark represents a node, whose position error is already under the defined threshold. The more iteration the simulator performs, the higher probability of successful localization (low position error) is.

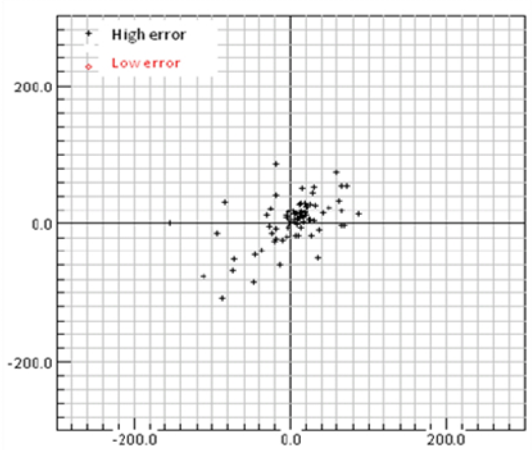


**Fig. 5:** Node deployment after 50 iterations of Vivaldi algorithm with adaptive iteration step.

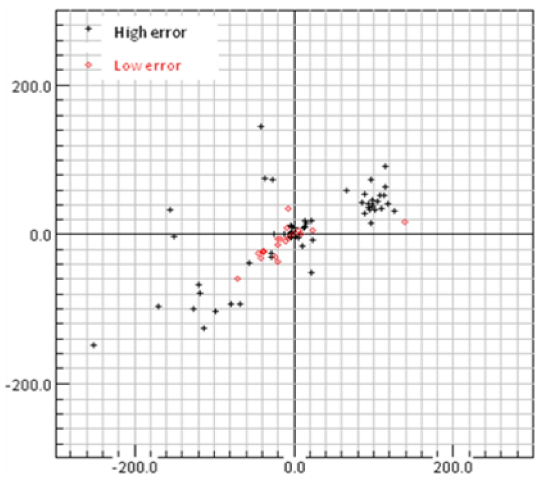


**Fig. 6:** Node deployment after 700 iterations of Vivaldi algorithm with adaptive iteration step.

The Fig. 8 depicts the sample simulation result where the error is evaluated. We have both absolute error and relative error at disposal. Since the original Vivaldi algorithm uses a time distances between nodes for position estimation and for localization optimization the absolute error is expressed in ms. The absolute error is a difference between the RTT of nodes at their real locations and the RTT of the nodes in a new network arrangement calculated by the localization algorithm.

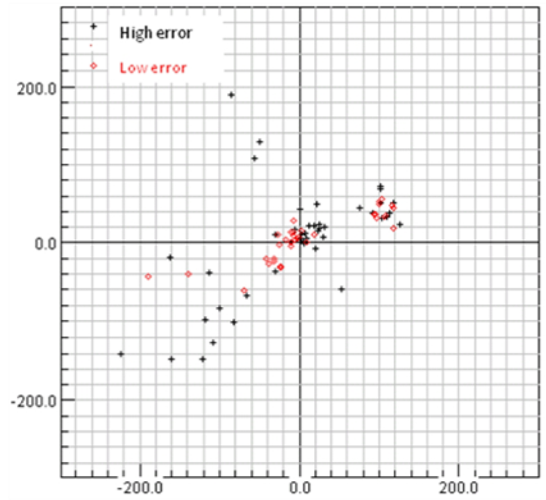


**Fig. 7:** Node deployment after 1500 iterations of Vivaldi algorithm with adaptive iteration step.

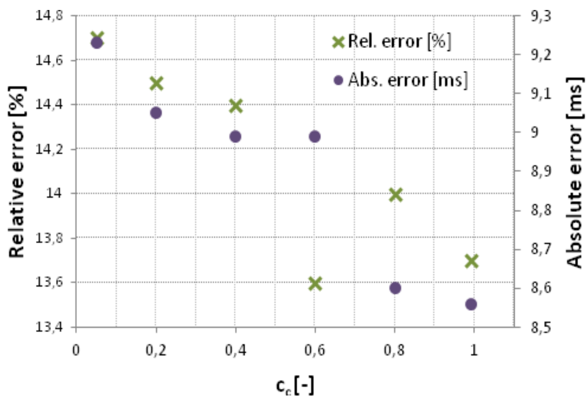


**Fig. 8:** Relative and absolute error of sample scenario after the simulation in dependency on the parameter $c_c$ of EAVA.

Besides that the simulator incorporates the embedded editor of simulated topologies with import and export functions. Moreover, the various quantities and their evolution are presented in clearly arranged graphs with the possibility of subsequent export of all the data into a Matlab environment. History of coordinates is also a useful feature.

## 6. Conclusion and Future Work

Localization in WSN is a challenging task and there is a broad variety of approaches to this topic. Because of the particularity of these networks it is very difficult to simply implement protocols from different networks. However, although it is impossible to transfer protocols directly, it is promising to use at least some their features, which allowed their successful deployment in IP based networks. Therefore, we proposed modified version of Vivaldi algorithm called EAVA, which is adjusted to WSN. The protocol considers RSS measurement for distance estimation and strictly controls the energy consumption during localization. The main idea is to exploit cooperation of nodes based on mass spring principle and at the same time use as little energy as possible. In IP based networks the Vivaldi algorithm features promising results but at the cost of high communication. This is not acceptable in WSN, so radical change has to be done.

For the simulation purposes, we proposed and developed a new simulator tool VivaldiMonitor. It implements successfully Vivaldi algorithm and its modification into static networks. It offers modularity and elaborated graphical output with user-friendly interface with data export and import option. The next phase is devoted to the development of a library implementing EAVA and the modification of the simulator for WSN specific features with development of energy module to control energy depletion during localization.

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# References

[1] IEEE Standard for Information Technology Part 15.4: *Wireless medium access control (MAC) and physical layer (PHY) specifications for low-rate wireless personal area networks (WPANs)*, IEEE Std 802.15.4-2006 (Revision of IEEE Std 802.15.4- 2003), pp. 1–305, 2006.

[2] *Zigbee Alliance*, [online]. Available at WWW: <www.zigbee.org.>.

[3] AKYILDIZ, F., I.; SU, W.; SANKARASUBRAMANIAM, Y.; CAYIRCI, E. Wireless sensor networks: A survey. *Computer Networks*, 2002, Vol. 38, No. 4, pp. 393–422. ISSN 1389-1286.

[4] HUANG, W.; WANG, Y.; GUAN, H. The current situation and prospect of localization in wireless sensor network. In *Computer Science and Engineering, 2009. WCSE '09. Second International Workshop*, 28-30 Oct. 2009, pp. 483-487. ISBN 978-0-7695-3881-5.

[5] MAO, G.; FIDAN, B.; ANDERSON, B., D., O. Wireless sensor network localization techniques. *Computer Networks*, 2007, Vol. 51, No. 10, pp. 2529-2553. ISSN 1389-1286.

[6] MORÁVEK, P.; KOMOSNÝ, D.; SALA, D., G.; GUILLÉN, A., L. Received signal strength uncertainty in energy-aware localization in wireless sensor networks. In *Environment and Electrical Engineering (EEEIC), 2010 9th International Conference on*, 2010. pp. 538-541, ISBN 978-1-4244-5370-2.

[7] MORAVEK, Patrik; KOMOSNY, Dan; SIMEK, Milan; JELINEK Mojmir; GIRBAU, Sala, David LAZARO, Guillen, Antoni. Signal Propagation and Distance Estimation in Wireless Sensor Networks. In *The 33rd International Conference on Telecommunication and Signal Processing, TSP 2010*. 2010. pp. 35-40, ISBN 978-963-88981-0-4.

[8] SHAVITT, Y.; TANKEL, T. On the curvature of the Internet and its usage for overlay construction and distance estimation. In *INFOCOM 2004 - Twenty-third Annual Joint Conference of the IEEE Computer and Communications Societies*. IEEE, 2004. Vol. 1, ISBN 0-7803-8355-9.

[9] NG, E.; HUI, Z. Predicting Internet network distance with coordinates-based approaches. In *INFOCOM 2002. Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies*. Proceedings. IEEE, 2002. Vol. 1, pp. 170 – 179, ISBN 0-7803-7476-2.

[10] PIAS, M.; CROWCROFT, J.; WILBUR, S.; HARRIS, T.; BHATTI, S. *Lighthouses for Scalable Distributed Location*. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). Springer Berlin, Heidelberg, 2003. pp. 278-291, ISBN 978-3-540-40724-9.

[11] DABEK, F.; COX, R.; KAASHOEK, F.; MORRIS, R. Vivaldi: A decentralized network coordinate system. In *ACM SIGCOMM Computer Communication Review*. Association for Computing Machinery, 2004. Vol. 34, No. 4, pp. 15-26. ISSN 0146-4833.

[12] FRUCHTERMAN, T.; REINGOLD, E. *Graph Drawing by Force-directed Placement*. Software - Practice and Experience (SPE), November 1991, ISSN 1097-024X.

[13] LEDLIE, J.; GARDNER, P.; SELTZER, M. Network Coordinates in the Wild In *Proceedings of 4th USENIX Symposium on Networked Systems Design & Implementation 2007*. [online] Cambridge (USA): Harvard School of Engineering and Applied Sciences and Aelitis, 2007. pp. 299–311, Available at WWW: <http://www.eecs.harvard.edu/ syrah/nc/wild07.pdf>.

[14] MORAVEK, Patrik; KOMOSNY Dan; SIMEK Milan; SVEDA, Jaromir; HANDL, Tomas. Vivaldi and other localization methods. In *Proceeding of 32nd International Conference on Telecommunications and Signal Processing, TSP 2009*. 2009. pp. 1-5. ISBN 978-963-06-7716-5.

[15] MORAVEK, Patrik; KOMOSNY Dan; BURGET Radim; SVEDA, Jaromir; HANDL, Tomas. Study and Performance of Localization Methods in IP Based Networks: Vivaldi Algorithm. *Journal of Network and Computer Applications*, 2010. Vol. 34, No. 1, pp. 1-17. ISSN 1084-8045.

# About Authors

**Patrik MORAVEK** is a doctoral student in the Department of Telecommunication at the Brno University of Technology. He gained his Master's degree at the same university in 2008. His study specialization is TCP/IP stack and communication in ad-hoc networks. Nowadays, he is focused on wireless sensor network technologies and especially on the energy efficiency of radio communication and localization process.

**Dan KOMOSNY** received his Ph.D. degree in Teleinformatics in 2003. His research is focused on wireless sensor networks, IP networks and network operating systems. He gives lectures in courses dealing with Linux operating systems and communication in IP networks. He is an internal member of technical program committee of IEEE and IASTED conferences.

**Pavel VAJSAR** gained his Master degree at the Faculty of Electrical Engineering and Communication Technologies at the Brno University of Technology. Nowadays, he is a doctoral student at the same faculty. His major interest covers wireless sensor networks and their monitoring. Moreover, his research contributes to routing in MANET networks considering quality of service. He is also an OPNET modeler expert.

**Jaroslav SVEDA** gained his Master degree at the Faculty of Electrical Engineering and Communication Technologies at the Brno University of Technology in 2009. His interest covers network technologies and simulations.

**Tomas HANDL** gained his Master degree at the Faculty of Electrical Engineering and Communication Technologies at the Brno University of Technology in 2009. His field of expertise is mostly in IP based networks.