ISSN 1726-5479

SENSORS & TRANSDUCERS

3/12 vol. 14-2 Special

Physical and Chemical Sensors & Wireless Sensor Networks

International Frequency Sensor Association Publishing

Sensors & Transducers

Volume 14-2, Special Issue
March 2012

www.sensorsportal.com

ISSN 1726-5479

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA). Available in electronic and on CD.

Sensors & Transducers Journal

Contents

Volume 14-2
Special Issue
March 2012

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm

International Frequency Sensor Association (IFSA).

Sensors & Transducers Journal, Vol. 14-2, Special Issue, February 2012, pp. 164-178

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Mobility Model for Self-Organizing and Cooperative MSN and MANET Systems

Andrzej Sikora and Ewa Niewiadomska-Szynkiewicz
Institute of Control and Computation Engineering,
Warsaw University of Technology
ul. Nowowiejska 15/19, 00-665 Warsaw, Poland
Research and Academic Computer Network (NASK),
ul. Wawozowa 18, 02-796 Warsaw, Poland
E-mail: asikora@elka.pw.edu.pl, ens@ia.pw.edu.pl, andrzej.sikora@nask.pl, ewan@nask.pl

Received: 12 November 2011 /Accepted: 20 December 2011 /Published: 12 March 2012

Abstract: Self-organization mechanisms are used for building scalable systems consisting of a huge number of subsystems. In computer networks, self-organizing is especially important in ad hoc networking. A self-organizing ad hoc network is a collection of wireless devices that collaborate with each other to form a network system that adapts to achieve a goal or goals. Such network is often built from mobile devices that may spontaneously create a network and dynamically adapted to changes in an unknown environment. Mobility pattern is a critical element that influences the performance characteristics of mobile sensor networks (MSN) and mobile ad hoc networks (MANET). In this paper, we survey main directions to mobility modeling. We describe a novel algorithm for calculating mobility patterns for mobile devices that is based on a cluster formation and an artificial potential function. Finally, we present the simulation results of its application to a rescue mission planning. *Copyright © 2012 IFSA.*

Keywords: Self-organizing network, Ad hoc network, Mobile sensor network, MSN, MANET, Mobility model; Artificial potential function, Network simulation.

1. Introduction to MSN and MANET

Ubiquitous communication, sensing and actuation are new area of research that will hold the tremendous potential in many areas of everyday life, and is rapidly increasing its advance into different areas of technology. A Self-organization is an important concept for building large scale, scalable and cooperative ad hoc network systems for sensing and actuation. Wireless sensor networks (WSN) and mobile ad hoc networks (MANET) are distributed, self-organizing and cooperative multi-agent architectures formed by a set of wireless devices that can freely and dynamically organize themselves into temporary network topologies [1, 2, 4-6, 11, 12, 26].

Typical WSN usually consists of a large number of stationary sensors densely distributed in a deployment area. The nodes often have to cooperate to perform the distributed sensing tasks. The large number of nodes usually precludes manual configuration. Moreover, the system dynamics precludes a pre-configuration. Therefore, nodes have to self-configure and self-organize to establish a topology that provides communication and sensing coverage. In many real life applications networks formed by stationary nodes suffer insufficiency. Therefore, there is a need for mobile sensor network (MSN) that is capable to change its layout and position. Such a network is formed by mobile sensor devices.

Mobile ad hoc networks (MANET) comprise self-configuring mobile wireless communication devices which combine the roles of terminals and routers. Each device can run applications and participate in transferring data to recipients within its range. Network nodes can move in space, and direct communication between each pair of nodes is not usually possible. No network infrastructure is required for communication, there are no central network management points, and no device has a specific location assigned.

The lack of fixed network infrastructure components in MSN and MANET systems allows creating unique topologies and enables the dynamic adjustment of individual nodes to the current network structure in order to execute assigned tasks. Specific configurations usually operate for a short time in order to meet the current requirements.

This paper considers issues concerning self-organizing MSN and MANET systems design and development. We focus on network systems formed by mobile, wireless devices that may spontaneously create a network, manage movement of nodes, assemble the network themselves, and dynamically react to changes in the domain and network requirements. The potential applications include an optimal coverage for monitoring of an unknown environment, producing a well connected network despite the limited resources, providing a connection between data sources and data sinks, which are not necessarily uniformly distributed across the network, and others [15, 16]. It is obvious that the mobility of sensor networks can be used to improve its performance characteristics, such as sensing coverage or network connectivity [4]. The question is how the mobility can efficiently be managed toward a better network system performance. We describe a novel approach to design a mobile network. The proposed concept of mobility patterns calculation is based on a cluster formation and an idea of potential function commonly used in robots navigation.

The rest of the paper is organized as follows: section 2 presents a brief overview of mobility models, section 3 describes our proposed PFM model and its application, section 4 presents simulation results. We conclude this paper in section 5 with intended future work.

2. Mobility Modeling

Modeling of node mobility plays the crucial role in design and development of MSN and MANET systems. In general, the results of simulations show that the communication protocols performance may vary drastically across mobility models and performance rankings of protocols may vary with the mobility models used [3, 21]. Therefore, studying the performance of ad hoc networking protocols and application services in the presence of mobility is an important stage of the design process. It implies that the characteristics of mobility models of nodes need to be analyzed and studied very carefully. It is obvious that real-life movement patterns are very difficult to obtain, and realistic models are usually very complicated. A number of less and more detailed mobility models have been introduced, and are described in literature. The survey and discussion of main directions to mobility modeling and the taxonomies of mobility models are available in [3] and [21].

Two approaches for mobility patterns modeling are distinguished [4, 21, 22]:

- *Motion traces models* (TM). The deterministic models that require the accurate information about mobility patters (i.e., positions of nodes in time).
- *Syntactic models* (SM). The analytical random-motion models that use randomness in calculation of traversing patterns from one place to another. They can be classified:
  - based on the description of mobility patterns into *individual movements* and *group movements*,
  - based on the degree of randomness into: *constrained topology-based models* and *statistical models*.

In constrained topology-based models the movement is restricted by various constraints: pathways, speed limits, obstacles, etc. In statistical model the node is allowed to move anywhere in the domain, hence the model is based on total randomness.

Bai et al. [3] classify the mobility models based on their basic mobility characteristics:

- *Random models*. As in statistical models, nodes move randomly, and can be classified further based on the degree of randomness. A Random Mobility model (RM) that implements Brownian-like motion, and a Random Waypoint model (RWP) with randomly generated destination point and velocity are commonly used models from this group.
- *Models with temporal dependency*. The mobility patterns are influenced by the previously generated movement patterns. A Gauss-Markov and smooth random mobility model fall into this category.
- *Models with spatial dependency*. Nodes tend to move in a correlated manner. A reference point group mobility model belongs to this category.
- *Models with geographical restrictions*. Movements of all nodes are constrained by streets, roads, obstacles, etc. Path-based and obstacle mobility models fall into this category.

Roy [21] provides the alternative classification. He divides mobility models into seven groups:

- *Individual mobility models*. A mobility pattern for the individual node is calculated.
- *Group mobility models*. A mobility pattern for a group of cooperative nodes is calculated.
- *Autoregressive mobility models*. Mobility patterns are correlated with the mobility states (i.e.: position, velocity, acceleration at consecutive time instants).
- *Flocking and swarm mobility models*. Mobility patterns imitate the trajectories performed by dynamic nodes of self-organizing networks in nature (like swarms).
- *Virtual game-driven mobility models*. A mobility pattern is calculated due to the interactions with all other nodes in a network or with groups of nodes.
- *Non-recurrent mobility models*. It is assumed that a network permanently changes its topology in time. A node moves in a totally unknown way, and previous patterns are not repeated.
- *Social-based mobility models*. The family of the mobility models those are associated as a community of groups within a society. The models describe non-homogenous behaviors in both space and time.

The mobility models that fall into all above-quoted categories of models are collected in Table 1.

3. Mobility Model for Self-organizing MSN and MANET

Let us consider a problem of design of self-organizing network formed by mobile nodes, connected by wireless links. We assume that to achieve goal network nodes should collaborate, and a whole network should enable continuous communication with the base station, hence the network must be connected. A collective motion is often required in mobile sensing networks. It involves communication among and between individual nodes or clusters of nodes to coordinate their movement. We assume that the network system should change its topology to achieve a goal. The objective is to calculate mobility patterns for all network nodes. The use of relatively simple random mobility models (RM, RWP) did not give satisfactory results in our experiments. Therefore, we have developed a novel algorithm to calculate mobility patterns for a mobile sensor network. Our model resembles a collision-free movement of a group of mobile devices. It can be used in design, development and evaluation of MSN and MANET systems, and for motion planning for real ad hoc systems.

Table 1. Mobility models.

Group of models	Models
Individual mobility models	Random walk mobility
	Random waypoint mobility
	Smooth random mobility
	Geographic constraint mobility
	Realistic random direction mobility
	Deterministic mobility
	Partially deterministic mobility
	Random Gauss-Markov mobility
	Semi-Markov smooth mobility
	Steady-state generic mobility
	Graph-based mobility
	Hierarchical influence mobility
	Boundless simulation area mobility
	Behavioral mobility
	Fluid-flow mobility
	Potential field mobility
	Correlated diffusion mobility
	Particle-based mobility
Group mobility models	Reference point mobility
	Reference velocity mobility
	Reference velocity & acceleration mobility
	Structured mobility
	Virtual track-based mobility
	Drift mobility
	Group force mobility
Autoregressive models	Autoregressive individual mobility
	Autoregressive group mobility
Flocking and swarm models	Flocking mobility
	Swarm group mobility
Virtual game-driven models	Virtual game-driven mobility
Non-recurrent models	Non-recurrent mobility
Social-based models	Time-variant mobility
	Community-based mobility
	Orbit-based mobility
	Entropy-based mobility
	Knowledge-driven mobility

In our research we have focused on the individual mobility where the mobility pattern of an individual node is considered. Our model combines two approaches – potential field and particle-based mobility modeling. The concept to build an artificial potential field where the mobile devices move from a high-value state to a low-value state, and define an associated potential function that captures both operational goals and the environment of a network is a popular direction in motion planning in mobile robotics [7] and mobile ad hoc networks [14]. Due to such model, the determined mobility pattern of each node includes attraction to the destination and repulsion from each obstacle. In these approaches sensor nodes not only receive forces from the surrounding environment, but also receive forces from one another. The particle-based mobility modeling [21] that considers each mobile node as a ”self-driven” moving particle in the physics of Newtonian mechanics or quantum mechanics is the other popular technique in management of mobile devices. Each node is characterized by a sum of forces, describing its desire to move to the direction, avoiding collisions with other nodes and obstacles. The driving force is associated with each node, and is self-produced.

3.1. Problem Formulation and Network System Description

Let us consider a set of mobile wireless devices that compose a mobile network, and are assumed to operate in a three-dimensional field filled with obstacles. Each node navigates itself to a particular location to achieve the goal. The objective is to calculate the optimal motion trajectory from one configuration to another that meets the following requirements:

1) the mobility should be managed toward a better coverage and well connected network that enables a continuous communication with a base station,
2) the traversing pattern from one place to another has to be collision free and should allow to push the network node through the narrow passage,
3) the traversing pattern has to capture the environment requirements (the signal propagation can change in time).

We have proposed the scheme for management of nodes' movement based on a cluster formation and application of an artificial potential function that captures the above-quoted requirements. In our formulation all network nodes and obstacles form a set S of N entities; $O_i, i = 1, \dots, N$. We assume that our obstacles can move as well (nodes can be obstacles for other nodes in the network), hence the obstacles are the same type of entities as the network nodes. We define each entity O_i as a solid body, which position is described by three Cartesian coordinates [x_i, y_i, z_i] and orientation is given by a quaternion [7]: $Q^i = q_0^i + q_1^i\mathbf{i} + q_2^i\mathbf{j} + q_3^i\mathbf{k}$. We consider objects that are of different shapes. To simplify the calculation we made an assumption that the interactions between each pair of entities (O_i and O_j) are described by the interactions between points selected from O_i and O_j (see Fig. 1). Hence, in case of O_i the set of selected points is as follows: $P^i = \mathbf{p}_1^i, \dots, \mathbf{p}_{M_i}^i, P^i \in O^i$ with $\mathbf{p}_1^i = \mathbf{c}^i$, where $\mathbf{c}^i$ is the central point, and $M_i - 1$ other points are selected by the user. Such a representation of a node allows us to implement translation and rotation, hence it is easy to rotate the network node and push through the narrow passage, Fig. 2. The rotation is given by a quaternion product.

Obviously, it is possible to simplify the description – each object O_i can be described by a single point $\mathbf{c}^i$ (similarly to commonly used mobility models). In such an approach the mobility pattern calculation simplifies, but the generated trajectory is less realistic.

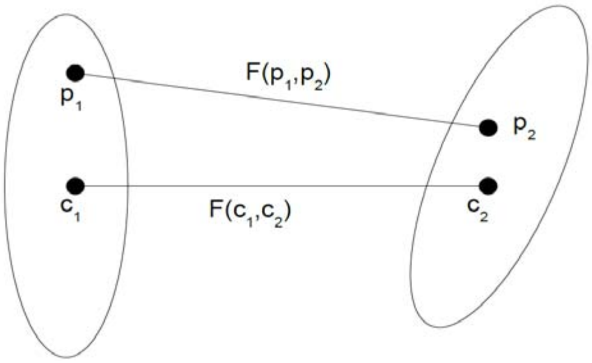

Fig. 1. The node description.

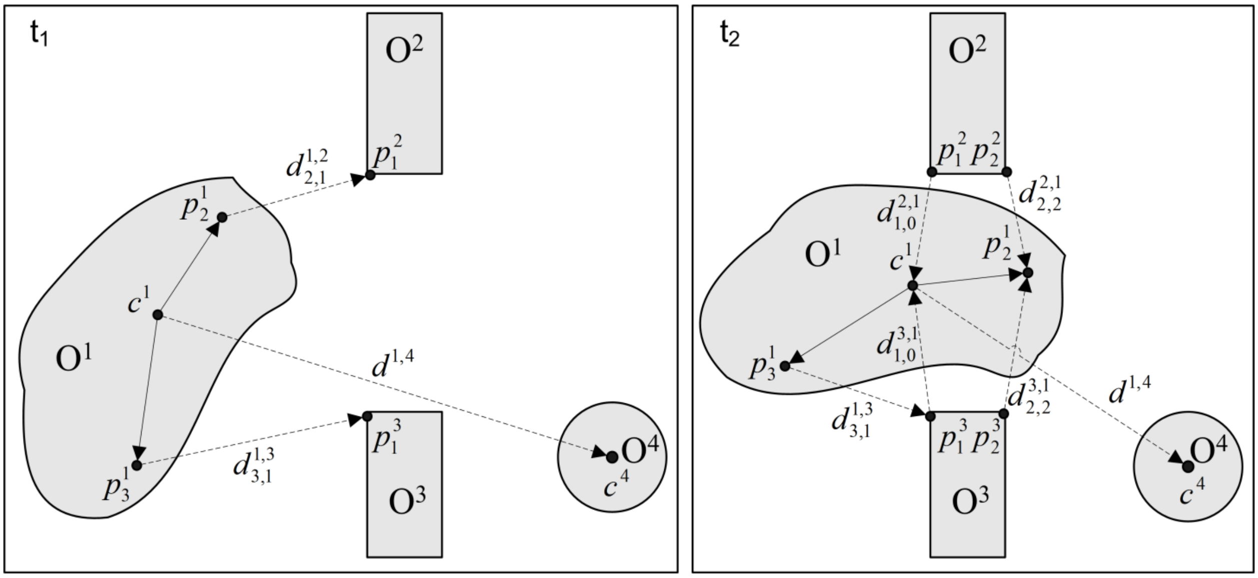

Fig. 2. The rotation of the mobile device.

3.2. Potential Field Mobility Model (PFM)

Inspired by classical dynamics that study the motion of objects in the concept of an artificial potential fields and particle-based modeling we have developed a model in which the mobility of each node in the network is governed by the description of an artificial potential function. The potential function U is a differentiable real valued function, which value can be viewed as energy, and hence the gradient of the potential is a force. The gradient is a vector which points in the direction that locally maximally increases U . The potential function can be constructed as a sum of attractive and repulsive potentials. The meaning of the attractive/repulsive is straightforward: the goal attracts the mobile device while the obstacle repels it. Therefore, the sum of attractive and repulsive influences draws the mobile device to the goal while deflecting it from obstacles. The gravity mobility model, which is based on the use of Newton’s gravitational law of motion in classical dynamics to calculate a mobility pattern is the example of this approach. Unfortunately, it is insufficient in many applications. The model often introduces oscillations into the movement of nodes. The oscillations are hard to eliminate. To address this problem, we have constructed a simple potential function that captures all the requirements for calculated mobility pattern mentioned in the previous subsection. The inspiration came from classical mechanics and liquid crystals where it is popular to model the interactions between a pair of neutral atoms or molecules via Lennard-Jones potential function (see [25] for details). We have proposed the simpler function with similar characteristics:

$$U_{ab}^{ij}\left(\hat{d}_{ab}^{ij}\right)=\begin{cases}\varepsilon m_a^i m_b^j\left(\dfrac{\bar{d}_{ab}^{ij}}{\hat{d}_{ab}^{ij}}-1\right)^2 & \left|\bar{d}_{ab}^{ij}-\hat{d}_{ab}^{ij}\right|>\tau_{ab}^{ij}\\ 0 & \left|\bar{d}_{ab}^{ij}-\hat{d}_{ab}^{ij}\right|\le\tau_{ab}^{ij}\end{cases} \tag{1}$$

where $\hat{d}_{ab}^{ij}$ denotes the estimated distance between points p_a^i and p_b^j, $\bar{d}_{ab}^{ij}$ the reference inter-node distance (calculated due to maximal radio range), ε, m_a^i, m_b^j and τ_{ab}^{ij} are parameters. The point reaches an unstable equilibrium for $\hat{d}_{ab}^{ij}\in\left[\bar{d}_{ab}^{ij}-\tau_{ab}^{ij},\bar{d}_{ab}^{ij}+\tau_{ab}^{ij}\right]$, as depicted in Fig. 3. Similarly to the Lennard-Jones potential the form of U_{ab}^{ij} has no theoretical justification. In the reference position of our node $\hat{d}_{ab}^{ij}=\bar{d}_{ab}^{ij}$ we obtain $U_{ab}^{ij}\approx 0$; it means the best coverage on condition of full connected network. However, in unknown environment with obstacles it is usually impossible to move a node to an optimal position. Hence, we can calculate the estimated distance $\hat{d}_{ab}^{ij}$ solving the optimization problem

$$\min_{\hat{d}_{ab}^{ij}} U_{ab}^{ij}\left(\hat{d}_{ab}^{ij}\right) \tag{2}$$

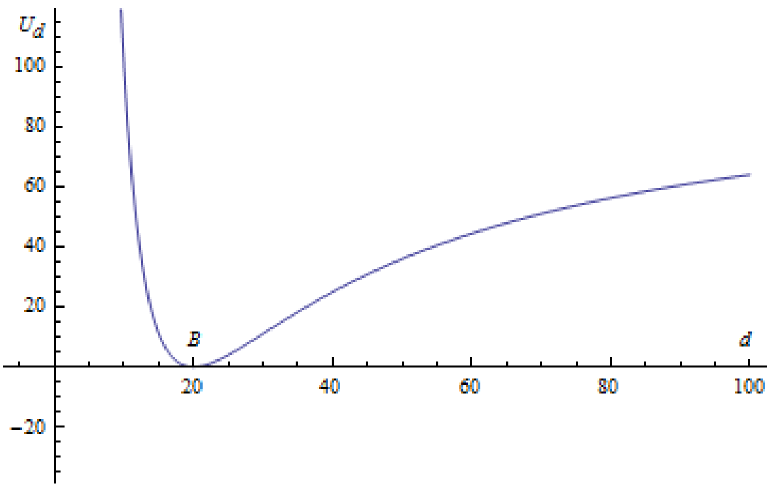

Fig. 3. The artificial potential function.

It is obvious that the calculation of the whole trajectory since the node reaches the equilibrium point is not an easy task because of the numerous actors operating in the scene. However, we can describe our mobile network as a physical system consisting of objects that are forced to move in the advisable direction with the adequate speed. The algorithm for traversing pattern calculation at time instants $t_0+\Delta t, t_0+2\Delta t, \ldots$ for *i*-th node is as follows:

Algorithm 1.

- *Step 1.* Calculate the reference inter-node distances due to current maximal radio range and environment characteristics (for all points of O^i).
- *Step 2.* Calculate the values of $\hat{d}_{ab}^{ij}$ for all points of O^i using the formula (1).
- *Step 3.* Calculate the displacement for the whole object O^i (the *i*-th node) for results of *Step 2*.
- *Step 4.* Move the i -th node to the new position in the domain.
- *Step 5.* Rotate the i -th node (if necessary).

- *Step 6.* Calculate and broadcast to the network the new positions of all points of O^i.

Return to *Step 1*.

3.3. Reference Distances Calculation

In the first step of our algorithm we have to calculate the reference distances for all points selected from a given node, due to the current maximal radio range and assumed probability of connection between nodes in a network. To solve this problem we can use Q -function defined in [20]. Unfortunately, Q -function depends on two parameters: n called "distance-power gradient" that indicates the rate at which a signal strength decreases with a distance, and the signal disturbance X_σ that is a zero-mean Gaussian distributed random variable with standard deviation σ . To estimate both these parameters we apply the commonly used radio signal propagation model that indicates that received signal power decreases with a distance, both in outdoor and indoor environments. Therefore, the power of the signal received by a receiver P^r at a distance d is defined as

$$P^r(d)[dBm] = P^t[dBm] - PL(d)[dB] , \tag{3}$$

where P^t denotes power used by a sender to transmit the signal and $PL(d)$ the average signal degradation (path loss) with a distance d . A path loss $PL(d)$ is modeled as follows:

$$PL(d)[dB] = PL(d_0)[dB] + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma + \sum_i PAF_i , \tag{4}$$

where d_0 is a close-in reference distance (for IEEE 802.15.4 usually d_0=1m), PAF_i is a partition attenuation factor for *i*-th wall (experimentally determined).

We calculate n and X_σ using formulas (3) and (4), assuming $d = d_c^{ij}$ (d_c^{ij} is a real distance between nodes i and j calculated for known nodes locations) and measured P^r. We assume that all nodes are equipped in any location system and are aware of their own location. The detailed description of n and X_σ computing can be found in [20].

3.4. Self-organizing Mobile Network Design

Consider a situation where the task is to create a network that enables the continuous communication with a base station to achieve a given goal or goals. We can form a cluster structured mobile network that covers the area between the base station and the cell containing a goal or a set of goals. The cluster formation is based on the following characteristics:

- all nodes are grouped into overlapping clusters with two, three or four elements, Fig. 4,
- nodes in a cell must be able to communicate with each other,
- each cluster can communicate with all neighboring clusters.

The design of a self-configuring network is performed in two steps. We can distinguish two groups of calculation units: the central unit (the base station) and the set of local units – the mobile nodes (see Fig. 4).

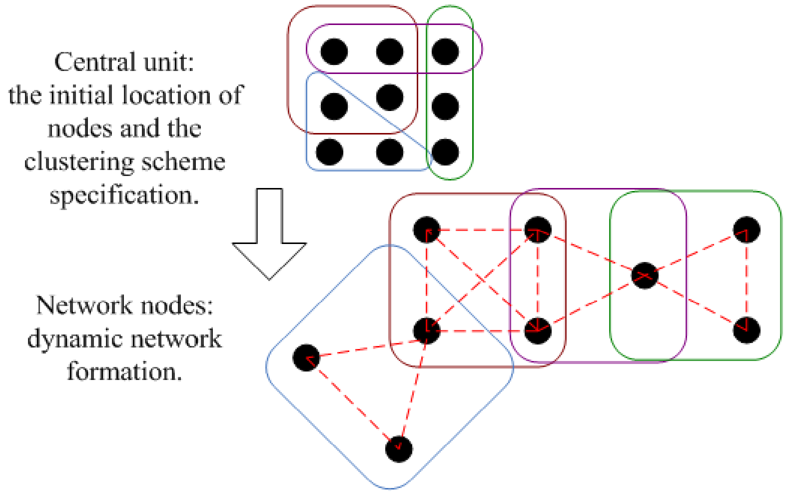

Fig. 4. Two steps in formation of a mobile sensor network.

Central unit: The central unit task is to determine the initial location of nodes and the clustering scheme i.e., the number of cells and the assignment of nodes to clusters. Decomposition of a network into clusters may be predefined or calculated by the dedicated clustering algorithm.

Network nodes: Each node sends at time instants $t_0 + \Delta t$, $t_0 + 2\Delta t$,… broadcast messages with its location, transmitted signal power P^t, cluster (or clusters) identifier (*id*), data about neighbors. We use MAC protocol with beacon synchronization. Next, the node calculates its displacement using the Algorithm 1 presented in subsection 3.2. The calculations are performed based on current distances between nodes and the measured signal power strength. We assume that for reference distances in the formula (1) the probability of connection between nodes in cluster has to be equal to 99 percent or higher.

Finally, the network consisting of calculated clusters is formed. It should be pointed that the value of the reference distance is adaptively modified due to the dynamic changes both in the deployment area and the set of network devices (decreased energy resources).

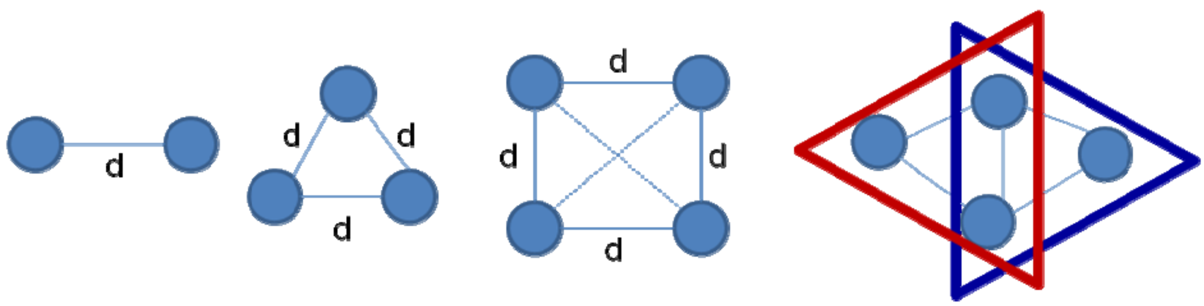

Fig. 5. Two steps in formation of a mobile sensor network.

4. Test and Evaluation

In order to evaluate the performance of our PFM mobility model simulations of various ad hoc network topologies and tasks have been performed. All experiments were done using our simulator MobASim.

4.1. MobASim Simulator

The software frameworks for ad hoc simulation are developed by many research institutes and universities [8, 13, 17, 19]. All of them provide various facilities, and focus on various applications. We have developed our simulation environment MobASim for parallel, synchronous and asynchronous simulation of WSN, MSN and MANET. In our system the network considered is described by different parameters defined by the user, thus we can perform the experiments for various topologies, wireless devices, mobility models, routing protocols, localization capabilities, etc. We apply the discrete event systems methodology to model network systems, i.e., the operation of each component of a given network is modeled through events that occur at discrete instants of time. To provide high performance and scalability of the MobASim software we utilized the paradigm of federating disparate simulators [9, 23] and asynchronous simulation [18, 27].

The system consists of following components (see Fig 6): *basic library* - a collection of classes implementing basic elements of a simulator (logical processes, events, etc.), *communication models library* - a collection of classes implementing models of wireless transmission and wireless communication standards, *mobility models library* - a collection of classes implementing mobility models, *runtime infrastructure* - the library of classes that provide communication between the processes and machines, *synchronization protocols library* - a collection of classes implementing synchronization algorithms, *XML Schema specification* for building XML file with description of a given network model, *GUI* - the graphical interface.

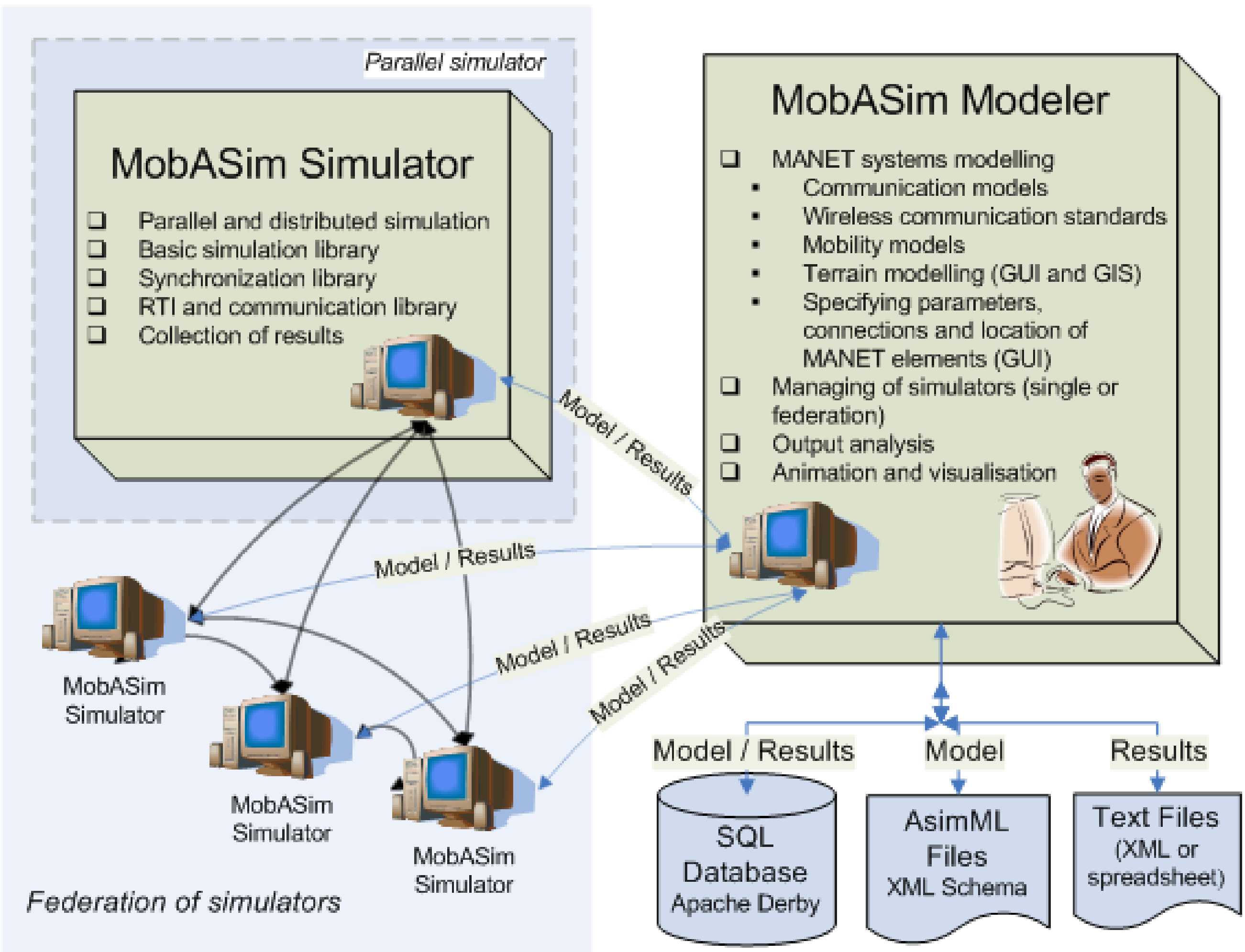

Fig. 6. Components of the MobASim system.

The user's task is to define the model of a network considered. The network topology is created using GUI or can be loaded from a disk file. All input parameters, i.e.: number of nodes, wireless transmission model, radio communication range, minimal and maximal speed, mobility model, routing protocol, energy reserve, etc., are determined. The deployment area (type of geographical data) is defined. Within the next step the user is asked to define the simulation setup, i.e., simulation type (synchronous, asynchronous), simulation horizon, etc. In the experimental stage all calculation processes are executed and the results of simulation - time varying topology (animation) and statistics are displayed.

MobAsim implements two models of wireless transmission: long-distance and log-normal shadowing described in [10, 20, 22]. The main difference to typical solutions is that in case of our implementations the obstacles are included and changes in wireless signal due to the obstacles influence the simulation. The IEEE 802.15.4 standard for wireless communication is supplied. We have implemented physical and MAC (Medium Access Control) layer protocols according to the specification drawn up by the IEEE Computer Society, network and application layers protocols according to the specification drawn up by ZigBee Standard Organization [28].

Three types of mobility models, i.e., PFM model described in section 3 and two simple models mentioned in section 2 - RWP (two variants) and path-based mobility model - were implemented. A map of deployment area can be generated in two ways. A user can define the simple objects in the domain as polygons. For more detailed description of a terrain to be considered the simulator provides the interface to the GeoTools toolkit (http://geotools.codehaus.org/), which is an open source Java coded library containing standard methods for the manipulation of geospatial data.

The performance of MobASim, and its application to ad hoc network design and evaluation is presented and discussed in [24].

4.2. Simulation Results

In this paper, we present the application of PFM mobility model for design of a self-organizing, cooperative network that enables a continuous connection between a goal and a base station.

Consider a situation where the fixed network infrastructure in a disaster area was damaged due to an explosion at a chemical plant. We plan to send several rescue teams to work on the disaster scene (0.36 km^2). A rescue mission requires that new communication channels be quickly established. Mobile ad hoc networks can be successfully used to solve this problem. It can enable communications with an adequate quality and can adapt to changing conditions and requirements in the danger zone. In case when we plan a rescue action it is useful to check various possible scenarios taking into account all constraints concerned with the environmental conditions. In presented problem the developed MSN should provide the continuous communication with all rescuers during the rescue action. Simulations were performed in the MobASim system. The goal of the experiments was to create a network topology with minimal number of nodes that ensures the connection between all rescuers and the base station. The network was composed of 4 rescuers and 10 mobile devices used for re-establishing the communication infrastructure. The mixed outdoor and indoor environment was considered (Fig. 7).

We present the simulation of 180 seconds of given ad hoc network operation. As a final result of our simulations we obtained the network consisting of eight clusters with irregular shapes, as presented in Fig. 8. The estimated values of calculated inter-node distances in clusters 0, 1, 5 and 6 computed at given time instants are presented in Table 2. In case of outdoor environment the final topology was formed by eight clusters with regular shapes (Fig. 9).

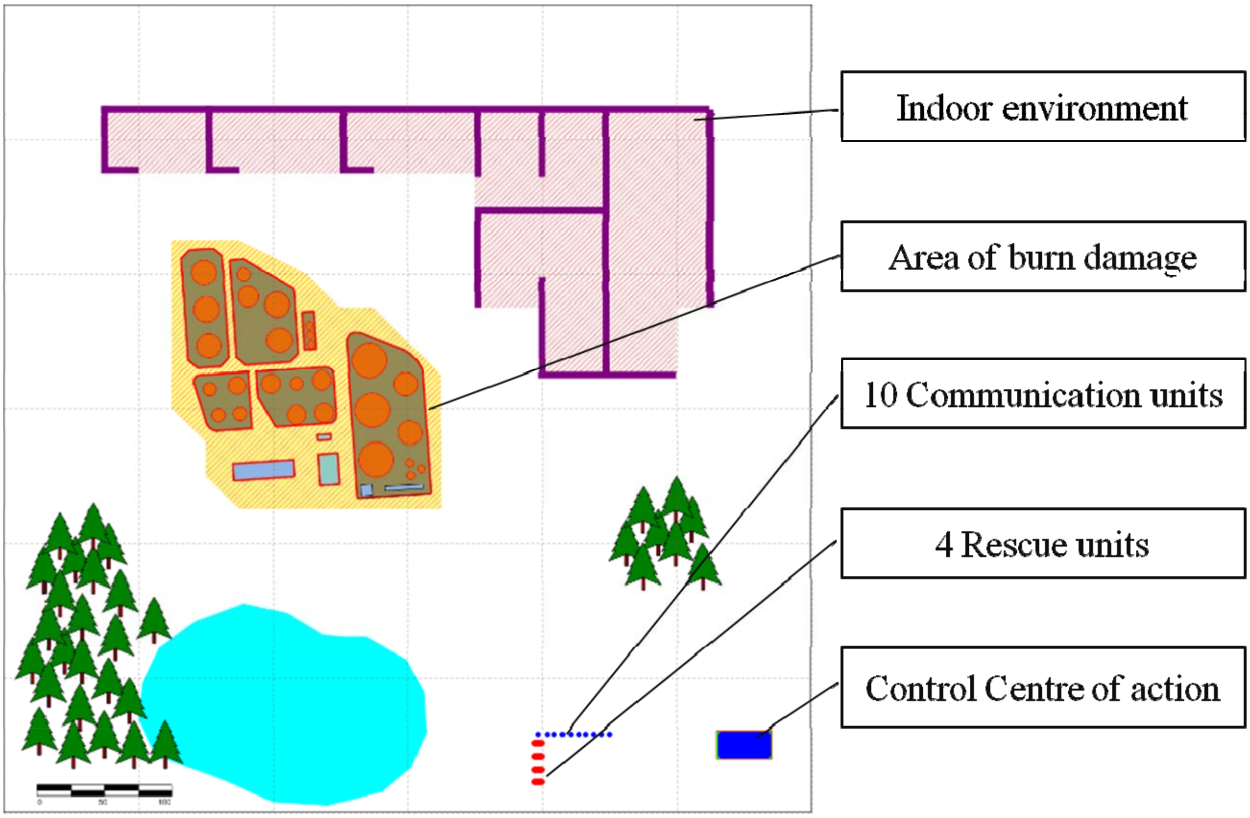

Fig. 7. The disaster scene.

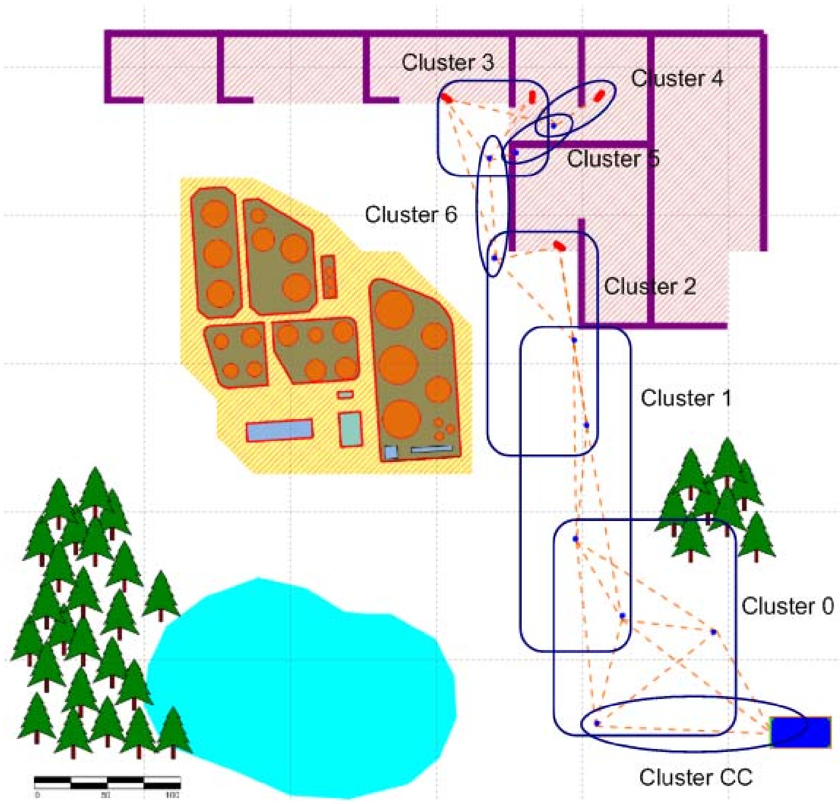

Fig. 8. The topology formed in mixed outdoor and indoor environment; eight clusters with irregular shapes.

Table 2. The temporal inter-node distances $\hat{d}$ (clusters 0, 1, 5, 6).

Cluster 0		Cluster 1		Cluster 5		Cluster 6	
T[s]	$\hat{d}$[m]	T[s]	$\hat{d}$[m]	T[s]	$\hat{d}$[m]	T[s]	$\hat{d}$[m]
101	80.754	101	82.438	101	6.608	101	17.781
102	82.914	102	83.124	102	6.688	102	17.926
106	83.164	103	84.108	103	6.999	103	18.081
107	83.555	104	85.824	105	7.284	107	20.034
108	84.577	105	86.740	106	7.629	108	20.866
109	85.399	132	87.150				
110	86.674	133	87.874				
111	87.629	139	88.175				
117	89.152	142	89.094				
118	89.747	143	88.668				
122	90.016	144	89.094				
139	90.359	147	88.783				
		174	89.403				

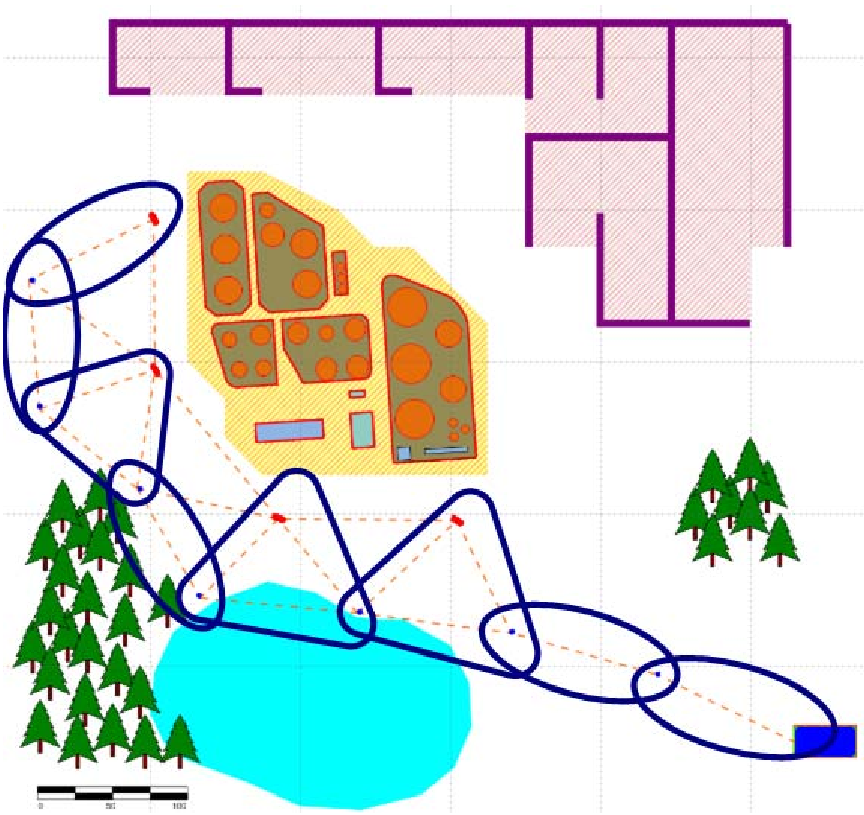

Fig. 9. The topology formed in outdoor environment; eight clusters with regular shapes.

5. Summary and Conclusions

In this paper, we have described the novel approach to managing the mobility of network systems formed by mobile devices that may spontaneously create a network. Our model combines potential field and particle-based scheme for calculating the mobility patterns. We have defined the suitable artificial potential function for the optimal inter-node distances calculation that captures the task and environment of mobile network (MSN or MANET) requirements. In our opinion the proposed mobility model is a good compromise between representativeness and simplicity. The presented case study showed that by employing a multihop wireless communication and mobile nodes acting as communication relay stations, with movement calculated due to our model even relatively distant points in the deployment area will be able to communicate with the base station. Hence, nodes can self-configure to establish a topology that provides communication and sensing coverage. It should be pointed, that our model can be used both to a simulation-based design of network systems and to a motion planning for real, physical MSN or MANET. In future work we plan to test our mobility model in a testbed formed by real wireless devices equipped with sensors.

Acknowledgements

This work was partially supported by National Science Centre grant NN514 672940.

References

[1]. G. Aggelou, Mobile Ad Hoc Networks. From Wireless LANs to 4G Networks, *McGraw-Hill*, USA 2005.
[2]. I. F. Akyildiz, M. C. Vuran, Wireless Sensor Networks, *John Wiley & Sons, Ltd*, West Sussex, UK, 2010.
[3]. F. Bai, N. Sadagopan, A. Helmy, IMPORTANT: A Framework of Systematically Analyze the Impact of Mobility on Performance of Routing Protocols for Ad Hoc Networks, in *Proc. of the INFOCOM*, San Francisco, USA, Vol. 2, 2003, pp. 825-835.
[4]. S. Basagni, M. Conti, S. Giordano, I. Stojmenovic, Mobile Ad Hoc Networking, *Wiley-Interscience*, *IEEE Press*, 2004.
[5]. P. H. Bauer, New Challenges in Dynamical Systems: The Networked Case, *International Journal of Applied Mathematics and Computer Science*, University of Zielona Gora Press, Vol. 18, No. 3, 2008, pp. 271-278.
[6]. J. Beutel, Handbook of Sensor Networks Compact Wireless and Wired Sensing Systems, *CRC Press*, Boca Raton, 2005.
[7]. H. Choset, K. M. Lynch, S. Hutchinson, G. Kantor, W. Burgard, L. E. Kavraki, S. Thrun, Principles of Robot Motion, *The MIT Press*, Cambridge, 2005.
[8]. G. A. Di Caro, Analysis of Simulation Environments for Mobile Ad Hoc Networks, *IDSIA-24-03*, Switzerland, 2003.
[9]. S. L. Ferenci, K. S. Perumalla, R. M. Fujimoto, An Approach for Federating Parallel Simulators, in *Proc. of the PADS 2000*, Bologna, 2000, pp. 63-70.
[10]. B. A. Forouzan, Data Communications and Networking, *McGraw-Hill*, 2004.
[11]. Z. Karakehayov, Multiobjective Design of Wireless Ad Hoc Networks: Security, Real-time and Lifetime, *Journal of Telecommunications and Information Technology*, Vol. 2, 2009, pp. 13-21.
[12]. H. Karl, A. Willig, Protocols and Architectures for Wireless Sensor Networks, *John Wiley & Sons, Ltd*, West Sussex, UK, 2005.
[13]. W. T. Kasch, J. R. Ward, J. Andrusenko, Wireless Network Modeling and Simulation Tools for Designers and Developers, *IEEE Communications Magazine*, Vol. 46, No. 12, 2008, pp. 120-127.
[14]. K. Ma., Y. Zhang, W. Trappe, Managing the Mobility of a Mobile Sensor Network Using Network Dynamics, *IEEE Transactions on Parallel and Distributed Systems*, Vol. 19, No. 2, 2008, pp. 106-120.
[15]. M. Marks, A Survey of Multi-objective Deployment in Wireless Sensor Networks, *Journal of Telecommunications and Information Technology*, Vol. 3, 2010, pp. 36-41.
[16]. Y. Mostafi, Compressive Sensing on Mobile Computing, *IEEE Transactions on Mobile Computing*, Vol. 10, No. 10, 2011, pp. 1769-1784.
[17]. M. Niazi, A. Hussain, Agent-Based Tools for Modeling and Simulation of Self-Organization in Peer-to-Peer, Ad Hoc, and Other Complex Networks, *IEEE Communications Magazine*, Vol. 46, No. 12, 2008, pp. 166-173.
[18]. D. M. Nicol, R. Fujimoto, Parallel Simulation Today, *Annals of Operations Research*, Vol. 53, 1994, pp. 249-285.

[19]. L. F. Perrone, Y. Yuan, D. M. Nicol, Simulation of Large Scale Networks II: Modeling and Simulation

Best Practices for Wireless Ad Hoc Networks, in *Proc. of the 35th Winter Simulation Conference*, 2003, pp. 685-693.
[20]. T. S. Rappaport, Wireless Communications. Principles and Practice, *Prentice Hall*, USA, 2009.
[21]. R. R. Roy, Handbook of Mobile Ad Hoc Networks for Mobility Models, *Springer*, USA, 2010.
[22]. P. Santi, Topology Control in Wireless Ad Hoc and Sensor Networks, *John Wiley & Sons, Ltd*, UK, 2006.
[23].A. Sikora, E. Niewiadomska-Szynkiewicz, A Federated Approach to Parallel and Distributed Simulation of Complex Systems, *International Journal of Applied Mathematics and Computer Science*, Vol. 17, 2007, pp. 99-106.
[24].A. Sikora, E. Niewiadomska-Szynkiewicz, A Parallel and Distributed Simulation of Ad Hoc Networks, *Journal of Telecommunications and Information Technology*, Vol. 3, 2009, pp. 76-84.
[25].S. Singh, Liquid Crystals. Fundamentals, *World Scientific Publishing Co. Pte. Ltd.*, Singapore, 2002.
[26].R. Verdone, D. Dardari, G. Mazzini, A. Conti, Wireless Sensors and Actuator Networks. Technologies, Analysis and Design, *Elsevier*, 2008.
[27].B. P. Zeigler, H. Praehofer, H. T. G. Kim, Theory of Modeling and Simulation, *Academic Press*, 2000.
[28].ZigBee Specification, Document 053474r06, Ver. 1.0, 2005.

___

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2012.pdf