MODELING A SPATIAL COMMUNICATION ACTIVITY IN WIRELESS SENSORS NETWORK

Jan Nikodem [(a)], Ryszard Klempous[(a)], Maciej Nikodem[(a)], Marek Woda[(a)], Zenon Chaczko[(b)]

[(a)] Wroclaw University of Technology, Poland
[(b)] University of Technology Sydney, NSW, Australia

[(a)]{jan.nikodem, ryszard.klempous, maciej.nikodem, marek.woda}@pwr.wroc.pl, [(b)]zenon.chaczko@uts.edu.au

ABSTRACT

This paper presents a novel method of modeling spatial communication activity in wireless sensor network (WSN). We define native aspects of communication in WSN. Focusing on local/global activity dilemma, cooperation, interference, network topology, and optimization aspects. A neighborhood abstraction is defined and we involve three binary relations: subordination, tolerance and collision to describe the cooperation in WSN. Using digital terrain model tools we model communication activity aspects as surfaces, stretched over WSN network. A network topology features are modeled using bare drainage surface. It is a component of a topographic map, which gives a direction towards the base station, determined by a slope of the modeled surface. Modeling node's instant energy level, we construct another surface represents node's instant level of consumed energy. Finally, we construct a drainage surface spread over each node neighborhood as superposition of bare drainage surface, energy consumed and relational surfaces.

Keywords: wireless sensors network, spatial communication, relations in complex system

1. INTRODUCTION

Regular node's measure parameters of the environment they reside. Their basic task is to measure, collect and to send a data to the base station (BS). Wireless Sensor Networks have been studied for a long time and there are plenty of publications in this subject focusing on different aspects of network operation (Vaidya 2005; Cohn 1997; Braginsky 2002). Multiplicity of issues and topics leads to restrictions and assumptions that aim at simplifying the analysis and focus on a particular case. Unfortunately, taking assumptions usually cause some aspects to be omitted. This may not be desirable especially when these aspects are important for some reasons. That is why in our paper we first focus on native aspects of WSN and communication activities. Native aspects are the most important ones and cannot be omitted in modeling process, especially if we try to get reasonable simulation results. We define five native aspects of WSN and communication in WSN:

1. principle task of the WSN is to measure, collect and send data from nodes to the BS (one or many).
2. any WSN is created to achieve some globally defined aims. From this point of view, we may treat the WSN as one device performing tasks. However, WSN is a collection of spatially spread nodes, which take actions based on local information they have. Moreover, software that runs nodes is also implemented and executed on every node independently, having no information about the whole network, but rather some neighborhood of the node. It has to be ensured that local actions taken by each node cause the whole WSN to perform the globally defined aim.
3. cooperation and interference means that nodes influence each other through cooperation and disruption. Since disruptions arise from WSN properties and are unavoidable, thus one can only try to minimize its influence through proper cooperation between nodes. Cooperation is even more important in multi-hop networks where nodes cannot fulfill commissioned tasks on their own. In such situations, cooperation between nodes is crucial and is the only one way to achieve global aims. Positive aspect of cooperation and interference is the possibility to model both aspects of communication.
4. concerning network topology we assume that the topology remains unchanged throughout the whole lifespan of the network. Based on such assumption we can adjust topology of the WSN only once, during the deployment of the network.
5. optimization problem is focused on a maximization of WSN lifespan. Lifespan can be defined in many different ways (e.g. until the first nodes dies) but taking into account the principle task of the WSN we may assume that network dies when it cannot collect and send data from nodes to the BS.

2. NOVEL APPROACH BASED ON SETS AND RELATIONS

2.1. Motivation

Basic problem of our work is how to model a behavior of data flow (generated in WSN nodes) which traverses a network towards base station (BS). Even considering a simple model of such transmission, we came up against many problems. We consider a sensors network composed of nodes, which all reside in the communication range of the base station. Sensor measures parameters of its surrounding environment and transmits this data to the BS. This is a typical way people used to think about the WSN simplifying its operation to point-to-point communication.

It is usually assumed that network is a set of independent homogenous nodes and such simplification of communication activity model is unacceptable due to number of different transmission aspects. Practically, separation of two transmissions: from node *A* to the BS (A→BS) and (B→BS) is inadmissible. These two transmissions use the same radio communication channel , causing collisions, arbitration and priorities important and native issues that have to be solved. Assumption of point-to-point transmission omits vital aspects of WSN communication activity, so it is unacceptable. In fact, in order to model WSN communication activity it is necessary to consider set-to-set (set of sensors to set of base stations) transmission.

A multi-hop WSN networks with limited radio communication range and restricted energy are also widely studied in the literature (Fang 2005; Veyseh 2005). In order to send data from a node to the BS in such networks, it is necessary to use relayed transmission. It causes even more challenging problems because collisions could occur for any element of the routing path. An abundance of routing path elements yields collision, arbitration or priorities problems.

Abundance of interferences forces again point-to-point approach of a transmission. We determine routing path between data source and base station and next we model a multi-hop transmission. Such approach settles and simplifies our theoretical consideration, but a process of path determining causes new problems. If we determine routing path rarely it causes abundant load of routing path nodes (unbalanced distribution of energy consumption). If we determine path too often, we waste energy and communication channel resources more than necessary.

This is a reason why a number of papers focus on optimization of routing path selection in WSN. Developing flat (Burmester 2007), data-centric, hierarchical (Manjeshwar 2001; Sung-Min 2007) or location based routing protocols as well as developing reactive or proactive scenarios. We are working on problems that result from accepted assumption but are not native WSN problems.

Communication activity in WSN should be considered as set-to-set (set of sensors to set of base stations) transmission. Hence, we postulate a set theory as a tool for modeling this type of WSN activity. Such decision is very well justified. Already published works take advantages of functions, which are defined using the language of a set theory. Therefore using a set theory in our approach allows integrating novel approaches with solutions proposed so far.

Functions are nothing but restricted relations and relations can be viewed as a multivalued functions. Restricting relations into function for modeling communication activities in WSN leads to many problems and difficulties. Hence, we postulate relational approach as more general one. However at any time and whenever it is necessary, it is possible to reduce prepared model to traditional (functional) conditions.

2.2. Relations

As mentioned above, the novel approach proposed in this paper is based on such abstract fields of mathematics like theory of relations and sets. To describe communication activities in WSN we involve three binary relations, which are defined on a set of actions (*Act*). These relations (represented as a set of ordered pairs $<x,y>$; where $x,y \in Act$), namely: subordination, tolerance and collision (Jaron 1978, Nikodem 2008) are defined as follows:

Subordination $$\pi := \{<x,y>; x,y \in Act \mid x\,\pi\,y\}, \tag{1}$$

where $x\,\pi\,y$ – means that the action x is subordinated to action y. In other words y dominates over x.

Tolerance $$\vartheta := \{<x,y>; x,y \in Act \mid x\,\vartheta\,y\}, \tag{2}$$

where $x\,\vartheta\,y$ – states that actions x and y tolerate each other.

Collision $$\chi := \{<x,y>; x,y \in Act \mid x\,\chi\,y\}, \tag{3}$$

where expression $x\,\chi\,y$ – means that actions x and y are in collision one to another.

Basic properties of π, ϑ and χ relations were discussed in (Jaron 1978). Here we outline only some of them:

$$\pi \cup \vartheta \cup \chi \subset Act \times Act \neq \emptyset, \tag{4}$$

and

$$\iota \cup (\pi \cdot \pi) \subset \pi, \tag{5}$$

where ι is the identity on the set *Act*. Eq. (4) states that all three relations are binary on non-empty set of actions *Act*. Eq. (5) states that subordination is reflexive ($\iota \subset \pi$) and transitive ($\pi \cdot \pi \subset \pi$).

Further

$$\pi \cup \vartheta^{-1} \cup (\vartheta \cdot \pi) \subset \vartheta, \tag{6}$$

where ϑ^{-1} is inverse of ϑ, means that:

- subordination implies tolerance - if π holds for some $x,y \in$ Act, then ϑ also holds for these,
- tolerance is symmetrical - if x ϑ y $\Rightarrow$ y ϑ x,
- subordinated action tolerates all actions tolerated by the dominant - if (x π y $\wedge$ y ϑ z) $\Rightarrow$ x ϑ z.

For collision relation we have that

$$\chi^{-1} \cup (\pi \circ \chi) \subset \chi \subset \vartheta', \tag{7}$$

where ϑ' is the complement of ϑ. Eq. (7) states that collision is symmetric ($\chi^{-1} \subset \chi$) and disjoint to tolerance ($\chi \subset \vartheta'$). Moreover all subordinated actions must be in collision with action being in collision with its dominant (($\pi \circ \chi$)$\subset \chi$).

2.3. Neighborhood abstraction

A neighborhood abstraction, is defined (Nikodem, Klempous and Chaczko 2008) by a set of criteria for choosing neighbors and set of common resources to be shared, is very useful in almost all algorithms of WSN routing protocols. Realizing distributed operation in which nodes communicate only with other nodes within vicinity; sensor network takes advantage of some concept of a neighborhood. Each node selects some set of important neighbors within the network community and its activity is restricted to this set of nodes. Routing trees, graphs as well as ranges and clusters are specific types of neighborhoods.

Now, let us define *Map(X, Y)* as a set of mapping functions from *X* onto *Y* (surjection). Where Sub*(X)* is defined as a family of all *X* subsets. We define the neighborhood *N* as follows:

$$\mathcal{N} \in Map(Nodes, Sub(Nodes)). \tag{8}$$

Thus, *N(k)* is the neighborhood of node *k* defined as:

$$\mathcal{N}(k)\big|_{k \in Nodes} = \{y \in Nodes \mid y\, R_{\mathcal{N}}\, k\}, \tag{9}$$

In the paper (Nikodem 2009), the native neighborhood was advised as the most suitable form of the local range. Therefore, we define an indexed family of sets $\{N_i \mid i \in I\}$, where I denotes the index set and N_i has the following properties:

$$(\forall i \in I)(N_i \neq \varnothing) \wedge \bigcup N_i = Nodes, \tag{10}$$

$$(\forall i, j \in I \mid i \neq j)(N_i \cap N_j \neq \varnothing). \tag{11}$$

It means that native neighborhoods do not divide a set of WSN nodes into mutually exclusive subsets. Using a neighborhood abstraction we can try to decompose globally defined activities to locally performed identical task ascribed to each node of the network. It will not be an easy task to cast all global dependencies from network area to the neighborhood one. It will be even more difficult because neighborhood conditions for the network nodes might be, and usually are, quite dissimilar.

3. BASIC CONCEPT

A local/global activity dilemma is a starting point of our consideration of modeling communication activity in WSN. We split all-important aspects of communication activity into two classes. First class is composed of invariable aspects, second class relates to_aspects with local/global or $local_1/local_2$ sensibility.

The network topology and node's energy states constitute the first (invariable aspects) class. In contrast, cooperation and interference have been taking into account as second (relative aspects) class.

3.1. Digital terrain model and drained surface

Using digital terrain model (DTM) tools, we model communication activity aspects as surfaces, stretched over WSN network. According to this methodology, a result is obtained as a superposition of a few digital surface models (DSM). Each component (i.e. digitally modeled surface) describes some aspect-related additive properties.

When modeling data flow from network area towards base station we do this similar to rainwater surface flow. Data produced in WSN nodes flow like raindrops which streaming down in a direction determined by a slope of the modeled surface. During this process, drops merge with another (data aggregation), carve terrain or build it like lava tears (energy consumption). A resulted flow has been finally conditioned by the local neighborhood conditions and environmental stimulus (cooperation and interference).

We model natural network topology features using digital surface model (DSM). It is a component of a topographic map (bare drainage surface), which gives a basic reference frame that ensures messages are send towards the BS. In a real WSN network nodes usually have no information about their Euclidean distance from the BS. Therefore in the paper (Nikodem, Klempous, Nikodem, Chaczko and Woda 2009) we propose a measure of *dis(k)* (distance between BS and node *k*) based on maximal node's energy (E_{max}) and the amount of hops (*h*) required to send data from node *k* to the BS

$$dis^h(k) = 0.95 * h * E_{\max}. \tag{12}$$

Now, a bare drainage surface can be defined as follows:

$$D(x, y, z) = \{z = dis^h(k) \mid k(x, y) \in N\}. \tag{13}$$

The data required for representation (13) is collected and processed by the whole WSN area during the self-organization process. This enables to determine nodes that are one hop closer to the BS immediately. It is vital that the message from a node k traverses in a direction determined by a slope of the modeled surface (13). Surface D created in such a way corresponds to spatial localization of WSN and is invariant in time since we assume that the network is not mobile. For these reasons, digital surface model (13) is used in our algorithm as bare drainage surface.

For the purpose of modeling node's instant energy level, we construct another surface

$$L_{en}(x,y,z) = \{z = E_{con} \mid k(x,y) \in N\}. \qquad (14)$$

In that case we assign nodes the energy E_{con} they spent (their consumed energy). Therefore, if more energy is used by a node, then greater value of the coordinate *z* will have a surface above this node.

Modeled surface L_{en} represents node's instant level of consumed energy. The communication activity during a network lifetime declines these levels, so a surface (14) also tends to fall off. Because of that surface L_{en} is recalculated all the time during the simulation process.

3.2. Cooperation and interference relational model

In case of cooperation and interference (Vakil 2006), the problem is more sophisticated than considered above. For a modeling: cooperation and interference purpose it is not reasonable to construct surface draped over WSN network. Aspect of cooperation and interference relates not only on global/local dilemma but first of all varies from one neighborhood to another. This is the reason that attempts to model cooperation and interference based on modeling of global surface stretched over WSN have been failed.

We focused our attention on two aspects when modeling cooperation and interference in WSN. First is a cooperation interpreted as a method of achieving globally defined strategy through tactics i.e. activities performed locally by each node. This aspect can be ensured if relational attempt is used.

Global strategy determined by intensity quotients of π, ϑ, χ relations is determined by base stations that adopt the strategy to the actual state of the WSN and situation. Later on, this strategy is send to nodes that setup their tactics in order to achieve the strategy. Using tactics each node performs operations within its neighborhood interacting and sending data to its neighbors. Additionally node's measure parameters of the environment they reside and align their operation accordingly.

Because both: node's neighborhood and environment differs for each node therefore for a given global strategy each node chooses some of its neighbors, he will cooperate according to subordination, tolerance and collision relations. Since these relations may differ for each node, we are not able to represent tactics as one common surface spread over the whole WSN. On the other hand, cooperation can be modeled individually for each neighbor as follows:

$$L_{rel}^{N(k)} = \{z = f(n,\pi,\vartheta,\chi) \mid n(x,y) \in N(k)\}. \qquad (15)$$

Second aspect concerns how to bind together different tactics that implement the same global strategy. Due to different local conditions and interactions with environment, tactics performed by each node may vary. If there are w nodes in the neighborhood of node *k*, then there may be up to *w+1* different tactics neighboring nodes may take in order to achieve the strategy.

DTM approach requires a construction of a surface that represents cooperation and interference. Surface that represents the global strategy is simply a plane since there is only one strategy for the whole network. On the other hand, surface that represents tactics of all nodes such that local interactions with the environment are also considered is difficult to draw. It is so, since surfaces representing the tactics of each node are different and span over the neighborhood area rather than the whole WSN. Therefore, for a network consisting of *n* nodes we get *n* surfaces that overlap. Since surfaces may differ, therefore it is difficult to draw one common surface that represents tactics of all nodes. On the other hand, tactics are implemented and performed by nodes and in this perspective; the interpretation of the model is easier.

Based on DTM each node may construct a drainage surface spread over its neighborhood. When constructing this function nodes can use bare drainage surface (13) and information about energy consumed (14), restricted both to its neighborhood. It can also use a relational surface (15) and superposition of these surfaces (13)-(15) constitutes drainage surface over the node's neighborhood.

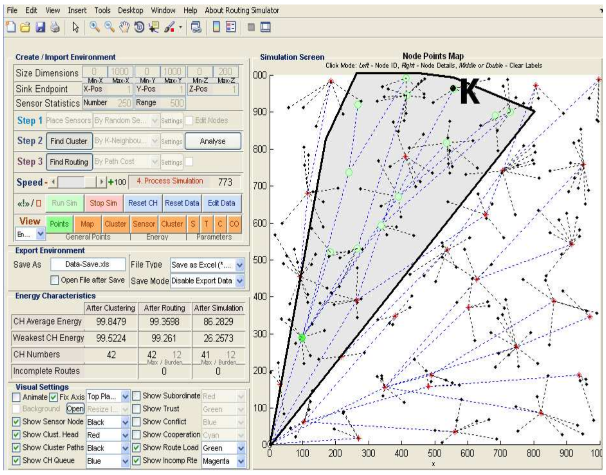


Figure 1: Modeling a spatial communication in WSN

4. CONCLUSIONS

Proposed application of sets theory and relations, allows solving the compliance dilemma posed against global net of requirements along with their distributed local implementation within nodes of the network. At the same time, it proved that the data transmission treated

There is a demo situation presented on the fig.1, as set-to-set relation makes available new, feasible features to WSN modeling. It shows how a node *K* constructs to a routing path set which is simply an area (marked with grey color) through which data from *K* node is transmitted to the BS. Fig 1 compares proposed routing path set approach with traditional cluster and routing paths solutions.

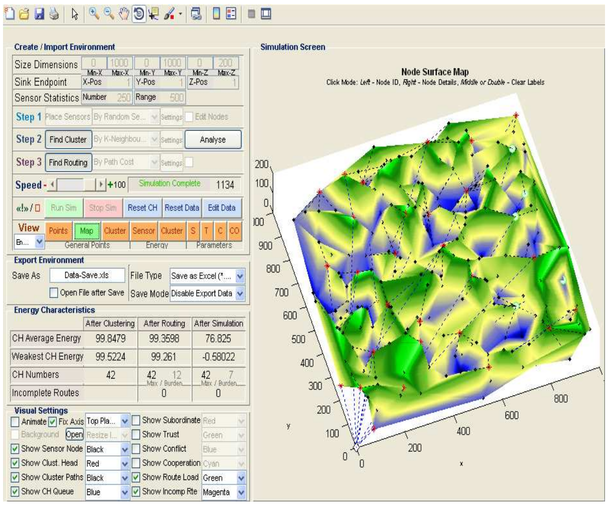


Figure 2: Modeling a drained surface in WSN

Fig. 2 presents a drainage surface generated for a certain network. Base modeled surface, was not so diverse at the beginning of simulation, a distinct surface slope clearly indicated drainage direction towards the BS. However, after a number of transmissions one may notice erosion of the drainage surface. One may also observe unevenness of energy use in particular nodes (cluster heads). These aforementioned inequalities can be leveled by a different tactic definition, from one, which is being currently used.

REFERENCES

Braginsky, D., Estrin, D., 2002. Rumor Routing Algorithm for Sensor Networks, *Proc. of the 1-st Workshop on Sensor Networks and Applications*, Atlanta, GA.

Burmester, M., Le T.V., Yasinsac, A., 2007. Adaptive gossip protocols: Managing security and redundancy in dense ad hoc networks, *Ad Hoc Networks*, Volume 5, Issue 3, pp.313-32.

Cohn, A.G., Bennett, B., Gooday, J.M., Gotts, N.M., 1997. Representing and Reasoning with Qalitative Spatial Relations about Regions. In: Cohn, A.G., Bennett B., Gooday J.M., Gotts N.M, eds. Spatial and Temporal Reasoning, Dordrecht, Kulwer, 97-134

Fang O., Gao J., Guibas L.J., de Silva V., Zhang L., 2005. GLIDER: gradient landmark-based distributed routing for sensor networks, *24th Annual Joint Conference of the IEEE Computer and Communications Societies*. INFOCOM 2005, 13-17 March 2005, vol.1, pp. 339-350.

Jaroń, J., 1978. Systemic Prolegomena to Theoretical Cybernetics, *Scient. Papers of Inst. of Techn. Cybernetics*, Wroclaw Techn. Univ., no. 45, Wroclaw.

Manjeshwar, A., Agrawal, D.P., 2001. TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks, *15th International Parallel and Distributed Processing Symposium* (IPDPS'01), *Parallel and Distributed Processing Symposium, International*, vol. 3, pp. 30189a, Workshops.

.Nikodem, J., 2008. Autonomy and Cooperation as Factors of Dependability in Wireless Sensor Network, *Proceedings of the Conference in Dependability of Computer Systems*, DepCoS - RELCOMEX, pp.406-413. Szklarska Poreba, Poland.

Nikodem, J., Klempous R., Chaczko, Z., 2008. Modelling of immune functions in a wireless sensors network.W: *20th European Modeling and Simulation Symposium*. EMSS 2008, Campora S. Giovanni, Italy.

Nikodem, J., 2009. Relational Approach Towards Feasibility Performance for Routing Algorithms in Wireless Sensor Network, *12 International Conference on Computer Aided Systems Theory and Technology* EUROCAST'2009,, *in: Lecture Notes in Computer Science* (in printing), Springer-Verlag Berlin Heidelberg.

Nikodem, J., Klempous, R., Nikodem, M., Chaczko, Z., Woda, M., 2009. Directed Communication in Wireless Sensor Network Based on Digital Terrain Model, *2nd International Symposium on Logistics and Industrial Informatics* (in printing), September 2009, Linz, Austria.

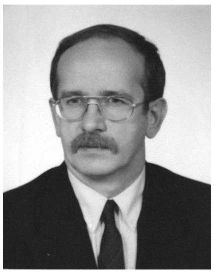
Sung-Min, J., Young-Ju, H., Tai-Myoung, C, 2007. The Concentric Clustering Scheme for Efficient Energy Consumption in the PEGASIS, *9th International Conference on Advanced Communi-cation Technology*, Vol.1, page(s): 260-265

Vaidya, D., Peng, J., Yang, L., Rozenblit, J.W., 2005. A Framework for Sensor Management in Wireless and Heterogeneous Sensor Network, *12th IEEE International Conference on the Engineering of Computer-Based Systems*, pp.155-162. 4-7 April 2005, Greenbelt, USA.

Vakil, S., Liang, B., 2006. Balancing Cooperation and Interference in Wireless Sensor Networks, *IEEE Communications Society on Sensor and Ad Hoc Communications and Networks*, SECON '06, vol.1, pp.198-206.

Veyseh, M., Wei, B., Mi,r N.F., 2005. An Information Management Protocol to Control Routing and Clustering in Sensor Networks, *Journal of Computing and Information Technology* - CIT 13 (1), pp.53-68.

AUTHORS BIOGRAPHY



Jan Nikodem received the B.Sc. in electrical engineering, M.Sc. in artificial intelligence in 1979 and Ph.D. degree in computer science in 1982 from Wroclaw University of Technology (WUT), Poland. Since 1986, he has been an Assistant Professor in the Institute of Technical Cybernetics, WUT. Since 2005 in the Institute of Computer Engineering, Automatics and Robotics (ICEAR). His current research are focused on the area of complex and distributed systems, cybernetics, wireless sensor networks and digital data transmission.

Ryszard Klempous holds a M.Sc. in Automation (1971) and Ph.D. in Computer Science (1980) from Wroclaw University of Technology (WUT). Since 1980 he has been an Assistant Professor in the Institute of Computer Engineering, Automatics and Robotics, WUT. Senior member of IEEE and NYAS, has already published over 90 papers in Optimization Methods and Algorithms, Simulation and Data Processing and Transmission.

Maciej Nikodem graduated a M.Sc. in Computer Science in 2003 and a M.Sc. in Control and Robotics in 2005 from the Wroclaw University of Technology, Wroclaw in Poland. In 2008 he completed Ph.D. studies in Computer Science at Faculty of Electronics, Wroclaw University of Technology. For last 5 years Maciej Nikodem has worked on Countermeasures to Fault Analysis, Boundary Scan Security as well as security aspects of Wireless Sensor Networks. Maciej Nikodem is a Assistant Professor in the Institute of Computer Science, Control and Robotics, Faculty of Electronics at WUT.

Zenon Chaczko completed a B.Sc. in Cybernetics and Informatics in 1980 and a M.Sc. in Economics in 1981 at the University of Economics, Wroclaw in Poland., as well as completed MEng in Control Engineering at the NSWIT 1986, Australia. For over 20 years Mr Chaczko has worked on Sonar and Radar Systems, Simulators, Systems Architecture, Telecommunication network management systems, large distributed Real-Time system architectures, network protocols and system software middleware. Mr Chaczko is a Senior Lecturer in the Information and Communication Group within the Faculty of Engineering at UTS.

Marek Woda is an Assistant Professor in the Institute of Computer Engineering, Control and Robotics at Wroclaw University of Technology. In 2001 he graduated at WUT. In 2007, he got PhD degree in Computer Science from the Faculty of Electronics WUT. His research interests focus on multi-agents systems, e-learning, Internet technologies. He participated in international projects sponsored by European Union (e.g. PL96-1046 INCO-COPERNICUS project "Multimedia Education: An Experiment in Delivering CBL Material", VI FP Integrated Project FP6-IST 26600 DESEREC "Dependability and Security by Enhanced Reconfigurability"). He is the author of about 30 scientific articles and conference papers.